3

Observations: Temperature Records

Introduction

The Intergovernmental Panel on Climate Change (IPCC) claims to have found evidence in paleoclimatic data that higher levels of atmospheric CO_2 can cause or amplify an increase in global temperatures (IPCC, 2007-I, Chapter 6). The IPCC further claims to have evidence of an anthropogenic effect on climate in the earth's temperature history during the past century (Chapters 3, 9), in the pattern (or "fingerprint") of more recent warming (Chapter 9, Section 9.4.1.4), in data from land-based temperature stations and satellites (Chapter 3), and in the temperature records of the Artic region and Antarctica where models predict anthropogenic global warming should be detected first (Chapter 11, Section 8). In this chapter, we critically examine the data used to support each of these claims, starting with the relationship between CO_2 and temperature in ancient climates.

References

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

3.1. Paleoclimatic Data

Rothman (2002) derived a 500-million-year history of the air's CO_2 content based on considerations related to the chemical weathering of rocks, volcanic and metamorphic degassing, and the burial of organic carbon, along with considerations related to the isotopic content of organic carbon and strontium in marine sedimentary rocks. The results of this analysis suggest that over the majority of the half-billion-year record, earth's atmospheric CO_2 concentration fluctuated between values that were two to four times greater than those of today at a dominant period on the order of 100 million years. Over the last 175 million years, however, the data depict a long-term decline in the air's CO_2 content.

Rothman reports that the CO_2 history "exhibits no systematic correspondence with the geologic record of climatic variations at tectonic time scales." A visual examination of Rothman's plot of CO_2 and concomitant major cold and warm periods indicates the three most striking peaks in the air's CO_2 concentration occur either totally or partially within periods of time when earth's climate was relatively cool.

A more detailed look at the most recent 50 million years of earth's thermal and CO_2 history was prepared by Pagani *et al.* (2005). They found about 43 million years ago, the atmosphere's CO_2 concentration was approximately 1400 ppm and the oxygen isotope ratio (a proxy for temperature) was

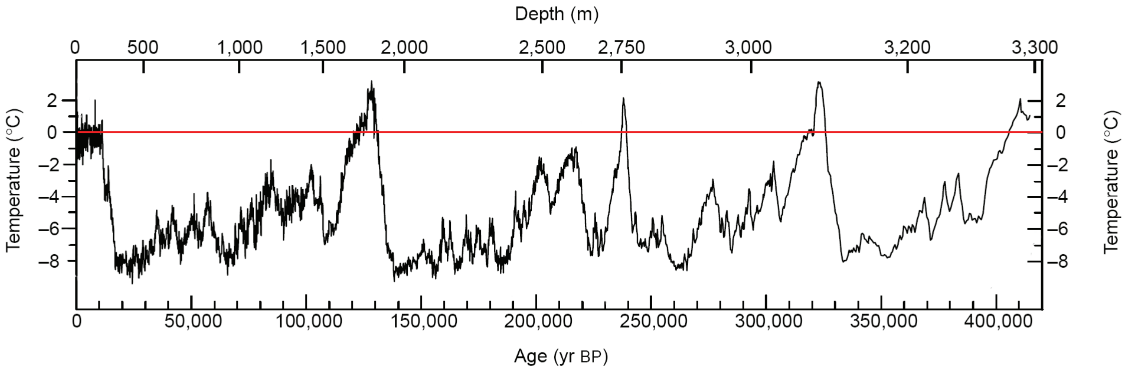

Figure 3.1. Temperature history derived by Petit *et al.* (1999) from an ice core extracted from the Russian Vostok drilling station in East Antarctica.

about 1.0 per mil. Then, over the next ten million years, the air's CO_2 concentration experienced three huge oscillations on the order of 1000 ppm from peak to valley. In the first two oscillations, temperature did not appear to respond at all to the change in CO_2, exhibiting an uninterrupted slow decline. Following the third rise in CO_2, however, temperatures seemed to respond, but in the direction opposite to what the greenhouse theory of global warming predicts, as the rise in CO_2 was followed by the sharpest drop in temperature of the entire record.

Following this large drop in temperature between 34 and 33 million years before present (Ma BP), the oxygen isotope ratio hovered around a value of 2.7 per mil from about 33 to 26 Ma BP, indicating little change in temperature over that period. The corresponding CO_2 concentration, on the other hand, experienced about a 500 ppm increase around 32 Ma BP, after which it dropped 1,000 ppm over the next two million years, only to rise again by a few hundred ppm, refuting – three times – the CO_2-induced global warming hypothesis. Next, around 26 Ma BP, the oxygen isotope ratio dropped to about 1.4 per mil (implying a significant *rise* in temperature), during which time the air's CO_2 content declined. From 24 Ma BP to the end of the record at 5 Ma BP, there were relatively small variations in atmospheric CO_2 content but relatively large variations in oxygen isotope values, both up and down. All of these many observations, according to Pagani *et al.* (2005), "argue for a decoupling between global climate and CO_2."

Moving closer to the modern era, Fischer *et al.* (1999) examined trends of atmospheric CO_2 and air temperature derived from Antarctic ice core data that extended back in time a quarter of a million years. Over this period, the three most dramatic warming events experienced on earth were the terminations of the last three ice ages; and for each of these climatic transitions, earth's air temperature always rose well in advance of the increase in atmospheric CO_2. In fact, the air's CO_2 content did not begin to rise until 400 to 1,000 years after the planet began to warm.

Another research team, Petit *et al.* (1999), studied the beginnings rather than the ends of glacial ages. They discovered that during all glacial inceptions of the past half million years, temperature always dropped well before the decline in the air's CO_2 concentration. They said their data indicate that "the CO_2 decrease lags the temperature decrease by several thousand years." Petit *et al.* also found the current interglacial is the coolest of the five most recent such periods. In fact, the peak temperatures of the four interglacials that preceded it were, on average, more than 2°C warmer than that of the one in which we currently live. (See Figure 3.1.)

Figure 3.1 tells us three things about the current warm period. First, temperatures of the last decades of the twentieth century were "unprecedented" or "unusual" only because they were *cooler* than during past interglacial peaks. Second, the current temperature of the globe cannot be taken as evidence of an anthropogenic effect since it was warmer during parts of all preceding interglacials for which we have good proxy temperature data. And third, the higher temperatures of the past four interglacials cannot be attributed to higher CO_2 concentrations caused by some non-human influence because atmospheric CO_2 concentrations during all four prior interglacials never rose above approximately 290 ppm, whereas the air's CO_2 concentration today stands at nearly 380 ppm.

Likewise, Mudelsee (2001) determined that variations in atmospheric CO_2 concentration lagged behind variations in air temperature by 1,300 to 5,000 years over the past 420,000 years. During certain climatic transitions characterized by rapid warmings of several degrees Centigrade, which were followed by slower coolings that returned the climate to essentially full glacial conditions, Staufer *et al*. (1998) observed the atmospheric CO_2 concentration derived from ice core records typically varied by less than 10 ppm. They, too, considered the CO_2 perturbations to have been caused by the changes in climate, rather than vice versa.

Other studies have also demonstrated this reverse coupling of atmospheric CO_2 and temperature (e.g., Cheddadi *et al*., 1998; Gagan *et al*., 1998; Raymo *et al*., 1998), where temperature is the independent variable that appears to induce changes in CO_2. Steig (1999) noted cases between 7,000 and 5,000 years ago when atmospheric CO_2 concentrations increased by just over 10 ppm at a time when temperatures in both hemispheres cooled.

Caillon *et al*. (2003) measured the isotopic composition of argon – specifically, δ^{40}Ar, which they argue "can be taken as a climate proxy, thus providing constraints about the timing of CO_2 and climate change" – in air bubbles in the Vostok ice core over the period that comprises what is called Glacial Termination III, which occurred about 240,000 years ago. The results of their tedious but meticulous analysis led them to conclude that "the CO_2 increase lagged Antarctic deglacial warming by 800 ± 200 years." This finding, in their words, "confirms that CO_2 is not the forcing that initially drives the climatic system during a deglaciation."

Indermuhle *et al*. (1999) determined that after the termination of the last great ice age, the CO_2 content of the air gradually rose by approximately 25 ppm in almost linear fashion between 8,200 and 1,200 years ago, over a period of time that saw a slow but steady *decline* in global air temperature. On the other hand, when working with a high-resolution temperature and atmospheric CO_2 record spanning the period 60 to 20 thousand years ago, Indermuhle et al. (2000) discovered four distinct periods when temperatures rose by approximately 2°C and CO_2 rose by about 20 ppm. However, one of the statistical tests they performed on the data suggested that the shifts in the air's CO_2 content during these intervals *followed* the shifts in air temperature by approximately 900 years; while a second statistical test yielded a mean CO_2 lag time of 1,200 years.

Another pertinent study is that of Siegenthaler *et al*. (2005), who analyzed CO_2 and proxy temperature (δD, the ratio of deuterium to hydrogen) data derived from an ice core in Antarctica. Results of their analysis revealed a coupling of Antarctic temperature and CO_2 in which they obtained the best correlation between CO_2 and temperature "for a lag of CO_2 of 1900 years." Specifically, over the course of glacial terminations V to VII, they indicate that "the highest correlation of CO_2 and deuterium, with use of a 20-ky window for each termination, yields a lag of CO_2 to deuterium of 800, 1600, and 2800 years, respectively." In addition, they note that "this value is consistent with estimates based on data from the past four glacial cycles," citing in this regard the work of Fischer *et al*. (1999), Monnin *et al*. (2001) and Caillon *et al*. (2003).

These observations seem to undermine the IPCC's claims that the CO_2 produced by the burning of fossil fuels will lead to catastrophic global warming. Nevertheless, Siegenthaler *et al.* stubbornly state that the new findings "do not cast doubt ... on the importance of CO_2 as a key amplification factor of the large observed temperature variations of glacial cycles." The previously cited Caillon *et al.* also avoid the seemingly clear implication of their own findings, that CO2 doesn't *cause* global warming. We find such disclaimers disingenuous.

When temperature is found to lead CO_2 by thousands of years, during both glacial terminations and inceptions (Genthon *et al*., 1987; Fischer *et al*., 1999; Petit *et al*., 1999; Indermuhle *et al*., 2000; Monnin *et al*., 2001; Mudelsee, 2001; Caillon *et al*., 2003), it is extremely likely that CO_2 plays only a minor role in enhancing temperature changes that are induced by something else. Compared with the mean conditions of the preceding four interglacials, there is currently 90 ppm more CO_2 in the air and yet it is currently more than 2°C colder than it was then. There is no way these real-world observations can be construed to suggest that a significant increase in atmospheric CO_2 would necessarily lead to *any* global warming, much less the catastrophic type that is predicted by the IPCC.

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3.2. Past 1,000 Years

The IPCC claims “average Northern Hemisphere temperatures during the second half of the 20th century were *very likely* higher than during any other 50-year period in the past 500 years and *likely* the highest in at least the past 1,300 years [italics in the original]” (IPCC, 2007-I, p. 9). Later in that report, the IPCC says “the warming observed after 1980 is unprecedented compared to the levels measured in the previous 280 years” (p. 466) and “it is likely that the 20th century was the warmest in at least the past 1.3 kyr. Considering the recent instrumental and longer proxy evidence together, it is very likely that average NH [Northern Hemisphere] temperatures during the second half of the 20th century were higher than for any other 50-year period in the last 500 years” (p. 474).

The notions that the warming of the second half of the twentieth century was "unprecedented" and that temperatures during the twentieth century were "the warmest in at least the past 1.3 kyr" will be questioned and tested again and again in the present report. We start here with an examination of the work of Mann *et al.* (1998, 1999, 2004) and Mann and Jones (2003), which captured the attention of the world in the early years of the twenty-first century and upon which the IPCC still relies heavily for its conclusions. We then present a thorough examination of temperature records around the world to test the IPCC's claim that there was no Medieval Warm Period during which temperatures exceeded those of the twentieth century, starting with data from Africa and then from Antarctica, the Arctic, Asia, Europe, North America, and finally South America. We return to Antarctica and the Arctic at the end of this chapter to discuss more recent temperature trends.

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3.2.1. The Hockey Stick

One of the most famous pieces of "evidence" for anthropogenic global warming (AGW) brought forth in recent years was the "hockey stick" diagram of Michael Mann and colleagues (Mann *et al.*, 1998; Mann *et al.,* 1999; Mann and Jones, 2003). (See Figure 3.2.1.) Because the graph played such a big role in mobilizing concern over global warming in the years since it was first released, and since the IPCC continues to rely upon and defend it in its latest report (see IPCC, 2007-I, pp. 466-471), we devote some space here to explaining its unusual origins and subsequent rejection by much of the scientific community.

The hockey stick graph first appeared in a 1998 study led by Michael Mann, a young Ph.D. from the University of Massachusetts (Mann *et al.*, 1998). Mann and his colleagues used several temperature proxies (but primarily tree rings) as a basis for assessing past temperature changes from 1000 to 1980. They then grafted the surface temperature record of the twentieth century onto the pre-1980 proxy record. The effect was visually dramatic. (See Figure 3.2.1.) Gone were the difficult-to-explain Medieval Warming and the awkward Little Ice Age. Mann gave us nine hundred years of stable global temperatures—until about 1910. Then the twentieth century's temperatures seem to rocket upward out of control.

The Mann study gave the Clinton administration the quick answer it wanted to the argument that natural climate variations exceed whatever effect human activity might have had in the twentieth century by claiming, quite simply, that even the very biggest past historic changes in temperatures *simply never happened.* The Clinton administration featured it as the first visual in the *U.S. National Assessment of the Potential Consequences of Climate Variability and Change* (later published as *Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change* (National Assessment Synthesis Team, 2001)). Mann was named an IPCC lead author and his graph was prominently displayed in the IPCC's Third Assessment Report (IPCC-TAR, 2001), and it subsequently appeared in Al Gore's movie, "An Inconvenient Truth." Mann was named an editor of *The Journal of Climate*, a major professional journal, signaling the new order of things to the rest of his profession.

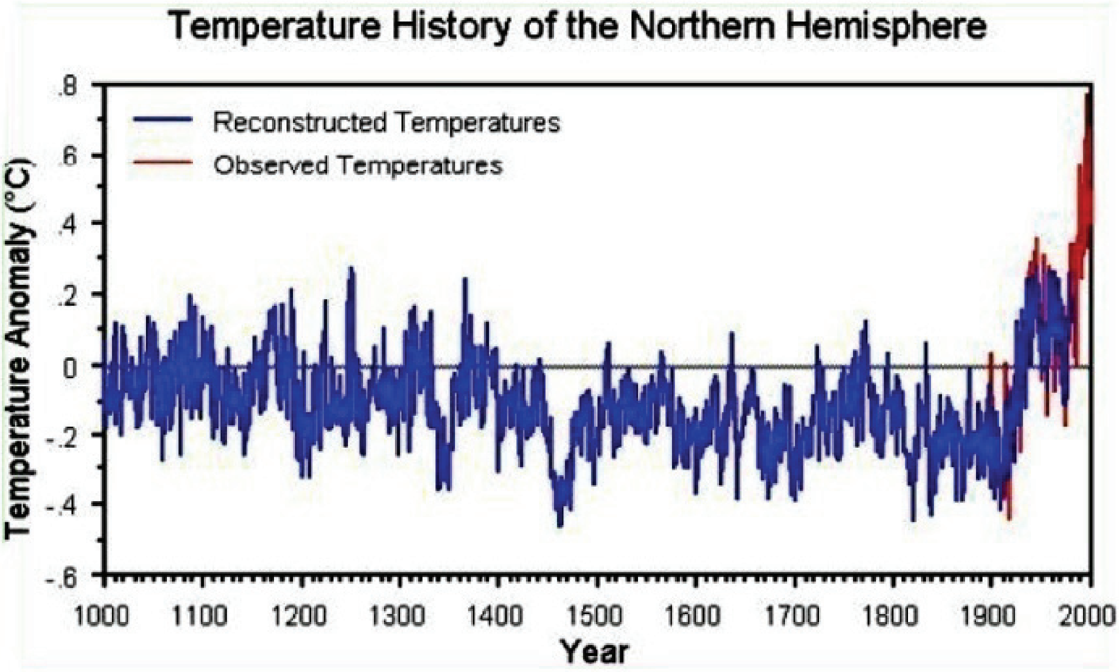

Figure 3.2.1. The 'hockey stick' temperature graph was used by the IPCC to argue that the twentieth century was unusually warm (IPCC-TAR 2001, p. 3).

The "hockey stick" graph was severely critiqued by two Canadian nonscientists who were well trained in statistics—metals expert Stephen McIntyre of Toronto and economist Ross McKitrick from Canada's University of Guelph (McIntyre and McKitrick, 2003, 2005). McIntyre and McKitrick requested the original study data from Mann. It was provided—haltingly and incompletely—indicating that no one else had previously requested the data for a peer review in connection with the original publication in *Nature*. They found the data did not produce the claimed results "due to collation errors, unjustifiable truncation or extrapolation of source data, obsolete data, geographical location errors, incorrect calculation of principal components and other quality control defects."

In their exchanges with the Mann research team, McIntyre and McKitrick learned that the Mann studies give by far the heaviest weight to tree-ring data from 14 sites in California's Sierra Nevada Mountains. At those sites, ancient, slow-growing, high-elevation bristlecone pine trees (which can live 5,000 years) showed a strong twentieth century growth spurt. The growth ring data from those trees were collected and presented in a 1993 paper by Donald Graybill and Sherwood Idso. Significantly, that paper was titled "Detecting the Aerial Fertilization Effect of Atmospheric CO_2 Enrichment in Tree Ring Chronologies" (Graybill and Idso, 1993). Graybill and Idso specifically pointed out in their study that neither local nor regional temperature changes could account for the twentieth century growth spurt in those already-mature trees. But CO_2 acts like fertilizer for trees and plants and also increases their water-use efficiency. All trees with more CO_2 in their atmosphere are very likely to grow more rapidly. Trees like the high-altitude bristlecone pines, on the margins of both moisture and fertility, are likely to exhibit very strong responses to CO_2 enrichment—which was the point of the Graybill and Idso study.

McIntyre and McKitrick demonstrated that removing the bristlecone pine tree data eliminates the distinctive rise at the end of the "hockey stick." Mann and his coauthors could hardly have escaped knowing the CO_2 reality, since it was clearly presented in the title of the study from which they derived their most heavily weighted data sites. Using corrected and updated source data, McIntyre and McKitrick recalculated the Northern Hemisphere temperature index for the period 1400–1980 using Mann's own methodology. This was published in *Energy & Environment,* with the data refereed by the World Data Center for Paleoclimatology (McIntyre and

McKitrick, 2003). "The major finding is that the [warming] in the early 15th century exceed[s] any [warming] in the 20th century," report McIntyre and McKitrick. In other words, the Mann study was fundamentally wrong.

Mann and his team were forced to publish a correction in *Science* admitting to errors in their published proxy data, but they still claimed that "none of these errors affect our previously published results" (Mann *et al.,* 2004). That claim, too, was contradicted by later work by McIntyre and McKitrick (2005), by statistics expert Edward Wegman (Wegman *et al.,* 2006), and by a National Academy of Sciences report (NAS, 2006). The NAS skipped lightly over the errors of the hockey-stick analysis and concluded it showed only that the twentieth century was the warmest in 400 years, but this conclusion is hardly surprising, since the Little Ice Age was near its nadir 400 years ago, with temperatures at their lowest. It was the claim that temperatures in the second half of the twentieth century were the highest in the last millennium that properly generated the most attention.

Where does the IPCC stand today regarding the "hockey stick"? Surprisingly, it still defends and relies on it. It appears in a series of graphs on page 467. Critiques by Soon and Baliunas (2003) and McIntyre and McKitrick are reported briefly but both are dismissed, the first because "their qualitative approach precluded any quantitative summary of the evidence at precise times," and the latter by citing a defense of Mann by Wahl and Ammann (2006) "who show the impact on the amplitude of the final reconstruction is very small (~0.05ºC)" (IPCC, 2007-I, p. 466). The Medieval Warm Period appears only in quotes in the index and body of the IPCC 2007-I report. In the glossary (Annex I), it is defined as "an interval between AD 1000 and 1300 in which some Northern Hemisphere regions were warmer than during the Little Ice Age that followed" (p. 949). In the text it is referred to as "the so-called 'Medieval Warm Period.'" In a boxed discussion of "Hemispheric Temperatures in the 'Medieval Warm Period,'" it says "medieval warmth was heterogeneous in terms of its precise timing and regional expression" and "the warmest period prior to the 20th century very likely occurred between 950 and 1100, but temperatures were probably between 0.1ºC and 0.2ºC below the 1961 to 1990 mean and significantly below the level shown by instrumental data after 1980" (p. 469).

One can disprove the IPCC's claim by demonstrating that about 1,000 years ago, there was a world-wide Medieval Warm Period (MWP) when global temperatures were equally as high as or higher than they were over the latter part of the twentieth century, despite there being approximately 25 percent less CO_2 in the atmosphere than there is today. This real-world fact conclusively demonstrates there is nothing unnatural about the planet's current temperature, and that whatever warming occurred during the twentieth century was likely caused by the recurrence of whatever cyclical phenomena created the equal or even greater warmth of the MWP.

The degree of warming and climatic influence during the MWP varied from region to region and, hence, its consequences were manifested in several ways. But that it occurred and was a global phenomenon is certain; there are literally hundreds of peer-reviewed scientific articles that bear witness to this truth.

The Center for the Study of Carbon Dioxide and Global Change has analyzed more than 200 peer-reviewed research papers produced by more than 660 individual scientists working in 385 separate institutions from 40 different countries that comment on the MWP. Figure 3.2.2 illustrates the spatial distribution of these studies. Squares denote studies where the scientists who conducted the work provided quantitative data that enable one to determine the degree by which the peak temperature of the MWP differed from the peak temperature of the Current Warm Period (CWP). Circles denote studies where the scientists who conducted the work provided qualitative data that enable one to determine which of the two periods was warmer, but not by how much. Triangles denote studies where the MWP was evident in the study's data, but the data did not provide a means by which the warmth of the MWP could be compared with that of the CWP. The third category includes studies that are based on data related to parameters other than temperature, such as precipitation. As can be seen from the figure, evidence of the MWP has been uncovered at locations throughout the world, revealing the truly global nature of this phenomenon.

A second question often posed with respect to the MWP is: When did it occur? A histogram of the timeframe (start year to end year) associated with the MWP of the studies plotted in Figure 3.2.2 is shown in Figure 3.2.3. The peak timeframe of all studies occurs around 1050 AD, within a more generalized 800 to 1300 AD warm era.

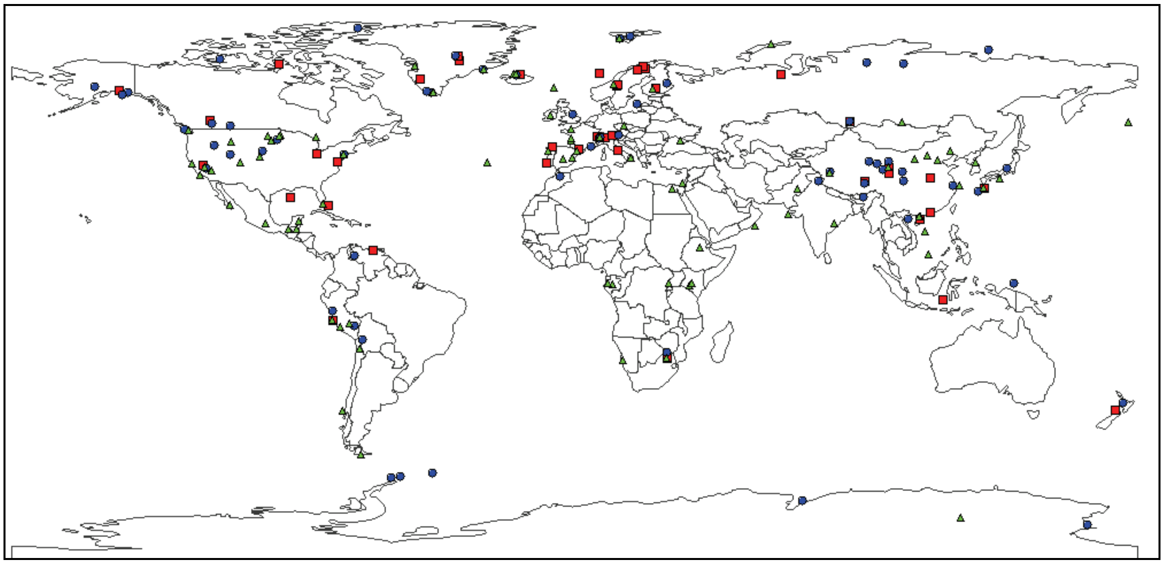

Figure 3.2.2. Plot of the locations of proxy climate studies for which (a) quantitative determinations of the temperature difference between the MWP and CWP can be made (squares), (b) qualitative determinations of the temperature difference between the MWP and CWP can be made (circles), and (c) neither quantitative nor qualitative determinations can be made, with the studies simply indicating that the Medieval Warm Period did indeed occur in the studied region (triangles).

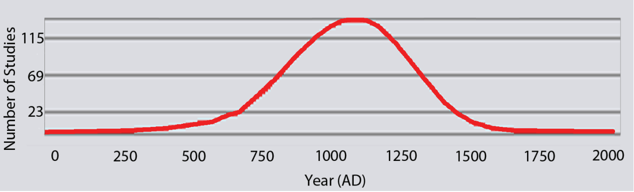

Figure 3.2.3. Histogram showing the timeframe associated with all MWP studies plotted in Figure 3.2.2.

With respect to how warm it was during this period, we have plotted the frequency distribution of all MWP-CWP temperature differentials from all quantitative studies (squares) shown in Figure 3.2.2 to create Figure 3.2.4. This figure reveals there are a few studies in which the MWP was determined to have been cooler than the CWP, but the vast majority of the temperature differentials are positive, indicating the MWP was warmer than the CWP. The average of all such differentials is 1.01°C, while the median is 0.90°C.

We can further generalize the superior warmth of the MWP by analyzing the qualitative studies in Figure 3.2.2, which we have done in Figure 3.2.5. Here we have plotted the number of studies in Figure 3.2.2 in which the MWP was warmer than, cooler than, or about the same as, the CWP, based upon data presented by the authors of the original works. The vast majority of studies indicates the MWP was warmer than the CWP.

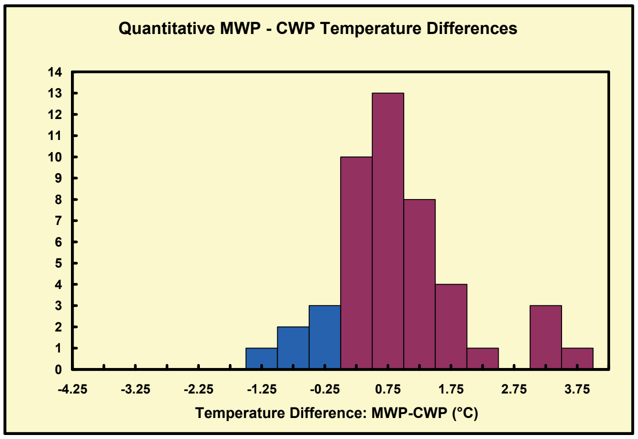

Figure 3.2.4. The distribution, in 0.5°C increments, of studies that allow one to identify the degree by which peak Medieval Warm Period temperatures either exceeded or fell short of peak Current Warm Period temperatures.

It is often claimed that temperatures over the latter part of the twentieth century were higher than those experienced at any other time over the past one to two millennia. Based upon the synthesis of real-world data presented here (and hereafter), however, that claim is seen to be false.

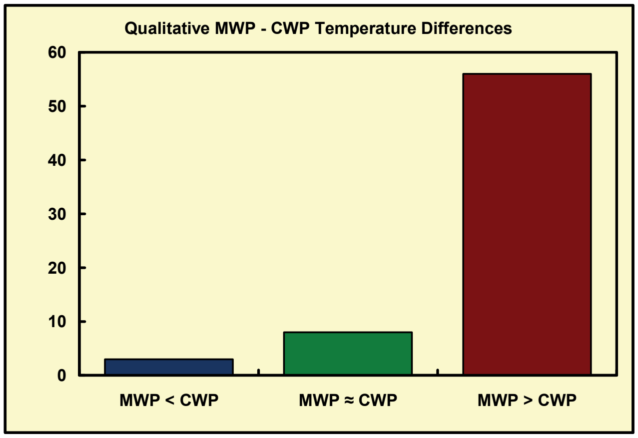

Figure 3.2.5. The distribution of studies that allow one to determine whether peak Medieval Warm Period temperatures were warmer than, equivalent to, or cooler than peak Current Warm Period temperatures.

