4. CLIMATE OBSERVATIONS

Models predict numerous changes in various climate parameters all across the globe in consequence of earth's rising atmospheric CO_2 concentration, yet some claim the future predictions are fast upon us and that CO_2-induced global warming is already occurring, citing many climate-related phenomena as proof of their thesis. In this chapter, we examine a number of the most frequently-cited claims, evaluating their validity as reported in the peer-reviewed scientific literature. Due to space constraints, we examine only a few of those claims in this document. A more comprehensive analysis can be found online at *CO_2 Science* (see http://www.co2science.org/subject/subject.php) by selecting a topic of interest in their Subject Index.

4.1. Glaciers

Model studies indicate that CO_2-induced global warming will result in significant melting of earth's glaciers, contributing to a rise in global sea level. In this section, we examine observational trends in glaciers to see if they match with the model projections. Additional information on this topic, including reviews of glaciers not discussed here, can be found at http://www.co2science.org/subject/g/subject_g.php under the heading Glaciers.

4.1.1. Global

The advance/buildup or retreat/melting of glacial ice is often interpreted as a sign of climate change; and teams of glaciologists have been working for years to provide an assessment of the state of the world's many glaciers as one of several approaches to deciphering global climate trends. Although this effort has only scratched the surface of what must ultimately be done, many have already rendered their verdict: there has been a massive and widespread retreat of glaciers over the past century, which they predict will only intensify under continued CO_2-induced global warming. This assessment, however, may be a bit premature.

The full story must begin with a clear recognition of just how few glacier data exist. Of the 160,000 glaciers presently in existence, only 67,000 (42%) have been inventoried to any degree (Kieffer *et al*., 2000); and there are only a tad over 200 glaciers for which mass balance data exist *for but a single year* (Braithwaite and Zhang, 2000). When the length of record increases to *five* years, this number drops to 115; and if both winter and summer mass balances are required, the number drops to 79. Furthermore, if *ten* years of record is used as a cutoff, only 42 glaciers qualify. This lack of glacial data, in the words of Braithwaite and Zhang, highlights "one of the most important problems for mass-balance glaciology" and demonstrates the "sad fact that many glacierized regions of the world remain unsampled, or only poorly sampled," suggesting that we really know very little about the true state of most of the world's glaciers.

Recognizing the need for "more comprehensive, more homogeneous in detail and quality" glacier data (Kieffer *et al*., 2000), we shift our attention to the few glaciers for which such data exist. During the 15th through 19th centuries, widespread and major glacier advances occurred during a period of colder global temperature known as the Little Ice Age (Broecker, 2001; Grove, 2001). Following the peak of Little Ice Age coldness, it should come as no surprise that many records indicate widespread glacial retreat, as temperatures began to rise in the mid- to late-1800s and many glaciers returned to positions characteristic of pre-Little Ice Age times. What people may find surprising, however, is that in many instances the *rate* of glacier retreat has not increased over the past 70 years; and in some cases glacier mass balance has actually increased, all during a time when the atmosphere experienced the bulk of the increase in its CO_2 content.

In an analysis of Arctic glacier mass balance, for example, Dowdeswell *et al*. (1997) found that of the 18 glaciers with the longest mass balance histories, just over 80% displayed negative mass balances over their periods of record. Yet they additionally report that "almost 80% of the mass balance time series also have a *positive* trend, toward a *less negative* mass balance [our italics]." Hence, although these Arctic glaciers continue to lose mass, as they have probably done since the end of the Little Ice Age, they are losing smaller amounts each year, in the mean, which is hardly what one would expect in the face of what some incorrectly call the "unprecedented" warming of the latter part of the twentieth century.

Similar results have been reported by Braithwaite (2002), who reviewed and analyzed mass balance measurements of 246 glaciers from around the world that were made between 1946 and 1995. According to Braithwaite, "there are several regions with highly negative mass balances in agreement with a public perception of 'the glaciers are melting,' but there are also regions with positive balances." Within Europe, for example, he notes that "Alpine glaciers are generally shrinking, Scandinavian glaciers are growing, and glaciers in the Caucasus are close to equilibrium for 1980-95." And when results for the whole world are combined for this most recent period of time, Braithwaite notes that "there is no obvious common or global trend of increasing glacier melt in recent years."

As for the glacier with the longest mass balance record of all, the Storglaciaren in northern Sweden, for the first 15 years of its 50-year record it exhibited a negative mass balance of little trend. Thereafter, however, its mass balance began to trend upward, actually becoming positive over about the last decade (Braithwaite and Zhang, 2000).

So, the story glaciers have to tell us about past climate change is both far from clear and far from being adequately resolved.

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

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4.1.2. Africa

On the floor of the U.S. Senate during debate on Senate Bill 139 back in 2004, Arizona Senator John McCain described his affection for the writings of Ernest Hemingway, especially his famous short story "The Snows of Kilimanjaro." Then, showing photos of the magnificent landmark taken in 1993 and 2000, he attributed the decline of glacial ice atop the mount during the intervening years to CO_2-induced global warming, calling this attribution not only a *fact*, but a fact "that cannot be refuted by any scientist."

In subsequent debate on the same bill, New York Senator Hillary Clinton echoed Senator McCain's sentiments. Displaying a second set of photos taken from the same vantage point in 1970 and 1999 - the first depicting "a 20-foot-high glacier" and the second "only a trace of ice" - she said that in those pictures "we have evidence in the most dramatic way possible of the effects of 29 years of global warming." Nevertheless, and in spite of the *absolute certitude* with which the two senators expressed their views on the subject - which allowed for no "wiggle room" whatsoever - both of them were as *wrong* as they could possibly be.

Modern glacier recession on Kilimanjaro began around 1880, approximately the same time the planet began to recover from the several-hundred-year cold spell of the Little Ice Age. As a result, a number of people who apparently have yet to learn that *correlation does not prove causation* have vociferously declared that the ice fields retreated *because* of the rising temperatures, encouraged in this contention by a few reports in the scientific literature that promoted the same scenario (Alverson *et al*., 2001; Irion, 2001; Thompson *et al*., 2002). This view of the subject, however, is "highly simplified," in the words of Molg *et al*. (2003b), who went on to demonstrate that it is also *just plain wrong*.

The trio of glaciologists began their analysis of the topic by reviewing some pertinent facts about the historic, climatic and geographic context of the long-term retreat of the Kilimanjaro ice fields. They noted, first of all, that "glacierization in East Africa is limited to three massifs close to the equator: Kilimanjaro (Tanzania, Kenya), Mount Kenya (Kenya), and Rwenzori (Zaire, Uganda)," all three of which sites experienced strong ice field recession over the past century or more. In that part of the world, however, they report "there is no evidence of a sudden change in temperature at the end of the 19th century (Hastenrath, 2001)," and that "East African long-term temperature records of the 20th century show diverse trends and do not exhibit a uniform warming signal (King'uyu *et al*., 2000; Hay *et al*., 2002)." Moreover, with respect to Kilimanjaro, they say that "since February 2000 an automatic weather station has operated on a horizontal glacier surface at the summit's Northern Icefield," and that "monthly mean air temperatures only vary slightly around the annual mean of -7.1°C, and air temperatures [measured by ventilated sensors, e.g., Georges and Kaser (2002)] never rise above the freezing point," which makes it pretty difficult to understand how ice could *melt* under such conditions.

So what caused the ice fields of Kilimanjaro to recede so steadily for so many years? Citing "historical accounts of lake levels (Hastenrath, 1984; Nicholson and Yin, 2001), wind and current observations in the Indian Ocean and their relationship to East African rainfall (Hastenrath, 2001), water balance models of lakes (Nicholson and Yin, 2001), and paleolimnological data (Verschuren *et al*., 2000)," Molg *et al*. (2003b) say "all data indicate that modern East African climate experienced an abrupt and marked drop in air humidity around 1880," and they add that the resultant "strong reduction in precipitation at the end of the 19th century is the main reason for modern glacier recession in East Africa," as it considerably reduces glacier mass balance accumulation, as has been demonstrated for the region by Kruss (1983) and Hastenrath (1984). In addition, they note that "increased incoming shortwave radiation due to decreases in cloudiness - both effects of the drier climatic conditions - plays a decisive role for glacier retreat by increasing ablation, as demonstrated for Mount Kenya and Rwenzori (Kruss and Hastenrath, 1987; Molg *et al*., 2003a)."

In further investigating this phenomenon, Molg *et al*. (2003b) applied a radiation model to an idealized representation of the 1880 ice cap of Kilimanjaro, calculating the spatial extent and geometry of the ice cap for a number of subsequent points in time and finding that "the basic evolution in spatial distribution of ice bodies on the summit is modeled well." The model they used, which specifically addresses the unique configuration of the summit's vertical ice walls, additionally provided, in their words, "a clear indication that solar radiation is the main climatic parameter governing and maintaining ice retreat on the mountain's summit plateau in the drier climate since ca. 1880." Consequently, Molg *et al*. (2003b) concluded that "modern glacier retreat on Kilimanjaro is much more complex than simply attributable to 'global warming only'." Indeed, they say it is "a process driven by a complex combination of changes in several different climatic parameters [e.g., Kruss, 1983; Kruss and Hastenrath, 1987; Hastenrath and Kruss, 1992;

Kaser and Georges, 1997; Wagnon *et al*., 2001; Kaser and Osmaston, 2002; Francou *et al*., 2003; Molg *et al*., 2003b], with humidity-related variables dominating this combination."