In the rest of this section, we highlight the results of studies from regions across the globe that show the existence of a Medieval Warm Period. Additional information on this topic, including reviews on the Medieval Warm Period not discussed here, can be found at http://www.co2science.org/subject/m/subject_m.php under the heading Medieval Warm Period.

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3.2.2. Africa

Based on the temperature and water needs of the crops that were cultivated by the first agropastoralists of southern Africa, Huffman (1996) constructed a climate history of the region based on archaeological evidence acquired from various Iron Age settlements. In the course of completing this project, dated relic evidence of the presence of cultivated sorghum and millets was considered by Huffman to be so strong as to essentially prove that the climate of the subcontinent-wide region must have been warmer and wetter than it is today from approximately AD 900-1300, for these crops cannot be grown in this part of southern Africa under current climatic conditions, which are much too cool and dry.

Other evidence for this conclusion comes from Tyson *et al.* (2000), who obtained a quasi-decadal record of oxygen and carbon-stable isotope data from a well-dated stalagmite of Cold Air Cave in the Makapansgat Valley (30 km southwest of Pietersburg, South Africa), which they augmented with five-year-resolution temperature data that they reconstructed from color variations in banded growth-layer laminations of the stalagmite that were derived from a relationship calibrated against actual air temperatures obtained from a surrounding 49-station climatological network over the period 1981-1995, which had a correlation of +0.78 that was significant at the 99 percent confidence level. This record revealed the existence of a significantly warmer-than-present period that began prior to AD 1000 and lasted to about AD 1300. Tyson *et al.* report that the "maximum warming at Makapansgat at around 1250 produced conditions up to 3-4°C hotter than those of the present."

In a similar study, Holmgren *et al.* (2001) derived a 3,000-year temperature record for South Africa that revealed several multi-century warm and cold periods. They found a dramatic warming at approximately AD 900, when temperatures reached a level that was 2.5°C higher than that prevailing at the time of their analysis of the data.

Lamb *et al.* (2003) provided strong evidence for the hydrologic fingerprint of the Medieval Warm Period in Central Kenya in a study of pollen data obtained from a sediment core taken from Crescent Island Crater, which is a sub-basin of Lake Naivasha. Of particular interest in this regard is the strong similarity between their results and those of Verschuren *et al.* (2000). The most striking of these correspondences occurred over the period AD 980 to 1200, when lake-level was at an 1,100-year low and woody taxa were significantly underrepresented in the pollen assemblage.

Holmgren *et al.* (2003) developed a 25,000-year temperature history from a stalagmite retrieved from Makapansgat Valley's Cold Air Cave based on $\delta^{18}O$ and $\delta^{13}C$ measurements dated by ^{14}C and high-precision thermal ionization mass spectrometry using the $^{230}Th/^{234}U$ method. This work revealed, in the words of the nine researchers (together with our interspersed notes), that "cooling is evident from ~6 to 2.5ka [thousand years before present, during the long interval of coolness that preceded the Roman Warm Period], followed by warming between 1.5 and 2.5 ka [the Roman Warm Period] and briefly at ~AD 1200 [the Medieval Warm Period, which followed the Dark Ages Cold Period]," after which "maximum Holocene cooling occurred at AD 1700 [the depth of the Little Ice Age]." They also note that "the Little Ice Age covered the four centuries between AD 1500 and 1800 and at its maximum at AD 1700 represents the most pronounced negative $\delta^{18}O$ deviation in the entire record." This new temperature record from far below the equator (24°S) reveals the existence of all of the major millennial-scale oscillations of climate that are evident in data collected from regions surrounding the North Atlantic Ocean.

Two years later, Kondrashov *et al.* (2005) applied advanced spectral methods to fill data gaps and locate interannual and interdecadal periodicities in historical records of annual low- and high-water levels on the Nile River over the 1,300-year period AD 622-1922. In doing so, several statistically significant periodicities were noted, including cycles at 256, 64, 19, 12, 7, 4.2 and 2.2 years. With respect to the causes of these cycles, the three researchers say that the 4.2- and 2.2-year oscillations are likely due to El Niño-Southern Oscillation variations, that the 7-year cycle may be related to North Atlantic influences, and that the longer-period oscillations could be due to astronomical forcings. They also note that the annual-scale resolution of their results provides a "sharper and more reliable determination of climatic-regime transitions" in tropical east Africa, including the documentation of fairly abrupt shifts in river flow at the beginning and end of the Medieval Warm Period.

Ngomanda *et al.* (2007) derived high-resolution (<40 years) paleoenvironmental reconstructions for the past 1,500 years based on pollen and carbon isotope data obtained from sediment cores retrieved from Lakes Kamalete and Nguene in the lowland rainforest of Gabon. The nine researchers state that after a sharp rise at ~1200 cal yr BP, "A/H [aquatic/hygrophytic] pollen ratios showed intermediate values and varied strongly from 1150 to 870 cal yr BP, suggesting decadal-scale fluctuations in the water balance during the 'Medieval Warm Period'." Thereafter, lower A/H pollen ratios "characterized the interval from ~500 to 300 cal yr BP, indicating lower water levels during the 'Little Ice Age'." In addition, they report that "all inferred lake-level low stands, notably between 500 and 300 cal yr BP, are associated with decreases in the score of the TRFO [Tropical Rainforest] biome."

In discussing their findings, Ngomanda *et al*. state that "the positive co-variation between lake level and rainforest cover changes may indicate a direct vegetational response to regional precipitation variability," noting that "evergreen rainforest expansion occurs during wet intervals, with contraction during periods of drought." It appears that in this part of Western Equatorial Africa, the Little Ice Age was a time of low precipitation, low lake levels, and low evergreen rainforest presence, while much the opposite was the case during the Medieval Warm Period, when fluctuating wet-dry conditions led to fluctuating lake levels and a greater evergreen rainforest presence.

Placing these findings within a broader temporal context, Ngomanda *et al*. additionally note that "rainforest environments during the late Holocene in western equatorial Africa are characterized by successive millennial-scale changes according to pollen (Elenga *et al*., 1994, 1996; Reynaud-Farrera *et al*., 1996; Maley and Brenac, 1998; Vincens *et al*., 1998), diatom (Nguetsop *et al*., 2004), geochemical (Delegue *et al*., 2001; Giresse *et al*., 1994), and sedimentological data (Giresse *et al*., 2005; Wirrmann *et al*., 2001)," and that "these changes were essentially driven by natural climatic variability (Vincens *et al*., 1999; Elenga *et al*., 2004)."

Esper *et al*. (2007) used *Cedrus atlantica* ring-width data "to reconstruct long-term changes in the Palmer Drought Severity Index (PDSI) over the past 953 years in Morocco, Northwest Africa." They report "the long-term PDSI reconstruction indicates generally drier conditions before ~1350, a transition period until ~1450, and generally wetter conditions until the 1970s," after which there were "dry conditions since the 1980s." In addition, they determined that "the driest 20-year period reconstructed is 1237-1256 (PDSI = -4.2)," adding that "1981-2000 conditions are in line with this historical extreme (-3.9)." Also of significance, the six researchers note that "millennium-long temperature reconstructions from Europe (Buntgen *et al*., 2006) and the Northern Hemisphere (Esper *et al*., 2002) indicate that Moroccan drought changes are broadly coherent with well-documented temperature fluctuations including warmth during medieval times, cold in the Little Ice Age, and recent anthropogenic warming," which latter coherency would tend to suggest that the peak warmth of the Medieval Warm Period was at least as great as that of the last two decades of the twentieth century throughout the entire Northern Hemisphere; and, if the coherency is strictly interpreted, it suggests that the warmth of the MWP was likely even greater than that of the late twentieth century.

In light of these research findings, it appears that (1) the Medieval Warm Period did occur over wide reaches of Africa, and (2) the Medieval Warm Period was probably more extreme in Africa than has been the Current Warm Period to this point in time.

Additional information on this topic, including reviews of newer publications as they become available, can be found at http://www.co2science.org/subject/a/africamwp.php.

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3.2.3. Antarctica

Hemer and Harris (2003) extracted a sediment core from beneath the Amery Ice Shelf, East Antarctica, at a point that is currently about 80 km landward of the location of its present edge. In analyzing the core's characteristics over the past 5,700 ^{14}C years, the two scientists observed a peak in absolute diatom abundance in general, and the abundance of *Fragilariopsis curta* in particular—which parameters, in their words, "are associated with increased proximity to an area of primary production, such as the sea-ice zone"—at about 750 ^{14}C yr B.P., which puts the time of maximum Ice Shelf retreat in close proximity to the historical time frame of the Medieval Warm Period.

Khim *et al*. (2002) likewise analyzed a sediment core removed from the eastern Bransfield Basin just off the northern tip of the Antarctic Peninsula, including grain size, total organic carbon content, magnetic susceptibility, biogenic silica content, ^{210}Pb geochronology, and radiocarbon (^{14}C) age, all of which data clearly depicted, in their words, the presence of the "Little Ice Age and Medieval Warm period, together with preceding climatic events of similar intensity and duration."

Hall and Denton (2002) mapped the distribution and elevation of surficial deposits along the southern Scott Coast of Antarctica in the vicinity of the Wilson Piedmont Glacier, which runs parallel to the coast of the western Ross Sea from McMurdo Sound north to

Granite Harbor. The chronology of the raised beaches they studied was determined from more than 60 ^{14}C dates of incorporated organic materials they had previously collected from hand-dug excavations (Hall and Denton, 1999); the record the dates helped define demonstrated that near the end of the Medieval Warm Period, "as late as 890 ^{14}C yr BP," as Hall and Denton describe it, "the Wilson Piedmont Glacier was still less extensive than it is now," demonstrating that the climate of that period was in all likelihood considerably warmer than it is currently.

Noon *et al.* (2003) used oxygen isotopes preserved in authigenic carbonate retrieved from freshwater sediments of Sombre Lake on Signy Island (60°43'S, 45°38'W) in the Southern Ocean to construct a 7,000-year history of that region's climate. This work revealed that the general trend of temperature at the study site has been downward. Of most interest to us, however, is the millennial-scale oscillation of climate that is apparent in much of the record. This climate cycle is such that approximately 2,000 years ago, after a thousand-year gap in the data, Signy Island experienced the relative warmth of the last vestiges of the Roman Warm Period, as delineated by McDermott *et al.* (2001) on the basis of a high-resolution speleothem $\delta^{18}O$ record from southwest Ireland. Then comes the Dark Ages Cold period, which is also contemporaneous with what McDermott *et al.* observe in the Northern Hemisphere, after which the Medieval Warm Period appears at the same point in time and persists for the same length of time that it does in the vicinity of Ireland, whereupon the Little Ice Age sets in just as it does in the Northern Hemisphere. Finally, there is an indication of late twentieth century warming, but with still a long way to go before conditions comparable to those of the Medieval Warm Period are achieved.

Two years later, Castellano *et al.* (2005) derived a detailed history of Holocene volcanism from the sulfate record of the first 360 meters of the Dome Concordia ice core that covered the period 0-11.5 kyr BP, after which they compared their results for the past millennium with similar results obtained from eight other Antarctic ice cores. Before doing so, however, they normalized the results at each site by dividing its several volcanic-induced sulfate deposition values by the value produced at that site by the AD 1816 Tambora eruption, in order to reduce deposition differences among sites that might have been induced by differences in local site characteristics. This work revealed that most volcanic events in the early last millennium (AD 1000-1500) exhibited greater among-site variability in normalized sulphate deposition than was observed thereafter.

Citing Budner and Cole-Dai (2003) in noting that "the Antarctic polar vortex is involved in the distribution of stratospheric volcanic aerosols over the continent," Castellano *et al.* say that assuming the intensity and persistence of the polar vortex in both the troposphere and stratosphere "affect the penetration of air masses to inland Antarctica, isolating the continental area during cold periods and facilitating the advection of peripheral air masses during warm periods (Krinner and Genthon, 1998), we support the hypothesis that the pattern of volcanic deposition intensity and geographical variability [higher values at coastal sites] could reflect a warmer climate of Antarctica in the early last millennium," and that "the re-establishment of colder conditions, starting in about AD 1500, reduced the variability of volcanic depositions."

Describing this phenomenon in terms of what it implies, Castellano *et al.* say "this warm/cold step could be like a Medieval Climate Optimum-like to Little Ice Age-like transition." They additionally cite Goosse *et al.* (2004) as reporting evidence from Antarctic ice-core δD and $\delta^{18}O$ data "in support of a Medieval Warming-like period in the Southern Hemisphere, delayed by about 150 years with respect to Northern Hemisphere Medieval Warming." The researchers conclude by postulating that "changes in the extent and intra-Antarctic variability of volcanic depositional fluxes may have been consequences of the establishment of a Medieval Warming-like period that lasted until about AD 1500."

A year later, Hall *et al.* (2006) collected skin and hair (and even some whole-body mummified remains) from Holocene raised-beach excavations at various locations along Antarctica's Victoria Land Coast, which they identified by both visual inspection and DNA analysis as coming from southern elephant seals, and which they analyzed for age by radiocarbon dating. By these means they obtained data from 14 different locations within their study region—which they describe as being "well south" of the seals' current "core sub-Antarctic breeding and molting grounds"—that indicate that the period of time they denominate the Seal Optimum began about 600 BC and ended about AD1400, the latter of which dates they describe as being "broadly contemporaneous with the onset of Little Ice Age climatic conditions in the Northern Hemisphere and with glacier advance near [Victoria Land's] Terra Nova Bay."

In describing the significance of their findings, the US, British, and Italian researchers say they are indicative of "warmer-than-present climate conditions" at the times and locations of the identified presence of the southern elephant seal, and that "if, as proposed in the literature, the [Ross] ice shelf survived this period, it would have been exposed to environments substantially warmer than present," which would have included both the Roman Warm Period and Medieval Warm Period.

More recently, Williams *et al*. (2007) presented methyl chloride (CH_3Cl) measurements of air extracted from a 300-m ice core that was obtained at the South Pole, Antarctica, covering the time period 160 BC to AD 1860. In describing what they found, the researchers say "CH_3Cl levels were elevated from 900-1300 AD by about 50 ppt relative to the previous 1000 years, coincident with the warm Medieval Climate Anomaly (MCA)," and that they "decreased to a minimum during the Little Ice Age cooling (1650-1800 AD), before rising again to the modern atmospheric level of 550 ppt." Noting that "today, more than 90% of the CH_3Cl sources and the majority of CH_3Cl sinks lie between 30°N and 30°S (Khalil and Rasmussen, 1999; Yoshida *et al*., 2004)," they say "it is likely that climate-controlled variability in CH_3Cl reflects changes in tropical and subtropical conditions." They go on to say that "ice core CH_3Cl variability over the last two millennia suggests a positive relationship between atmospheric CH_3Cl and *global* [our italics] mean temperature."

As best we can determine from the graphical representation of their data, the peak CH_3Cl concentration measured by Williams *et al*. during the MCA is approximately 533 ppt, which is within 3 percent of its current mean value of 550 ppt and well within the range of 520 to 580 ppt that characterizes methyl chloride's current variability. Hence, we may validly conclude that the mean peak temperature of the MCA (which we refer to as the Medieval Warm Period) over the latitude range 30°N to 30°S—and possibly over the entire globe—may not have been materially different from the mean peak temperature so far attained during the Current Warm Period.

This conclusion, along with the findings of the other studies we have reviewed of the climate of Antarctica, suggests there is nothing unusual, unnatural, or unprecedented about the current level of earth's warmth.

Additional information on this topic, including reviews of newer publications as they become available, can be found at http://www.co2science.org/subject/a/antarcticmwp.php.

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3.2.4. Arctic

Dahl-Jensen *et al.* (1998) used temperature measurements from two Greenland Ice Sheet boreholes to reconstruct the temperature history of this portion of the earth over the past 50,000 years. Their data indicate that after the termination of the glacial period, temperatures steadily rose to a maximum of 2.5°C warmer than at present during the Holocene Climatic Optimum (4,000 to 7,000 years ago). The Medieval Warm Period and Little Ice Age were also documented in the record, with temperatures 1°C warmer and 0.5-0.7°C cooler than at present, respectively. After the Little Ice Age, they report that temperatures once again rose, but that they "have decreased during the last decades." These results thus clearly indicate that the Medieval Warm Period in this part of the Arctic was significantly warmer than current temperatures.

Wagner and Melles (2001) also worked on Greenland, where they extracted a 3.5-m-long sediment core from a lake (Raffels So) on an island (Raffles O) located just off Liverpool Land on the east coast of Greenland, which they analyzed for a number of properties related to the past presence of seabirds there, obtaining a 10,000-year record that tells us much about the region's climatic history. Key to the study were biogeochemical data that, in the words of the researchers, reflect "variations in seabird breeding colonies in the catchment which influence nutrient and cadmium supply to the lake."

Wagner and Melles' data reveal sharp increases in the values of the parameters they measured between about 1100 and 700 years before present (BP), indicative of the summer presence of significant numbers of seabirds during that "medieval warm period," as they describe it, which had been preceded by a several-hundred-year period (Dark Ages Cold Period) of little to no bird presence. Thereafter, their data suggest another absence of birds during what they call "a subsequent Little Ice Age," which they note was "the coldest period since the early Holocene in East Greenland."

The Raffels So data also show signs of a "resettlement of seabirds during the last 100 years, indicated by an increase of organic matter in the lake sediment and confirmed by bird observations." However, values of the most recent measurements are not as great as those obtained from the earlier Medieval Warm Period, which indicates that higher temperatures prevailed during the period from 1,100 to 700 years BP than what has been observed over the most recent hundred years.

A third relevant Greenland study was conducted by Kaplan *et al.* (2002), who derived a climatic history of the Holocene by analyzing the physical-chemical properties of sediments obtained from a small lake in southern Greenland. They determined that the interval from 6,000 to 3,000 years BP was marked by warmth and stability, but that the climate cooled thereafter until its culmination in the Little Ice Age. From 1,300-900 years BP, however, there was a partial amelioration during the Medieval Warm Period, which was associated with an approximate 1.5°C rise in temperature.

In a non-Greenland Arctic study, Jiang *et al.* (2002) analyzed diatom assemblages from a high-resolution core extracted from the seabed of the north Icelandic shelf to reconstruct a 4,600-year history of mean summer sea surface temperature at that location. Starting from a maximum value of about 8.1°C at 4,400 years BP, the climate was found to have cooled fitfully for about 1,700 years and then more consistently over the final 2,700 years of the record. The most dramatic departure from this long-term decline was centered on about 850 years BP, during the Medieval Warm Period, when the temperature rose by more than 1°C above the line describing the long-term downward trend to effect an almost complete recovery from the colder temperatures of the Dark Ages Cold Period, after which temperatures continued their descent into the Little Ice Age, ending with a final most recent value of approximately 6.3°C. These data also clearly indicate that the Medieval Warm Period in this part of the Arctic was significantly warmer than it is there now.

Moore *et al*. (2001) analyzed sediment cores from Donard Lake, Baffin Island, Canada, producing a 1,240-year record of average summer temperatures for this Arctic region. Over the entire period from AD 750-1990, temperatures averaged 2.9°C. However, anomalously warm decades with summer temperatures as high as 4°C occurred around AD 1000 and 1100, while at the beginning of the thirteenth century, Donard Lake witnessed "one of the largest climatic transitions in over a millennium," as "average summer temperatures rose rapidly by nearly 2°C from 1195-1220 AD, ending in the warmest decade in the record" with temperatures near 4.5°C.

This rapid warming of the thirteenth century was followed by a period of extended warmth that lasted until an abrupt cooling event occurred around 1375 and made the following decade one of the coldest in the record. This event signaled the onset of the Little Ice Age, which lasted for 400 years, until a gradual warming trend began about 1800, which was followed by a dramatic cooling event in 1900 that brought temperatures back to levels similar to those of the Little Ice Age. This cold regime lasted until about 1950, whereupon temperatures warmed for about two decades but then tended downwards again all the way to the end of the record in 1990. Hence, in this part of the Arctic the Medieval Warm Period was also warmer than it is there currently.

Grudd *et al*. (2002) assembled tree-ring widths from 880 living, dead, and subfossil northern Swedish pines into a continuous and precisely dated chronology covering the period 5407 BC to AD 1997. The strong association between these data and summer (June-August) mean temperatures of the last 129 years of the period then enabled them to produce a 7,400-year history of summer mean temperature for northern Swedish Lapland.

The most dependable portion of this record, based upon the number of trees that were sampled, consisted of the last two millennia, which the authors say "display features of century-timescale climatic variation known from other proxy and historical sources, including a warm 'Roman' period in the first centuries AD and a generally cold 'Dark Ages' climate from about AD 500 to about AD 900." They also note that "the warm period around AD 1000 may correspond to a so-called 'Mediaeval Warm Period,' known from a variety of historical sources and other proxy records." Lastly, they say "the climatic deterioration in the twelfth century can be regarded as the starting point of a prolonged cold period that continued to the first decade of the twentieth century," which "Little Ice Age," in their words, is also "known from instrumental, historical and proxy records." Going back further in time, the tree-ring record displays several more of these relatively warmer and colder periods. They report that "the relatively warm conditions of the late twentieth century do not exceed those reconstructed for several earlier time intervals."

Seppa and Birks (2002) used a recently developed pollen-climate reconstruction model and a new pollen stratigraphy from Toskaljarvi—a tree-line lake in the continental sector of northern Fenoscandia (located just above 69°N latitude)—to derive quantitative estimates of annual precipitation and July mean temperature. As they describe it, their reconstructions "agree with the traditional concept of a 'Medieval Warm Period' (MWP) and 'Little Ice Age' in the North Atlantic region (Dansgaard *et al*., 1975) and in northern Fennoscandia (Korhola *et al*., 2000)." In addition, they report there is "a clear correlation between [their] MWP reconstruction and several records from Greenland ice cores," and that "comparisons of a smoothed July temperature record from Toskaljavri with measured borehole temperatures of the GRIP and Dye 3 ice cores (Dahl-Jensen *et al*., 1998) and the $\delta^{18}O$ record from the Crete ice core (Dansgaard *et al*., 1975) show the strong similarity in timing of the MWP between the records." Finally, they note that "July temperature values during the Medieval Warm Period (ca. 1400-1000 cal yr B.P.) were ca. 0.8°C higher than at present," where present means the last six decades of the twentieth century.

Noting that temperature changes in high latitudes are (1) sensitive indicators of *global* temperature changes, and that they can (2) serve as a basis for verifying climate model calculations, Naurzbaev *et al*. (2002) developed a 2,427-year proxy temperature history for the part of the Taimyr Peninsula of northern Russia that lies between 70°30' and 72°28' North latitude, based on a study of ring-widths of living and preserved larch trees, noting further that "it has been established that the main driver of tree-ring variability at the polar timber-line [where they worked] is temperature (Vaganov *et al*., 1996; Briffa *et al*., 1998; Schweingruber and Briffa, 1996)." In doing so, they found that "the warmest periods over the last two millennia in this region were clearly in the third [Roman Warm Period], tenth to twelfth [Medieval Warm Period] and during the twentieth [Current Warm Period] centuries."

With respect to the second of these periods, they emphasize that "the warmth of the two centuries AD 1058-1157 and 950-1049 attests to the reality of relative mediaeval warmth in this region." Their data also reveal three other important pieces of information: (1) the Roman and Medieval Warm Periods were both warmer than the Current Warm Period has been to date, (2) the "beginning of the end" of the Little Ice Age was somewhere in the vicinity of 1830, and (3) the Current Warm Period peaked somewhere in the vicinity of 1940. All of these observations are at odds with what is portrayed in the thousand-year Northern Hemispheric "hockey stick" temperature history of Mann *et al*. (1998, 1999) and its thousand-year global extension developed by Mann and Jones (2003).

Knudsen *et al*. (2004) documented climatic changes over the past 1,200 years by means of high-resolution multi-proxy studies of benthic and planktonic foraminiferal assemblages, stable isotopes, and ice-rafted debris found in three sediment cores retrieved from the North Icelandic shelf. This work revealed that "the time period between 1200 and around 7,800 cal. years BP, including the Medieval Warm Period, was characterized by relatively high bottom and surface water temperatures," after which "a general temperature decrease in the area marks the transition to ... the Little Ice Age." They also note that "minimum sea-surface temperatures were reached at around 350 cal. BP, when very cold conditions were indicated by several proxies." Thereafter, they say "a modern warming of surface waters ... is *not* [our italics] registered in the proxy data," and that "there is no clear indication of warming of water masses in the area during the last decades," even in sea surface temperatures measured over the period 1948-2002.

Grinsted *et al*. (2006) developed "a model of chemical fractionation in ice based on differing elution rates for pairs of ions ... as a proxy for summer melt (1130-1990)," based on data obtained from a 121-meter-long ice core they extracted from the highest ice field in Svalbard (Lomonosovfonna: 78°51'53"N, 17°25'30"E), which was "validated against twentieth-century instrumental records and longer historical climate proxies." This history indicated that "in the oldest part of the core (1130-1200), the washout indices [were] more than 4 times as high as those seen during the last century, indicating a high degree of runoff." In addition, they report they have performed regular snow pit studies near the ice core site since 1997 (Virkkunen, 2004) and that "the very warm 2001 summer resulted in similar loss of ions and washout ratios as the earliest part of the core." They then state that "this suggests that the Medieval Warm Period in Svalbard summer conditions [was] as warm (or warmer) as present-day, consistent with the Northern Hemisphere temperature reconstruction of Moberg *et al*. (2005)." In addition, they conclude that "the degree of summer melt was significantly larger during the period 1130-1300 than in the 1990s," which likewise suggests that a large portion of the Medieval Warm Period was significantly warmer than the peak warmth (1990s) of the Current Warm Period.

Besonen *et al*. (2008) derived thousand-year histories of varve thickness and sedimentation accumulation rate for Canada's Lower Murray Lake (81°20'N, 69°30'W), which is typically covered for about 11 months of each year by ice that reaches a thickness of 1.5 to 2 meters at the end of each winter. With respect to these parameters, they say—citing seven other studies—that "field-work on other High Arctic lakes clearly indicates that sediment transport and varve thickness are related to temperatures during the short summer season that prevails in this region, and we have no reason to think that this is not the case for Lower Murray Lake."

They found "the twelfth and thirteenth centuries were relatively warm," with their data indicating that Lower Murray Lake and its environs were often much warmer during this time period (AD 1080-1320) than they were at any point in the twentieth century, which has also been shown to be the case for Donard Lake (66.25°N, 62°W) by Moore *et al*. (2001).

The studies reviewed above indicate that the Arctic—which climate models suggest should be sensitive to greenhouse-gas-induced warming—is still not as warm as it was many centuries ago during portions of the Medieval Warm Period, when there was much less CO_2 and methane in the air than there is today. This further suggests the planet's more modest current warmth need not be the result of historical increases in these two greenhouse gases.

Additional information on this topic, including reviews of newer publications as they become available, can be found at http://www.co2science.org/subject/a/arcticmwp.php.

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3.2.5. Asia

3.2.5.1. China

Using a variety of climate records derived from peat, lake sediment, ice core, tree-ring and other proxy sources, Yang *et al.* (2002) identified a period of exceptional warmth throughout China between AD 800 and 1100. Yafeng *et al.* (1999) also observed a warm period between AD 970 and 1510 in $\delta^{18}O$ data obtained from the Guliya ice cap of the Qinghai-Tibet Plateau. Similarly, Hong *et al.* (2000) developed a 6,000-year $\delta^{18}O$ record from plant cellulose deposited in a peat bog in the Jilin Province (42° 20' N, 126° 22' E), within which they found evidence of "an obvious warm period represented by the high $\delta^{18}O$

from around AD 1100 to 1200 which may correspond to the Medieval Warm Epoch of Europe."

Shortly thereafter, Xu *et al*. (2002) determined from a study of plant cellulose $\delta^{18}O$ variations in cores retrieved from peat deposits at the northeastern edge of the Qinghai-Tibet Plateau that from AD 1100-1300 "the $\delta^{18}O$ of Hongyuan peat cellulose increased, consistent with that of Jinchuan peat cellulose and corresponding to the 'Medieval Warm Period'." In addition, Qian and Zhu (2002) analyzed the thickness of laminae in a stalagmite found in Shihua Cave, Beijing, from whence they inferred the existence of a relatively wet period running from approximately AD 940 to 1200.

Hong *et al*. (2000) also report that at the time of the MWP "the northern boundary of the cultivation of citrus tree (*Citrus reticulata* Blanco) and *Boehmeria nivea* (a perennial herb), both subtropical and thermophilous plants, moved gradually into the northern part of China, and it has been estimated that the annual mean temperature was 0.9-1.0°C higher than at present." Considering the climatic conditions required to successfully grow these plants, they further note that annual mean temperatures in that part of the country during the Medieval Warm Period must have been about 1.0°C higher than at present, with extreme January minimum temperatures fully 3.5°C warmer than they are today, citing De'er (1994).

Chu *et al*. (2002) studied the geochemistry of 1,400 years of dated sediments recovered from seven cores taken from three locations in Lake Huguangyan (21°9'N, 110°17'E) on the low-lying Leizhou Peninsula in the tropical region of South China, together with information about the presence of snow, sleet, frost, and frozen rivers over the past 1,000 years obtained from historical documents. They report that "recent publications based on the phenological phenomena, distribution patterns of subtropical plants and cold events (Wang and Gong, 2000; Man, 1998; Wu and Dang, 1998; Zhang, 1994) argue for a warm period from the beginning of the tenth century AD to the late thirteenth century AD," as their own data also suggest. In addition, they note there was a major dry period from AD 880-1260, and that "local historical chronicles support these data, suggesting that the climate of tropical South China was dry during the 'Mediaeval Warm Period'."

Paulsen *et al*. (2003) used high-resolution $\delta^{13}C$ and $\delta^{18}O$ data derived from a stalagmite found in Buddha Cave [33°40'N, 109°05'E] to infer changes in climate in central China for the past 1,270 years. Among the climatic episodes evident in their data were "those corresponding to the Medieval Warm Period, Little Ice Age and 20th-century warming, lending support to the global extent of these events." In terms of timing, the dry-then-wet-then-dry-again MWP began about AD 965 and continued to approximately AD 1475.

Also working with a stalagmite, this one from Jingdong Cave about 90 km northeast of Beijing, Ma *et al*. (2003) assessed the climatic history of the past 3,000 years at 100-year intervals on the basis of $\delta^{18}O$ data, the Mg/Sr ratio, and the solid-liquid distribution coefficient of Mg. They found that between 200 and 500 years ago, "air temperature was about 1.2°C lower than that of the present," but that between 1,000 and 1,300 years ago, there was an equally aberrant but *warm* period that "corresponded to the Medieval Warm Period in Europe."

Based on 200 sets of phenological and meteorological records extracted from a number of historical sources, many of which are described by Gong and Chen (1980), Man (1990, 2004), Sheng (1990), and Wen and Wen (1996), Ge *et al*. (2003) produced a 2,000-year history of winter half-year temperature (October to April, when CO_2-induced global warming is projected to be most evident) for the region of China bounded by latitudes 27° and 40°N and longitudes 107° and 120°E. Their work revealed a significant warm epoch that lasted from the AD 570s to the 1310s, the peak warmth of which was "about 0.3-0.6°C higher than present for 30-year periods, but over 0.9°C warmer on a 10-year basis."

Bao *et al*. (2003) utilized proxy climate records (ice-core $\delta^{18}O$, peat-cellulose $\delta^{18}O$, tree-ring widths, tree-ring stable carbon isotopes, total organic carbon, lake water temperatures, glacier fluctuations, ice-core CH4, magnetic parameters, pollen assemblages, and sedimentary pigments) obtained from 20 prior studies to derive a 2,000-year temperature history of the northeastern, southern and western sections of the Tibetan Plateau. In each case, there was more than one prior 50-year period of time when the mean temperature of each region was warmer than it was over the most recent 50-year period. In the case of the northeastern sector of the plateau, all of the maximum-warmth intervals occurred during the Medieval Warm Period; in the case of the western sector, they occurred near the end of the Roman Warm Period, and in the case of the southern sector they occurred during both warm periods.

From these several studies, it is evident that for a considerable amount of time during the Medieval

Warm Period, many parts of China exhibited warmer conditions than those of modern times. Since those earlier high temperatures were caused by something other than high atmospheric CO_2 concentrations, whatever was responsible for them could be responsible for the warmth of today.

Additional information on this topic, including reviews of newer publications as they become available, can be found at http://www.co2science.org/subject/m/mwpchina.php.

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3.2.5.2. Russia

Demezhko and Shchapov (2001) studied a borehole extending to more than 5 km depth, reconstructing an 80,000-year history of ground surface temperature in the Middle Urals within the western rim of the Tagil subsidence (58°24' N, 59°44'E). The reconstructed temperature history revealed the existence of a number of climatic excursions, including, in their words, the "Medieval Warm Period with a culmination about 1000 years ago."

Further north, Hiller *et al*. (2001) analyzed subfossil wood samples from the Khibiny mountains on the Kola Peninsula of Russia (67-68°N, 33-34°E) in an effort to reconstruct the region's climate history over the past 1,500 years. They determined that between AD 1000 and 1300 the tree-line was located at least 100-140 m above its current elevation. This observation, in their words, suggests that mean summer temperatures during this "Medieval climatic optimum" were "at least 0.8°C higher than today," and that "the Medieval optimum was the most pronounced warm climate phase on the Kola Peninsula during the last 1500 years."

Additional evidence for the Medieval Warm Period in Russia comes from Naurzbaev and Vaganov (2000), who developed a 2,200-year proxy temperature record (212 BC to 1996 AD) using tree-ring data obtained from 118 trees near the upper timberline in Siberia. Based on their results, they concluded that the warming experienced in the twentieth century was "not extraordinary," and that "the warming at the border of the first and second millennia was longer in time and similar in amplitude."

Krenke and Chernavskaya (2002) present an impressive overview of what is known about the MWP within Russia, as well as throughout the world, based on historical evidence, glaciological evidence, hydrologic evidence, dendrological data, archaeological data, and palynological data. Concentrating on data wholly from within Russia, they report large differences in a number of variables between the Little Ice Age (LIA) and MWP. With respect to the annual mean temperature of northern Eurasia, they report an MWP to LIA drop on the order of 1.5°C. They also say that "the frequency of severe winters reported was increased from once in 33 years in the early period of time, which corresponds to the MWP, to once in 20 years in the LIA," additionally noting that "the abnormally severe winters [of the LIA] were associated with the spread of Arctic air masses over the entire Russian Plain." Finally, they note that the data they used to draw these conclusions were "not used in the reconstructions performed by Mann *et al*.," which perhaps explains why the Mann *et al*. temperature history of the past millennium does not depict the coolness of the LIA or the warmth of the MWP nearly as well as the more appropriately derived temperature history of Esper *et al*. (2002).

In discussing their approach to the subject of global warming detection and attribution, the Russians state that "an analysis of climate variations over 1000 years should help … reveal natural multicentennial variations possible at present but not detectable in available 100-200-year series of instrumental records." In this endeavor, they were highly successful, stating unequivocally that "the Medieval Warm Period and the Little Ice Age existed globally."

Additional information on this topic, including reviews of newer publications as they become available, can be found at http://www.co2science.org/subject/m/mwprussia.php.

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3.2.5.3. Other Asia Locations

In addition to China and Russia, the Medieval Warm Period (MWP) has been identified in several other parts of Asia.

Schilman *et al*. (2001) analyzed foraminiferal oxygen and carbon isotopes, together with the physical and geochemical properties of sediments, contained in two cores extracted from the bed of the southeastern Mediterranean Sea off the coast of Israel, where they found evidence for the MWP centered on AD 1200. In discussing their findings, they note there is an abundance of other evidence for the existence of the MWP in the Eastern Mediterranean as well, including, in their words, "high Saharan lake levels (Schoell, 1978; Nicholson, 1980), high Dead Sea levels (Issar *et al*., 1989, 1991; Issar, 1990, 1998; Issar and Makover-Levin, 1996), and high levels of the Sea of Galilee (Frumkin *et al*., 1991; Issar and Makover-Levin, 1996)," in addition to "a precipitation maximum at the Nile headwaters (Bell and Menzel, 1972; Hassan, 1981; Ambrose and DeNiro, 1989) and in the northeastern Arabian Sea (von Rad *et al*., 1999)."

Further to the east, Kar *et al*. (2002) explored the nature of climate change preserved in the sediment profile of an outwash plain two to three km from the snout of the Gangotri Glacier in the Uttarkashi district of Uttranchal, Western Himalaya. Between 2,000 and 1,700 years ago, their data reveal the existence of a relatively cool climate. Then, from 1,700 to 850 years ago, there was what they call an "amelioration of climate," during the transition from the depth of the Dark Ages Cold Period to the midst of the Medieval Warm Period. Subsequent to that time, Kar *et al*.'s data indicate the climate "became much cooler," indicative of its transition to Little Ice Age conditions, while during the last 200 years there has been a rather steady warming, as shown by Esper *et al*. (2002a) to have been characteristic of the entire Northern Hemisphere.

At a pair of other Asian locations, Esper *et al*. (2002b) used more than 200,000 ring-width measurements obtained from 384 trees at 20 individual sites ranging from the lower to upper timberline in the Northwest Karakorum of Pakistan (35-37°N, 74-76°E) and the Southern Tien Shan of Kirghizia (40°10'N, 72°35'E) to reconstruct regional patterns of climatic variations in Western Central Asia since AD 618. According to their analysis, the Medieval Warm Period was already firmly established and growing even warmer by the early seventh century; and between AD 900 and 1000, tree growth was exceptionally rapid, at rates they say "cannot be observed during any other period of the last millennium."

Between AD 1000 and 1200, however, growing conditions deteriorated; and at about 1500, minimum tree ring-widths were reached that persisted well into the seventeenth century. Towards the end of the twentieth century, ring-widths increased once again; but Esper *et al*. (2002b) report that "the twentieth-century trend does not approach the AD 1000 maximum." In fact, there is almost no comparison between the two periods, with the Medieval Warm Period being much more conducive to good tree growth than the Current Warm Period. As the authors describe the situation, "growing conditions in the twentieth century exceed the long-term average, but the amplitude of this trend is not comparable to the conditions around AD 1000."

The latest contribution to Asian temperature reconstruction is the study of Esper *et al*. (2003), who processed several extremely long juniper ring-width chronologies for the Alai Range of the western Tien Shan in Kirghizia in such a way as to preserve multi-centennial growth trends that are typically "lost during the processes of tree ring data standardization and chronology building (Cook and Kairiukstis, 1990; Fritts, 1976)." In doing so, they used two techniques that maintain low frequency signals: long-term mean standardization (LTM) and regional curve standardization (RCS), as well as the more conventional spline standardization (SPL) technique that obscures (actually *removes*) long-term trends.

Carried back in time a full thousand years, the SPL chronologies depict significant inter-decadal variations but no longer-term trends. The LTM and RCS chronologies, on the other hand, show long-term decreasing trends from the start of the record until about AD 1600, broad minima from 1600 to 1800, and long-term increasing trends from about 1800 to the present. As a result, in the words of Esper *et al*. (2003), "the main feature of the LTM and RCS Alai Range chronologies is a multi-centennial wave with high values towards both ends."

This grand result has essentially the same form as the Northern Hemisphere extratropic temperature history of Esper *et al*. (2002a), which is vastly different from the hockey stick temperature history of Mann *et al*. (1998, 1999) and Mann and Jones (2003), in that it depicts the existence of both the Little Ice Age and preceding Medieval Warm Period, which are nowhere to be found in the Mann reconstructions. In addition, the new result—especially the LTM chronology, which has a much smaller variance than the RCS chronology—depicts several periods in the first half of the last millennium that were warmer than any part of the last century. These periods include much of the latter half of the Medieval Warm Period and a good part of the first half of the fifteenth century, which has also been found to have been warmer than it is currently by McIntyre and McKitrick (2003) and by Loehle (2004).

In commenting on their important findings, Esper *et al*. (2003) remark that "if the tree ring reconstruction had been developed using 'standard' detrending procedures only, it would have been limited to inter-decadal scale variation and would have missed some of the common low frequency signal." We would also remark, with respect to the upward trend of their data since 1800, that a good portion of that trend may have been due to the aerial fertilization effect of the concomitantly increasing atmospheric CO_2 content, which is known to greatly stimulate the growth of trees. Properly accounting for this very real effect would make the warmer-than-present temperatures of the first half of the past millennium even warmer, relative to those of the past century, than they appear to be in Esper *et al*.'s LTM and RCS reconstructions.

Additional information on this topic, including reviews of newer publications as they become available, can be found at http://www.co2science.org/subject/a/asiamwp.php.

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3.2.6. Europe

Based on analyses of subfossil wood samples from the Khibiny mountains on the Kola Peninsula of Russia, Hiller *et al*. (2001) were able to reconstruct a 1,500-year history of alpine tree-line elevation. This record indicates that between AD 1000 and 1300, the tree-line there was located at least 100 to 140 meters above its current location. The researchers state that this fact implies a mean summer temperature that was "at least 0.8°C higher than today."

Moving from land to water, in a study of a well-dated sediment core from the Bornholm Basin in the southwestern Baltic Sea, Andren *et al*. (2000) found evidence for a period of high primary production at approximately AD 1050. Many of the diatoms of that period were warm water species that the scientists say "cannot be found in the present Baltic Sea." This balmy period, they report, "corresponds to the time when the Vikings succeeded in colonizing Iceland and Greenland." The warmth ended rather abruptly, however, at about AD 1200, when they note there was "a major decrease in warm water taxa in the diatom assemblage and an increase in cold water taxa," which latter diatoms are characteristic of what they call the Recent Baltic Sea Stage that prevails to this day.

In another marine study, Voronina *et al*. (2001) analyzed dinoflagellate cyst assemblages in two sediment cores retrieved from the southeastern Barents Sea, one spanning a period of 8,300 years and one spanning a period of 4,400 years. The longer of the two cores indicated a warm interval from about 8,000 to 3,000 years before present, followed by cooling pulses coincident with lowered salinity and extended ice cover in the vicinity of 5,000, 3,500, and 2,500 years ago. The shorter core additionally revealed cooling pulses at tentative dates of 1,400, 300, and 100 years before present. For the bulk of the past 4,400 years, however, ice cover lasted only two to three months per year, as opposed to the modern mean of 4.3 months per year. In addition, August temperatures ranged between 6° and 8°C, significantly warmer than the present mean of 4.6°C.

Moving back towards land, Mikalsen *et al*. (2001) made detailed measurements of a number of properties of sedimentary material extracted from the bottom of a fjord on the west coast of Norway, deriving a relative temperature history of the region that spanned the last five millennia. This record revealed the existence of a period stretching from A.D. 1330 to 1600 that, in their words, "had the highest bottom-water temperatures in Sulafjorden during the last 5000 years."

In eastern Norway, Nesje *et al*. (2001) analyzed a sediment core obtained from Lake Atnsjoen, deriving a 4,500-year record of river flooding. They observed "a period of little flood activity around the Medieval period (AD 1000-1400)," which was followed by "a period of the most extensive flood activity in the Atnsjoen catchment." This flooding, in their words, resulted from the "post-Medieval climate deterioration characterized by lower air temperature, thicker and more long-lasting snow cover, and more frequent storms associated with the 'Little Ice Age'."

Working in both Norway and Scotland, Brooks and Birks (2001) studied midges, the larval-stage head capsules of which are well preserved in lake sediments and are, in their words, "widely recognized as powerful biological proxies for inferring past climate change." Applying this technique to sediments derived from a lake in the Cairngorms region of the Scottish Highlands, they determined that temperatures there peaked at about 11°C during what they refer to as the "Little Climatic Optimum"—which we typically call the Medieval Warm Period—

"before cooling by about 1.5°C which may coincide with the 'Little Ice Age'."

These results, according to Brooks and Birks, "are in good agreement with a chironomid stratigraphy from Finse, western Norway (Velle, 1998)," where summer temperatures were "about 0.4°C warmer than the present day" during the Medieval Warm Period. This latter observation also appears to hold for the Scottish site, since the upper sample of the lake sediment core from that region, which was collected in 1993, "reconstructs the modern temperature at about 10.5°C," which is 0.5°C less than the 11°C value the authors found for the Medieval Warm Period.

Moving to Switzerland, Filippi *et al.* (1999) analyzed a sediment core extracted from Lake Neuchatel in the western Swiss Lowlands. During this same transition from the Medieval Warm Period (MWP) to the Little Ice Age (LIA), they detected a drop of approximately 1.5°C in mean annual air temperature. To give some context to this finding, they say that "the warming during the 20th century does not seem to have fully compensated the cooling at the MWP-LIA transition." And to make the message even more clear, they add that during the Medieval Warm Period, the mean annual air temperature was "on average higher than at present."

In Ireland, in a cave in the southwestern part of the country, McDermott *et al.* (2001) derived a $\delta^{18}O$ record from a stalagmite that provided evidence for climatic variations that are "broadly consistent with a Medieval Warm Period at ~1000 ± 200 years ago and a two-stage Little Ice Age." Also evident in the data were the $\delta^{18}O$ signatures of the earlier Roman Warm Period and Dark Ages Cold Period that comprised the preceding millennial-scale cycle of climate in that region.

In another study of three stalagmites found in a cave in northwest Germany, Niggemann *et al.* (2003) discovered that the climate records they contained "resemble records from an Irish stalagmite (McDermott *et al.*, 1999)," specifically noting that their own records provide evidence for the existence of the Little Ice Age, the Medieval Warm Period and the Roman Warm Period, which evidence also implies the existence of what McDermott *et al.* (2001) call the Dark Ages Cold Period that separated the Medieval and Roman Warm Periods, as well as the existence of the unnamed cold period that preceded the Roman Warm Period.

Bodri and Cermak (1999) derived individual ground surface temperature histories from the temperature-depth logs of 98 separate boreholes drilled in the Czech Republic. From these data they detected "the existence of a medieval warm epoch lasting from A.D. 1100-1300," which they describe as "one of the warmest postglacial times. Noting that this spectacular warm period was followed by the Little Ice Age, they went on to suggest that "the observed recent warming may thus be easily a natural return of climate from the previous colder conditions back to a 'normal'."

Filippi *et al.* (1999) share similar views, as is demonstrated by their citing of Keigwin (1996) to the effect that "sea surface temperature (SST) reconstructions show that SST was ca. 1°C cooler than today about 400 years ago and ca. 1°C warmer than today during the MWP." Citing Bond *et al.* (1997), they further note that the MWP and LIA are merely the most recent manifestations of "a pervasive millennial-scale coupled atmosphere-ocean climate oscillation," which, we might add, has absolutely nothing to do with variations in the air's CO_2 content.

Lastly, we report the findings of Berglund (2003), who identified several periods of expansion and decline of human cultures in northwest Europe and compared them with a history of reconstructed climate "based on insolation, glacier activity, lake and sea levels, bog growth, tree line, and tree growth." In doing so, he determined there was a positive correlation between human impact/land-use and climate change. Specifically, in the latter part of the record, where both cultural and climate changes were best defined, there was, in his words, a great "retreat of agriculture" centered on about AD 500, which led to "reforestation in large areas of central Europe and Scandinavia." He additionally notes that "this period was one of rapid cooling indicated from tree-ring data (Eronen *et al.*, 1999) as well as sea surface temperatures based on diatom stratigraphy in [the] Norwegian Sea (Jansen and Koc, 2000), which can be correlated with Bond's event 1 in the North Atlantic sediments (Bond *et al.*, 1997)."

Next came what Berglund calls a "boom period" that covered "several centuries from AD 700 to 1100." This interval of time proved to be "a favourable period for agriculture in marginal areas of Northwest Europe, leading into the so-called Medieval Warm Epoch," when "the climate was warm and dry, with high treelines, glacier retreat, and reduced lake catchment erosion." This period "lasted until around AD 1200, when there was a gradual change to cool/moist climate, the beginning of the

Little Ice Age ... with severe consequences for the agrarian society."

The story from Europe seems quite clear. There was a several-hundred-year period in the first part of the last millennium that was significantly warmer than it is currently. In addition, there is reason to believe the planet may be on a natural climate trajectory that is taking it back to a state reminiscent of the Medieval Warm Period. There is nothing we can do about this natural cycle except, as is implied by the study of Berglund (2003), reap the benefits.

Additional information on this topic, including reviews of newer publications as they become available, can be found at http://www.co2science.org/subject/e/europemwp.php.

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3.2.7. North America

Arseneault and Payette (1997) analyzed tree-ring and growth-form sequences obtained from more than 300 spruce remains buried in a presently treeless peatland in northern Quebec to produce a proxy record of climate for this region of the continent between 690 and 1591 AD. Perhaps the most outstanding feature of this history was the warm period it revealed between 860 and 1000 AD. Based on the fact that the northernmost twentieth century location of the forest tree-line is presently 130 km south of their study site, the scientists concluded that the "Medieval Warm Period was approximately 1°C warmer than the 20th century."

Shifting to the other side of the continent, Calkin *et al.* (2001) carefully reviewed what they termed "the most current and comprehensive research of Holocene glaciation" along the northernmost Gulf of Alaska between the Kenai Peninsula and Yakutat Bay, where they too detected a Medieval Warm Period that lasted for "at least a few centuries prior to A.D. 1200." Also identifying the Medieval Warm Period, as well as other major warm and cold periods of the millennial-scale climatic oscillation that is responsible for them, was Campbell (2002), who analyzed the grain sizes of sediment cores obtained from Pine Lake, Alberta, Canada (52°N, 113.5°W) to provide a non-vegetation-based high-resolution record of climate variability for this part of North America over the past 4,000 years. Periods of both increasing and decreasing grain size (related to moisture availability) were noted throughout the 4,000-year record at decadal, centennial, and millennial time scales. The most predominant departures were several-centuries-long epochs that corresponded to the Little Ice Age (about AD 1500-1900), the Medieval Warm Period (about AD 700-1300), the Dark Ages Cold Period (about BC 100 to AD 700), and the Roman Warm Period (about BC 900-100).

Laird *et al.* (2003) studied diatom assemblages in sediment cores taken from three Canadian and three United States lakes situated within the northern prairies of North America, finding that "shifts in drought conditions on decadal through multicentennial scales have prevailed in this region for at least the last two millennia." In Canada, major shifts occurred near the beginning of the Medieval Warm Period, while in the United States they occurred near its end. In giving some context to these findings, the authors state that "distinct patterns of abrupt change in the Northern Hemisphere are common at or near the termination of the Medieval Warm Period (*ca.* A.D. 800-1300) and the onset of the Little Ice Age (*ca.* A.D. 1300-1850)." They also note that "millennial-scale shifts over at least the past 5,500 years, between sustained periods of wetter and drier conditions, occurring approximately every 1,220 years, have been reported from western Canada (Cumming *et al.*, 2002)," and that "the striking correspondence of these shifts to large changes in fire frequencies, inferred from two sites several hundreds of kilometers to the southwest in the mountain hemlock zone of southern British Columbia (Hallett *et al.*, 2003), suggests that these millennial-scale dynamics are linked and operate over wide spatial scales."

In an effort to determine whether these climate-driven millennial-scale cycles are present in the terrestrial pollen record of North America, Viau *et al.* (2002) analyzed a set of 3,076 ^{14}C dates from the North American Pollen Database used to date sequences in more than 700 pollen diagrams across North America. Results of their statistical analyses indicated there were nine millennial-scale oscillations during the past 14,000 years in which continent-wide synchronous vegetation changes with a periodicity of roughly 1,650 years were recorded in the pollen records. The most recent of the vegetation transitions was centered at approximately 600 years BP (before present). This event, in the words of the authors, "culminat[ed] in the Little Ice Age, with maximum cooling 300 years ago." Prior to that event, a major transition that began approximately 1,600 years BP represents the climatic amelioration that "culminat[ed] in the maximum warming of the Medieval Warm Period 1000 years ago."

And so it goes, on back through the Holocene and into the preceding late glacial period, with the times of all major pollen transitions being "consistent," in the words of the authors of the study, "with ice and marine records." Viau *et al.* additionally note that "the large-scale nature of these transitions and the fact that they are found in different proxies confirms the hypothesis that Holocene and late glacial climate variations of millennial-scale were abrupt transitions between climatic regimes as the atmosphere-ocean system reorganized in response to some forcing." They go on to say that "although several mechanisms for such *natural* [our italics] forcing have been advanced, recent evidence points to a potential solar forcing (Bond *et al.*, 2001) associated with ocean-atmosphere feedbacks acting as global teleconnections agents." Furthermore, they note that "these transitions are identifiable across North America and presumably the world."

Additional evidence for the solar forcing of these millennial-scale climate changes is provided by Shindell *et al.* (2001), who used a version of the Goddard Institute for Space Studies GCM to estimate climatic differences between the period of the Maunder Minimum in solar irradiance (mid-1600s to early 1700s) and a century later, when solar output was relatively high for several decades. Their results compared so well with historical and proxy climate data that they concluded, in their words, that "colder winter temperatures over the Northern Hemispheric continents during portions of the 15th through the 17th centuries (sometimes called the Little Ice Age) and warmer temperatures during the 12th through 14th centuries (the putative Medieval Warm Period) may have been influenced by long-term solar variations."

Rounding out our mini-review of the Medieval Warm Period in North America are two papers dealing with the climatic history of the Chesapeake Bay region of the United States. The first, by Brush (2001), consists of an analysis of sediment cores obtained from the Bay's tributaries, marshes and main stem that covers the past millennium, in which it is reported that "the Medieval Climatic Anomaly and the Little Ice Age are recorded in Chesapeake sediments by terrestrial indicators of dry conditions for 200 years, beginning about 1000 years ago, followed by increases in wet indicators from about 800 to 400 years ago."

Willard *et al*. (2003) studied the same region for the period 2,300 years BP to the present, via an investigation of fossil dinoflagellate cysts and pollen from sediment cores. Their efforts revealed that "several dry periods ranging from decades to centuries in duration are evident in Chesapeake Bay records." The first of these periods of lower-than-average precipitation, which spanned the period 200 BC-AD 300, occurred during the latter part of the Roman Warm Period, as delineated by McDermott *et al*. (2001) on the basis of a high-resolution speleothem $\delta^{18}O$ record from southwest Ireland. The next such dry period (~AD 800-1200), in the words of the authors, "corresponds to the 'Medieval Warm Period', which has been documented as drier than average by tree-ring (Stahle and Cleaveland, 1994) and pollen (Willard *et al*., 2001) records from the southeastern USA."

Willard *et al*. go on to say that "mid-Atlantic dry periods generally correspond to central and southwestern USA 'megadroughts', described by Woodhouse and Overpeck (1998) as major droughts of decadal or more duration that probably exceeded twentieth-century droughts in severity." They further indicate that "droughts in the late sixteenth century that lasted several decades, and those in the 'Medieval Warm Period' and between ~AD 50 and AD 350 spanning a century or more have been indicated by Great Plains tree-ring (Stahle *et al*., 1985; Stahle and Cleaveland, 1994), lacustrine diatom and ostracode (Fritz *et al*., 2000; Laird *et al*., 1996a, 1996b) and detrital clastic records (Dean, 1997)."

It is evident that the Medieval Warm Period has left its mark throughout North America in the form of either warm temperature anomalies or periods of relative dryness.

Additional information on this topic, including reviews of newer publications as they become available, can be found at http://www.co2science.org/subject/n/northamericamwp.php.

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3.2.8. South America

In Argentina, Cioccale (1999) assembled what was known at the time about the climatic history of the central region of that country over the past 1,400 years, highlighting a climatic "improvement" that began some 400 years before the start of the last millennium, which ultimately came to be characterized by "a marked increase of environmental suitability, under a relatively homogeneous climate." As a result of this climatic amelioration that marked the transition of the region from the Dark Ages Cold Period to the Medieval Warm Period, Cioccale says "the population located in the lower valleys ascended to higher areas in the Andes," where they remained until around AD 1320, when the transition to the stressful and extreme climate of the Little Ice Age began.