Also reviewing a wealth of data pertinent to the subject of African glaciers were Kaser *et al*. (2004), who similarly concluded that "changes in air humidity and atmospheric moisture content (e.g. Soden and Schroeder, 2000) seem to play an underestimated key role in tropical high-mountain climate (Broecker, 1997)." Noting that all glaciers in equatorial East Africa exhibited strong recession trends over the past century, they report that "the dominant reasons for this strong recession in modern times are reduced precipitation (Kruss, 1983; Hastenrath, 1984; Kruss and Hastenrath, 1987; Kaser and Noggler, 1996) and increased availability of shortwave radiation due to decreases in cloudiness (Kruss and Hastenrath, 1987; Molg *et al*., 2003b)," both of which phenomena they relate to a dramatic drying of the regional atmosphere that occurred around 1880 and the ensuing dry climate that subsequently prevailed throughout the 20th century. Consequently, Kaser *et al*. likewise demonstrated that all relevant "observations and facts" clearly indicate that "climatological processes other than air temperature control the ice recession in a direct manner" on Kilimanjaro, and that "positive air temperatures have not contributed to the recession process on the summit," directly contradicting Irion (2002) and Thompson *et al*. (2002), who, in their words, see the recession of Kilimanjaro's glaciers as "a direct consequence solely of increased air temperature."

In a subsequent study of the ice fields of Kilimanjaro, Molg and Hardy (2004) derived an energy balance for the horizontal surface of the glacier that comprises the northern ice field of Kibo - the only one of the East African massif's three peaks that is presently glaciated - based on data obtained from an automated weather station. This work revealed, in their words, that "the main energy exchange at the glacier-atmosphere interface results from the terms accounting for net radiation, governed by the variation in net shortwave radiation," which is controlled by surface albedo and, thus, precipitation variability, which determines the reflective characteristics of the glacier's surface. Much less significant, according to the two researchers, is the temperature-driven turbulent exchange of sensible heat, which they say "remains considerably smaller and of little importance."

Molg and Hardy therefore went on to conclude that "modern glacier retreat on Kilimanjaro and in East Africa in general [was] initiated by a drastic reduction in precipitation at the end of the nineteenth century (Hastenrath, 1984, 2001; Kaser *et al*., 2004)," and that reduced accumulation and increased ablation have "maintained the retreat until the present (Molg *et al*., 2003b)." Buttressing their findings is the fact, as they report it, that "detailed analyses of glacier retreat in the global tropics uniformly reveal that changes in climate variables related to air humidity prevail in controlling the modern retreat [e.g., Kaser and Georges (1997) for the Peruvian Cordillera Blanca and Francou *et al*. (2003) for the Bolivian Cordillera Real (both South American Andes); Kruss (1983), Kruss and Hastenrath (1987), and Hastenrath (1995) for Mount Kenya (East Africa); and Molg *et al*. (2003a) for the Rwenzori massif (East Africa)]." Hence, the take-home message of their study is essentially the same as that of Kaser *et al*. (2004): "positive air temperatures have not contributed to the recession process on the summit."

Two years later in a study that describes what has actually happened to Kilimanjaro's glaciers, Cullen *et al*. (2006) report that "all ice bodies on Kilimanjaro have retreated drastically between 1912-2003," but they add that the highest glacial recession rates on Kilimanjaro "occurred in the first part of the 20th century, with the most recent retreat rates (1989-2003) *smaller than in any other interval* [our italics]." In addition, they say that no temperature trends over the period 1948-2005 have been observed at the approximate height of the Kilimanjaro glaciers, but that there has been a small decrease in the region's specific humidity over this period.

In terms of *why* glacier retreat on Kilimanjaro was so dramatic over the 20th century, the six researchers note that for the mountain's *plateau* glaciers, there is no alternative for them "other than to continuously retreat once their vertical margins are exposed to solar radiation," which appears to have happened sometime in the latter part of the 19th century. They also say, in this regard, that the "vertical wall retreat that governs the retreat of plateau glaciers is irreversible, and changes in 20th century climate have not altered their continuous demise." Consequently, the 20th-century retreat of Kilimanjaro's plateau glaciers is a long-term response to what we could call "relict climate change" that likely occurred in the late 19th century.

In the case of the mountain's *slope* glaciers, Cullen *et al*. say that their rapid recession in the first part of the 20th century clearly shows they "were drastically out of equilibrium," which they take as evidence that the glaciers "were responding to a large *prior* [our italics] shift in climate." In addition, they report that "no footprint of multidecadal changes in areal extent of slope glaciers to fluctuations in 20th century climate is observed, but their ongoing demise does suggest they are still out of equilibrium," and in this regard they add that their continuing but decelerating demise could be helped along by the continuous slow decline in the air's specific humidity. Consequently, and in light of all the facts they present and the analyses they and others have conducted over many years, Cullen *et al*. confidently conclude that the glaciers of Kilimanjaro "are merely remnants of a past climate rather than sensitive indicators of 20th century climate change," the adamant prior statements of U.S. Senators McCain and Clinton notwithstanding.

Continuing on the same theme, Mote and Kaser (2007) and Duane *et al*. (2008) additionally reject the temperature-induced decline hypothesis for Kilimanjaro, with Duane *et al*. concluding that "the reasons for the rapid decline in Kilimanjaro's glaciers are not primarily due to increased air temperatures, but a lack of precipitation," and Mote and Kaser reporting that "warming fails *spectacularly* [our italics] to explain the behavior of the glaciers and plateau ice on Africa's Kilimanjaro massif .. and to a lesser extent other tropical glaciers." Clearly, the misguided rushes to judgment that have elevated Kilimanjaro's predicted demise by CO_2-induced global warming to iconic status should give everyone pause to more carefully evaluate the evidence, or lack thereof, for many similar claims related to the ongoing rise in the air's CO_2 content.

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

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4.1.3. Antarctica

Sometime in early November of 2001, a large iceberg separated from West Antarctica's Pine Island Glacier. This event was of great interest to scientists, because the Pine Island Glacier is currently the fastest moving glacier in Antarctica and the continent's largest discharger of ice, which facts have led some to speculate that this event could herald the "beginning of the end" of the West Antarctic Ice Sheet. A number of scientific studies, however, suggest otherwise.

Rignot (1998) employed satellite radar measurements of the grounding line of Pine Island Glacier from 1992 to 1996 to determine whether or not it was advancing or retreating. The data indicated a retreat rate of 1.2 ± 0.3 kilometers per year over the four-year period of the study. Because this period was so short, however, Rignot says that the questions the study raises concerning the long-term stability of the West Antarctic Ice Sheet "cannot be answered at present."

In a subsequent study, Stenoien and Bentley (2000) mapped the catchment region of Pine Island Glacier using radar altimetry and synthetic aperture radar interferometry, after which they used the data to develop a velocity map that revealed a system of tributaries that channel ice from the catchment area into the fast-flowing glacier. By combining these velocity data with information on ice thickness and snow accumulation rates, they were ultimately able to calculate an approximate mass balance for the glacier; and within an uncertainty of approximately 30%, their results suggested that the mass balance of the catchment region was not significantly different from zero.

In yet another study of Pine Island Glacier, Shepherd *et al*. (2001) used satellite altimetry and interferometry to determine the rate of change of thickness of its entire drainage basin between 1992 and 1999, determining that the grounded glacier thinned by up to 1.6 meters per year over this period. In commenting on this result, they note that "the thinning cannot be explained by short-term variability in accumulation and must result from glacier dynamics." And since glacier dynamics are typically driven by phenomena operating on time scales of hundreds to thousands of years, this observation would argue against 20th century warming being the cause of the thinning. Shepherd *et al*. additionally say they could "detect no change in the rate of ice thinning across the glacier over [the] 7-year period," which also suggests that a long-term phenomenon of considerable inertia must be at work in this particular situation.

But what if the rate of glacier thinning, which *sounds* pretty dramatic, continues unabated? Shepherd *et al*. state that "if the trunk continues to lose mass at the present rate it will be entirely afloat within 600 years." And if that happens? They say they "estimate the net contribution to eustatic sea level to be 6 mm," which means that for each century of the foreseeable future, we could expect global mean sea level to rise by approximately one millimeter ... or about the thickness of a common paper clip.

Turning to other glaciers, 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 was determined from more than 60 ^{14}C dates of organic materials they had previously collected from hand-dug excavations (Hall and Denton, 1999). They also evaluated more recent changes in snow and ice cover based on aerial photography and observations carried out since the late 1950s. So what did they find?

Near the end of the Medieval Warm Period - "as late as 890 ^{14}C yr BP," as Hall and Denton put it - "the Wilson Piedmont Glacier was still less extensive than it is now." Hence, they rightly conclude that the glacier had to have advanced within the last several hundred years, although they note that its eastern margin has retreated within the last 50 years. In addition, they report a number of similar observations by other investigators. Citing evidence collected by Baroni and Orombelli (1994a), they note there was "an advance of at least one kilometer of the Hell's Gate Ice Shelf ... within the past few hundred years." And they report that Baroni and Orombelli (1994b) "documented post-fourteenth century advance of a glacier near Edmonson's Point." Summarizing these and other findings, they conclude that evidence from the Ross Sea area suggests "late-Holocene climatic deterioration and glacial advance (within the past few hundred years) and twentieth century retreat."