Down at the southern tip of the country in Tierra del Fuego, Mauquoy *et al.* (2004) inferred similar changes in temperature and/or precipitation from plant macrofossils, pollen, fungal spores, testate amebae, and humification associated with peat monoliths collected from the Valle de Andorra. These new chronologies were compared with other chronologies of pertinent data from both the Southern and Northern Hemispheres in an analysis that indicated there was evidence for a period of warming-induced drier conditions from AD 960-1020, which, in their words, "seems to correspond to the Medieval Warm Period (MWP, as derived in the Northern Hemisphere)." They note that "this interval compares well to the date range of AD 950-1045 based on Northern Hemisphere extratropical tree-ring data (Esper *et al.*, 2002)," and they conclude that this correspondence "shows that the MWP was possibly synchronous in both hemispheres, as suggested by Villalba (1994)."

In Chile, Jenny *et al*. (2002) studied geochemical, sedimentological, and diatom-assemblage data derived from sediment cores extracted from one of the largest natural lakes (Laguna Aculeo) in the central part of the country. From 200 BC, when the record began, until AD 200, conditions there were primarily dry, during the latter stages of the Roman Warm Period. Subsequently, from AD 200-700, with a slight respite in the central hundred years of that period, there was a high frequency of flood events, during the Dark Ages Cold Period. Then came a several-hundred-year period of less flooding that was coeval with the Medieval Warm Period. This more benign period was then followed by another period of frequent flooding from 1300-1700 that was coincident with the Little Ice Age, after which flooding picked up again after 1850.

In Peru, Chepstow-Lusty *et al.* (1998) derived a 4,000-year climate history from a study of pollen in sediment cores obtained from a recently in-filled lake in the Patacancha Valley near Marcacocha. Their data indicated a several-century decline in pollen content after AD 100, as the Roman Warm Period gave way to the Dark Ages Cold Period. However, a "more optimum climate," as they describe it, with warmer temperatures and drier conditions, came into being and prevailed for several centuries after about AD 900, which was, of course, the Medieval Warm Period, which was followed by the Little Ice Age, all of which climatic periods are in nearly perfect temporal agreement with the climatic history derived by McDermott *et al.* (2001) from a study of a stalagmite recovered from a cave nearly half the world away in Ireland.

Subsequent work in this area was conducted by Chepstow-Lusty and Winfield (2000) and Chepstow-Lusty *et al.* (2003). Centered on approximately 1,000 years ago, Chepstow-Lusty and Winfield researchers identified what they describe as "the warm global climatic interval frequently referred to as the Medieval Warm Epoch." This extremely *arid* interval in this part of South America, in their opinion, may have played a significant role in the collapse of the Tiwanaku civilization further south, where a contemporaneous prolonged drought occurred in and around the area of Lake Titicaca (Binford *et al.*, 1997; Abbott *et al.*, 1997).

Near the start of this extended dry period, which had gradually established itself between about AD 700 and 1000, Chepstow-Lusty and Winfield report that "temperatures were beginning to increase after a sustained cold period that had precluded agricultural activity at these altitudes." This earlier colder and wetter interval was coeval with the Dark Ages Cold Period of the North Atlantic region, which in the Peruvian Andes had held sway for a good portion of the millennium preceding AD 1000, as revealed by a series of climatic records developed from sediment cores extracted from yet other lakes in the Central Peruvian Andes (Hansen *et al.*, 1994) and by proxy evidence of concomitant Peruvian glacial expansion (Wright, 1984; Seltzer and Hastorf, 1990).

Preceding the Dark Ages Cold Period in both parts of the world was what in the North Atlantic region is called the Roman Warm Period. This well-defined climatic epoch is also strikingly evident in the pollen records of Chepstow-Lusty *et al.* (2003), straddling the BC/AD calendar break with one to two hundred years of relative warmth and significant aridity on both sides of it.

Returning to the Medieval Warm Period and proceeding towards the present, the data of Chepstow-Lusty *et al.* (2003) reveal the occurrence of the Little Ice Age, which in the Central Peruvian Andes was characterized by relative coolness and wetness. These characteristics of that climatic interval are also evident in ice cores retrieved from the Quelccaya ice cap in southern Peru, the summit of which extends 5,670 meters above mean sea level (Thompson *et al.*, 1986, 1988). Finally, both the Quelccaya ice core data and the Marcacocha pollen data reveal the transition to the drier Current Warm Period that occurred over the past 100-plus years.

In harmony with these several findings are the related observations of Rein *et al.* (2004), who derived a high-resolution flood record of the entire Holocene from an analysis of the sediments in a 20-meter core retrieved from a sheltered basin situated on the edge of the Peruvian shelf about 80 km west of Lima. These investigators found a major Holocene anomaly in the flux of lithic components from the continent onto the Peruvian shelf during the Medieval period. Specifically, they report that "lithic concentrations were very low for about 450 years during the Medieval climatic anomaly from A.D. 800 to 1250." In fact, they state that "all known terrestrial deposits of El Niño mega-floods (Magillian and Goldstein, 2001; Wells, 1990) precede or follow the medieval anomaly in our marine records and none of the El Niño mega-floods known from the continent date within the marine anomaly." In addition, they report that "this precipitation anomaly also occurred in other high-resolution records throughout the ENSO domain," citing 11 other references in support of this statement.

Consequently, because heavy winter rainfalls along and off coastal Peru occur only during times of maximum El Niño strength, and because El Niños are typically more prevalent and stronger during cooler as opposed to warmer periods (see El Niño (Relationship to Global Warming) in Chapter 5), the lack of strong El Niños from A.D. 800 to 1250 suggests that this period was truly a Medieval Warm Period; and the significance of this observation was not lost on Rein *et al.* In the introduction to their paper, they note that "discrepancies exist between the Mann curve and alternative time series for the Medieval period." Most notably, to use their words, "the global Mann curve has no temperature optimum, whereas the Esper *et al.* (2002) reconstruction shows northern hemisphere temperatures almost as high as those of the 20th century" during the Medieval period. As a result, in the final sentence of their paper they suggest that "the occurrence of a Medieval climatic anomaly (A.D.

800-1250) with persistently weak El Niños may therefore assist the interpretation of some of the regional discrepancies in thermal reconstructions of Medieval times," which is a polite way of suggesting that the Mann *et al.* (1998, 1999) hockey stick temperature history is deficient in not depicting the presence of a true Medieval Warm Period.

In Venezuala, Haug *et al.* (2001) found a temperature/precipitation relationship that was different from that of the rest of the continent. In examining the titanium and iron concentrations of an ocean sediment core taken from the Cariaco Basin on the country's northern shelf, they determined that the concentrations of these elements were lower during the Younger Dryas cold period between 12.6 and 11.5 thousand years ago, corresponding to a weakened hydrologic cycle with less precipitation and runoff, while during the warmth of the Holocene Optimum of 10.5 to 5.4 thousand years ago, titanium and iron concentrations remained at or near their highest values, suggesting wet conditions and an enhanced hydrologic cycle. Closer to the present, higher precipitation was also noted during the Medieval Warm Period from 1.05 to 0.7 thousand years ago, followed by drier conditions associated with the Little Ice Age between 550 and 200 years ago.

In an update of this study, Haug *et al.* (2003) developed a hydrologic history of pertinent portions of the record that yielded "roughly bi-monthly resolution and clear resolution of the annual signal." This record revealed that "before about 150 A.D.," which according to the climate history of McDermott *et al.* corresponds to the latter portion of the Roman Warm Period (RWP), Mayan civilization had flourished. However, during the transition to the Dark Ages Cold Period (DACP), which was accompanied by a slow but long decline in precipitation, Haug *et al.* report that "the first documented historical crisis hit the lowlands, which led to the 'Pre-Classic abandonment' (Webster, 2002) of major cities."

This crisis occurred during the first intense multi-year drought of the RWP-to-DACP transition, which was centered on about the year 250 A.D. Although the drought was devastating to the Maya, Haug *et al.* report that when it was over, "populations recovered, cities were reoccupied, and Maya culture blossomed in the following centuries during the so-called Classic period." Ultimately, however, there came a time of reckoning, between about 750 and 950 A.D., during what Haug *et al.* determined was the driest interval of the entire Dark Ages Cold Period, when they report that "the Maya experienced a demographic disaster as profound as any other in human history," in response to a number of other intense multi-year droughts. During this Terminal Classic Collapse, as it is called, Haug *et al.* say that "many of the densely populated urban centers were abandoned permanently, and Classic Maya civilization came to an end."

In assessing the significance of these several observations near the end of their paper, Haug *et al.* conclude that the latter droughts "were the most severe to affect this region in the first millennium A.D." Although some of these spectacular droughts were "brief," lasting "only" between three and nine years, Haug *et al.* report "they occurred during an extended period of reduced overall precipitation that may have already pushed the Maya system to the verge of collapse."

Although the Mayan civilization thus faded away, Haug *et al.*'s data soon thereafter depict the development of the Medieval Warm Period, when the Vikings established their historic settlement on Greenland. Then comes the Little Ice Age, which just as quickly led to the Vikings' demise in that part of the world. This distinctive cold interval of the planet's millennial-scale climatic oscillation also must have led to hard times for the people of Mesoamerica and northern tropical South America; according to the data of Haug *et al.*, the Little Ice Age produced the lowest precipitation regime (of several hundred years' duration) of the last two millennia in that part of the world.

In conclusion, it is difficult to believe that the strong synchronicity of the century-long Northern Hemispheric and South American warm and cold periods described above was coincidental. It is much more realistic to believe it was the result of a millennial-scale oscillation of climate that is global in scope and driven by some regularly varying forcing factor. Although one can argue about the identity of that forcing factor and the means by which it exerts its influence, one thing should be clear: It is not the atmosphere's CO_2 concentration, which has exhibited a significant in-phase variation with global temperature change only over the Little Ice Age to Current Warm Period transition. This being the case, it should be clear that the climatic amelioration of the past century or more has had little or nothing to do with the concomitant rise in the air's CO_2 content but *everything* to do with the influential forcing factor that has governed the millennial-scale oscillation of earth's climate as far back in time as we have been able to detect it.

Additional information on this topic, including reviews of newer publications as they become available, can be found at http://www.co2science.org/subject/s/southamericamwp.php.

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3.3. Urban Heat Islands

How accurate are the surface temperature records cited by the IPCC as showing unprecedented millennial warmth over the past couple decades? The IPCC considers them very accurate and nearly free of any contaminating influence, yielding a 1905-2005 increase of 0.74°C ± 0.18°C (IPCC, 2007-I, p. 237). Warming in many growing cities, on the other hand, may have been a full order of magnitude greater. Since nearly all near-surface air temperature records of this period have been obtained from sensors located in population centers that have experienced significant growth, it is essential that urban heat island (UHI) effects be removed from all original temperature records when attempting to accurately assess what has truly happened in the natural non-urban environment.

The IPCC dismisses this concern, saying the UHI is "an order of magnitude smaller than decadal and longer time-scale trends" (p. 244) and "UHI effects are real but local, and have a negligible influence (less than 0.006° C per decade over land and zero over the oceans) on these [observed temperature] values" (p. 5). On this extremely important matter, the IPCC is simply wrong, as the rest of this section demonstrates.

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3.3.1. Global

Hegerl *et al*. (2001) describe UHI-induced temperature perversions as one of three types of systematic error in the surface air temperature record whose magnitude "cannot be assessed at present." Nevertheless, they go on to do just that, claiming "it has been estimated that temperature trends over rural stations only are very similar to trends using all station data, suggesting that the effect of urbanization on estimates of global-scale signals should be small." This statement is patently false.

De Laat and Maurellis (2004) used a global dataset developed by Van Aardenne *et al*. (2001), which reveals the spatial distribution of various levels of industrial activity over the planet as quantified by the intensity of anthropogenic CO_2 emissions to divide the surface of the earth into non-industrial and industrial sectors of various intensity levels, after which they plotted the 1979-2001 temperature trends (°C/decade) of the different sectors using data from both the surface and the lower and middle troposphere.

The two scientists report that "measurements of surface and lower tropospheric temperature change give a very different picture from climate model predictions and show strong observational evidence that the degree of industrialization is correlated with surface temperature increases as well as lower tropospheric temperature changes." Specifically, they find that the surface and lower tropospheric warming trends of all industrial regions are greater than the mean warming trend of the earth's non-industrial regions, and that the difference in warming rate between the two types of land use grows ever larger as the degree of industrialization increases.

In discussing the implications of their findings, De Laat and Maurellis say "areas with larger temperature trends (corresponding to higher CO_2 emissions) cover a considerable part of the globe," which implies that "the 'real' global mean surface temperature trend is very likely to be considerably smaller than the temperature trend in the CRU [Hadley Center/Climate Research Unit] data," since the temperature measurements that comprise that data base "are often conducted in the vicinity of human (industrial) activity." These observations, in their words, "suggest a hitherto-overlooked driver of local surface temperature increases, which is linked to the degree of industrialization" and "lends strong support to other indications that surface processes (possibly changes in land-use or the urban heat effect) are crucial players in observed surface temperature changes (Kalnay and Cai, 2003; Gallo *et al*., 1996, 1999)." They conclude that "the observed surface temperature changes might be a result of local surface heating processes and not related to radiative greenhouse gas forcing."

A similar study was conducted by McKitrick and Michaels (2004), who calculated 1979-2000 linear trends of monthly mean near-surface air temperature for 218 stations in 93 countries, based upon data they obtained from the Goddard Institute of Space Studies (GISS), after which they regressed the results against indicators of local economic activity—such as income, gross domestic product growth rates, and coal use—to see if there was any evidence of these socioeconomic factors affecting the supposedly "pristine as possible" temperature data. Then, they repeated the process using the gridded surface air temperature data of the IPCC.

The two scientists report that the spatial pattern of trends they derived from the GISS data was "significantly correlated with non-climatic factors, including economic activity and sociopolitical characteristics." Likewise, with respect to the IPCC data, they say "very similar correlations appear, despite previous attempts to remove non-climatic effects." These "socioeconomic effects," in the words of McKitrick and Michaels, "add up to a net warming bias," although they say "precise estimation of its magnitude will require further work."

We can get a good feel for the magnitude of the "socioeconomic effect" in some *past* work, such as that of Oke (1973), who measured the urban heat island strength of 10 settlements in the St. Lawrence Lowlands of Canada that had populations ranging from approximately 1,000 to 2,000,000 people, after which he compared his results with those obtained for a number of other cities in North America, as well as some in Europe. Over the population range studied, Oke found that the magnitude of the urban heat island was linearly correlated with the logarithm of population; this relationship indicated that at the lowest population value encountered, i.e., 1,000 inhabitants, there was an urban heat island effect of 2° to 2.5°C, which warming is more than twice as great as the increase in mean global air temperature believed to have occurred since the end of the Little Ice Age. It should be abundantly clear there is ample opportunity for large errors to occur in thermometer-derived surface air temperature histories of the twentieth century, and that error is probably best described as a large and growing warming bias.

That this urban heat island-induced error has indeed corrupted data bases that are claimed to be immune from it is suggested by the work of Hegerl and Wallace (2000), who attempted to determine if trends in recognizable atmospheric modes of variability could account for all or part of the observed trend in surface-troposphere temperature differential, i.e., lapse rate, which has been driven by the upward-inclined trend in surface-derived temperatures and the nearly level trend in satellite-derived tropospheric temperatures over the last two decades of the twentieth century. After doing everything they could conceive of doing, they had to conclude that "modes of variability that affect surface temperature cannot explain trends in the observed lapse rate," and that "no mechanism with clear spatial or time structure can be found that accounts for that trend." In addition, they had to acknowledge that "all attempts to explain all or a significant part of the observed lapse rate trend by modes of climate variability with structured patterns from observations have failed," and that "an approach applying model data to isolate such a pattern has also failed." Nor could they find any evidence "that interdecadal variations in radiative forcing, such as might be caused by volcanic eruptions, variations in solar output, or stratospheric ozone depletion alone, offer a compelling explanation." Hence, the two scientists ultimately concluded that "there remains a gap in our fundamental understanding of the processes that cause the lapse rate to vary on interdecadal timescales."

On the other hand, the reason why no meteorological or climatic explanation could be found for the ever-increasing difference between the surface- and satellite-derived temperature trends of the past 20-plus years may be that one of the temperature records is incorrect. Faced with this possibility, one would logically want to determine which of the records is likely to be erroneous and then assess the consequences of that determination. Although this task may seem daunting, it is really not that difficult. One reason why is the good correspondence Hegerl and Wallace found to exist between the satellite and radiosonde temperature trends, which leaves little reason for doubting the veracity of the satellite results, since this comparison essentially amounts to an *in situ* validation of the satellite record. A second important reason comes from the realization that it would be extremely easy for a spurious warming of 0.12°C per decade to be introduced into the surface air temperature trend as a consequence of the worldwide intensification of the urban heat island effect that was likely driven by the world population increase that occurred in most of the places where surface air temperature measurements were made over the last two decades of the twentieth century.

It appears almost certain that surface-based temperature histories of the globe contain a significant warming bias introduced by insufficient corrections for the *non*-greenhouse-gas-induced urban heat island effect. Furthermore, it may well be next to impossible to make proper corrections for this deficiency, as the urban heat island of even small towns *dwarfs* any concomitant augmented greenhouse effect that may be present.

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3.3.2. North America

In studying the urban heat island (UHI) of Houston, Texas, Streutker (2003) analyzed 82 sets of nighttime radiation data obtained from the split-window infrared channels of the Advanced Very High Resolution Radiometer on board the NOAA-9 satellite during March 1985 through February 1987 and from 125 sets of similar data obtained from the NOAA-14 satellite during July 1999 through June 2001. Between these two periods, it was found that the mean nighttime surface temperature of Houston rose by 0.82 ± 0.10 °C. In addition, Streutker notes that the growth of the Houston UHI, both in magnitude and spatial extent, "scales roughly with the increase in population," and that the mean rural temperature measured during the second interval was "virtually identical to the earlier interval."

This informative study demonstrates that the UHI phenomenon can sometimes be very powerful, for in just 12 years the UHI of Houston grew by more than the IPCC contends the mean surface air temperature of the planet rose over the entire past century, during which period earth's population rose by approximately 280 percent, or nearly an order of magnitude more than the 30 percent population growth experienced by Houston over the 12 years of Streutker's study.

A very different type of study was conducted by Maul and Davis (2001), who analyzed air and seawater temperature data obtained over the past century at the sites of several primary tide gauges maintained by the U.S. Coast and Geodetic Survey. Noting that each of these sites "experienced significant population growth in the last 100 years," and that "with the increase in maritime traffic and discharge of wastewater one would expect water temperatures to rise" (due to a maritime analogue of the urban heat island effect), they calculated trends for the 14 longest records and derived a mean century-long seawater warming of 0.74°C, with Boston registering a 100-year warming of 3.6°C. In addition, they report that air temperature trends at the tide gauge sites, which represent the standard urban heat island effect, were "much larger" than the seawater temperature trends.

In another different type of study, Dow and DeWalle (2000) analyzed trends in annual evaporation and Bowen ratio measurements on 51 eastern U.S. watersheds that had experienced various degrees of urbanization between 1920 and 1990. In doing so, they determined that as residential development progressively occurred on what originally were rural watersheds, watershed evaporation decreased and sensible heating of the atmosphere increased. And from relationships derived from the suite of watersheds investigated, they calculated that complete transformation from 100 percent rural to 100 percent urban characteristics resulted in a 31 percent decrease in watershed evaporation and a 13 W/m^2 increase in sensible heating of the atmosphere.

Climate modeling exercises suggest that a doubling of the air's CO_2 concentration will result in a nominal 4 W/m^2 increase in the radiative forcing of earth's surface-troposphere system, which has often been predicted to produce an approximate 4°C increase in the mean near-surface air temperature of the globe, indicative of an order-of-magnitude climate sensitivity of 1°C per W/m^2 change in radiative forcing. Thus, to a first approximation, the 13 W/m^2 increase in the sensible heating of the near-surface atmosphere produced by the total urbanization of a pristine rural watershed in the eastern United States could be expected to produce an increase of about 13°C in near-surface air temperature over the central portion of the watershed, which is consistent with maximum urban heat island effects observed in large and densely populated cities. Hence, a 10 percent rural-to-urban transformation could well produce a warming on the order of 1.3°C, and a mere 2 percent transformation could increase the near-surface air temperature by as much as a quarter of a degree Centigrade.

This powerful anthropogenic but non-greenhouse-gas-induced effect of urbanization on the energy balance of watersheds and the temperature of the boundary-layer air above them begins to express itself with the very first hint of urbanization and, hence, may be readily overlooked in studies seeking to identify a greenhouse-gas-induced global warming signal. In fact, the fledgling urban heat island effect may already be present in many temperature records that have routinely been considered "rural enough" to be devoid of all human influence.

A case in point is provided by the study of Changnon (1999), who used a series of measurements of soil temperatures obtained in a totally rural setting in central Illinois between 1889 and 1952 and a contemporary set of air temperature measurements made in an adjacent growing community (as well as similar data obtained from other nearby small towns), to evaluate the magnitude of unsuspected heat island effects that may be present in small towns and cities that are typically assumed to be free of urban-induced warming. This work revealed that soil temperature in the totally rural setting experienced an increase from the decade of 1901-1910 to the decade of 1941-1950 that amounted to 0.4°C.

This warming is 0.2°C *less* than the 0.6°C warming determined for the same time period from the entire dataset of the U.S. Historical Climatology Network, which is supposedly corrected for urban heating effects. It is also 0.2°C less than the 0.6°C warming determined for this time period by 11 benchmark stations in Illinois with the highest quality long-term temperature data, all of which are located in communities that had populations of less than 6,000 people as of 1990. And it is 0.17°C less than the 0.57°C warming derived from data obtained at the three benchmark stations closest to the site of the soil temperature measurements and with populations of less than 2,000 people.

Changnon says his findings suggest that "both sets of surface air temperature data for Illinois believed to have the best data quality with little or no urban effects may contain urban influences causing increases of 0.2°C from 1901 to 1950." He further notes—in a grand understatement—that "this could be significant because the IPCC (1995) indicated that the global mean temperature increased 0.3°C from 1890 to 1950."

DeGaetano and Allen (2002b) used data from the U.S. Historical Climatology Network to calculate trends in the occurrence of maximum and minimum temperatures greater than the 90th, 95th, and 99th percentile across the United States over the period 1960-1996. In the case of daily warm minimum temperatures, the slope of the regression line fit to the data of a plot of the annual number of 95th percentile exceedences vs. year was found to be 0.09 exceedences per year for rural stations, 0.16 for suburban stations, and 0.26 for urban stations, making the rate of increase in extreme warm minimum temperatures at urban stations nearly three times greater than the rate of increase at rural stations less affected by growing urban heat islands. Likewise, the rate of increase in the annual number of daily maximum temperature 95th percentile exceedences per year over the same time period was found to be 50 percent greater at urban stations than it was at rural stations.

Working on the Arctic Coastal Plain near the Chuckchi Sea at Barrow, Alaska—which is described by Hinkel *et al.* (2003) as "the northernmost settlement in the USA and the largest native community in the Arctic," the population of which "has grown from about 300 residents in 1900 to more than 4600 in 2000"—the four researchers installed 54 temperature-recording instruments in mid-June of 2001, half of them within the urban area and the other half distributed across approximately 150 km^2 of surrounding land, all of which provided air temperature data at hourly intervals approximately two meters above the surface of the ground. In this paper, they describe the results they obtained for the following winter. Based on urban-rural spatial averages for the entire winter period (December 2001-March 2002), they determined the urban area to be 2.2°C warmer than the rural area. During this period, the mean daily urban-rural temperature difference increased with decreasing temperature, "reaching a peak value of around 6°C in January-February." It was also determined that the daily urban-rural temperature difference increased with decreasing wind speed, such that under calm conditions (< 2 m s^{-1}) the daily urban-rural temperature difference was 3.2°C in the winter. Last of all, under simultaneous calm and cold conditions, the urban-rural temperature difference was observed to achieve hourly magnitudes exceeding 9°C.

Four years later, Hinkel and Nelson (2007) reported that for the period 1 December to 31 March of four consecutive winters, the spatially averaged temperature of the urban area of Barrow was about 2°C warmer than that of the rural area, and that it was not uncommon for the daily magnitude of the urban heat island to exceed 4°C. In fact, they say that on some days the magnitude of the urban heat island exceeded 6°C, and that values in excess of 8°C were sometimes recorded, while noting that the warmest individual site temperatures were "consistently observed in the urban core area."

These results indicate just how difficult it is to measure a background global temperature increase that is believed to have been less than 1°C over the past century (representing a warming of less than 0.1°C per decade), when the presence of a mere 4,500 people can create a winter heat island that may be two orders of magnitude greater than the signal being sought. Clearly, there is no way that temperature measurements made within the range of influence of even a small village can be adjusted to the degree of accuracy that is required to reveal the true magnitude of the pristine rural temperature change.

Moving south, we find Ziska *et al*. (2004) working within and around Baltimore, Maryland, where they characterized the gradual changes that occur in a number of environmental variables as one moves from a rural location (a farm approximately 50 km from the city center) to a suburban location (a park approximately 10 km from the city center) to an urban location (the Baltimore Science Center approximately 0.5 km from the city center). At each of these locations, four 2 x 2 m plots were excavated to a depth of about 1.1 m, after which they were filled with identical soils, the top layers of which contained seeds of naturally occurring plants of the area. These seeds sprouted in the spring of the year, and the plants they produced were allowed to grow until they senesced in the fall, after which all of them were cut at ground level, removed, dried and weighed.

Ziska *et al*. report that along the rural-to-suburban-to-urban transect, the only consistent differences in the environmental variables they measured were a rural-to-urban increase of 21 percent in average daytime atmospheric CO_2 concentration and increases of 1.6 and 3.3°C in maximum (daytime) and minimum (nighttime) daily temperatures, respectively, which changes, in their words, are "consistent with most short-term (~50 year) global change scenarios regarding CO_2 concentration and air temperature." In addition, they determined that "productivity, determined as final above-ground biomass, and maximum plant height were positively affected by daytime and soil temperatures as well as enhanced CO_2, increasing 60 and 115% for the suburban and urban sites, respectively, relative to the rural site."

The three researchers say their results suggest that "urban environments may act as a reasonable surrogate for investigating future climatic change in vegetative communities," and those results indicate that rising air temperatures and CO_2 concentrations tend to produce dramatic increases in the productivity of the natural ecosystems typical of the greater Baltimore area and, by inference, probably those of many other areas as well.

Three years later, George *et al*. (2007) reported on five years of work at the same three transect locations, stating that "atmospheric CO_2 was consistently and significantly increased on average by 66 ppm from the rural to the urban site over the five years of the study," and that "air temperature was also consistently and significantly higher at the urban site (14.8°C) compared to the suburban (13.6°C) and rural (12.7°C) sites." And they again noted that the increases in atmospheric CO_2 and air temperature they observed "are similar to changes predicted in the short term with global climate change, therefore providing an environment suitable for studying future effects of climate change on terrestrial ecosystems," specifically noting that "urban areas are currently experiencing elevated atmospheric CO_2 and temperature levels that can significantly affect plant growth compared to rural areas."

Working further south still, LaDochy *et al.* (2007) report that "when speculating on how global warming would impact the state [of California], climate change models and assessments often assume that the influence would be uniform (Hansen *et al.*, 1998; Hayhoe *et al.*, 2004; Leung *et al.*, 2004)." Feeling a need to assess the validity of this assumption, they calculated temperature trends over the 50-year period 1950-2000 to explore the extent of warming in various sub-regions of the state, after which they attempted to evaluate the influence of human-induced changes to the landscape on the observed temperature trends and determine their significance compared to those caused by changes in atmospheric composition, such as the air's CO_2 concentration.

In pursuing this protocol, the three researchers found that "most regions showed a stronger increase in minimum temperatures than with mean and maximum temperatures," and that "areas of intensive urbanization showed the largest positive trends, while rural, non-agricultural regions showed the least warming." In fact, they report that the Northeast Interior Basins of the state actually experienced *cooling*. Large urban sites, on the other hand, exhibited rates of warming "over twice those for the state, for the mean maximum temperature, and over five times the state's mean rate for the minimum temperature." Consequently, they concluded that "if we assume that global warming affects all regions of the state, then the small increases seen in rural stations can be an estimate of this general warming pattern over land," which implies that "larger increases," such as those they observed in areas of intensive urbanization, "must then be due to local or regional surface changes."

Noting that "breezy cities on small tropical islands ... may not be exempt from the same local climate change effects and urban heat island effects seen in large continental cities," Gonzalez *et al.* (2005) describe the results of their research into this topic, which they conducted in and about San Juan, Puerto Rico. In this particular study, a NASA Learjet—carrying the Airborne Thermal and Land Applications Sensor (ATLAS) that operates in visual and infrared wavebands—flew several flight lines, both day and night, over the San Juan metropolitan area, the El Yunque National Forest east of San Juan, plus other nearby areas, obtaining surface temperatures, while strategically placed ground instruments recorded local air temperatures. This work revealed that surface temperature differences between urbanized areas and limited vegetated areas were higher than 3°C during daytime, creating an urban heat island with "the peak of the high temperature dome exactly over the commercial area of downtown," where noontime air temperatures were as much as 3°C greater than those of surrounding rural areas. In addition, the eleven researchers report that "a recent climatological analysis of the surface [air] temperature of the city has revealed that the local temperature has been increasing over the neighboring vegetated areas at a rate of 0.06°C per year for the past 30 years."

In discussing their findings, Gonzalez *et al.* state that "the urban heat island dominates the sea breeze effects in downtown areas," and they say that "trends similar to those reported in [their] article may be expected in the future as coastal cities become more populated." Indeed, it is probable that this phenomenon has long been operative in coastal cities around the world, helping to erroneously inflate the surface air temperature record of the planet and contributing to the infamous "hockey stick" representation of this parameter that has been so highly touted by the Intergovernmental Panel on Climate Change.

One year later, Velazquez-Lozada *et al.* (2006) evaluated the thermal impacts of historical land cover and land use (LCLU) changes in San Juan, Puerto Rico over the last four decades of the twentieth century via an analysis of air temperatures measured at a height of approximately two meters above ground level within four different LCLU types (urban-coastal, rural-inland, rural-coastal and urban-inland), after which they estimated what the strength of the urban heat island might be in the year 2050, based on anticipated LCLU changes and a model predicated upon their data of the past 40 years. In doing so, their work revealed "the existence of an urban heat island in the tropical coastal city of San Juan, Puerto Rico that has been increasing at a rate of 0.06°C per year for the last 40 years." In addition, they report that predicted LCLU changes between now and 2050 will lead to an urban heat island effect "as high as 8°C for the year 2050."

Noting that a mass population migration from rural Mexico into medium- and large-sized cities took place throughout the second half of the twentieth century, Jáuregui (2005) examined the effect of this rapid urbanization on city air temperatures, analyzing the 1950-1990 minimum air temperature series of seven large cities with populations in excess of a million people and seven medium-sized cities with populations ranging from 125,000 to 700,000 people. This work indicated that temperature trends were positive at all locations, ranging from 0.02°C per decade to 0.74°C per decade. Grouped by population, the average trend for the seven large cities was 0.57°C per decade, while the average trend for the seven mid-sized cities was 0.37°C per decade. In discussing these results, Jáuregui says they "suggest that the accelerated urbanization process in recent decades may have substantially contributed to the warming of the urban air observed in large cities in Mexico."

One additional question that may arise in relation to this topic is the direct heating of near-surface air in towns and cities by the urban CO_2 dome that occurs above them. Does it contribute significantly to the urban heat island?

In a study designed to answer this question, Balling *et al*. (2002) obtained vertical profiles of atmospheric CO_2 concentration, temperature, and humidity over Phoenix, Arizona from measurements made in association with once-daily aircraft flights conducted over a 14-day period in January 2000 that extended through, and far above, the top of the city's urban CO_2 dome during the times of its maximum manifestation. They then employed a one-dimensional infrared radiation simulation model to determine the thermal impact of the urban CO_2 dome on the near-surface temperature of the city. These exercises revealed that the CO_2 concentration of the air over Phoenix dropped off rapidly with altitude, returning from a central-city surface value on the order of 600 ppm to a normal non-urban background value of approximately 378 ppm at an air pressure of 800 hPa, creating a calculated surface warming of only 0.12°C at the time of maximum CO_2-induced warming potential, which is about an order of magnitude less than the urban heat island effect of cities the size of Phoenix. In fact, the authors concluded that the warming induced by the urban CO_2 dome of Phoenix is possibly two orders of magnitude smaller than that produced by other sources of the city's urban heat island. Although the doings of man are indeed responsible for high urban air temperatures (which can sometimes rise 10°C or more above those of surrounding rural areas), these high values are not the result of a local CO_2-enhanced greenhouse effect.

Meteorologist Anthony Watts (2009), in research too new to have appeared yet in a peer-reviewed journal, discovered compelling evidence that the temperature stations used to reconstruct the U.S. surface temperature are unreliable and systemically biased toward recording more warming over time. Watts recruited a team of more than 650 volunteers to visually inspect the temperature stations used by the National Oceanic and Atmospheric Administration (NOAA) and the National Aeronautics and Space Administration (NASA) to measure changes in temperatures in the U.S. In the researcher's words, "using the same quality standards established by NOAA, they found that 89 percent of the stations – nearly 9 of every 10 – fail to meet NOAA's own siting requirements for stations with an expected reporting error of less than 1º C. Many of them fall *far* short of that standard [italics in the original]."

Watts goes on to report finding stations "located next to the exhaust fans of air conditioning units, causing them to report much- higher-than-actual temperatures. We found stations surrounded by asphalt parking lots and located near roads, sidewalks, and buildings that absorb and radiate heat. We found 68 stations located at wastewater treatment plants, where the process of waste digestion causes temperatures to be higher than in surrounding areas."

Watts also discovered that failure to adequately account for changes in the technology used by temperature stations over time—including moving from whitewash to latex paint and from mercury thermostats to digital technology—"have further contaminated the data, once again in the direction of falsely raising temperature readings." Watts is also extremely critical of adjustments to the raw data made by both NOAA and NASA, which "far from correcting the warming biases, actually compounded the measurement errors."

The results of these several North American studies demonstrate that the impact of population growth on the urban heat island effect is very real and can be very large, overshadowing the effects of natural temperature change. This insight is not new: more than three decades ago, Oke (1973) demonstrated that towns with as few as a thousand inhabitants typically create a warming of the air within them that is more than twice as great as the increase in mean global air temperature believed to have occurred since the end of the Little Ice Age, while the urban heat islands of the great metropolises of the world create warmings that rival those that occur between full-fledged ice ages and interglacials. Extensive research conducted since then by independent scientists has confirmed Oke's finding. Due to extensive corruption of land-based temperature data from urban heat islands, the North

American temperature record cannot be cited as providing reliable data in support of the greenhouse theory of global warming.

Additional information on this topic, including reviews of newer publications as they become available, can be found at http://www.co2science.org/subject/u/uhinorthamerica.php.

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3.3.3. Asia

Hasanean (2001) investigated surface air temperature trends with data obtained from meteorological stations located in eight Eastern Mediterranean cities: Malta, Athens, Tripoli, Alexandria, Amman, Beirut, Jerusalem, and Latakia. The period of analysis varied from station to station according to available data, with Malta having the longest temperature record (1853-1991) and Latakia the shortest (1952-1991). Four of the cities exhibited overall warming trends and four of them cooling trends. In addition, there was an important warming around 1910 that began nearly simultaneously at all of the longer-record stations, as well as a second warming in the 1970s; but Hasanean reports that the latter warming was "not uniform, continuous or of the same order" as the warming that began about 1910, nor was it evident at all of the stations. One interpretation of this non-uniformity of temperature behavior in the 1970s is that it may have been the result of temporal differences in city urbanization histories that were accentuated about that time, which could have resulted in significantly different urban heat island trajectories at the several sites over the latter portions of their records.

In a more direct study of the urban heat island effect that was conducted in South Korea, Choi *et al.* (2003) compared the mean station temperatures of three groupings of cities (one comprised of four large urban stations with a mean 1995 population of 4,830,000, one comprised of six smaller urban stations with a mean 1995 population of 548,000, and one comprised of six "rural" stations with a mean 1995 population of 214,000) over the period 1968-1999. This analysis revealed, in their words, that the "temperatures of large urban stations exhibit higher urban bias than those of smaller urban stations and that the magnitude of urban bias has increased since the late 1980s." Specifically, they note that "estimates of the annual mean magnitude of urban bias range from 0.35°C for smaller urban stations to 0.50°C for large urban stations." In addition, they indicate that "none of the rural stations used for this study can represent a true non-urbanized environment." Hence, they correctly conclude that their results are underestimates of the true urban effect, and that "urban growth biases are very serious in South Korea and must be taken into account when assessing the reliability of temperature trends."

In a second study conducted in South Korea, Chung *et al.* (2004a) report there was an "overlapping of the rapid urbanization-industrialization period with the global warming era," and that the background climatic trends from urbanized areas might therefore be contaminated by a growing urban heat island effect. To investigate this possibility, they say "monthly averages of daily minimum, maximum, and mean temperature at 14 synoptic stations were prepared for 1951-1980 (past normal) and 1971-2000 (current normal) periods," after which "regression equations were used to determine potential effects of urbanization and to extract the net contribution of regional climate change to the apparent temperature change." Twelve of these stations were growing urban sites of various size, while two (where populations actually *decreased*) were rural, one being located inland and one on a remote island.

In terms of change over the 20 years that separated the two normal periods, Chung *et al.* report that in Seoul, where population increase was greatest, annual mean daily minimum temperature increased by 0.7°C, while a mere 0.1°C increase was detected at one of the two rural sites and a 0.1°C decrease was detected at the other, for no net change in their aggregate mean value. In the case of annual mean daily maximum temperature, a 0.4°C increase was observed at Seoul and a 0.3°C increase was observed at the two rural sites. Hence, the change in the annual mean daily mean temperature was an increase of 0.15°C at the two rural sites (indicative of regional background warming of 0.075°C per decade), while the change of annual mean daily mean temperature at Seoul was an increase of 0.55°C, or 0.275°C per decade (indicative of an urban-induced warming of 0.2°C per decade in addition to the regional background warming of 0.075°C per decade). Also, corresponding results for urban areas of intermediate size defined a linear relationship that connected these two extreme results when plotted against the logarithm of population increase over the two-decade period.

In light of the significantly intensifying urban heat island effect detected in their study, Chung *et al.* say it is "necessary to subtract the computed urbanization effect from the observed data at urban stations in order to prepare an intended nationwide climatic atlas," noting that "rural climatological normals should be used instead of the conventional normals to simulate ecosystem responses to climatic change, because the urban area is still much smaller than natural and agricultural ecosystems in Korea."

A third study of South Korea conducted by Chung *et al.* (2004b) evaluated temperature changes at 10 urban and rural Korean stations over the period 1974-2002. They found "during the last 29 years, the increase in annual mean temperature was 1.5°C for Seoul and 0.6°C for the rural and seashore stations," while increases in mean January temperatures ranged from 0.8 to 2.4°C for the 10 stations. In addition, they state that "rapid industrialization of the Korean Peninsula occurred during the late 1970s and late 1980s," and that when plotted on a map, "the remarkable industrialization and expansion ... correlate with the distribution of increases in temperature." Consequently, as in the study of Chung *et al.* (2004a), Chung *et al.* (2004b) found that over the past several decades, much (and in many cases *most*) of the warming experienced in the urban areas of Korea was the result of local urban influences that were not indicative of regional background warming.

Shifting attention to China, Weng (2001) evaluated the effect of land cover changes on surface temperatures of the Zhujiang Delta (an area of slightly more than 17,000 km^2) via a series of analyses of remotely sensed Landsat Thematic Mapper data. They found that between 1989 and 1997, the area of land devoted to agriculture declined by nearly 50 percent, while urban land area increased by close to the same percentage. Then, upon normalizing the surface radiant temperature for the years 1989 and 1997, they used image differencing to produce a radiant temperature change image that they overlaid with images of urban expansion. The results indicated, in Weng's words, that "urban development between 1989 and 1997 has given rise to an average increase of 13.01°C in surface radiant temperature."

In Shanghai, Chen *et al*. (2003) evaluated several characteristics of that city's urban heat island, including its likely cause, based on analyses of monthly meteorological data from 1961 to 1997 at 16 stations in and around this hub of economic activity that is one of the most flourishing urban areas in all of China. Defining the urban heat island of Shanghai as the mean annual air temperature difference between urban Longhua and suburban Songjiang, Chen *et al.* found that its strength increased in essentially linear fashion from 1977 to 1997 by 1°C.

Commenting on this finding, Chen *et al.* say "the main factor causing the intensity of the heat island in Shanghai is associated with the increasing energy consumption due to economic development," noting that in 1995 the Environment Research Center of Peking University determined that the annual heating intensity due to energy consumption by human activities was approximately 25 Wm^{-2} in the urban area of Shanghai but only 0.5 Wm^{-2} in its suburbs. In addition, they point out that the 0.5°C/decade intensification of Shanghai's urban heat island is an order of magnitude greater than the 0.05°C/decade global warming of the earth over the past century, which is indicative of the fact that ongoing intensification of even strong urban heat islands cannot be discounted.

Simultaneously, Kalnay and Cai (2003) used differences between trends in directly observed surface air temperature and trends determined from the NCEP-NCAR 50-year Reanalysis (NNR) project (based on atmospheric vertical soundings derived from satellites and balloons) to estimate the impact of land-use changes on surface warming. Over undisturbed rural areas of the United States, they found that the surface- and reanalysis-derived air temperature data yielded essentially identical trends, implying that differences between the two approaches over urban areas would represent urban heat island effects. Consequently, Zhou *et al*. (2004) applied the same technique over southeast China, using an improved version of reanalysis that includes newer physics, observed soil moisture forcing, and a more accurate characterization of clouds.

For the period January 1979 to December 1998, the eight scientists involved in the work derived an "estimated warming of mean surface [air] temperature of 0.05°C per decade attributable to urbanization," which they say "is much larger than previous estimates for other periods and locations, including the estimate of 0.027°C for the continental U.S. (Kalnay and Cai, 2003)." They note, however, that because their analysis "is from the winter season over a period of rapid urbanization and for a country with a much higher population density, we expect our results to give higher values than those estimated in other locations and over longer periods."

In a similar study, Frauenfeld *et al*. (2005) used daily surface air temperature measurements from 161 stations located throughout the Tibetan Plateau (TP) to calculate the region's mean annual temperature for each year from 1958 through 2000, while in the second approach they used 2-meter temperatures from the European Centre for Medium-Range Weather Forecasts (ECMWF) reanalysis (ERA-40), which temperatures, in their words, "are derived from rawinsonde profiles, satellite retrievals, aircraft reports, and other sources including some surface observations." This approach, according to them, results in "more temporally homogeneous fields" that provide "a better assessment of large-scale temperature variability across the plateau."

Frauenfeld *et al*. report that over the period 1958-2000, "time series based on aggregating all station data on the TP show a statistically significant positive trend of 0.16°C per decade," as has also been reported by Liu and Chen (2000). However, they say that "no trends are evident in the ERA-40 data for the plateau as a whole."

In discussing this discrepancy, the three scientists suggest that "a potential explanation for the difference between reanalysis and station trends is the extensive local and regional land use change that has occurred across the TP over the last 50 years." They note, for example, that "over the last 30 years, livestock numbers across the TP have increased more than 200% due to inappropriate land management practices and are now at levels that exceed the carrying capacity of the region (Du *et al*., 2004)." The resultant overgrazing, in their words, "has caused land degradation and desertification at an alarming rate (Zhu and Li, 2000; Zeng *et al*., 2003)," and they note that "in other parts of the world, land degradation due to overgrazing has been shown to cause significant local temperature increases (e.g., Balling *et al*., 1998)."

Another point they raise is that "urbanization, which can result in 8°-11°C higher temperatures than in surrounding rural areas (e.g., Brandsma *et al*., 2003), has also occurred extensively on the TP," noting that "construction of a gas pipeline in the 1970s and highway expansion projects in the early 1980s have resulted in a dramatic population influx from other parts of China, contributing to both urbanization and a changed landscape." In this regard, they say that "the original Tibetan section of Lhasa (i.e., the pre-1950 Lhasa) now only comprises 4% of the city, suggesting a 2400% increase in size over the last 50 years." And they add that "similar population increases have occurred at other locations across the TP," and that "even villages and small towns can exhibit a strong urban heat island effect."

In concluding their analysis of the situation, Frauenfeld *et al*. contend that "these local changes are reflected in station temperature records." We note that when the surface-generated anomalies are removed, as in the case of the ERA-40 reanalysis results they present, it is clear there has been no warming of the Tibetan Plateau since at least 1958. Likewise, we submit that the other results reported in this section imply much the same about other parts of China and greater Asia.

In conclusion, a large body of research conducted by scores of scientists working in countries around the world reveals that the twentieth century warming claimed by the IPCC, Mann *et al*. (1998, 1999), and Mann and Jones (2003) to represent mean global background conditions is likely significantly biased towards warming over the past 30 years and is therefore not a true representation of earth's recent thermal history.

Additional information on this topic, including reviews of newer publications as they become available, can be found at http://www.co2science.org/subject/u/uhiasia.php

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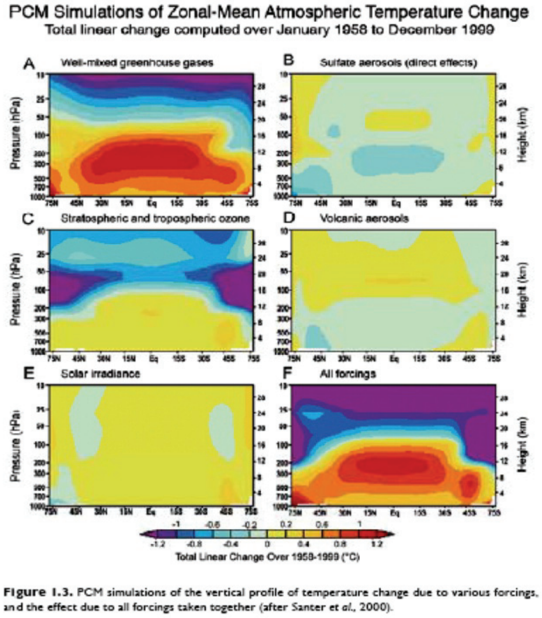
3.4. Fingerprints

Is there a method that can distinguish anthropogenic global warming from natural warming? The IPCC (IPCC-SAR, 1996, p. 411; IPCC, 2007-I, p. 668) and many scientists believe the "fingerprint" method is the only reliable one. It compares the observed pattern of warming with a pattern calculated from greenhouse models. While an agreement of such fingerprints cannot prove an anthropogenic origin for warming, it would be consistent with such a conclusion. A mismatch would argue strongly against any significant contribution from greenhouse gas (GHG) forcing and support the conclusion that the observed warming is mostly of natural origin.

Climate models all predict that, if GHG is driving climate change, there will be a unique fingerprint in the form of a warming trend increasing with altitude in the tropical troposphere, the region of the atmosphere up to about 15 kilometers. (See Figure 3.4.1.) Climate changes due to solar variability or other known natural factors will not yield this pattern; only sustained greenhouse warming will do so.

The fingerprint method was first attempted in the IPCC's Second Assessment Report (SAR) (IPCC-SAR, 1996, p. 411). Its Chapter 8, titled "Detection and Attribution," attributed observed temperature changes to anthropogenic factors—greenhouse gases and aerosols. The attempted match of warming trends with altitude turned out to be spurious, since it depended entirely on a particular choice of time interval for the comparison (Michaels and Knappenberger, 1996). Similarly, an attempt to correlate the observed and calculated geographic distribution of surface temperature trends (Santer *et al.* 1996) involved making changes on a published graph that could and did mislead readers (Singer, 1999, p. 9; Singer, 2000, pp. 15, 43-44). In spite of these shortcomings, IPCC-SAR concluded that "the balance of evidence" supported AGW.

With the availability of higher-quality temperature data, especially from balloons and satellites, and with improved GH models, it has become possible to apply the fingerprint method in a more realistic way. This was done in a report issued by the U.S. Climate Change Science Program (CCSP) in April 2006—making it readily available to the IPCC for its Fourth Assessment Report—and it permits the most realistic comparison of fingerprints (Karl *et al.,* 2006).



PCM Simulations of Zonal-Mean Atmospheric Temperature Change
Total linear change computed over January 1958 to December 1999

Figure 1.3. PCM simulations of the vertical profile of temperature change due to various forcings, and the effect due to all forcings taken together (after Santer *et al.*, 2000).

Figure 3.4.1. Model-calculated zonal mean atmospheric temperature change from 1890 to 1999 (degrees C per century) as simulated by climate models from [A] well-mixed greenhouse gases, [B] sulfate aerosols (direct effects only), [C] stratospheric and tropospheric ozone, [D] volcanic aerosols, [E] solar irradiance, and [F] all forcings (U.S. Climate Change Science Program 2006, p. 22). Note the pronounced increase in warming trend with altitude in figures A and F, which the IPCC identified as the 'fingerprint' of greenhouse forcing.

The CCSP report is an outgrowth of an NAS report "Reconciling Observations of Global Temperature Change" issued in January 2000 (NAS, 2000). That NAS report compared surface and troposphere temperature trends and concluded they cannot be reconciled. Six years later, the CCSP report expanded considerably on the NAS study. It is

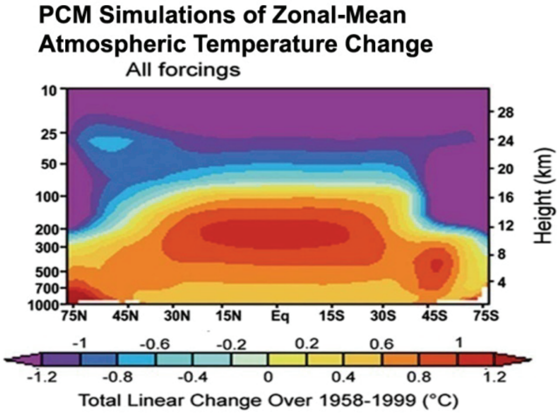


Figure 3.4.2. Greenhouse-model-predicted temperature trends versus latitude and altitude; this is figure 1.3F from CCSP 2006, p. 25. Note the increased temperature trends in the tropical mid_troposphere, in agreement also with the IPCC result (IPCC-AR4 2007, p. 675).

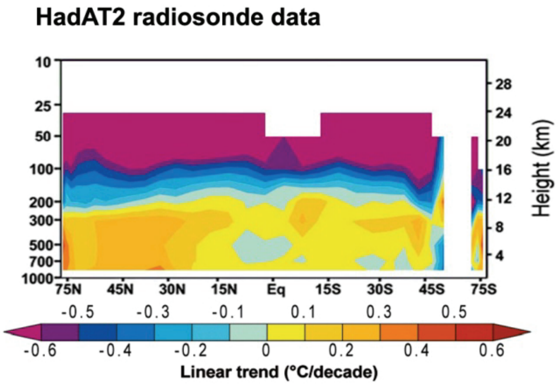
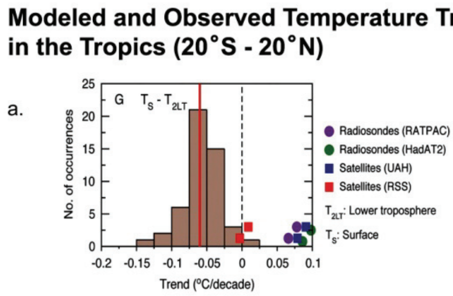


Figure 3.4.3. By contrast, observed temperature trends versus latitude and altitude; this is figure 5.7E from CCSP 2006, p. 116. These trends are based on the analysis of radiosonde data by the Hadley Centre and are in good agreement with the corresponding U.S. analyses. Notice the absence of increased temperature trends in the tropical mid-troposphere.

essentially a specialized report addressing the most crucial issue in the global warming debate: Is current global warming anthropogenic or natural? The CCSP result is unequivocal. While all greenhouse models show an increasing warming trend with altitude, peaking around 10 km at roughly two times the surface value, the temperature data from balloons give the opposite result: no increasing warming, but rather a slight cooling with altitude in the tropical zone. See Figures 3.4.2 and 3.4.3, taken directly from the CCSP report.

The CCSP executive summary inexplicably claims agreement between observed and calculated patterns, the opposite of what the report itself documents. It tries to dismiss the obvious disagreement shown in the body of the report by suggesting there might be something wrong with both balloon and satellite data. Unfortunately, many people do not read beyond the summary and have therefore been misled to believe the CCSP report supports anthropogenic warming. It does not.

The same information also can be expressed by plotting the difference between surface trend and troposphere trend for the models and for the data (Singer, 2001). As seen in Figure 3.4.4 and 3.4.5, the models show a histogram of negative values (i.e. surface trend less than troposphere trend) indicating that atmospheric warming will be greater than surface warming. By contrast, the data show mainly positive values for the difference in trends, demonstrating that measured warming is occurring principally on the surface and not in the atmosphere.



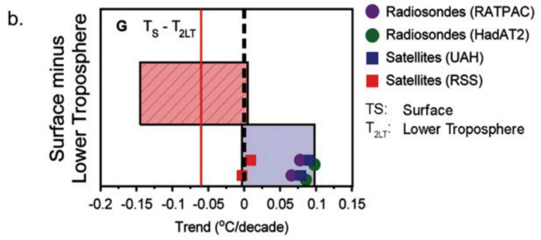


Figure 3.4.4. Another way of presenting the difference between temperature trends of surface and lower troposphere; this is figure 5.4G from CCSP 2006, p. 111. The model results show a spread of values (histogram); the data points show balloon and satellite trend values. Note the model results hardly overlap with the actual observed trends. (The apparent deviation of the RSS analysis of the satellite data is as yet unexplained.)

Figure 3.4.5. By contrast, the executive summary of the CCSP report presents the same information as Figure 3.4.4 in terms of 'range' and shows a slight overlap between modeled and observed temperature trends (Figure 4G, p. 13). However, the use of 'range' is clearly inappropriate (Douglass et al. 2007) since it gives undue weight to 'outliers.'

The same information can be expressed in yet a different way, as seen in research papers by Douglass *et al.* (2004, 2007), as shown in Figure 3.4.6. The models show an increase in temperature trend with altitude but the observations show the opposite.

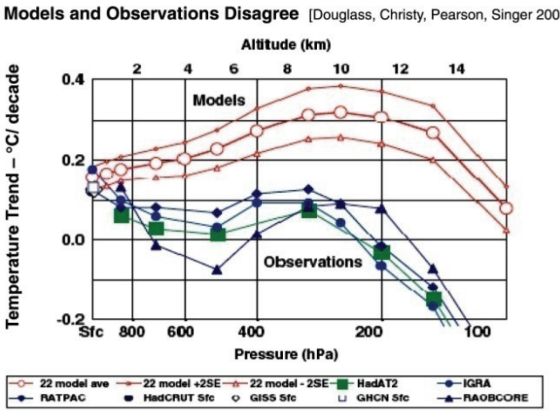


Figure 3.4.6. A more detailed view of the disparity of temperature trends is given in this plot of trends (in degrees C/decade) versus altitude in the tropics [Douglass et al. 2007]. Models show an increase in the warming trend with altitude, but balloon and satellite observations do not.

This mismatch of observed and calculated fingerprints clearly falsifies the hypothesis of anthropogenic global warming (AGW). We must conclude therefore that anthropogenic greenhouse gases can contribute only in a minor way to the current warming, which is mainly of natural origin. The IPCC seems to be aware of this contrary evidence but has tried to ignore it or wish it away. The summary for policymakers of IPCC's Fourth Assessment Report (IPCC 2007-I, p. 5) distorts the key result of the CCSP report: "New analyses of balloon-borne and satellite measurements of lower- and mid-tropospheric temperature show warming rates that are similar to those of the surface temperature record, and are consistent within their respective uncertainties, largely reconciling a discrepancy noted in the TAR." How is this possible? It is done partly by using the concept of "range" instead of the statistical distribution shown in Figure 12a. But "range" is not a robust statistical measure because it gives undue weight to "outlier" results (Figure 12b). If robust probability distributions were used they would show an exceedingly low probability of any overlap of modeled and the observed temperature trends.