In speaking of the significance of the "recent advance of the Wilson Piedmont Glacier," Hall and Denton report that it "overlaps in time with the readvance phase known in the Alps [of Europe] as the 'Little Ice Age'," which they further note "has been documented in glacial records as far afield as the Southern Alps of New Zealand (Wardle, 1973; Black, 2001), the temperate land mass closest to the Ross Sea region." They further note that "Kreutz *et al*. (1997) interpreted the Siple Dome [Antarctica] glaciochemical record as indicating enhanced atmospheric circulation intensity at AD ~1400, similar to that in Greenland during the 'Little Ice Age' (O'Brien *et al*., 1995)." In addition, they report that "farther north, glaciers in the South Shetland Islands adjacent to the Antarctic Peninsula underwent a late-Holocene advance, which has been correlated with the 'Little Ice Age' (Birkenmajer, 1981; Clapperton and Sugden, 1988; Martinex de Pison *et al*., 1996; Bjoreck *et al*., 1996)."

In summarizing the results of their work, Hall and Denton say "the Wilson Piedmont Glacier appears to have undergone advance at approximately the same time as the main phase of the 'Little Ice Age', followed by twentieth-century retreat at some localities along the Scott Coast." This result and the others they cite make it very clear that glacial activity on Antarctica has followed the pattern of millennial-scale variability that is evident elsewhere in the world: recession to positions during the Medieval Warm Period that have not yet been reached in our day, followed by significant advances during the intervening Little Ice Age, which is quite a different story from what the infamous "hockeystick" temperature history suggests, when temperatures of the past few decades supposedly rose to levels unprecedented in the past millennium.

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

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4.1.4. Arctic

Computer simulations of global climate change have long indicated the world's polar regions should show the first and severest signs of CO_2-induced global warming. If the models are correct, these signs should be especially evident in the second half of the 20th century, when approximately two-thirds of the modern-era rise in atmospheric CO_2 occurred and earth's temperature supposedly rose to a level unprecedented in the entire past millennium. In this subsection, we examine historic trends in Arctic glacier behavior to determine the credibility of current climate models with respect to their polar predictions.

In a review of "the most current and comprehensive research of Holocene glaciation," along the northernmost Gulf of Alaska between the Kenai Peninsula and Yakutat Bay, Calkin *et al*. (2001) report there were several periods of glacial advance and retreat over the past 7000 years. Over the most recent of those seven millennia, there was a general retreat during the Medieval Warm Period that lasted for "at least a few centuries prior to A.D. 1200." Then came three major intervals of Little Ice Age glacial advance: the early 15th century, the middle 17th century, and the last half of the 19th century. During these very cold periods, glacier equilibrium-line altitudes were depressed from 150 to 200 m below present values, as Alaskan glaciers "reached their Holocene maximum extensions."

Subsequent to this time, as the planet emerged from the depths of the Little Ice Age, the mass balance records of the 18 Arctic glaciers with the longest observational histories were studied by Dowdeswell *et al*. (1997). Their analysis showed that over 80% of the glaciers displayed negative mass balances over the periods of their observation, as would logically be expected for glaciers emerging from the coldest part of the past millennium. Nevertheless, the scientists report that "ice-core records from the Canadian High Arctic islands indicate that the generally negative glacier mass balances observed over the past 50 years [when the vast majority of the CO_2 resulting from human activities entered the atmosphere] have probably been typical of

Arctic glaciers *since the end of the Little Ice Age* [our italics]," when the magnitude of anthropogenic CO_2 emissions was a whole lot less than it has been from 1950 onward.

These observations suggest that Arctic glaciers are not experiencing *any* adverse effects of anthropogenic CO_2 emissions. In fact, Dowdeswell *et al*. say "there is no compelling indication of increasingly negative balance conditions which might, *a priori*, be expected from anthropogenically induced global warming." Quite to the contrary, they report that "almost 80% of the mass balance time series also have a *positive* trend, toward a *less* negative mass balance [our italics]." Hence, although most Arctic glaciers continue to lose mass, as they have probably done since the end of the Little Ice Age, they are losing smaller amounts each year, in the mean, which is hardly what one would expect in the face of what climate alarmists say is happening to earth's climate.

Additional evidence that the Arctic's glaciers are not responding to human-induced warming comes from the studies of Zeeberg and Forman (2001) and Mackintosh *et al*. (2002), who indicate there has been an *expansion* of glaciers in the European Arctic over the past few decades.

Zeeberg and Forman analyzed 20th-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 a quantitative assessment of the effects of temperature and precipitation on glacial mass balance. The results of their study showed a significant and accelerated post-Little Ice Age glacial retreat in the first and second decades of the 20th century. By 1952, however, the region's glaciers had experienced between 75 to 100% of their net 20th-century retreat; and during the next 50 years, the recession of over half of the glaciers stopped, while many tidewater glaciers actually began to advance.

These glacial stabilizations and advances were attributed by the authors to observed increases in precipitation and/or decreases in temperature. For the four decades since 1961, for example, weather stations on Novaya Zemlya show summer temperatures were 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 that earlier period. These observations, the authors say, are "counter to warming of the Eurasian Arctic predicted for the twenty-first century by climate models, particularly for the winter season"

Other glacier observations that run counter to climate model predictions are discussed by Mackintosh *et al*. (2002), who concentrated on the 300-year history of the Solheimajokull outlet glacier on the southern coast of Iceland. In 1705, this glacier had a length of about 14.8 km; and by 1740 it had grown to 15.2 km in length. Thereafter, it began to retreat, reaching a minimum length of 13.2 km in 1783. Rebounding rapidly, however, the glacier returned to its 1705 position by 1794; and by 1820 it equaled its 1740 length. This maximum length was maintained for the next half-century, after which the glacier began a slow retreat that continued to about 1932, when its length was approximately 14.75 km. Then it wasted away more rapidly, reaching a second minimum-length value of approximately 13.8 km about 1970, whereupon it began to *rapidly expand*, growing to 14.3 km by 1995.

The current position of the outlet glacier terminus is by no means unusual. In fact, it is about midway between its maximum and minimum positions of the past three centuries. It is also interesting to note that the glacier has been *growing* in length since about 1970. In addition, Mackintosh *et al*. report that "the recent advance (1970-1995) resulted from a combination of cooling and enhancement of precipitation."

In another study of the Arctic, Humlum *et al*. (2005) evaluated climate dynamics and their respective impacts on high-latitude glaciers 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 reveals it "has increased in length from about 3 km to its present size of about 5 km during the last c. 1100 years," and they say that "the meteorological setting of *non-surging* [our italics] Longyearbreen suggest 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."

Climate change in Svalbard over the 20th century was 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 climatic 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 or current interglacial, and at a time when atmospheric CO_2 concentrations are higher than they have likely been for *millions* of years, both of which observations are also at odds with what climate alarmists claim about the strong warming power of atmospheric CO_2 enrichment. Hence, there is little reason to put much faith in their claims, or to get too excited if the Arctic *were* to warm a bit ... or even *substantially* and at a *rapid rate*. It's done so before, and it will likely do so again. In fact, it's only to be *expected*, seeing the region has a long way to go to recover from some of the coldest temperatures of the entire interglacial.

Lastly, 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 glacier fluctuations and using lichenometry and tephrostratigraphy to date glacial landforms created by the glacier over the past four centuries. Results indicated that "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 that "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, they say the retreat "slowed in the 1960s," and they report "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. In fact, they find that "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."

Bradwell *et al*.'s findings suggest that 20th-century summer air temperature in southeast Iceland *and the wider region* peaked in the 1930s and 1940s, and was followed by a cooling that persisted through the end of the century. This thermal behavior is about as different as one could imagine from the *claim* that the warming of the globe over the last two decades of the 20th century was *unprecedented over the past two millennia*; and especially is this so for a high-northern-latitude region, where climate alarmists claim CO_2-induced global warming should be *earliest and most strongly expressed*.

Apparently, Iceland and many other high-latitude regions "just don't get it." Or is it the *climate alarmists* that suffer this malady, failing to realize (or, worse yet, *refusing to acknowledge*) that many key parts of the world that are supposedly super-sensitive to greenhouse-gas forcing are just not responding to anthropogenic CO_2 emissions the way they say they should?

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

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4.1.5. Europe

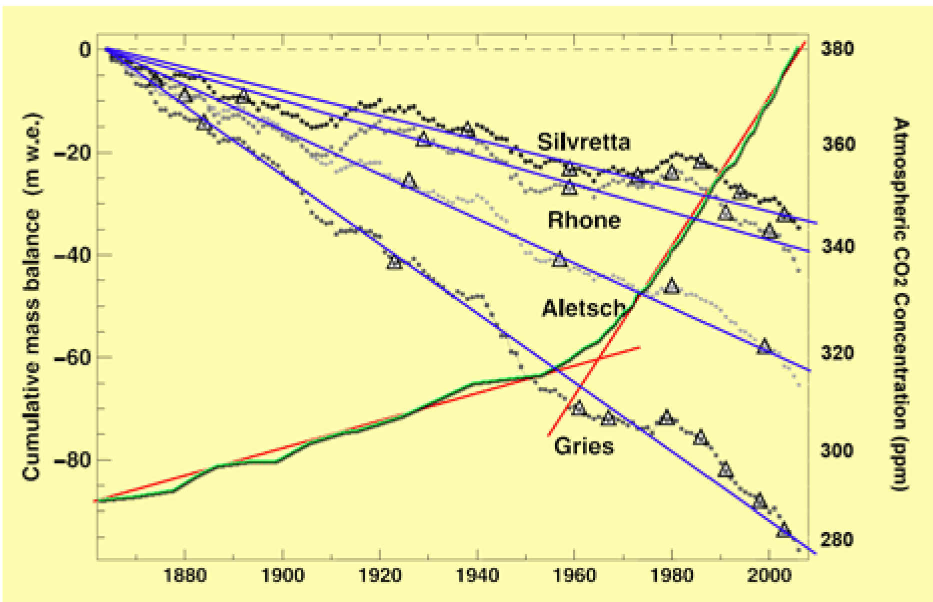
Joerin *et al*. (2006) examined glacier recessions in the Swiss Alps over the past ten thousand years based on radiocarbon-derived ages of materials found in proglacial fluvial sediments of subglacial origin, focusing on subfossil remains of wood and peat. Combining their results with earlier data of a similar nature, they then constructed a master chronology of Swiss glacier fluctuations over the course of the Holocene. So what did they find?