If one takes greenhouse model results seriously, then the greenhouse fingerprint would suggest the true surface trend should be only 30 to 50 percent of the observed balloon/satellite trends in the troposphere. In that case, one would end up with a much-reduced surface warming trend, an insignificant AGW effect, and a minor greenhouse-induced warming in the future.

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3.5. Satellite Data

The IPCC claims that data collected by satellite-mounted microwave sounding units (MSU) and advanced MSU measurements since 1979 reveal a warming trend of 0.12° C to 0.19° C per decade, which it says "is broadly consistent with surface temperature trends" (IPCC, 2007-I, p. 237). This would be surprising, since we indicated in the previous section that the surface-based temperature record is unreliable and biased toward a spurious warming trend. In this section we investigate the truth of the IPCC's claim in this regard and report other findings based on satellite data.

Most climate models predict that the troposphere should warm about 1.2 times more than the surface globally, and about 1.5 times more in the tropics. Although the MSUs mounted on satellites sent into orbit by NASA for the National Oceanic and Atmospheric Administration (NOAA) were not originally intended to be used to measure temperatures in the troposphere, they have been used for this purpose since 1979 and, despite some ongoing debate, are acknowledged to be a reliable source of information about temperatures in the troposphere (Christy *et al.,* 2003, 2007; Santer *et al.,* 2005). As Wentz and Schabel observed in an article in *Nature* in 1998, "the detection and measurement of small changes in the Earth's climate require extremely precise global observations of a broad spectrum of complementary physical variables. In this endeavour, satellite observations are playing an increasingly important role. As compared to conventional *in situ* observations, satellites provide daily near-global coverage with a very high statistical precision that results from averaging millions of individual observations" (Wentz and Schabel, 1998).

Four groups currently report MSU measurements: the University of Alabama in Huntsville (UAH), Remote Sensing System (RSS) (a small private weather forecasting firm led by the previously cited Frank Wentz), the University of Maryland (UMd), and a group from NOAA whose data series begins in 1987. RSS and UAH produce estimates of temperatures for the lower troposphere (LT), mid-troposphere (MT), and lower stratosphere (LS). UMd produces estimates only for MT (Christy and Norris, 2006). New data for the UAH series is posted every month on a Web site maintained at the University of Alabama at Huntsville.

The first satellite record was produced by Roy Spencer, then with NASA and now the U.S. Science Team leader for the Advanced Microwave Scanning Radiometer flying on NASA's Aqua satellite, and John Christy, distinguished professor of atmospheric science and director of the Earth System Science Center at the University of Alabama in Huntsville. Published in *Science* in 1990 (Spencer and Christy, 1990), the article presented the first 10 years of satellite measurements of lower atmospheric temperature changes (from 1979 to 1988) and found "no obvious trend for the 10-year period." Although this finding covered too short a period of time to prove a trend, it seemed to contradict claims by some scientists at the time that a warming trend was underway. It triggered a long-running debate, which continues to this day, over the accuracy of the satellite data.

In 1997, Kevin Trenberth, of the U.S. National Center for Atmospheric Research (NCAR) and later a lead author of the IPCC's Third Assessment Report, along with coauthors challenged the reliability of the satellite data (Trenberth, 1997; Trenberth and Hurrell, 1997; Hurrell and Trenberth, 1997). Trenberth argued that Spencer and Christy had failed to properly calibrate the sensors on each new satellite as older satellites were retired and new ones launched into orbit, based on a surface-satellite comparison. Spencer and Christy, however, showed that the surface and tropospheric discrepancy was real, as it also was found in independent balloon comparisons (Christy *et al.,* 1997).

Critics of the satellite data pointed to other possible and actual errors in the satellite record, and Spencer and Christy made two adjustments based on these external criticisms for such things as orbit decay and changes in technology. One of the larger changes was made to correct for drift in local crossing time (i.e., change in the time-of-day that the measures are taken), an error discovered by Mears and Wentz (2005) and subsequently corrected by Christy and Spencer (2005). Many of the adjustments made by Christy and Spencer resulted in the satellite record showing a small warming trend of 0.123 ºC between 1979 and 2005.

In 2006, a panel of the U.S. Climate Change Science Program (CCSP) attempted to reconcile differences between satellite and surface-station data. While the executive summary of the report claimed (as the IPCC does) that "this significant discrepancy [between surface station records and satellite records] no longer exists because errors in the satellite and radiosonde data have been identified and corrected," in fact significant differences in some values (especially in the important region of the tropics, as discussed in Section 3.4. Fingerprints) remained unsolved (CCSP, 2006).

Satellite data allow us to check the accuracy of the warming trend during the last three decades reported by the three combined land-surface air temperature and sea-surface temperature (SST) records used by the IPCC: CRU (from the Climate Research Unit (CRU) at the University of East Anglia, in Norwich, England), NCDC (from the National Climatic Data Center), and GISS (from NASA's Goddard Institute for Space Studies). The IPCC lists temperature trends (ºC /decade) for each record for the periods 1850-2005, 1901-2005, and 1979-2005 (IPCC, 2007-I, Table 3.3, p. 248). All three surface temperature records used by the IPCC show positive trends in global temperatures during the 1979-2005 period (the period that can be checked against satellite data) of between 0.163º C/decade and 0.174 ºC /decade, compared to the UAH record of only 0.123º C/decade. This means the IPCC's estimates of warming are between 33 percent and 41.5 percent more rapid than the most scientifically accurate record we have of global temperatures during this 26-year period. The IPCC claims an even higher estimate of 0.177º C/decade (44 percent higher than UAH) in a graph on page 253, a variation of which appears in the Summary for Policymakers (p. 6). Finally, we note that none of the warming rates reported in the IPCC's Table 3.3 reaches the 0.19º C that the IPCC claimed to be the upper end of the range of credible estimates, while the UAH record of 0.128º C/decade sits very close to the lowest estimate of 0.12º C.

Similarly, the IPCC's temperature records for the Northern Hemisphere are CRU's 0.234º C and NCDC's 0.245º C, approximately 17 percent to 22.5 percent higher than the UAH's record of 0.20º C. For the Southern Hemisphere, the IPCC's estimates are 0.092º C (CRU) and 0.096 ºC (NCDC), or a very large 84 percent and 92 percent higher than the UAH's 0.05º C. To say this is "broadly consistent," as the IPCC does, is not accurate. In light of the large discrepancy between satellite and surface records for the Southern Hemisphere, it is notable that Christy has been using the UAH database to detect and correct errors in the Australian radiosondes record (Christy and Norris, 2009) and the surface station record in East Africa (Christy *et al.,* 2009).

Satellite data also allow us to compare real-world temperatures to the predictions (or "scenarios") offered by those who have been predicting warming since the 1980s. Figure 3.5.1. compares the UAH and RSS temperature records "adjusted to mimic surface temperature variations for an apples to apples comparison with the model projections (factor of 1.2, CCSP SAP 1.1)" to three model projections of global surface temperature presented by NASA's James Hansen in Senate testimony in 1988 (Christy, 2009). "GISS-A 88" and "GISS-B 88," at the top of the graph, are Hansen's two "business-as-usual" model projections of temperature which assumed greenhouse gas emissions would be similar to what actually has happened. "GISS-C 88" is Hansen's temperature forecast if drastic GHG reductions were made. Obviously, real-world temperatures have failed to rise as Hansen had predicted, and indeed, global temperatures in 2009 were no higher than when Hansen testified in 1988. As Christy comments, "Even the model projection for drastic CO_2 cuts still overshot the observations. This would be considered a failed hypothesis test for the models from 1988" (Christy, 2009).

By 2008, the UAH data series indicated that global temperatures in the lower atmosphere had warmed at the slightly higher rate of about 0.14º C/decade from January 1979 through December 2007, while the RSS data series showed a warming rate of 0.17º C/decade. Recent research by Randall and Herman (2009) using data collected from a subset of weather balloon observations thought to be most reliable suggests the RSS data incorporate an improper handling of diurnal cycle effects that causes a small warming bias over global land areas, thus suggesting that the lower UAH estimate of 0.14º C/decade may have been closer to correct. Graphs showing both data sets and a third graph showing the difference between the two data sets appear in Figure 3.5.2.

Explanations exist for two of the biggest differences between the two datasets. The first is a sudden warming in RSS relative to UAH in January 1992. This feature has been found in comparison with

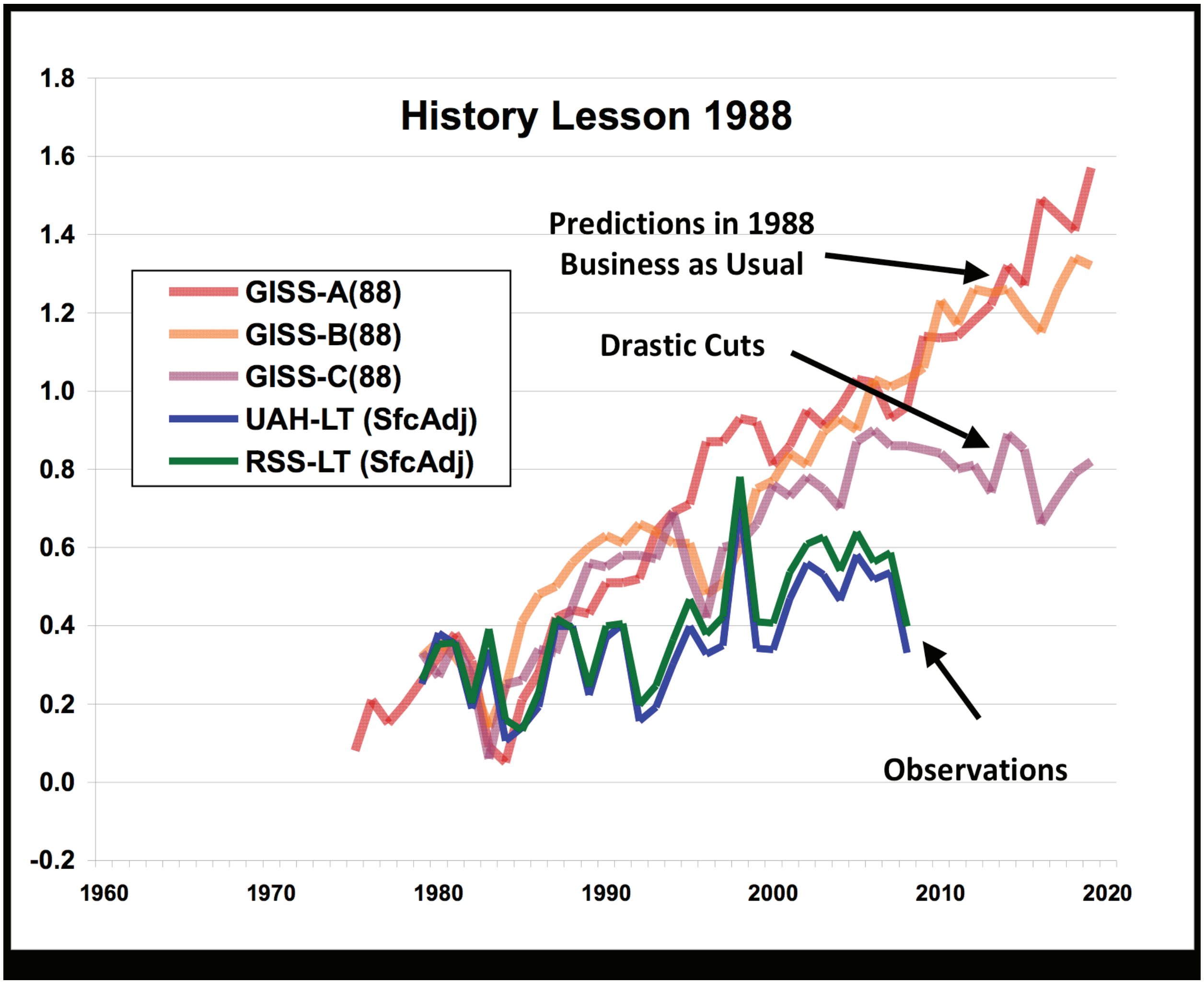

Figure 3.5.1. Actual temperature changes from UAH and RSS satellite data, adjusted to mimic surface temperatures, compared to predictions made by James Hansen to Congress in 1988. Source: Christy, J.R. 2009. Written testimony to House Ways and Means Committee. 25 February. http://waysandmeans.house.gov/media/pdf/111/ctest.pdf, last accessed May 10, 2009

every other surface and tropospheric temperature dataset, indicating RSS contains a spurious warming shift at that time (Christy *et al.*, 2007). The second feature is the relative cooling of RSS vs. UAH since 2006. This can be explained by the fact UAH uses a spacecraft (NASA's Aqua) that is not subject to orbital drifting, whereas RSS relies on NOAA-15, which is drifting into warmer diurnal times. The implication here is that RSS is overcorrecting for this spurious warming by reporting too much cooling. Overall, the shifts unique to RSS create a spurious warming in the record, which is being slowly mitigated by the more recent spurious cooling.

The graphs show that the temperature anomalies in the RSS dataset for November 2007 and December 2007 were below the 1979-1998 mean average for the first time since 2000. Both data series show the rate of warming has slowed dramatically during the past seven to 12 years. Between the end of 2007 and early 2009, global temperature anomalies fell even further, effectively returning the world to the temperatures that prevailed in the late 1980s and early 1990s. See Figure 3.5.3. below.

The new trend toward less warming has prompted some scientists to wonder if the world's climate experienced a trend break in 2001-2002, similar to ones that occurred around 1910 (ending a cooling trend), the early 1940s (ending a warming trend), and the mid-1970s (ending a cooling trend). Swanson and Anastasios (2009), writing in *Geophysical Research Letters*, say "a break in the global mean temperature trend from the consistent warming over the 1976/77–2001/02 period may have occurred." Moreover, the episodic nature of temperature changes during the

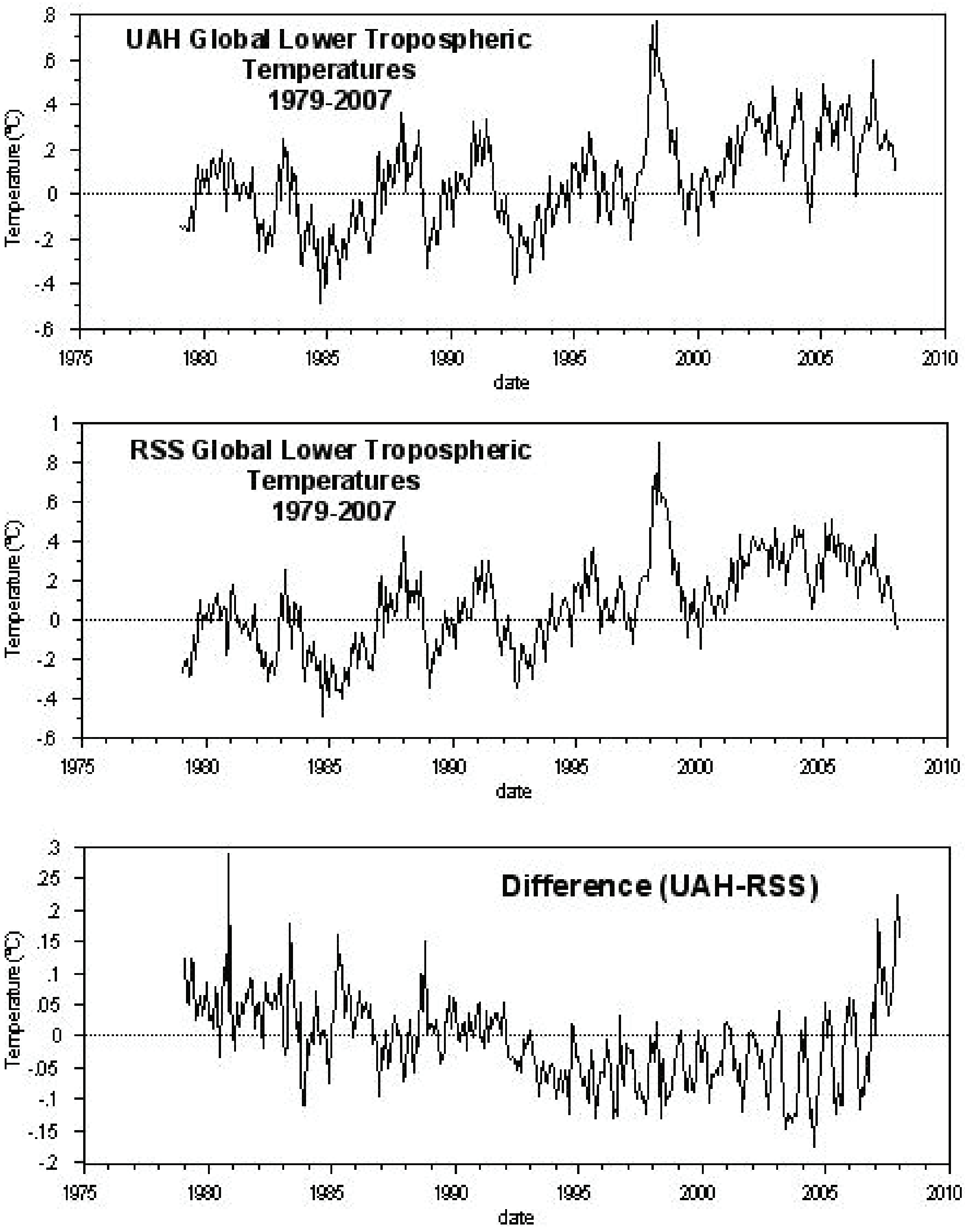

Figure 3.5.2. Global temperature anomalies from the lower troposphere. January 1979 through December 2007. (top) Data compiled at the University of Alabama, (middle) data compiled by Remote Sensing Systems, (bottom) difference between the two datasets (UAH minus RSS). Graphs were produced by Patrick Michaels using UAH and RSS data and first appeared in *World Climate* Report on February 7, 2008, http://www.worldclimatereport.com/index.php/category/temperature-history/satelliteballoons/.

past century is "difficult to reconcile with the presumed smooth evolution of anthropogenic greenhouse gas and aerosol radiative forcing with respect to time" and "suggests that an internal reorganization of the climate system may underlie such shifts."

Noel Keenlyside, a scientist with Germany's Leibniz Institute of Marine Science, writing with colleagues in a letter published in *Nature,* said "the climate of the North Atlantic region exhibits fluctuations on decadal timescales that have large societal consequences" and "these multidecadal

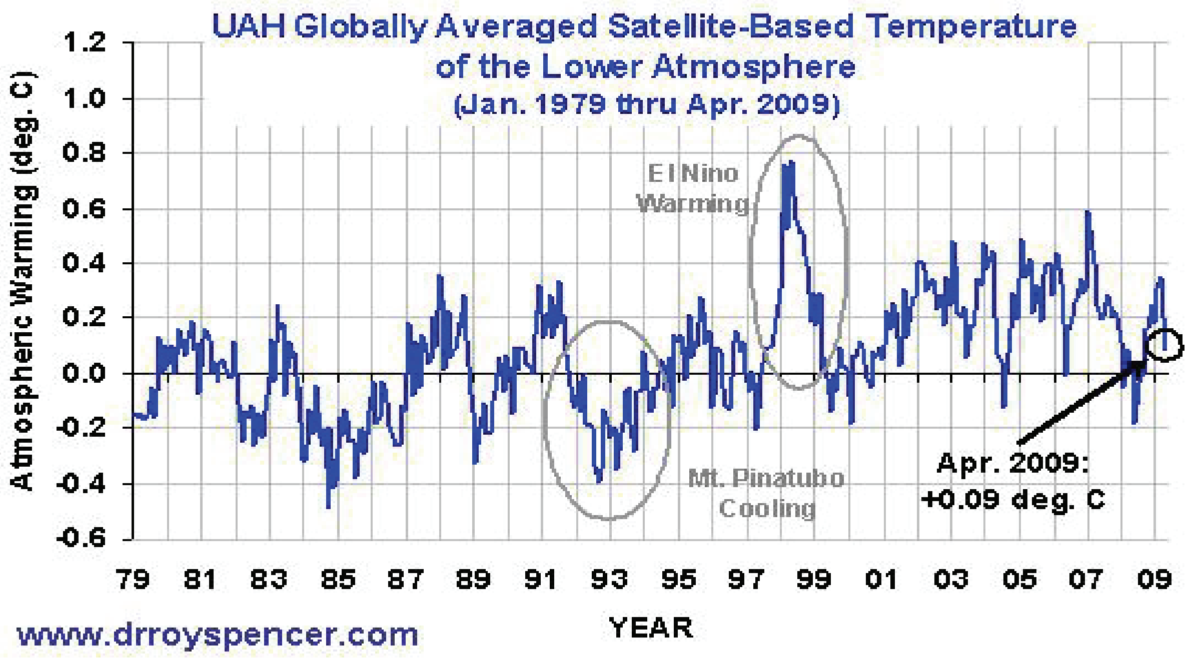

Figure 3.5.3. UAH Globally Averaged Satellite-Based Temperature of the Lower Atmosphere, January 1979 – April 2009. Source: Roy Spencer, http://www.drroyspencer.com/latest-global-temperatures/, last accessed May 10, 2009.

variations are potentially predictable if the current state of the ocean is known" (Keenlyside *et al.*, 2008). Using a database of sea-surface temperature (SST) observations, they "make the following forecast: over the next decade, the current Atlantic meridional overturning circulation will weaken to its long-term mean; moreover, North Atlantic SST and European and North American surface temperatures will cool slightly, whereas tropical Pacific SST will remain almost unchanged. Our results suggest that global surface temperature may not increase over the next decade, as natural climate variations in the North Atlantic and tropical Pacific temporarily offset the projected anthropogenic warming."

We predict more predictions of this kind as more scientists recognize, first, that estimates of past warming have been exaggerated by reliance on surface-station data that have been discredited by physical observation and by testing against superior satellite data; second, that recent temperature trends contradict past and recent forecasts by the IPCC and other prominent advocates of the theory that temperatures will steadily rise in response to increasing forcing by rising CO_2 levels in the atmosphere; and third, as attention turns to natural cycles like those modeled by Keenlyside *et al.*, as most scientists have known all along are more influential than the small effects of rising CO_2 in the atmosphere.

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3.6. Arctic

The IPCC claims "average arctic temperatures increased at almost twice the global average rate in the past 100 years," though it then acknowledges that "arctic temperatures have high decadal variability, and a warm period was also observed from 1925 to 1945" (IPCC 2007-I, p. 7). Later in the report, the IPCC says "the warming over land in the Arctic north of 65° is more than double the warming in the global mean from the 19th century to the 21st century and also from about the late 1960s to the present. In the arctic series, 2005 is the warmest year" (p. 248). But the IPCC then admits that "a few areas have cooled since 1901, most notably the northern North Atlantic near southern Greenland" (p. 252). So has the Artic really experienced the so-called unprecedented warming of the twentieth century?

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3.6.1. Greenland

Dahl-Jensen *et al.* (1998) used data from two ice sheet boreholes to reconstruct the temperature history of Greenland over the past 50,000 years. Their analysis indicated that temperatures on the Greenland Ice Sheet during the Last Glacial Maximum (about 25,000 years ago) were 23 ± 2 °C colder than at present. After the termination of the glacial period, however, temperatures increased steadily to a value that was 2.5°C *warmer* than at present, during the Climatic Optimum of 4,000 to 7,000 years ago. The Medieval Warm Period and Little Ice Age were also evident in the borehole data, with temperatures 1°C warmer and 0.5-0.7°C cooler than at present, respectively. Then, after the Little Ice Age, the scientists report "temperatures reached a maximum around 1930 AD" and that "temperatures have *decreased* [our italics] during the last decades."

The results of this study stand in stark contrast to the predictions of general circulation models of the atmosphere, which consistently suggest there should have been a significant CO_2-induced warming in high northern latitudes over the past several decades. They also depict large temperature excursions over the past 10,000 years, when the air's CO_2 content was relatively stable. Each of these observations raises serious doubts about the models' ability to correctly forecast earth's climatic response to the ongoing rise in the air's CO_2 content.

In another study of Greenland climate that included both glacial and interglacial periods, Bard (2002) reviews the concept of rapid climate change. Of this phenomenon, he writes that "it is now recognized that the ocean-atmosphere system exhibits several stable regimes under equivalent external forcings," and that "the transition from one state to another occurs very rapidly when certain climatic parameters attain threshold values." Specifically, he notes that in the models "a slight increase in the freshwater flux above the modern level *F* produces a decrease in the NADW [North Atlantic Deep Water] convection and a moderate cooling in the North Atlantic," but that "the system flips to another state once the flux reaches a threshold value *F* + delta*F*," which state has no deep convection and "is characterized by surface temperatures up to 6°C lower in and around the North Atlantic."

With respect to what has been learned from observations, Bard concentrates on the region of the North Atlantic, describing glacial-period millennial-scale episodes of dramatic warming called Dansgaard-Oeschger events (with temperature increases "of more than 10°C"), which are evident in Greenland ice core records, as well as episodes of "drastic cooling" called Heinrich events (with temperature drops "of up to about 5°C"), which are evident in sea surface temperature records derived from the study of North Atlantic deep-sea sediment cores.

In the Greenland record, according to Bard, the progression of these events is such that "the temperature warms abruptly to reach a maximum and then slowly decreases for a few centuries before reaching a threshold, after which it drops back to the cold values that prevailed before the warm event." He also reports that "models coupling the atmosphere, ocean, and ice sheets are still unable to correctly simulate that variability on all scales in both time and space," which suggests we do not fully understand the dynamics of these rapid climate changes. Bard states, "all the studies so far carried out fail to answer the crucial question: How close are we to the next bifurcation [which could cause a rapid change-of-state in earth's climate system]?" In this regard, he notes that "an intense debate continues in the modeling community about the reality of such instabilities under warm conditions," which is a particularly important point, since all dramatic warming and cooling events that have been detected to date have occurred in either full glacials or transitional periods between glacials and interglacials.

This latter real-world fact clearly suggests we are unlikely to experience any dramatic warming or cooling surprises in the near future, as long as the earth does not begin drifting towards glacial conditions, which is another reason to not be concerned about the ongoing rise in the air's CO_2 content. In fact, it suggests that allowing more CO_2 to accumulate in the atmosphere provides an "insurance policy" against abrupt climate change; interglacial warmth seems to inoculate the planet against climatic instabilities, allowing only the mild millennial-scale climatic oscillation that alternately brings the earth slightly warmer and cooler conditions typical of the Medieval Warm Period and Little Ice Age.

Focusing on the more pertinent period of the current interglacial or Holocene, we next consider a number of papers that bear upon the reality of the Medieval Warm Period and Little Ice Age: two well-known multi-century periods of significant climatic aberration. These periods of modest climatic aberration, plus the analogous warm and cool periods that preceded them (the Roman Warm Period and

Dark Ages Cold Period), provide strong evidence for the existence of a millennial-scale oscillation of climate that is unforced by changes in the air's CO_2 content, which in turn suggests that the global warming of the Little Ice Age-to-Current Warm Period transition was likely totally independent of the coincidental concomitant increase in the air's CO_2 content that accompanied the Industrial Revolution.

We begin with the study of Keigwin and Boyle (2000), who briefly reviewed what is known about the millennial-scale oscillation of earth's climate that is evident in a wealth of proxy climate data from around the world. Stating that "mounting evidence indicates that the Little Ice Age was a global event, and that its onset was synchronous within a few years in both Greenland and Antarctica," they remark that in Greenland it was characterized by a cooling of approximately 1.7°C. Likewise, in an article titled "Was the Medieval Warm Period Global?" Broecker (2001) answers yes, citing borehole temperature data that reveal the magnitude of the temperature drop over Greenland from the peak warmth of the Medieval Warm Period (800 to 1200 A.D.) to the coldest part of the Little Ice Age (1350 to 1860 A.D.) to have been approximately 2°C, and noting that as many as six thousand borehole records from all continents of the world confirm that the earth was a significantly warmer place a thousand years ago than it is today.