First of all, Joerin *et al*. report discovering that "alpine glacier recessions occurred at least 12 times during the Holocene," once again demonstrating the reality of the millennial-scale oscillation of climate that has reverberated throughout glacial and interglacial periods alike as far back in time as scientists have searched for the phenomenon. As a result of this finding, it is clear that 20th-century global warming was *not* **unusual**. It is was merely the latest example of what has been the *norm* throughout hundreds of thousands of years.

Second, they determined that glacier recessions have been decreasing in frequency since approximately 7000 years ago, and especially since 3200 years ago, "culminating in the maximum glacier extent of the 'Little Ice Age'." Consequently, the significant warming of the 20th century cannot be considered strange, since it represents a climatic rebounding from the *coldest period of the current interglacial*, which interglacial just happens to be the coldest of the last *five* interglacials (Petit *et al*., 1999). And when the earth has been *that* cold for a few centuries, it is *not* **unnatural** to expect that, once started, warming would be rather significant.

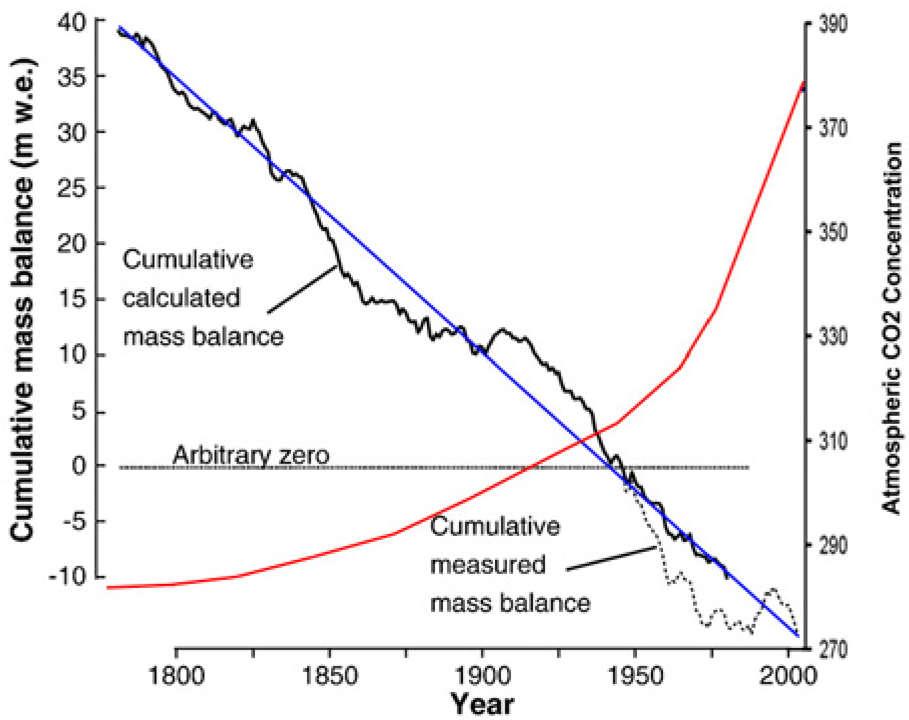
Third, the last of the major glacier recessions in the Swiss Alps occurred between about 1400 and 1200 years ago, according to Joerin *et al*.'s data, but between 1200 and 800 years ago, according to the data of Holzhauser *et al*. (2005) for the Great Aletsch Glacier. Of this discrepancy, Joerin *et al*. say that given the uncertainty of the radiocarbon dates, the two records need not be considered inconsistent with each other. What is more, their presentation of the Great Aletsch Glacier data indicates that the glacier's length at about AD 1000 - when there was fully 100 ppm *less* CO_2 in the air than there is today - was just slightly less than its length in 2002, suggesting that the peak temperature of the Medieval Warm Period likely was slightly higher than the peak temperature of the 20th century. Consequently, 20th-century warming has likely *not* been **unprecedented** over the past millennium.

Also in the Swiss Alps, Huss *et al*. (2008) examined various ice and meteorological measurements made between 1865 and 2006 in an effort to compute the yearly mass balances (positive for growth, negative for shrinkage) of four glaciers. The results of their computations can be seen in the figure below. The most obvious conclusion to be drawn from these data -- and the conclusion climate alarmists are quick to promote -- is the fact that each of the four glaciers has indeed decreased in size. But even more important than this observation is the fact that the *rate* of shrinkage *has not accelerated over time*, as evidenced by the long-term trend lines we have fit to the data (solid blue lines). What is more, there is no compelling evidence that this 14-decade-long glacial decline has had anything at all to do with the air's CO_2 content.



Consider, for example, the changes in atmospheric CO_2 concentration experienced over the same time period (solid green line). If we compute the mean rate-of-rise of the air's CO_2 content from the start of the record to about 1950, and from about 1970 to 2006 (solid red lines), we see that between 1950 and 1970 the rate-of-rise of the atmosphere's CO_2 concentration increased by *more than five-fold,* yet there were no related increases in the long-term mass balance trends of the four glaciers. Hence, it is clear that the ice loss history of the glaciers was not unduly influenced by the huge increase in the rate-of-rise of the air's CO_2 content that occurred between 1950 and 1970, and that their rate of shrinkage was also not materially altered by what climate alarmists call the *unprecedented warming* of the last few decades, which they claim was greater than any other warming of the last one to two thousand years.

Moving to northern Europe, Linderholm et al. (2007) examined "the world's longest ongoing continuous mass-balance record" of "Storglaciaren in northernmost Sweden," which they report "is generally well correlated to glaciers included in the regional mass balance program (Holmlund and Jansson, 1999), suggesting that it represents northern Swedish glaciers." The results of their work are depicted in the figure below, where we have also plotted the contemporaneous history of the atmosphere's CO_2 concentration.



The cumulative reconstructed net mass balance (bN) history of Sweden's Storglaciaren (to which we have added the fit-by-eye descending linear relationship), in blue, and the history of the atmosphere's CO_2 concentration, in red. Adapted from Linderholm et al. (2007).

In viewing the figure, it should be evident to all that the historical increase in the air's CO_2 content has had absolutely *no discernable impact whatsoever* on the net mass balance history of Sweden's Storglaciaren over the past two and a quarter centuries. Whereas the mean rate-of-rise of the air's CO_2 concentration over the last half-century of Storglaciaren mass balance data is fully *fifteen times greater* than what it was over the first half-century of mass balance data (and some *forty* times greater if the first and last *quarter*-centuries are considered), there has been no sign of any change in the long-term trend of Storglaciaren's net mass balance, which just keeps doing its own thing, seemingly *totally oblivious* to the concurrent *huge acceleration* in the rate-of-rise of the atmosphere's CO_2 concentration.

In addition to the results of the two papers referenced above, other studies have shown that not all European glaciers are experiencing a current retreat. A typical example is described by D'Orefice *et al*. (2000), who assembled and analyzed a wealth of historical data to derive a history of post-LIA shrinkage of the surface area of the southernmost glacier of Europe, Ghiacciaio del Calderone. From the first available information on the glacier's surface area in 1794, there was a very slow ice wastage that lasted until 1884, whereupon the glacier began to experience a more rapid area reduction that continued, with some irregularities, to 1990, resulting in a loss of just over half the glacier's LIA surface area.

Not all European glaciers, however, have experienced continuous declines since the end of the Little Ice Age. Hormes *et al*. (2001), for example, report that glaciers in the Central Swiss Alps experienced two periods of *readvancement*, one around 1920 and another as recent as 1980. In addition, Braithwaite (2002) reports that for the period 1980-1995, "Scandinavian glaciers [have been] growing, and glaciers in the Caucasus are close to equilibrium," while "there is no obvious common or global trend of increasing glacier melt."

Fifty years of mass balance data from the storied Storglaciaren of northwestern Sweden also demonstrate a trend reversal in the late 20th Century. According to Braithwaite and Zhang (2000), there has been a significant upward trend in the mass balance of this glacier over the past 30-40 years, and it has been in a state of mass *accumulation* for at least the past decade. Additional evidence for post-LIA glacial expansion is provided by the history of the Solheimajokull outlet glacier on the southern coast of Iceland. In a review of its length over the past 300 years, Mackintosh *et al*. (2002) report a post-LIA minimum of 13.8 km in 1970, whereupon the glacier began to expand, growing to a length of about 14.3 km by 1995. The minimum length of 13.8 km observed in 1970 also did not eclipse an earlier minimum in which the glacier had decreased from a 300-year maximum length of 15.2 km in 1740 to a 300-year minimum of 13.2 km in 1783.

Still more recent glacial advances have been reported in Norway. According to Chin *et al*. (2005), glacial recession in Norway was most strongly expressed in "the middle of the 20th century," ending during the late 1950s to early 1960s." Then, "after some years with more or less stationary glacier front positions, [the glaciers] began to advance, accelerating in the late 1980s." Around 2000, a portion of the glaciers began to slow, while some even ceased moving; but they say that "most of the larger outlets with longer reaction times are continuing to advance." In fact, Chin *et al*. report that "the distances regained and the duration of this recent advance episode are both far greater than any previous readvance since the Little Ice Age maximum, making the recent resurgence a significant event." Mass balance data reveal much the same thing, "especially since 1988" and "at all [western] maritime glaciers in both southern and northern Norway," where "frequent above-average winter balances are a main cause of the positive net balances at the maritime glaciers during the last few decades."