McDermott *et al*. (2001) derived a $\delta^{18}O$ record from a stalagmite discovered in Crag Cave in southwestern Ireland, after which they compared this record with the $\delta^{18}O$ records from the GRIP and GISP2 ice cores from Greenland. In doing so, they found evidence for "centennial-scale $\delta^{18}O$ variations that correlate with subtle $\delta^{18}O$ changes in the Greenland ice cores, indicating regionally coherent variability in the early Holocene." They additionally report that the Crag Cave data "exhibit variations that are broadly consistent with a Medieval Warm Period at ~1000 ± 200 years ago and a two-stage Little Ice Age, as reconstructed by inverse modeling of temperature profiles in the Greenland Ice Sheet." Also evident in the Crag Cave data were the $\delta^{18}O$ signatures of the earlier Roman Warm Period and Dark Ages Cold Period that comprised the prior such cycle of climate in that region. In concluding they reiterate the important fact that the coherent $\delta^{18}O$ variations in the records from both sides of the North Atlantic "indicate that many of the subtle multicentury $\delta^{18}O$ variations in the Greenland ice cores reflect regional North Atlantic margin climate signals rather than local effects."

Another study that looked at temperature variations on both sides of the North Atlantic was that of Seppa and Birks (2002), who used a recently developed pollen-climate reconstruction model and a new pollen stratigraphy from Toskaljavri, a tree-line lake in the continental sector of northern Fenoscandia (located just above 69°N latitude), to derive quantitative estimates of annual precipitation and July mean temperature. The two scientists say their reconstructions "agree with the traditional concept of a 'Medieval Warm Period' (MWP) and 'Little Ice Age' in the North Atlantic region (Dansgaard *et al*., 1975)." Specifically, they report there is "a clear correlation between our MWP reconstruction and several records from Greenland ice cores," and that "comparisons of a smoothed July temperature record from Toskaljavri with measured borehole temperatures of the GRIP and Dye 3 ice cores (Dahl-Jensen *et al*., 1998) and the $\delta^{18}O$ record from the Crete ice core (Dansgaard *et al*., 1975) show the strong similarity in timing of the MWP between the records." Last of all, they note that "July temperature values during the Medieval Warm Period (ca. 1400-1000 cal yr B.P.) were ca. 0.8°C higher than at present," where present means the last six decades of the twentieth century.

Concentrating solely on Greenland and its immediate environs are several other papers, among which is the study of Wagner and Melles (2001), who retrieved a sediment core from a lake on an island situated just off Liverpool Land on the east coast of Greenland. Analyzing it for a number of properties related to the past presence of seabirds there, they obtained a 10,000-year record that tells us much about the region's climatic history.

Key to the study were certain biogeochemical data that reflected variations in seabird breeding colonies in the catchment area of the lake. These data revealed high levels of the various parameters measured by Wagner and Melles between about 1,100 and 700 years before present (BP) that were indicative of the summer presence of significant numbers of seabirds during that "medieval warm period," as they describe it, which had been preceded by a several-hundred-year period of little to no inferred bird presence. Then, after the Medieval Warm Period, the data suggested another absence of birds during what they refer to as "a subsequent Little Ice Age," which they note was "the coldest period since the early Holocene in East Greenland." Their data also showed signs of a "resettlement of seabirds during the last 100 years, indicated by an increase of organic matter in the lake sediment and confirmed by bird observations." However, values of the most recent data were not as great as those obtained from the earlier Medieval Warm Period; and temperatures derived from two Greenland ice cores led to the same conclusion: it was warmer at various times between 1,100 to 700 years BP than it was over the twentieth century.

Kaplan *et al*. (2002) also worked with data obtained from a small lake, this one in southern Greenland, analyzing sediment physical-chemical properties, including magnetic susceptibility, density, water content, and biogenic silica and organic matter concentrations. They discovered that "the interval from 6000 to 3000 cal yr BP was marked by warmth and stability." Thereafter, however, the climate cooled "until its culmination during the Little Ice Age," but from 1,300-900 years BP, there was a partial amelioration of climate (the Medieval Warm Period) that was associated with an approximate 1.5°C rise in temperature.

Following another brief warming between AD 1500 and 1750, the second and more severe portion of the Little Ice Age occurred, which was in turn followed by "naturally initiated post-Little Ice Age warming since AD 1850, which is recorded throughout the Arctic." They report that Viking "colonization around the northwestern North Atlantic occurred during peak Medieval Warm Period conditions that ended in southern Greenland by AD 1100," noting that Norse movements around the region thereafter "occurred at perhaps the worst time in the last 10,000 years, in terms of the overall stability of the environment for sustained plant and animal husbandry."

We can further explore these aspects of Greenland's climatic history from three important papers that reconstructed environmental conditions in the vicinity of Igaliku Fjord, South Greenland, before, during, and after the period of Norse habitation of this and other parts of the ice-covered island's coast, beginning with the study of Lassen *et al*. (2004), who provide some historical background to their palaeoclimatic work by reporting that "the Norse, under Eric the Red, were able to colonize South Greenland at AD 985, according to the Icelandic Sagas, owing to the mild Medieval Warm Period climate with favorable open-ocean conditions." They also mention, in this regard, that the arrival of the gritty Norsemen was "close to the peak of Medieval warming recorded in the GISP2 ice core which was dated at AD 975 (Stuiver *et al*., 1995)," while we additionally note that Esper *et al*. (2002) independently identified the peak warmth of this period throughout North American extratropical latitudes as "occurring around 990." Hence, it would appear that the window of climatic opportunity provided by the peak warmth of the Medieval Warm Period was indeed a major factor enabling seafaring Scandinavians to establish long-enduring settlements on the coast of Greenland.

As time progressed, however, the glowing promise of the apex of Medieval warmth gave way to the debilitating reality of the depth of Little Ice Age cold. Jensen *et al*. (2004), for example, report that the diatom record of Igaliku Fjord "yields evidence of a relatively moist and warm climate at the beginning of settlement, which was crucial for Norse land use," but that "a regime of more extreme climatic fluctuations began soon after AD 1000, and after AD c. 1350 cooling became more severe." Lassen *et al*. additionally note that "historical documents on Iceland report the presence of the Norse in South Greenland for the last time in AD 1408," during what they describe as a period of "unprecedented influx of (ice-loaded) East Greenland Current water masses into the innermost parts of Igaliku Fjord." They also report that "studies of a Canadian high-Arctic ice core and nearby geothermal data (Koerner and Fisher, 1990) correspondingly show a significant temperature lowering at AD 1350-1400," when, in their words, "the Norse society in Greenland was declining and reaching its final stage probably before the end of the fifteenth century." Consequently, what the relative warmth of the Medieval Warm Period provided the Norse settlers, the relative cold of the Little Ice Age took from them: the ability to survive on Greenland.

More details of the saga of five centuries of Nordic survival at the foot of the Greenland Ice Cap are provided by the trio of papers addressing the palaeohistory of Igaliku Fjord. Based on a high-resolution record of the fjord's subsurface water-mass properties derived from analyses of benthic foraminifera, Lassen *et al.* conclude that stratification of the water column, with Atlantic water masses in its lower reaches, appears to have prevailed throughout the last 3,200 years, except for the Medieval Warm Period. During this period, which they describe as occurring between AD 885 and 1235, the outer part of Igaliku Fjord experienced enhanced vertical mixing (which they attribute to increased wind stress) that would have been expected to increase nutrient availability there. A similar conclusion was reached by Roncaglia and Kuijpers (2004), who found evidence of increased bottom-water ventilation between AD 960 and 1285. Hence, based on these findings, plus evidence of the presence of *Melonis barleeanus* during the Medieval Warm Period (the distribution of which is mainly controlled by the presence of partly decomposed organic matter), Lassen *et al*. conclude that surface productivity in the fjord during this interval of unusual relative warmth was "high and thus could have provided a good supply of marine food for the Norse people."

Shortly thereafter, the cooling that led to the Little Ice Age was accompanied by a gradual re-stratification of the water column, which curtailed nutrient upwelling and reduced the high level of marine productivity that had prevailed throughout the Medieval Warm Period. These linked events, according to Lassen *et al*., "contributed to the loss of the Norse settlement in Greenland." Indeed, with deteriorating growing conditions on land and simultaneous reductions in oceanic productivity, the odds were truly stacked against the Nordic colonies, and it was only a matter of time before their fate was sealed. As Lassen *et al*. describe it, "around AD 1450, the climate further deteriorated with further increasing stratification of the water-column associated with stronger advection of (ice-loaded) East Greenland Current water masses." This development, in their words, led to an even greater "increase of the ice season and a decrease of primary production and marine food supply," which "could also have had a dramatic influence on the local seal population and thus the feeding basis for the Norse population."

The end result of these several conjoined phenomena, in the words of Lassen *et al*., was that "climatic and hydrographic changes in the area of the Eastern Settlement were significant in the crucial period when the Norse disappeared." Also, Jensen *et al*. report that "geomorphological studies in Northeast Greenland have shown evidence of increased winter wind speed, particularly in the period between AD 1420 and 1580 (Christiansen, 1998)," noting that "this climatic deterioration coincides with reports of increased sea-ice conditions that caused difficulties in using the old sailing routes from Iceland westbound and further southward along the east coast of Greenland, forcing sailing on more southerly routes when going to Greenland (Seaver, 1996)."

In light of these observations, Jensen *et al.* state that "life conditions certainly became harsher during the 500 years of Norse colonization," and that this severe cooling-induced environmental deterioration "may very likely have hastened the disappearance of the culture." At the same time, it is also clear that the more favorable living conditions associated with the peak warmth of the Medieval Warm Period—which occurred between approximately AD 975 (Stuiver *et al*., 1995) and AD 990 (Esper *et al*., 2002)—were what originally enabled the Norse to successfully colonize the region. In the thousand-plus subsequent years, there has never been a sustained period of comparable warmth, nor of comparable terrestrial or marine productivity, either locally or hemispherically (and likely globally, as well), the strident protestations of Mann *et al*. (2003) notwithstanding.

Concentrating on the twentieth century, Hanna and Cappelen (2003) determined the air temperature history of coastal southern Greenland from 1958-2001, based on data from eight Danish Meteorological Institute stations in coastal and near-coastal southern Greenland, as well as the concomitant sea surface temperature (SST) history of the Labrador Sea off southwest Greenland, based on three previously published and subsequently extended SST datasets (Parker *et al*., 1995; Rayner *et al*., 1996; Kalnay *et al*., 1996). The coastal temperature data showed a *cooling* of 1.29°C over the period of study, while two of the three SST databases also depicted cooling: by 0.44°C in one case and by 0.80°C in the other. Both the land-based air temperature and SST series followed similar patterns and were strongly correlated, but with no obvious lead/lag either way. In addition, it was determined that the cooling was "significantly inversely correlated with an increased phase of the North Atlantic Oscillation (NAO) over the past few decades." The two researchers say this "NAO-temperature link doesn't explain what caused the observed cooling in coastal southern Greenland but it does lend it credibility."

In referring to what they call "this important regional exception to recent 'global warming'," Hanna and Cappelen note that the "recent cooling may have significantly added to the mass balance of at least the southern half of the [Greenland] Ice Sheet." Consequently, since this part of the ice sheet is the portion that would likely be the first to experience melting in a warming world, it would appear that whatever caused the cooling has not only protected the Greenland Ice Sheet against warming-induced disintegration but actually fortified it against that possibility.

Several other studies have also reported late-twentieth century cooling on Greenland. Based on mean monthly temperatures of 37 Arctic and seven sub-Arctic stations, as well as temperature anomalies of 30 grid-boxes from the updated dataset of Jones, for example, Przybylak (2000) found that "the level of temperature in Greenland in the last 10-20 years is similar to that observed in the 19th century." Likewise, in a study that utilized satellite imagery of the Odden ice tongue (a winter ice cover that occurs in the Greenland Sea with a length of about 1,300 km and an aerial coverage of as much as 330,000 square kilometers) plus surface air temperature data from adjacent Jan Mayen Island, Comiso *et al.* (2001) determined that the ice phenomenon was "a relatively smaller feature several decades ago," due to the warmer temperatures that were prevalent at that time. In addition, they report that observational evidence from Jan Mayen Island indicates temperatures there cooled at a rate of 0.15 ± 0.03°C per decade during the past 75 years.

Taurisano *et al.* (2004) examined the temperature history of the Nuuk fjord during the last century, where their analyses of all pertinent regional data led them to conclude that "at all stations in the Nuuk fjord, both the annual mean and the average temperature of the three summer months (June, July and August) exhibit a pattern in agreement with the trends observed at other stations in south and west Greenland (Humlum 1999; Hanna and Cappelen, 2003)." As they describe it, the temperature data "show that a warming trend occurred in the Nuuk fjord during the first 50 years of the 1900s, followed by a cooling over the second part of the century, when the average annual temperatures decreased by approximately 1.5°C." Coincident with this cooling trend there was also what they describe as "a remarkable increase in the number of snowfall days (+59 days)." What is more, they report that "not only did the cooling affect the winter months, as suggested by Hannna and Cappelen (2002), but also the summer mean," noting that "the summer cooling is rather important information for glaciological studies, due to the ablation-temperature relations."

In a study of three coastal stations in southern and central Greenland that possess almost uninterrupted temperature records between 1950 and 2000, Chylek *et al*. (2004) discovered that "summer temperatures, which are most relevant to Greenland ice sheet melting rates, do not show any persistent increase during the last fifty years." In fact, working with the two stations with the longest records (both over a century in length), they determined that coastal Greenland's peak temperatures occurred between 1930 and 1940, and that the subsequent decrease in temperature was so substantial and sustained that current coastal temperatures "are about 1°C below their 1940 values." Furthermore, they note that "at the summit of the Greenland ice sheet the summer average temperature has decreased at the rate of 2.2°C per decade since the beginning of the measurements in 1987." Hence, as with the Arctic as a whole, it would appear that Greenland has not experienced any net warming over the most dramatic period of atmospheric CO_2 increase on record. In fact, it has *cooled* during this period.

At the start of the twentieth century, however, Greenland was warming, as it emerged, along with the rest of the world, from the depths of the Little Ice Age. Between 1920 and 1930, when the atmosphere's CO_2 concentration rose by a mere 3 to 4 ppm, there was a phenomenal warming at all five coastal locations for which contemporary temperature records are available. In the words of Chylek *et al*., "average annual temperature rose between 2 and 4°C [and by as much as 6°C in the winter] in less than ten years." And this warming, as they note, "is also seen in the $^{18}O/^{16}O$ record of the Summit ice core (Steig *et al*., 1994; Stuiver *et al*., 1995; White *et al*., 1997)."

In commenting on this dramatic temperature rise, which they call the "great Greenland warming of the 1920s," Chylek *et al*. conclude that "since there was no significant increase in the atmospheric greenhouse gas concentration during that time, the Greenland warming of the 1920s demonstrates that a large and rapid temperature increase can occur over Greenland, and perhaps in other regions of the Arctic, due to internal climate variability such as the NAM/NAO [Northern Annular Mode/North Atlantic Oscillation], without a significant anthropogenic influence." These facts led them to speculate that "the NAO may play a crucial role in determining local Greenland climate during the 21st century, resulting in a local climate that may defy the global climate change."

Clearly, there is no substance to the claim that Greenland provides evidence for an impending CO_2-induced warming. These many studies of the temperature history of Greenland depict long-term oscillatory cooling ever since the Climatic Optimum of the mid-Holocene, when it was perhaps 2.5°C warmer than it is now, within which cooling trend is included the Medieval Warm Period, when it was about 1°C warmer than it is currently, and the Little Ice Age, when it was 0.5 to 0.7°C cooler than now, after which temperatures rebounded to a new maximum in the 1930s, only to fall steadily thereafter.

Additional information on this topic, including reviews of newer publications as they become available, can be found at http://www.co2science.org/subject/g/greenland.php.

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3.6.1.2. Rest of Arctic

Overpeck *et al.* (1997) combined paleoclimatic records obtained from lake and marine sediments, trees, and glaciers to develop a 400-year history of circum-Arctic surface air temperature. From this record they determined that the most dramatic warming of the last four centuries of the past millennium (1.5°C) occurred between 1840 and 1955, over which period the air's CO_2 concentration rose from approximately 285 ppm to 313 ppm, or by 28 ppm. Then, from 1955 to the end of the record (about 1990), the mean circum-Arctic air temperature declined by 0.4°C, while the air's CO_2 concentration rose from 313 ppm to 354 ppm, or by 41 ppm. On the basis of these observations, which apply to the entire Arctic, it is not possible to assess the influence of atmospheric CO_2 on surface air temperature or even to conclude it has any effect at all. Why? Because over the first 115 years of warming, as the air's CO_2 concentration rose by an average of 0.24 ppm/year, air temperature rose by an average of 0.013°C/year; over the final 35 years of the record, when the air's CO_2 content rose at a mean rate of 1.17 ppm/year (nearly five times the rate at which it had risen in the prior period), the rate-of-rise of surface air temperature decelerated, to a mean value (0.011°C/year) that was nearly the same as the rate at which it had previously risen.

Naurzbaev and Vaganov (2000) developed a 2,200-year temperature history using tree-ring data obtained from 118 trees near the upper-timberline in Siberia for the period 212 BC to AD 1996, as well as a similar history covering the period of the Holocene Climatic Optimum (3300 to 2600 BC). They compared their results with those obtained from an analysis of isotopic oxygen data extracted from a Greenland ice core. This work revealed that fluctuations in average annual temperature derived from the Siberian record agreed well with air temperature variations reconstructed from the Greenland data, suggesting to the two researchers that "the tree ring chronology of [the Siberian] region can be used to analyze both regional peculiarities and global temperature variations in the Northern Hemisphere."

Naurzbaev and Vaganov reported that several warm and cool periods prevailed for several multi-century periods throughout the last two millennia: a cool period in the first two centuries AD, a warm period from AD 200 to 600, cooling again from 600 to 800 AD, followed by the Medieval Warm Period from about AD 850 to 1150, the cooling of the Little Ice Age from AD 1200 though 1800, followed by the recovery warming of the twentieth century. In regard to this latter temperature rise, however, the two scientists say it was "not extraordinary," and that "the warming at the border of the first and second millennia [AD 1000] was longer in time and similar in amplitude." In addition, their reconstructed temperatures for the Holocene Climatic Optimum revealed there was an even warmer period about 5,000 years ago, when temperatures averaged 3.3°C more than they did over the past two millennia.

Contemporaneously, Vaganov *et al.* (2000) also used tree-ring width as a temperature proxy, reporting temperature variations for the Asian subarctic region over the past 600 years. Their graph of these data reveals that temperatures in this region exhibited a small positive trend from the beginning of the record until about AD 1750. Thereafter, a severe cooling trend ensued, followed by a 130-year warming trend from about 1820 through 1950, after which temperatures fell once again.

In analyzing the entire record, the researchers determined that the amplitude of twentieth century warming "does not go beyond the limits of reconstructed natural temperature fluctuations in the Holocene subarctic zone." And in attempting to determine the cause or causes of the temperature fluctuations, they report finding a significant correlation with solar radiation and volcanic activity over the entire 600-year period (r = 0.32 for solar radiation, r = -0.41 for volcanic activity), which correlation improved over the shorter interval (1800-1990) of the industrial period (r = 0.68 for solar radiation, r = -0.59 for volcanic activity). It is also enlightening to note, in this regard, that in this region of the world, where climate models predict large increases in temperature as a result of the historical rise in the air's CO_2 concentration, real-world data show an actual cooling trend since around 1940. Where warming does exist in the record—between about 1820 and 1940—much of it correlates with changes in solar irradiance and volcanic activity, two factors that are free of anthropogenic influence.

One year later, Moore *et al.* (2001) analyzed sediment cores extracted from Donard Lake, Baffin Island, Canada (~66.25°N, 62°W), to produce a 1,240-year record of mean summer temperature for this region that averaged 2.9°C over the period AD 750-1990. Within this period there were several anomalously warm decades with temperatures that were as high as 4°C around AD 1000 and 1100, while at the beginning of the thirteenth century Donard Lake witnessed what they called "one of the largest climatic transitions in over a millennium," as "average summer temperatures rose rapidly by nearly 2°C from AD 1195-1220, ending in the warmest decade in the record," with temperatures near 4.5°C. This latter temperature rise was then followed by a period of extended warmth that lasted until an abrupt cooling event occurred around AD 1375, resulting in the following decade being one of the coldest in the record and signaling the onset of the Little Ice Age on Baffin Island, which lasted 400 years. At the modern end of the record, a gradual warming trend occurred over the period 1800-1900, followed by a dramatic cooling event that brought temperatures back to levels characteristic of the Little Ice Age, which chilliness lasted until about 1950. Thereafter, temperatures rose once more throughout the 1950s and 1960s, whereupon they trended downwards toward cooler conditions to the end of the record in 1990.

Gedalof and Smith (2001) compiled a transect of six tree ring-width chronologies from stands of mountain hemlock growing near the treeline that extends from southern Oregon to the Kenai Peninsula, Alaska. Over the period of their study (AD 1599-1983), they determined that "much of the pre-instrumental record in the Pacific Northwest region of North America [was] characterized by alternating regimes of relatively warmer and cooler SST [sea surface temperature] in the North Pacific, punctuated by abrupt shifts in the mean background state," which were found to be "relatively common occurrences." They concluded that "regime shifts in the North Pacific have occurred 11 times since 1650." A significant aspect of these findings is the fact that the abrupt 1976-77 shift in this Pacific Decadal Oscillation, as it is generally called, is what was responsible for the vast majority of the past half-century's warming in Alaska, which some commentators wrongly point to as evidence of CO_2-induced global warming.

About the same time, Kasper and Allard (2001) examined soil deformations caused by ice wedges (a widespread and abundant form of ground ice in permafrost regions that can grow during colder periods and deform and crack the soil). Working near Salluit, northern Quebéc (approx. 62°N, 75.75°W), they found evidence of ice wedge activity prior to AD 140, reflecting cold climatic conditions. Between AD 140 and 1030, however, this activity decreased, reflective of warmer conditions. Then, from AD 1030 to 1500, conditions cooled; and from 1500 to 1900 ice wedge activity was at its peak, when the Little Ice Age ruled, suggesting this climatic interval exhibited the coldest conditions of the past 4,000 years. Thereafter, a warmer period prevailed, from about 1900 to 1946, which was followed by a return to cold conditions during the last five decades of the twentieth century, during which time more than 90 percent of the ice wedges studied reactivated and grew by 20-30 cm, in harmony with a reported temperature decline of 1.1°C observed at the meteorological station in Salluit.

In another study from the same year, Zeeberg and Forman (2001) analyzed twentieth century changes in glacier terminus positions on north Novaya Zemlya, a Russian island located between the Barents and Kara Seas in the Arctic Ocean, providing in the process a quantitative assessment of the effects of temperature and precipitation on glacial mass balance. This work revealed a significant and accelerated post-Little Ice Age glacial retreat in the first and second decades of the twentieth century; but by 1952, the region's glaciers had experienced between 75 to 100 percent of their net twentieth century retreat. During the next 50 years, the recession of more than half of the glaciers stopped, and many tidewater glaciers actually began to advance. These glacial stabilizations and advances were attributed by the two scientists to observed increases in precipitation and/or decreases in temperature. In the four decades since 1961, for example, weather stations at Novaya Zemlya show summer temperatures to have been 0.3° to 0.5°C colder than they were over the prior 40 years, while winter temperatures were 2.3° to 2.8°C colder than they were over the prior 40-year period. Such observations, in Zeeberg and Forman's words, are "counter to warming of the Eurasian Arctic predicted for the twenty-first century by climate models, particularly for the winter season."

Comiso *et al*. (2000) utilized satellite imagery to analyze and quantify a number of attributes of the Odden ice, including its average concentration, maximum area, and maximum extent over the period 1979-1998. They used surface air temperature data from Jan Mayen Island, located within the region of study, to infer the behavior of the phenomenon over the past 75 years.

The Odden ice tongue was found to vary in size, shape, and length of occurrence during the 20-year period, displaying a fair amount of interannual variability. Quantitatively, trend analyses revealed that the ice tongue had exhibited no statistically significant change in any of the parameters studied over the short 20-year period. However, a proxy reconstruction of the Odden ice tongue for the past *75* years revealed the ice phenomenon to have been "a relatively smaller feature several decades ago," due to the significantly warmer temperatures that prevailed at that time.

The fact that the Odden ice tongue has persisted, virtually unchanged in the mean during the past 20 years, is in direct contrast with predictions of rapid and increasing warmth in earth's polar regions as a result of CO_2-induced global warming. This observation, along with the observational evidence from Jan Mayen Island that temperatures there actually cooled at a rate of 0.15 ± 0.03°C per decade during the past 75 years, bolsters the view that there has been little to no warming in this part of the Arctic, as well as most of its other parts, over the past seven decades.

Polyakov *et al*. (2002b) used newly available long-term Russian observations of surface air temperature from coastal stations to gain new insights into trends and variability in the Arctic environment poleward of 62°N. Throughout the 125-year history they developed, they identified "strong intrinsic variability, dominated by multi-decadal fluctuations with a timescale of 60-80 years"; they found temperature trends in the Arctic to be highly dependent on the particular time period selected for analysis. They found they could "identify periods when Arctic trends were actually smaller or *of different sign* [our italics] than Northern Hemisphere trends." Over the bulk of the twentieth century, when they say "multi-decadal variability had little net effect on computed trends," the temperature histories of the two regions were "similar," but they did "not support amplified warming in polar regions predicted by GCMs."

In a concomitant study, Naurzbaev *et al*. (2002) developed a 2,427-year proxy temperature history for the part of the Taimyr Peninsula, northern Russia, lying between 70°30' and 72°28' North latitude, based on a study of ring-widths of living and preserved larch trees, noting that it has been shown that "the main driver of tree-ring variability at the polar timber-line [where they worked] is temperature (Vaganov *et al*., 1996; Briffa *et al*., 1998; Schweingruber and Briffa, 1996)." This work revealed that "the warmest periods over the last two millennia in this region were clearly in the third [Roman Warm Period], tenth to twelfth [Medieval Warm Period] and during the twentieth [Current Warm Period] centuries." With respect to the second of these three periods, they emphasize that "the warmth of the two centuries AD 1058-1157 and 950-1049 attests to the reality of relative mediaeval warmth in this region." Their data also reveal three other important pieces of information: (1) the Roman and Medieval Warm Periods were both warmer than the Current Warm Period has been to date, (2) the beginning of the end of the Little Ice Age was somewhere in the vicinity of 1830, and (3) the Current Warm Period peaked somewhere in the vicinity of 1940.

All of these observations are at odds with what is portrayed in the Northern Hemispheric "hockey stick" temperature history of Mann *et al*. (1998, 1999) and its thousand-year global extension developed by Mann and Jones (2003), wherein (1) the Current

Warm Period is depicted as the warmest such era of the past two millennia, (2) recovery from the Little Ice Age does not begin until after 1910, and (3) the Current Warm Period experiences it highest temperatures in the latter part of the twentieth century's final decade.

Przybylak (2002) conducted a detailed analysis of intraseasonal and interannual variability in maximum, minimum, and average air temperature and diurnal air temperature range for the entire Arctic—as delineated by Treshnikov (1985)—for the period 1951-1990, based on data from 10 stations "representing the majority of the climatic regions in the Arctic." This work indicated that trends in both the intraseasonal and interannual variability of the temperatures studied did not show any significant changes, leading Przybylak to conclude that "this aspect of climate change, as well as trends in average seasonal and annual values of temperature investigated earlier (Przybylak, 1997, 2000), proves that, in the Arctic in the period 1951-90, no tangible manifestations of the greenhouse effect can be identified."

Isaksson *et al*. (2003) retrieved two ice cores (one from Lomonosovfonna and one from Austfonna) far above the Arctic Circle in Svalbard, Norway, after which the 12 cooperating scientists from Norway, Finland, Sweden, Canada, Japan, Estonia, and the Netherlands used $\delta^{18}O$ data to reconstruct a 600-year temperature history of the region. As would be expected—in light of the earth's transition from the Little Ice Age to the Current Warm Period—the international group of scientists reported that "the $\delta^{18}O$ data from both Lomonosovfonna and Austfonna ice cores suggest that the twentieth century was the warmest during at least the past 600 years." However, the warmest decade of the twentieth century was centered on approximately 1930, while the instrumental temperature record at Longyearbyen also shows the decade of the 1930s to have been the warmest. In addition, the authors remark that, "as on Svalbard, the 1930s were the warmest decade in the Trondheim record." Consequently, there was no net warming over the last seven decades of the twentieth century in the parts of Norway cited in this study.