The advances and retreats of glaciers are often interpreted as signs of climate change; and teams of glaciologists have been working for years to provide an assessment of the state of the world's many glaciers to help decipher global climate trends. Although this effort has only scratched the surface of what must ultimately be done, some climate alarmists have already concluded there has been a massive and widespread retreat of glaciers over the past century, which they predict will only intensify under continued CO_2-induced global warming. In considering the results of the studies summarized above, however, it would appear that several

European glaciers are marching to the beat of a different drummer: holding their own -- or actually *advancing* -- over the past quarter century, a period of time in which the climate alarmists claim the earth has warmed to its highest temperature of the past thousand years.

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

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4.1.6. North America

Does the history of North American glacial activity support the claim that anthropogenic CO_2 emissions drove temperatures to new and unprecedented heights near the end of the 20th century? We here review some studies of North American glaciers that speak to this issue.

Dowdeswell *et al*. (1997) analyzed the mass balance histories of the 18 Arctic glaciers that have the longest observational records, finding that just over 80% of them displayed negative mass balances over the last half of the 20th century. However, they note that "ice-core records from the Canadian High Arctic islands indicate that the generally negative glacier mass balances observed over the past 50 years have probably been typical of Arctic glaciers since the end of the Little Ice Age." Also, they emphatically state "there is no compelling indication of increasingly negative balance conditions which might, *a priori*, be expected from anthropogenically induced global warming." Quite to the contrary, they report that "almost 80% of the mass balance time series also have a positive trend, toward a less negative mass balance." Hence, although most of these High Arctic Canadian glaciers continue to lose mass, as they have probably done since the end of the Little Ice Age, they are losing smaller amounts each year, in the mean, which is not what one would expect in the face of rapidly rising atmospheric CO_2 concentrations if they truly drive global warming as dramatically as climate-alarmists say they do.

Also reporting from Canada, Clague *et al*. (2004) documented glacier and vegetation changes at high elevations in the upper Bowser River basin in the northern Coast Mountains of British Columbia, based on studies of the distributions of glacial moraines and trimlines, tree-ring data, cores from two small lakes that were sampled for a variety of analyses (magnetic susceptibility, pollen, diatoms, chironomids, carbon and nitrogen content, ^{210}Pb, ^{137}Cs, ^{14}C), similar analyses of materials obtained from pits and cores from a nearby fen, and by accelerator mass spectrometry radiocarbon dating of plant fossils, including wood fragments, tree bark, twigs and conifer needles and cones. All this evidence suggested a glacial advance that began about 3000 years ago and may have lasted for hundreds of years, which would have placed it within the unnamed cold period that preceded the Roman Warm Period. There was also evidence for a second minor phase of activity that began about 1300 years ago but was of short duration, which would have placed it within the Dark Ages Cold Period. Finally, the third and most extensive Neoglacial interval began shortly after AD 1200, following the Medieval Warm Period, and ended in the late 1800s, which was, of course, the Little Ice Age, during which time Clague *et al*. say that "glaciers achieved their greatest extent of the past 3000 years and probably the last 10,000 years."

These data clearly depict the regular alternation between non-CO_2-forcecd multi-century cold and warm periods that is the trademark of the millennial-scale oscillation of climate that reverberates throughout glacial and interglacial periods alike. That a significant, but by no means unprecedented, warming followed the most recent cold phase of this cycle is in no way unusual, particularly since the Little Ice Age was likely *the coldest period of the last 10,000 years*. The significant warming of the 20th century would have occurred within the same timeframe and been just as strong even if the atmosphere's CO_2 content had remained constant at pre-industrial levels; it was simply the next scheduled phase of this ever-recurring natural climatic oscillation.

In a study based in Alaska, Calkin *et al*. (2001) reviewed the most current and comprehensive research of Holocene glaciation along the northernmost portion of the Gulf of Alaska between the Kenai Peninsula and Yakutat Bay, where several periods of glacial advance and retreat were noted during the past 7000 years. Over the latter part of this record, there was a general glacial retreat during the Medieval Warm Period that lasted for a few centuries prior to A.D. 1200, after which there were three major intervals of Little Ice Age glacial advance: the early 15th century, the middle 17th century, and the last half of the 19th century. During these latter time periods, glacier equilibrium line altitudes were depressed from 150 to 200 m below present values as Alaskan glaciers also "reached their Holocene maximum extensions." Hence, it is only to be expected that Alaska's temperatures would rise significantly and its glaciers would lose mass at significant rates during the planet's natural recovery from *the coldest period of the current interglacial*.

In another study from Alaska, Wiles *et al*. (2004) derived a composite Glacier Expansion Index (GEI) for the state based on "dendrochronologically-derived calendar dates from forests overrun by advancing ice and age estimates of moraines using tree-rings and lichens" for three climatically-distinct regions -- the Arctic Brooks Range, the southern transitional interior straddled by the Wrangell and St. Elias mountain ranges, and the Kenai, Chugach and St. Elias coastal ranges -- after which they compared this history of glacial activity with "the ^{14}C record preserved in tree rings corrected for marine and terrestrial reservoir effects as a proxy for solar variability" and with the history of the Pacific Decadal Oscillation (PDO) derived by Cook (2002). As a result of their efforts, Wiles *et al*. discovered that "Alaska shows ice expansions approximately every 200 years, compatible with a solar mode of variability," specifically, the de Vries 208-year solar cycle; and by merging this cycle with the cyclical behavior of the PDO, they obtained a dual-parameter forcing function that was even better correlated with the Alaskan composite GEI, with major glacial advances clearly associated with the Sporer, Maunder and Dalton solar minima.

In describing the rational for their study, Wiles *et al*. said that "increased understanding of solar variability and its climatic impacts is critical for separating anthropogenic from natural forcing and for predicting anticipated temperature change for future centuries." In this regard, it is most interesting that they made *no mention* of possible CO_2-induced global warming in discussing their results, presumably because *there was no need to do so*. Alaskan glacial activity, which in their words "has been shown to be primarily a record of summer temperature change (Barclay *et al*., 1999)," appears to be sufficiently well described within the context of centennial (solar) and decadal (PDO) variability superimposed upon the millennial-scale (non-

CO_2-forced) variability that produces longer-lasting Medieval Warm Period and Little Ice Age conditions.

Dropping down into the conterminous United States, Pederson *et al*. (2004) used tree-ring reconstructions of North Pacific surface temperature anomalies and summer drought as proxies for winter glacial accumulation and summer ablation, respectively, to create a 300-year history of regional glacial Mass Balance Potential (MBP), which they compared with historic retreats and advances of Glacier Park's extensively-studied Jackson and Agassiz glaciers. What they found was most interesting. As they describe it, "the maximum glacial advance of the Little Ice Age coincides with a sustained period of positive MBP that began in the mid-1770s and was interrupted by only one brief ablation phase (~1790s) prior to the 1830s," after which they report that "the mid-19th century retreat of the Jackson and Agassiz glaciers then coincides with a period marked by strong negative MBP." From about 1850 onward, for example, they note that "Carrara and McGimsey (1981) indicate a modest retreat (~3-14 m/yr) for both glaciers until approximately 1917." At that point, they report that "the MBP shifts to an extreme negative phase that persists for ~25 yr," during which period the glaciers retreated "at rates of greater than 100 m/yr."

Continuing with their history, Pederson *et al*. report that "from the mid-1940s through the 1970s retreat rates slowed substantially, and several modest advances were documented as the North Pacific transitioned to a cool phase [and] relatively mild summer conditions also prevailed." Thereafter, however, from the late 1970s through the 1990s, they say that "instrumental records indicate a shift in the PDO back to warmer conditions resulting in continuous, moderate retreat of the Jackson and Agassiz glaciers."

The first illuminating aspect of this glacial history is that the post-Little Ice Age retreat of the Jackson and Agassiz glaciers began just after 1830, in harmony with the findings of a number of other studies from various parts of the world (Vincent and Vallon, 1997; Vincent, 2001, 2002; Moore *et al*., 2002; Yoo and D'Odorico, 2002; Gonzalez-Rouco *et al*. 2003; Jomelli and Pech, 2004), *including the entire Northern Hemisphere* (Briffa and Osborn, 2002; Esper *et al*., 2002), which finding stands in stark contrast to what is suggested by the IPCC-endorsed "hockeystick" temperature history of Mann *et al*. (1998, 1999), which does not portray *any* Northern Hemispheric warming until around 1910. The second illuminating aspect of the glacial record is that the vast bulk of the glacial retreat in Glacier National Park occurred between 1830 and 1942, over which time the air's CO_2 concentration rose by only 27 ppm, which is less than a third of the total CO_2 increase experienced since the start of glacial recession. Then, from the mid-1940s through the 1970s, when the air's CO_2 concentration rose by another 27 ppm, Pederson *et al*. report that "retreat rates slowed substantially, and several modest advances were documented."

It is illuminating to note, in this regard, that the first 27 ppm increase in atmospheric CO_2 concentration coincided with the great preponderance of glacial retreat experienced since the start of the warming that marked the "beginning of the end" of the Little Ice Age, but that the next 27 ppm increase in the air's CO_2 concentration was accompanied by little if any additional glacial retreat, when, of course, there was little if any additional warming.

Clearly, and contrary to the strident claims of climate alarmists, something other than the historic rise in the air's CO_2 content has been responsible for the disappearing ice fields of Glacier National Park. It should also be clear to all that the historical behavior of North America's glaciers provides no evidence whatsoever for unprecedented or unnatural CO_2-induced global warming over any part of the 20th century.

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

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4.1.7. South America

The results of studies of past glacial activity in South America add to the accumulating evidence from around the world that suggests that the recent retreat of mountain glaciers is neither *unprecedented nor* CO_2*-induced*, but rather the *expected* result of the *natural* recovery of the earth from the *global* chill of the Little Ice Age, which latter period the world's climate alarmists strive to convince people was but a *regional* phenomenon confined to lands surrounding the North Atlantic Ocean.

Harrison and Winchester (2000) used dendrochronology, lichenometry and aerial photography to date 19th- and 20th-century fluctuations of the Arco, Colonia and Arenales glaciers on the eastern side of the Hielo Patagonico Norte in southern Chile. This work revealed that these glaciers, plus four others on the western side of the ice field, began to retreat, in the words of the two researchers, "from their Little Ice Age maximum positions" somewhere between 1850 and 1880, *well before the air's CO_2 content began to rise at a significant rate*. They also note that the trend continued "through the first half of the 20th century with various still-stands and oscillations between 1925 and 1960 ... with retreat increasing since the 1960s," just as has been observed at many sites in the Northern Hemisphere. Consequently, it is becoming ever more clear that even as far away from the lands that surround the North Atlantic Ocean as *southern Chile*, the Little Ice Age is evident in a variety of proxy climate records.

Still, however, the question remains: what caused the global warming that led to the Little Ice Age's demise throughout the world?

The likely answer to this question is provided by Glasser *et al*. (2004), who describe a large body of evidence related to glacier fluctuations in the two major ice fields of Patagonia: the Hielo Patagonico Norte and the Hielo Patagonico Sur. This evidence indicates that the most recent glacial advances in Patagonia occurred during the Little Ice Age, out of which serious cold spell the earth has been gradually emerging for the past century and a half, causing many glaciers to retreat. Prior to the Little Ice Age, however, their data indicate an interval of higher temperatures known as the Medieval Warm Period, when glaciers also decreased in size and extent; and this warm interlude was in turn preceded by a still earlier era of pronounced glacial activity that is designated the Dark Ages Cold Period, which was also preceded by a period of higher temperatures and retreating glaciers that is denoted the Roman Warm Period.

Prior to the Roman Warm Period, Glasser *et al*.'s presentation of the pertinent evidence suggests there was another period of significant glacial advance that also lasted several hundred years, which was preceded by a several-century interval when glaciers once again lost ground, which was preceded by yet another multi-century period of glacial advance, which was preceded by yet another long interval of glacier retrenchment, which was preceded by still another *full cycle* of such temperature-related glacial activity, which brings us all the way back to sometime between 6000 and 5000 ^{14}C years before present (BP).

Glasser *et al*. additionally cited the works of a number of other scientists that reveal a similar pattern of cyclical glacial activity over the preceding millennia in several other locations. Immediately to the east of the Hielo Patagonico Sur in the Rio Guanaco region of the Precordillera, for example, they report that Wenzens (1999) detected five distinct periods of glacial advancement: "4500-4200, 3600-3300, 2300-2000, 1300-1000 ^{14}C years BP and AD 1600-1850." With respect to the glacial advancements that occurred during the cold interval that preceded the Roman Warm Period, they say they constitute "part of a body of evidence for global climatic change around this time (e.g., Grosjean *et al*., 1998; Wasson and Claussen, 2002) which coincides with an abrupt decrease in solar activity," and they say that this observation was what "led van Geel *et al*. (2000) to suggest that variations in solar irradiance are more important as a driving force in variations in climate than previously believed."

Finally, with respect to the most recent recession of Hielo Patogonico Norte outlet glaciers from their late historic moraine limits at the end of the 19th century, Glasser *et al*. say that "a similar pattern can be observed in other parts of southern Chile (e.g., Kuylenstierna *et al*., 1996; Koch and Kilian, 2001)," to which we would also add the findings of Kaser and Georges (1997) for the Peruvian Cordillera Blanca and Francou *et al*. (2003) for the Bolivian Cordillera Real. Likewise, they note that "in areas peripheral to the North Atlantic and in central Asia the available evidence shows that glaciers underwent significant recession at this time (cf. Grove, 1988; Savoskul, 1997)," all of which evidence points to the operation of a globally-distributed forcing factor such as that provided by *cyclically-varying solar activity*.

In light of this significant body of evidence, and Glasser *et al*.'s analysis of it, it would appear that the history of glacial activity they describe suggests the existence of a millennial-scale oscillation of climate that operates on a broad scale that may, in fact, include the entire earth. Viewed in this light, the current recession of many of earth's glaciers is seen to be but the most recent and still-ongoing phase of a naturally-recurring phenomenon that has been "doing its thing," over and over, *without any help from variable atmospheric* CO_2 *concentrations*, throughout the entire last half of the Holocene.

But the story continues.

Based on various types of evidence collected by many investigators over the years, Georges (2004) constructed a 20th-century history of glacial fluctuations in the Cordillera Blanca of Peru, which is the largest glaciated area within the tropics. This history reveals, in Georges words, that "the beginning of the century was characterized by a glacier recession of unknown extent, followed by a marked readvance in the 1920s that nearly reached the Little Ice Age maximum." Then came the "very strong" 1930s-1940s glacial mass *shrinkage*, after which there was a period of quiescence that was followed by an "intermediate retreat from the mid-1970s until the end of the century."

In comparing the two periods of glacial wasting, Georges says that "the intensity of the 1930s-1940s retreat was more pronounced than that of the one at the end of the century." In fact, his graph of the ice area lost in both time periods suggests that the rate of wastage in the 1930s-1940s was *twice as great* as that of last two decades of the 20th century, which provides absolutely no support for the climate-alarmist claim that earth warmed at a rate, and to a level, that was *unprecedented over the past millennium or more* during the latter time period.

It is also interesting to note that Georges is quite at ease talking about the Little Ice Age south of the equator in Peru, which is a very long way from the lands that border the North Atlantic Ocean, which is the only region on earth where the world's climate alarmists willingly admit the existence of this chilly era of the planet's climatic history. What is perhaps even *more* interesting, however, is the fact that the glacial extensions of the Cordillera Blanca in the late 1920s were almost equivalent to those experienced there during the depths of the Little Ice Age, which is generally recognized as being the *coldest period of the current interglacial*, which suggests it is not at all strange that there should be a sizable warming of that part of the planet subsequent to its achieving a level of cold that was unprecedented over the past *several* millennia.

Moving south again, Koch and Kilian (2005) mapped and dated, by dendrochronological means, a number of moraine systems of Glaciar Lengua and neighboring glaciers of Gran Campo Nevado in the southernmost Andes of Chile, after which they compared their results with those of researchers who studied the subject in other parts of South America. According to their findings, in the Patagonian Andes "the culmination of the Little Ice Age glacier advances occurred between AD 1600 and 1700 (e.g., Mercer, 1970; Rothlisberger, 1986; Aniya, 1996)," but that "various glaciers at Hielo Patagonico Norte and Hielo Patagonico Sur also formed prominent moraines around 1870 and 1880 (Warren and Sugden, 1993; Winchester *et al*., 2001; Luckman and Villalba, 2001)." In addition, they note that their study "further supports this scenario," and that from their observations at Glaciar Lengua and neighboring glaciers at Gran Campo Nevado, it would appear that "the 'Little Ice Age' advance was possibly the most extensive one during the Holocene for this ice cap," which harmonizes with its being the coldest period of the past *several* millennia.

Last of all, and working with biogenic silica, magnetic susceptibility, total organic carbon (TOC), total nitrogen (TN), δ^{13}CTOC, δ^{15}NTN and C/N ratios derived from the sediment records of two Venezuelan watersheds, which they obtained from cores retrieved from Lakes Mucubaji and Blanca, together with ancillary data obtained from other studies that had been conducted in the same general region, Polissar *et al*. (2006) developed continuous decadal-scale histories of glacier activity and moisture balance in that part of the tropical Andes (the Cordillera de Merida) over the past millennium and a half, from which they were able to deduce contemporary histories of regional temperature and precipitation. So what did they learn?

The international team of scientists - representing Canada, Spain, the United States and Venezuela - write that "comparison of the Little Ice Age history of glacier activity with reconstructions of solar and volcanic forcing suggests that solar variability is the primary underlying cause of the glacier fluctuations," because (1) "the peaks and troughs in the susceptibility records match fluctuations of solar irradiance reconstructed from ^{10}Be and δ^{14}C measurements," (2) "spectral analysis shows significant peaks at 227 and 125 years in both the irradiance and magnetic susceptibility records, closely matching the de Vreis and Gleissberg oscillations identified from solar irradiance reconstructions," and (3) "solar and volcanic forcing are uncorrelated between AD 1520 and 1650, and the magnetic susceptibility record follows the solar-irradiance reconstruction during this interval." In addition, they write that "four glacial advances occurred between AD 1250 and 1810, coincident with solar-activity minima," and that "temperature declines of -3.2 ± 1.4°C and precipitation increases of ~20% are required to produce the observed glacial responses."

In discussing their findings, Polissar *et al*. say their results "suggest *considerable* [our italics] sensitivity of tropical climate to *small* [our italics] changes in radiative forcing from solar irradiance variability," which is something many people have had difficulty accepting in prior years. Hopefully, this paper will help them "see the light" a little clearer with respect to this subject. Not to be purveyors of *too* much good news, however, the six scientists say their findings imply "even greater probable responses to future anthropogenic forcing," and that "profound climatic impacts can be predicted for tropical montane regions."