In the same year, Polyakov *et al*. (2003) derived a surface air temperature history that stretched from 1875 to 2000, based on measurements carried out at 75 land stations and a number of drifting buoys located poleward of 62°N latitude. From 1875 to about 1917, the team of eight U.S. and Russian scientists found the surface air temperature of the huge northern region rose hardly at all; but then it climbed 1.7°C in just 20 years to reach a peak in 1937 that was not eclipsed over the remainder of the record. During this 20-year period of rapidly rising air temperature, the atmosphere's CO_2 concentration rose by a mere 8 ppm. But then, over the next six decades, when the air's CO_2 concentration rose by approximately 55 ppm, or nearly seven times more than it did throughout the 20-year period of dramatic warming that preceded it, the surface air temperature of the region poleward of 62°N experienced no net warming and, in fact, may have cooled.

Briffa *et al*. (2004) reviewed several prior analyses of maximum latewood density data obtained from a widespread network of tree-ring chronologies that spanned three to six centuries and were derived from nearly 400 locations. For the land area of the globe poleward of 20°N latitude, they too found that the warmest period of the past six centuries occurred in the 1930s and early 1940s. Thereafter, the region's temperature dropped dramatically, although it did recover somewhat over the last two decades of the twentieth century. Nevertheless, its final value was still less than the mean value of the entire 1400s and portions of the 1500s.

Averaged across all land area poleward of 50°N latitude, there was a large divergence of reconstructed and instrumental temperatures subsequent to 1960, with measured temperatures rising and reconstructed temperatures falling, such that by the end of the record there was an approximate 1.5°C difference between them. Briffa *et al*. attempted to relate this large temperature differential to a hypothesized decrease in tree growth that was caused by a hypothesized increase in ultraviolet radiation that they hypothesized to have been caused by declining stratospheric ozone concentrations over this period. The results of their effort, however, proved "equivocal," as they themselves described it, leaving room for a growing urban heat island effect in the instrumental temperature record to be the principal cause of the disconcerting data divergence. The three researchers wrote that these unsettled questions prevented them "from claiming unprecedented hemispheric warming during recent decades on the basis of these tree-ring density data."

About the same time that Briffa *et al*. were struggling with this perplexing problem, Polyakov *et al*. (2004) were developing a long-term history of Atlantic Core Water Temperature (ACWT) in the Arctic Ocean using high-latitude hydrographic measurements that were initiated in the late nineteenth century, after which they compared the results of this exercise with the long-term history of Arctic Surface Air Temperature (SAT) developed by Polyakov *et al*. (2003). Their ACWT record, to quote them, revealed the existence of "two distinct warm periods from the late 1920s to 1950s and in the late 1980s-90s and two cold periods, one at the beginning of the record (until the 1920s) and another in the 1960s-70s." The SAT record depicted essentially the same thing, with the peak temperature of the latter warm period being not quite as high as the peak temperature of the former warm period. In the case of the ACWT record, however, this relationship was reversed, with the peak temperature of the latter warm period slightly exceeding the peak temperature of the former warm period. But the most recent temperature peak was very short-lived; and it rapidly declined to hover around a value that was approximately 1°C cooler over the last few years of the record.

In discussing their findings, Polyakov *et al*. say that, like Arctic SATs, Arctic ACWTs are dominated, in their words, "by multidecadal fluctuations with a time scale of 50-80 years." In addition, both records indicate that late twentieth century warmth was basically no different from that experienced in the late 1930s and early 1940s, a time when the air's CO_2 concentration was fully 65 ppm less than it is today.

Knudsen *et al*. (2004) documented climatic changes over the past 1,200 years via high-resolution multi-proxy studies of benthic and planktonic foraminiferal assemblages, stable isotopes, and ice-rafted debris found in three sediment cores retrieved from the North Icelandic shelf. These efforts resulted in their learning that "the time period between 1200 and around 7-800 cal. (years) BP, including the Medieval Warm Period, was characterized by relatively high bottom and surface water temperatures," after which "a general temperature decrease in the area marks the transition to ... the Little Ice Age." They also found that "minimum sea-surface temperatures were reached at around 350 cal. BP, when very cold conditions were indicated by several proxies." Thereafter, they report that "a modern warming of surface waters ... is not registered in the proxy data," and that "there is no clear indication of warming of water masses in the area during the last decades," even in sea surface temperatures measured over the period 1948-2002.

Raspopov *et al*. (2004) presented and analyzed two temperature-related datasets. The first was "a direct and systematic air temperature record for the Kola Peninsula, in the vicinity of Murmansk," which covered the period 1880-2000, while the second was an "annual tree-ring series generalized for 10 regions (Lovelius, 1997) along the northern timberline, from the Kola Peninsula to Chukotka, for the period 1458-1975 in the longitude range from 30°E to 170°E," which included nearly all of northern Eurasia that borders the Arctic Ocean.

The researchers' primary objectives in this work were to identify any temporal cycles that might be present in the two datasets and to determine what caused them. With respect to this dual goal, they report discovering "climatic cycles with periods of around 90, 22-23 and 11-12 years," which were found to "correlate well with the corresponding solar activity cycles." Of even more interest, however, was what they learned about the temporal development of the Current Warm Period (CWP).

Raspopov *et al*.'s presentation of the mean annual tree-ring series for the northern Eurasia timberline clearly shows that the region's thermal recovery from the coldest temperatures of the Little Ice Age (LIA) may be considered to have commenced as early as 1820 and was in full swing by at least 1840. In addition, it shows that the rising temperature peaked just prior to 1950 and then declined to the end of the record in 1975. Thereafter, however, the Kola-Murmansk instrumental record indicates a significant temperature rise that peaked in the early 1990s at about the same level as the pre-1950 peak; but after that time, the temperature once again declined to the end of the record in 2000.

The latter of these findings (that there has been no net warming of this expansive high-latitude region over the last half of the twentieth century) is in harmony with the findings of the many studies reviewed above, while the former finding (that the thermal recovery of this climatically sensitive region of the planet began in the first half of the nineteenth century) is also supported by a number of other studies (Esper *et al*., 2002; Moore *et al*., 2002; Yoo and D'Odorico, 2002; Gonzalez-Rouco *et al*., 2003; Jomelli and Pech, 2004), all of which demonstrate that the Little Ice Age-to-Current Warm Period transition began somewhere in the neighborhood of 1820 to 1850, well before the date (~1910) that is indicated in the Mann *et al*. (1998, 1999) "hockey stick" temperature history.

One further study from 2004 yields much the same conclusion, but arrives at it by very different means. Benner *et al*. (2004) set the stage for what they did by stating that "thawing of the permafrost which underlies a substantial fraction of the Arctic could accelerate carbon losses from soils (Goulden *et* *al*., 1998).” In addition, they report that “freshwater discharge to the Arctic Ocean is expected to increase with increasing temperatures (Peterson *et al*., 2002), potentially resulting in greater riverine export of terrigenous organic carbon to the ocean.” And since the organic carbon in Arctic soils, in their words, “is typically old, with average radiocarbon ages ranging from centuries to millennia (Schell, 1983; Schirrmeister *et al*., 2002),” they set about to measure the age of dissolved organic carbon (DOC) in Arctic rivers to see if there were any indications of increasing amounts of older carbon being transported to the ocean, which (if there were) would be indicative of enhanced regional warming.

Specifically, they sampled two of the largest Eurasian rivers, the Yenisey and Ob’ (which drain vast areas of boreal forest and extensive peat bogs, accounting for about a third of all riverine DOC discharge to the Arctic Ocean), as well as two much smaller rivers on the north slope of Alaska, the Ikpikpuk and Kokolik, whose watersheds are dominated by Arctic tundra. In doing so, they found modern radiocarbon ages for all samples taken from all rivers, which indicates, in their words, that Arctic riverine DOC “is derived primarily from recently fixed plant litter and near-surface soil horizons.” Thus, because warming should have caused the average radiocarbon age of the DOC of Arctic rivers to increase, the absence of aging implied by their findings provides strong evidence for the absence of recent large-scale warming there.

Laidre and Heide-Jorgensen (2005) published a most unusual paper, in that it dealt with the danger of oceanic cooling. Using a combination of long-term satellite tracking data, climate data, and remotely sensed sea ice concentrations to detect localized habitat trends of narwhals—a species of whale with a long spear-like tusk—in Baffin Bay between Greenland and Canada, home to the largest narwhal population in the world. They studied the species’ vulnerability to recent and possible future climate trends. They found “since 1970, the climate in West Greenland has cooled, reflected in both oceanographic and biological conditions (Hanna and Cappelen, 2003),” with the result that “Baffin Bay and Davis Strait display strong significant increasing trends in ice concentrations and extent, as high as 7.5 percent per decade between 1979 and 1996, with comparable increases detected back to 1953 (Parkinson *et al*., 1999; Deser *et al*., 2000; Parkinson, 2000a,b; Parkinson and Cavalieri, 2002; Stern and Heide-Jorgensen, 2003).”

Humlum *et al*. (2005) noted that state-of-the-art climate models were predicting that “the effect of any present and future global climatic change will be amplified in the polar regions as a result of feedbacks in which variations in the extent of glaciers, snow, sea ice and permafrost, as well as atmospheric greenhouse gases, play key roles.” However, they also said Polyakov *et al*. (2002a,b) had “presented updated observational trends and variations in Arctic climate and sea-ice cover during the twentieth century, which do not support the modeled polar amplification of surface air-temperature changes observed by surface stations at lower latitudes,” and “there is reason, therefore, to evaluate climate dynamics and their respective impacts on high-latitude glaciers.” They proceeded to do just that for the Archipelago of Svalbard, focusing on Spitsbergen (the Archipelago’s main island) and the Longyearbreen glacier located in its relatively dry central region at 78°13’N latitude.

In reviewing what was already known about the region, Humlum *et al*. report that “a marked warming around 1920 changed the mean annual air temperature (MAAT) at sea level within only 5 years from about -9.5°C to -4.0°C,” which change, in their words, “represents the most pronounced increase in MAAT documented anywhere in the world during the instrumental period.” Then, they report that “from 1957 to 1968, MAAT dropped about 4°C, followed by a more gradual increase towards the end of the twentieth century.”

With respect to the Longyearbreen glacier, their own work revealed that it had “increased in length from about 3 km to its present size of about 5 km during the last c. 1100 years,” and they stated that “this example of late-Holocene glacier growth represents a widespread phenomenon in Svalbard and in adjoining Arctic regions,” which they describe as a “development towards cooler conditions in the Arctic” that “may explain why the Little Ice Age glacier advance in Svalbard usually represents the Holocene maximum glacier extension.”

As for what it all means, climate change in Svalbard over the twentieth century appears to have been a real rollercoaster ride, with temperatures rising more rapidly in the early 1920s than has been documented anywhere else before or since, only to be followed by a nearly equivalent temperature drop four decades later, both of which transitions were totally out of line with what climate models suggest should have occurred. In addition, the current location of the terminus of the Longyearbreen glacier suggests that, even now, Svalbard and "adjoining Arctic regions" are still experiencing some of the lowest temperatures of the entire Holocene, and at a time when atmospheric CO_2 concentrations are higher than they have been for millions of years.

In one final paper from 2005, Soon (2005) explores the question of what was the more dominant driver of twentieth century temperature change in the Arctic: the rising atmospheric CO_2 concentration or variations in solar irradiance. This he did by examining the roles the two variables may have played in forcing decadal, multi-decadal, and longer-term variations in surface air temperature (SAT). He performed a number of statistical analyses on (1) a composite Arctic-wide SAT record constructed by Polyakov *et al*. (2003), (2) global CO_2 concentrations taken from estimates made by the NASA GISS climate modeling group, and (3) a total solar irradiance (TSI) record developed by Hoyt and Schatten (1993, updated by Hoyt in 2005) over the period 1875-2000.

The results of Soon's analyses indicated a much stronger statistical relationship exists between SAT and TSI than between SAT and atmospheric CO_2 concentration. Solar forcing generally explained well over 75 percent of the variance in decadal-smoothed seasonal and annual Arctic temperatures, while CO_2 forcing explained only between 8 and 22 percent. Wavelet analysis further supported the case for solar forcing of SAT, revealing similar time-frequency characteristics for annual and seasonally averaged temperatures at decadal and multi-decadal time scales. By contrast, wavelet analysis gave little to no indication of a CO_2 forcing of Arctic SSTs. Based on these findings, it would appear that it is the sun, and not atmospheric CO_2, that has been driving temperature change in the Arctic over the twentieth century.

Hanna *et al*. (2006) developed a 119-year history of Icelandic Sea Surface Temperature (SST) based on measurements made at 10 coastal stations located between latitudes 63°24'N and 66°32'N. This work revealed the existence of past "long-term variations and trends that are broadly similar to Icelandic air temperature records: that is, generally cold conditions during the late nineteenth and early twentieth centuries; strong warming in the 1920s, with peak SSTs typically being attained around 1940; and cooling thereafter until the 1970s, followed once again by warming—but not generally back up to the level of the 1930s/1940s warm period."

Hansen *et al*. (2006) analyzed meteorological data from Arctic Station (69°15'N, 53°31'W) on Disko Island (West Greenland) for the period 1991-2004, after which their results were correlated, in the words of the researchers, "to the longest record available from Greenland at Ilulissat/Jakobshavn (since 1873)." Once this was done, marked changes were noted over the course of the study period, including "increasing mean annual air temperatures on the order of 0.4°C per year and 50% decrease in sea ice cover." In addition, due to "a high correlation between mean monthly air temperatures at the two stations (1991-2004)," Hansen *et al.* were able to place the air temperature trend observed at Disko "in a 130 years perspective." This exercise led them to conclude that the climate changes of the past decade were "dramatic," but that "similar changes in air temperatures [had] occurred previous[ly] within the last 130 years." More specifically, they report that the changes they observed over the last decade "are on the same order as changes [that] occurred between 1920 and 1930."

In Iceland, Bradwell *et al*. (2006) examined the link between late Holocene fluctuations of Lambatungnajokull (an outlet glacier of the Vatnajokull ice cap of southeast Iceland) and variations in climate, using geomorphological evidence to reconstruct patterns of past glacier fluctuations and lichenometry and tephrostratigraphy to date glacial landforms created by the glacier over the past four centuries. This work revealed "there is a particularly close correspondence between summer air temperature and the rate of ice-front recession of Lambatungnajokull during periods of overall retreat," and "between 1930 and 1950 this relationship is striking." They also report that "ice-front recession was greatest during the 1930s and 1940s, when retreat averaged 20 m per year." Thereafter, however, they say the retreat "slowed in the 1960s," and "there has been little overall retreat since the 1980s." The researchers also report that "the 20th-century record of reconstructed glacier-front fluctuations at Lambatungnajokull compares well with those of other similar-sized, non-surging, outlets of southern Vatnajokull," including Skaftafellsjokull, Fjallsjokull, Skalafellsjokull, and Flaajokull. They find "the pattern of glacier fluctuations of Lambatungnajokull over the past 200 years reflects the climatic changes that have occurred in southeast Iceland and the wider region."

Contemporaneously, Drinkwater (2006) decided "to provide a review of the changes to the marine ecosystems of the northern North Atlantic during the 1920s and 1930s and to discuss them in the light of contemporary ideas of regime shifts," where he defined regime shift as "a persistent radical shift in typical levels of abundance or productivity of multiple important components of the marine biological community structure, occurring at multiple trophic levels and on a geographical scale that is at least regional in extent." As a prologue to this effort, he first determined that "in the 1920s and 1930s, there was a dramatic warming of the air and ocean temperatures in the northern North Atlantic and the high Arctic, with the largest changes occurring north of 60°N," which warming "led to reduced ice cover in the Arctic and subarctic regions and higher sea temperatures," as well as northward shifts of multiple marine ecosystems. This change in climate occurred "during the 1920s, and especially after 1925," according to Drinkwater, when he reports that "average air temperatures began to rise rapidly and continued to do so through the 1930s," when "mean annual air temperatures increased by approximately 0.5-1°C and the cumulative sums of anomalies varied from 1.5 to 6°C between 1920 and 1940 with the higher values occurring in West Greenland and Iceland." Thereafter, as he describes it, "through the 1940s and 1950s air temperatures in the northernmost regions varied but generally remained relatively high," declining in the late 1960s in the northwest Atlantic and slightly earlier in the northeast Atlantic, which cooling has only recently begun to be reversed in certain parts of the region.

In the realm of biology, the early twentieth century warming of North Atlantic waters "contributed to higher primary and secondary production," in the words of Drinkwater, and "with the reduced extent of ice-covered waters, more open water allow[ed] for higher production than in the colder periods." As a result, cod "spread approximately 1200 km northward along West Greenland," and "migration of 'warmer water' species also changed with earlier arrivals and later departures." In addition, Drinkwater notes that "new spawning sites were observed farther north for several species or stocks while for others the relative contribution from northern spawning sites increased." Also, he writes that "some southern species of fish that were unknown in northern areas prior to the warming event became occasional, and in some cases, frequent visitors." Consequently, and considering all aspects of the event, Drinkwater states that "the warming in the 1920s and 1930s is considered to constitute the most significant regime shift experienced in the North Atlantic in the 20th century."

Groisman *et al.* (2006) reported using "a new Global Synoptic Data Network consisting of 2100 stations within the boundaries of the former Soviet Union created jointly by the [U.S.] National Climatic Data Center and Russian Institute for Hydrometeorological Information … to assess the climatology of snow cover, frozen and unfrozen ground reports, and their temporal variability for the period from 1936 to 2004." They determined that "during the past 69 years (1936-2004 period), an increase in duration of the period with snow on the ground over Russia and the Russian polar region north of the Arctic circle has been documented by 5 days or 3% and 12 days or 5%, respectively," and they note this result "is in agreement with other findings."

In commenting on this development, plus the similar findings of others, the five researchers say "changes in snow cover extent during the 1936-2004 period cannot be linked with 'warming' (particularly with the Arctic warming)." Why? Because, as they continue, "in this particular period the Arctic warming was absent."

A recent essay that appeared in *Ambio: A Journal of the Human Environment*, by Karlén (2005) asks if temperatures in the Arctic are "really rising at an alarming rate," as some have claimed. His answer is a resounding no. Focusing on Svalbard Lufthavn (located at 78°N latitude), which he later shows to be representative of much of the Arctic, Karlén reports that "the Svalbard mean annual temperature increased rapidly from the 1910s to the late 1930s," that "the temperature thereafter became lower, and a minimum was reached around 1970," and that "Svalbard thereafter became warmer, but the mean temperature in the late 1990s was still slightly cooler than it was in the late 1930s," indicative of a cooling trend of 0.11°C per decade over the last seventy years of the twentieth century.

Karlén goes on to say "the observed warming during the 1930s is supported by data from several stations along the Arctic coasts and on islands in the Arctic, e.g. *Nordklim* data from Bjornoya and Jan Mayen in the north Atlantic, Vardo and Tromso in northern Norway, Sodankylaeand Karasjoki in northern Finland, and Stykkisholmur in Iceland," and "there is also [similar] data from other reports; e.g. Godthaab, Jakobshavn, and Egedesmindde in Greenland, Ostrov Dikson on the north coast of Siberia, Salehard in inland Siberia, and Nome in western Alaska." All of these stations, to quote him further, "indicate the same pattern of changes in annual mean temperature: a warm 1930s, a cooling until around 1970, and thereafter a warming, although the temperature remains slightly below the level of the late 1930s." In addition, he says "many stations with records starting later than the 1930s also indicate cooling, e.g. Vize in the Arctic Sea north of the Siberian coast and Frobisher Bay and Clyde on Baffin Island." Finally, Karlén reports that the 250-year temperature record of Stockholm "shows that the fluctuations of the 1900s are not unique," and that "changes of the same magnitude as in the 1900s occurred between 1770 and 1800, and distinct but smaller fluctuations occurred around 1825."

Karlén notes that "during the 50 years in which the atmospheric concentration of CO_2 has increased considerably, the temperature has decreased," which leads him to conclude that "the Arctic temperature data do not support the models predicting that there will be a critical future warming of the climate because of an increased concentration of CO_2 in the atmosphere." And this is especially important, in Karlén's words, because the model-based prediction "is that changes will be strongest and first noticeable in the Arctic."

Chylek *et al.* (2006) provides a more up-to-date report on average summer temperatures recorded at Ammassalik, on Greenland's southeast coast, and Godthab Nuuk on the island's southwestern coast, covering the period 1905 to 2005. They found "the 1955 to 2005 averages of the summer temperatures and the temperatures of the warmest month at both Godthab Nuuk and Ammassalik are significantly lower than the corresponding averages for the previous 50 years (1905-1955). The summers at both the southwestern and the southeastern coast of Greenland were significantly colder within the 1955-2005 period compared to the 1905-1955."

Chylek *et al*. also compared temperatures for the 10-year periods of 1920-1930 and 1995-2005. They found the average summer temperature for 2003 in Ammassalik was a record high since 1895, but "the years 2004 and 2005 were closer to normal being well below temperatures reached in the 1930s and 1940s." Similarly, the record from Godthab Nuuk showed that while temperatures there "were also increasing during the 1995-2005 period,they stayed generally below the values typical for the 1920-1940 period." The authors conclude that "reports of Greenland temperature changes are .... diverse suggesting a long term cooling and shorter warming periods."

Additional information on this topic, including reviews of newer publications as they become available, can be found at http://www.co2science.org/subject/a/arctictemptrends.php.

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3.7. Antarctica

The study of Antarctic temperatures has provided valuable insight and spurred contentious debate on issues pertaining to global climate change. Key among the pertinent findings has been the observation of a large-scale correlation between proxy air temperature and atmospheric CO_2 measurements obtained from ice cores drilled in the interior of the continent. In the mid- to late-1980s, this broad correlation dominated much of the climate change debate. Many jumped on the global warming bandwagon, saying the correlation proved that changes in atmospheric CO_2 concentration caused changes in air temperature, and that future increases in the air's CO_2 content due to anthropogenic CO_2 emissions would therefore intensify global warming.

By the late 1990s and early 2000s, however, ice-coring instrumentation and techniques had improved considerably and newer studies with finer temporal resolution began to reveal that increases (decreases) in air temperature precede increases (decreases) in atmospheric CO_2 content, not vice versa (see Indermuhle *et al*. (2000), Monnin *et al*. (2001)). A recent study by Caillon *et al*. (2003), for example, demonstrated that during Glacial Termination III, "the CO_2 increase lagged Antarctic deglacial warming by 800 ± 200 years." This finding, in the authors' words, "confirms that CO_2 is not the forcing that initially drives the climatic system during a deglaciation."

A second major blow to the CO_2-induced global warming hypothesis comes from the contradiction between observed and model-predicted Antarctic temperature trends of the past several decades. According to nearly all climate models, CO_2-induced global warming should be most evident in earth's polar regions, but analyses of Antarctic near-surface and tropospheric air temperatures contradict this prediction.

Doran *et al*. (2002) examined temperature trends in the McMurdo Dry Valleys of Antarctica over the period 1986 to 2000, reporting a cooling rate of approximately 0.7°C per decade. This dramatic rate of cooling, they state, "reflects longer term continental Antarctic cooling between 1966 and 2000." In addition, the 14-year temperature decline in the dry valleys occurred in the summer and autumn, just as most of the 35-year cooling over the continent as a whole (which did not include any data from the dry valleys) also occurred in the summer and autumn.

Comiso (2000) assembled and analyzed Antarctic temperature data obtained from 21 surface stations and from infrared satellites operating since 1979. He found that for all of Antarctica, temperatures had declined by 0.08°C and 0.42°C per decade, respectively. Thompson and Solomon (2002) also report a cooling trend for the interior of Antarctica.

In spite of the decades-long cooling that has been observed for the continent as a whole, one region of Antarctica has actually bucked the mean trend and *warmed* over the same time period: the Antarctic Peninsula/Bellingshausen Sea region. But is the temperature increase that has occurred there evidence of CO_2-induced global warming?

According to Vaughan *et al*. (2001), "rapid regional warming" has led to the loss of seven ice shelves in this region during the past 50 years. However, they note that sediment cores from 6,000 to 1,900 years ago suggest the Prince Gustav Channel Ice Shelf—which collapsed in this region in 1995—"was absent and climate was as warm as it has been recently," when, of course there was much less CO_2 in the air.

Although it is tempting to cite the twentieth century increase in atmospheric CO_2 concentration as the cause of the recent regional warming, "to do so without offering a mechanism," say Vaughan *et al*., "is superficial." And so it is, as the recent work of Thompson and Solomon (2002) suggests that much of the warming can be explained by "a systematic bias toward the high-index polarity of the SAM," or Southern Hemispheric Annular Mode, such that the ring of westerly winds encircling Antarctica has recently been spending more time in its strong-wind phase.

That is also the conclusion of Kwok and Comiso (2002), who report that over the 17-year period 1982-1998, the SAM index shifted towards more positive values (0.22/decade), noting that a positive polarity of the SAM index "is associated with cold anomalies over most of Antarctica with the center of action over the East Antarctic plateau." At the same time, the SO index shifted in a negative direction, indicating "a drift toward a spatial pattern with warmer temperatures around the Antarctic Peninsula, and cooler temperatures over much of the continent." Together, the authors say the positive trend in the *coupled* mode of variability of these two indices (0.3/decade) represents a "significant bias toward positive polarity" that they describe as "remarkable."

Kwok and Comiso additionally report that "the tropospheric SH annular mode has been shown to be related to changes in the lower stratosphere (Thompson and Wallace, 2000)," noting that "the high index polarity of the SH annular mode is associated with the trend toward a cooling and strengthening of the SH stratospheric polar vortex during the stratosphere's relatively short active season in November," which is pretty much the same theory that has been put forth by Thompson and Solomon (2002).

In another slant on the issue, Yoon *et al*. (2002) report that "the maritime record on the Antarctic Peninsula shelf suggests close chronological correlation with Holocene glacial events in the Northern Hemisphere, indicating the possibility of coherent climate variability in the Holocene." In the same vein, Khim *et al*. (2002) say that "two of the most significant climatic events during the late Holocene are the Little Ice Age (LIA) and Medieval Warm Period (MWP), both of which occurred globally (Lamb, 1965; Grove, 1988)," noting further that "evidence of the LIA has been found in several studies of Antarctic marine sediments (Leventer and Dunbar, 1988; Leventer *et al*., 1996; Domack *et al*., 2000)." To this list of scientific journal articles documenting the existence of the LIA in Antarctica can now be added Khim *et al*.'s own paper, which also demonstrates the presence of the MWP in Antarctica, as well as earlier cold and warm periods of similar intensity and duration.

Further evidence that the Antarctic as a whole is in the midst of a cooling trend comes from Watkins and Simmonds (2000), who analyzed region-wide changes in sea ice. Reporting on trends in a number of Southern Ocean sea ice parameters over the period 1987 to 1996, they found statistically significant increases in sea ice area and total sea ice extent, as well as an increase in sea ice season length since the 1990s. Combining these results with those from a previous study revealed these trends to be consistent back to at least 1978. And in another study of Antarctic sea ice extent, Yuan and Martinson (2000) report that the net trend in the mean Antarctic ice edge over the past 18 years has been an equatorward expansion of 0.011 degree of latitude per year.

The temperature history of Antarctica provides no evidence for the CO_2-induced global warming hypothesis. In fact, it argues strongly against it. But what if the Antarctic *were* to warm as a result of some natural or anthropogenic-induced change in earth's climate? What would the consequences be?

For one thing, it would likely help to increase both the number and diversity of penguin species (Sun *et al*., 2000; Smith *et al*., 1999), and it would also tend to increase the size and number of populations of the continent's only two vascular plant species (Xiong *et al*., 2000). With respect to the continent's great ice sheets, there would not be much of a problem either, as not even a warming event as dramatic as 10°C is predicted to result in a net change in the East Antarctic Ice Sheet (Näslund *et al*., 2000), which suggests that predictions of catastrophic coastal flooding due to the melting of the world's polar ice sheets are way off the mark.

Additional information on this topic, including reviews of newer publications as they become available, can be found at http://www.co2science.org/subject/a/antarcticatemp.php.

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