With respect to these latter ominous remarks, we note that whereas Polissar *et al*.'s linking of significant climate changes with *solar* radiation variability is a *factual finding* of their work, their latter statements with respect to *hypothesized* CO_2-induced increases in down-welling *thermal* radiation are but *speculations* that need not follow from what they learned; for the two types of radiative forcing operate quite differently from each other, and there are many contemporaneous *biological* consequences of atmospheric CO_2 enrichment that may produce powerful *cooling* effects on earth's climate. Hence, there is no guarantee there will be *any* net impetus for warming as the atmosphere's CO_2 content continues to rise.

Another point worth noting in this regard is Polissar *et al*.'s acknowledgement that "during most of the past 10,000 years, glaciers were absent from all but the highest peaks in the Cordillera de Merida," which indicates that warmer-than-present temperatures are the *norm* for this part of the planet, and that any significant warming that might yet occur in this region (as well as most of the rest of the world) would only mark a *return* to more *typical* Holocene (or current interglacial) temperatures, which have themselves been significantly lower than those of *all four prior interglacials*. What is more, atmospheric CO_2 concentrations were *much lower* during all of those *much warmer* periods, providing further evidence that it is the *sun* that likely rules the world's climate, and not CO_2.

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

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4.2. Sea Ice

A number of claims have been made that CO_2-induced global warming is melting sea ice in both the Arctic and Antarctic, and that such melting will accelerate as time passes. In this next section, we analyze Antarctic and Arctic sea ice trends as reported in the scientific literature.

4.2.1. Antarctic

Utilizing Special Sensor Microwave Imager data obtained from the Defense Meteorological Satellite Program (DMSP) for the period December 1987-December 1996, Watkins and Simmonds (2000) analyzed temporal trends in different measures of the sea ice that surrounds Antarctica, noting that "it has been suggested that the Antarctic sea ice may show high sensitivity to any anthropogenic increase in temperature," as per the *canary-in-the-coal-mine* concept of high-latitude amplification and early detection of CO_2-induced global warming, further noting that most climate models predict that "any rise in surface temperature would result in a decrease in sea ice coverage." So what did they find?

Contrary to what one would expect on the basis of these predictions, and especially in light of what climate alarmists call the *unprecedented* warming of the past quarter-century, the two scientists observed statistically significant *increases* in both sea ice area and sea ice extent over the period studied; and when they combined their results with results for the preceding period of 1978-1987, both parameters continued to show increases over the sum of the two periods (1978-1996). In addition, they determined that the 1990s also experienced increases in the *length* of the sea ice season.

Watkins and Simmonds' findings, i.e., that Southern Ocean sea ice has increased in area, extent and season length since at least 1978, are also supported by a number of other studies. Hanna (2001), for example, published an updated analysis of Antarctic sea ice cover based on Special Sensor Microwave Imager data for the period October 1987-September 1999, finding that the serial sea ice data depict "an ongoing slight but significant hemispheric increase of 3.7(±0.3)% in extent and 6.6(±1.5)% in area." Likewise, Parkinson (2002) utilized satellite passive-microwave data to calculate and map the length of the sea-ice season throughout the Southern Ocean for each year of the period 1979-1999, finding that although there are opposing regional trends, a "much larger area of the Southern Ocean experienced an overall lengthening of the sea-ice season … than experienced a shortening." Updating the analysis two years later for the period November 1978 through December 2002, Parkinson (2004) reported a linear increase in 12-month running means of Southern Ocean sea ice extent of 12,380 ± 1,730 km_2 per year.

Zwally *et al*. (2002) also utilized passive-microwave satellite data to study Antarctic sea ice trends. Over the 20-year period 1979-1998, they report that the sea ice extent of the entire Southern Ocean increased by 11,181 ± 4,190 square km per year, or by 0.98 ± 0.37 percent per decade, while sea ice area increased by nearly the same amount: 10,860 ± 3,720 square km per year, or by 1.26 ± 0.43 percent per decade. And in contradiction of the claim that earth's climate should exhibit greater extremes when warming (which climate alarmists claim is occurring), they observed that the variability of monthly sea ice extent *declined* from 4.0% over the first ten years of the record, to 2.7% over the last ten years (which have supposedly been the warmest of the past millennium, according to the world's climate alarmists).

In yet another assessment of Antarctic sea ice behavior, Yuan and Martinson (2000) analyzed Special Sensor Microwave Imager data together with data derived from brightness temperatures measured by the Nimbus-7 Scanning Multichannel Microwave Radiometer. Among other things, they determined that the mean trend in the latitudinal location of the Antarctic sea ice edge over the prior 18 years was an *equatorward expansion* of 0.011 degree of latitude per year. But that is still not the end of the scientific testimony in this case.

Vyas *et al*. (2003) analyzed data from the multi-channel scanning microwave radiometer carried aboard India's OCEANSAT-1 satellite for the period June 1999-May 2001, which they combined with data for the period 1978-1987 that were derived from space-based passive microwave radiometers carried aboard earlier Nimbus-5, Nimbus-7 and DMSP satellites to study secular trends in sea ice extent about Antarctica over the period 1978-2001. Their work revealed that the mean rate of change of sea ice extent for the entire Antarctic region over this period was an *increase* of 0.043 M km² per year. In fact, they concluded that "the increasing trend in the sea ice extent over the Antarctic region may be *slowly accelerating* in time, particularly over the last decade," noting that the "continually increasing sea ice extent over the Antarctic Southern Polar Ocean, along with the observed decreasing trends in Antarctic ice surface temperature (Comiso, 2000) over the last two decades, is paradoxical in the global warming scenario resulting from increasing greenhouse gases in the atmosphere."

In a somewhat similar study, Cavalieri *et al*. (2003) extended prior satellite-derived Antarctic sea ice records several years by bridging the gap between Nimbus 7 and earlier Nimbus 5 satellite data sets with National Ice Center digital sea ice data, finding that sea ice extent about the continent increased at a mean rate of 0.10 ± 0.05 x 10^6 km² per decade between 1977 and 2002. Likewise, Liu *et al*. (2004) used sea ice concentration data retrieved from the scanning multichannel microwave radiometer on the Nimbus 7 satellite and the spatial sensor microwave/imager on several defense meteorological satellites to develop a quality-controlled history of Antarctic sea ice variability covering the period 1979-2002, which includes different states of the Antarctic Oscillation and several ENSO events, after which they evaluated total sea ice extent and area trends by means of linear least-squares regression. They found that "overall, the total Antarctic sea ice extent (the cumulative area of grid boxes covering at least 15% ice concentrations) has shown an increasing trend (~4,801 km²/yr)." In addition, they determined that "the total Antarctic sea ice area (the cumulative area of the ocean actually covered by at least 15% ice concentrations) has increased significantly by ~13,295 km^2/yr, exceeding the 95% confidence level," noting that "the upward trends in the total ice extent and area are robust for different cutoffs of 15, 20, and 30% ice concentrations (used to define the ice extent and area)."

Next, on a somewhat different note, Elderfield and Rickaby (2000) concluded that the sea ice cover of the Southern Ocean during glacial periods may have been as much as double the coverage of modern winter ice, suggesting that "by restricting communication between the ocean and atmosphere, sea ice expansion also provides a mechanism for reduced CO_2 release by the Southern Ocean and lower glacial atmospheric CO_2."

Finally, we present the results of three additional papers on Antarctic sea ice that were published in 2008. In the first paper, Laine (2008) determined 1981-2000 trends of Antarctic sea-ice *concentration* and *extent*, based on the Scanning Multichannel Microwave Radiometer and Special Sensor Microwave Imagers for the spring-summer period of November/December/January. These analyses were carried out for the continent as a whole, as well as five longitudinal sectors emanating from the south pole: 20°E-90°E, 90°E-160°E, 160°E-130°W, 130°W-60°W, and 60°W-20°E. Results indicated that "the sea ice concentration shows slight increasing trends in most sectors, where the sea ice extent trends seem to be near zero." As a result of these several findings, it is not surprising that Laine also reports that "the Antarctic region as a whole and all the sectors separately show slightly positive spring-summer albedo trends."

In the next study, Comiso and Nishio (2008) set out to provide updated and improved estimates of trends in Arctic and Antarctic sea ice cover for the period extending from November 1978 to December 2006, based on data obtained from the Advanced Microwave Scanning Radiometer (AMSR-E), the Special Scanning Microwave Imager (SSM/I) and the Scanning Multichannel Microwave Radiometer (SMMR), where the data from the last two instruments were adjusted to be consistent with the AMSR-E data. Their findings indicate that sea ice extent and area in the Antarctic grew by +0.9 ± 0.2 and +1.7 ± 0.3% per decade, respectively.

Lastly, in a study that "extends the analyses of the sea ice time series reported by Zwally *et al*. (2002) from 20 years (1979-1998) to 28 years (1979-2006)," Cavalieri and Parkinson (2008) derived new linear trends of Antarctic sea ice *extent* and *area*, based on satellite-borne passive microwave radiometer data. Results indicate that "the total Antarctic sea ice extent trend increased slightly, from 0.96 ± 0.61% per decade to 1.0 ± 0.4% per decade, from the 20- to 28-year period," noting that the latter trend is significant at the 95% confidence level. Corresponding numbers for the Antarctic sea ice *area* trend were 1.2 ± 0.7% per decade and 1.2 ± 0.5% per decade. Both sets of results also indicate a "tightening up" of the two relationships. Thus, over the last eight years of the study period, both the extent and area of Antarctic sea ice have continued to *increase*, with the former parameter increasing at a more rapid rate than it did over the 1979-1998 period.

In considering the findings of the several research papers described above that apply to the last few decades, if one were to infer anything about the planet in terms of what state-of-the-art climate models predict and what is known about real-world sea ice behavior around Antarctica, one would be tempted to conclude that the globe is currently in a *cooling* mode. Does that mean that the IPCC-endorsed air temperature history of the planet is in error? Or does it mean that the climate models are in error? Or does it mean that both are in error? All three of these important questions need to be pondered before rushing headlong into adopting expensive and economy-wrenching measures to battle what could well turn out to be an imaginary enemy, i.e., CO_2-induced 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/s/seaiceantarctic.php.

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4.2.2. Arctic

4.2.2.1. Extent

Arctic climate is incredibly complex, varying simultaneously on a number of different timescales for a number of different reasons (Venegas and Mysak, 2000); and against this backdrop of multiple causation and timeframe variability, it is extremely difficult to identify the increase in temperature that has been predicted to result from the burning of fossil fuels. The task is further complicated because many of the records that do exist contain only a few years to a few decades of data; and they yield different trends depending on the period of time studied. Such is also the case with the records of Arctic sea ice extent.

Consider, for example, the study of Johannessen *et al*. (1999), who analyzed Arctic sea ice extent over the period 1978-1998 and found it to have decreased by about 14%. This finding led them to suggest that "the balance of evidence," as small as it then was, indicates "an ice cover in transition," and that "if this apparent transformation continues, it may lead to a markedly different ice regime in the Arctic," as was also suggested by Vinnikov *et al*. (1999).

Reading Johannessen *et al*.'s assessment of the situation, one is left with the impression that a relatively consistent and ongoing transformation (a persistent reduction in the area of Arctic sea ice) is, in fact, in progress. However, and according to their own data, this assessment is highly debatable and possibly false. In viewing their plots of sea ice area, for example, it is readily evident that the decline in this parameter did not occur smoothly over the 20-year period of study. In fact, essentially all of the drop it experienced occurred rather abruptly over a single period of not more than three years (87/88-90/91) and possibly only one year (89/90-90/91). Furthermore, it could be argued from their data that from 1990/91 onward, sea ice area in the Arctic may have actually *increased*.

Support for this argument is found in the study of Kwok (2004), who estimated "the time-varying perennial ice zone (PIZ) coverage and construct[s] the annual cycles of multiyear (MY, including second year) ice coverage of the Arctic Ocean using QuikSCAT backscatter, MY fractions from RADARSAT, and the record of ice export from satellite passive microwave observations" for the years 199-2003. Based on the above-described data, Kwok calculated that the coverage of Arctic MY sea ice at the beginning of each year of the study was 3774 x 10^3 km^2 in 2000, 3896 x 10^3 km^2 in 2001, 4475 x 10^3 km^2 in 2002, and 4122 x 10^3 km^2 in 2003, representing an *increase* in sea ice coverage of 9% over but a *third* of a decade.

More questions are raised by the study of Parkinson (2000b), who utilized satellite-derived data of sea ice extent to calculate changes in this parameter for the periods 1979-1990 and 1990-1999. They report that in seven of the nine regions into which they divided the Arctic for their analysis, the "sign of the trend reversed from the 1979-1990 period to the 1990-1999 period," indicative of the ease with which significant decadal trends are often reversed in this part of the world.

In another study, Belchansky *et al*. (2004) report that from 1988 to 2001, total January multiyear ice area declined at a mean rate of 1.4% per year. In the autumn of 1996, however, they note that "a large multiyear ice recruitment of over 10^6 km^2 *fully replenished* [our italics] the previous 8-year decline in total area," but they add that the monumental replenishment "was followed by an accelerated and compensatory decline during the subsequent 4 years." In addition, they learned that 75% of the interannual variation in January multiyear sea area "was explained by linear regression on two atmospheric parameters: the previous winter's Arctic Oscillation index as a proxy to melt duration and the previous year's average sea level pressure gradient across the Fram Strait as a proxy to annual ice export."

Belchansky *et al*. conclude that their 14-year analysis of multiyear ice dynamics is "insufficient to project long-term trends." Hence, they also conclude it is insufficient to reveal "whether recent declines in multiyear ice area and thickness are indicators of anthropogenic exacerbations to positive feedbacks that will lead the Arctic to an unprecedented future of reduced ice cover [the climate-alarmist position], or whether they are simply ephemeral expressions of natural low frequency oscillations [our position]." It should be noted in this regard, however, that *low frequency oscillations are what the data actually reveal*; and such behavior is *not* what one would predict from a gradually increasing atmospheric CO_2 concentration.

In another study, Heige-Jorgensen and Laidre (2004) examined changes in the fraction of open-water found within various pack-ice microhabitats of Foxe Basin, Hudson Bay, Hudson Strait, Baffin Bay-Davis Strait, northern Baffin Bay and Lancaster Sound over a 23-year interval (1979-2001) using remotely-sensed microwave measurements of sea-ice extent, after which the trends they documented were "related to the relative importance of each wintering microhabitat for eight marine indicator species and potential impacts on winter success and survival were examined."

Results of the analysis indicate that Foxe Basin, Hudson Bay and Hudson Strait showed small increasing trends in the fraction of open-water, with the upward trends at all microhabitats studied ranging from 0.2 to 0.7% per decade. In Baffin Bay-Davis Straight and northern Baffin Bay, on the other hand, the open-water trend was *downward*, and at a mean rate for all open-water microhabitats studied of fully 1% per decade, while the trend in all Lancaster Sound open-water microhabitats was also downward, in this case at a mean rate of 0.6% per decade.
With respect to the context of these open-water declines, Heide-Jorgensen and Laidre report that "increasing trends in sea ice coverage in Baffin Bay and Davis Strait (resulting in declining

open-water) were as high as 7.5% per decade between 1979-1999 (Parkinson *et al*., 1999; Deser *et al*., 2000; Parkinson, 2000a,b; Parkinson and Cavalieri, 2002) and comparable significant increases have been detected back to 1953 (Stern and Heide-Jorgensen, 2003)." They additionally note that "similar trends in sea ice have also been detected locally along the West Greenland coast, with slightly lower increases of 2.8% per decade (Stern and Heide-Jorgensen, 2003)."

Another example of changing sea ice trends is provided by the study of Cavalieri *et al*. (2003), who extended prior satellite-derived Arctic sea ice records several years back in time by bridging the gap between Nimbus 7 and earlier Nimbus 5 satellite data sets via comparisons with National Ice Center digital sea ice data. For the newly-extended period of 1972-2002, they determined that Arctic sea ice extent had declined at a mean rate of $0.30 \pm 0.03 \times 10^6$ km^2 per decade; while for the shortened period from 1979-2002, they found a mean rate of decline of $0.36 \pm 0.05 \times 10^6$ km^2 per decade, or at a rate that was 20% greater than the full-period rate. In addition Serreze *et al*. (2002) determined that the downward trend in Arctic sea ice extent during the passive microwave era culminated with a record minimum value in 2002.

These results could readily be construed to be compatible with the spin that is typically given them by climate alarmists; that is, they indicate an increasingly greater rate of Arctic sea ice melting during the latter part of the 20th century, when global warming is claimed to have occurred at an increasingly greater rate. However, the results of these studies are not the end of the story, for still other studies have analyzed Arctic sea ice extent beyond the observational record using proxy data sources; and their results must be considered as well. As Grumet *et al*. (2001) have described the situation, recent trends in Arctic sea ice cover "can be viewed out of context because their brevity does not account for interdecadal variability, nor are the records sufficiently long to clearly establish a climate trend."

In an effort to overcome this "short-sightedness," Grumet *et al*. developed a 1000-year record of spring sea ice conditions in the Arctic region of Baffin Bay based on sea-salt records from an ice core obtained from the Penny Ice Cap on Baffin Island. In doing so, they determined that after a period of reduced sea ice during the 11th-14th centuries, enhanced sea ice conditions prevailed during the following 600 years. For the final century of this period, however, they report that "despite warmer temperatures during the turn of the century, sea-ice conditions in the Baffin Bay/Labrador Sea region, at least during the last 50 years, are within 'Little Ice Age' variability," suggesting that sea ice extent there has not yet emerged from the range of conditions characteristic of the Little Ice Age.

In an adjacent sector of the Arctic, this latter period of time was also studied by Comiso *et al*. (2001), who used satellite imagery to analyze and quantify a number of attributes of the Odden ice tongue - a winter ice-cover phenomenon that occurs in the Greenland Sea with a length of about 1300 km and an aerial coverage of as much as 330,000 square kilometers - over the period 1979-1998. By additionally utilizing surface air temperature data from Jan Mayen Island, which is located within the region of study, they were able to infer the behavior of this phenomenon over the past 75 years. Trend analyses revealed that the ice tongue has exhibited no statistically significant change in any of the parameters studied over the past 20 years; but the 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 warmer temperatures that prevailed at that time.

In another study of Arctic climate variability, Omstedt and Chen (2001) obtained a proxy record of the annual maximum extent of sea ice in the region of the Baltic Sea over the period 1720-1997. In analyzing this record, they found that a significant decline in sea ice occurred around 1877. In addition, they reported finding greater variability in sea ice extent in the colder 1720-1877 period than in the warmer 1878-1997 period.

Also at work in the Baltic Sea region, Jevrejeva (2001) reconstructed an even longer record of sea ice duration (and, therefore, extent) by examining historical data for the observed time of ice break-up between 1529 and 1990 in the northern port of Riga, Latvia. The long date-of-ice-break-up time series was best described by a fifth-order polynomial, which identified four distinct periods of climatic transition: (1) 1530-1640, warming with a tendency toward earlier ice break-up of 9 days/century, (2) 1640-1770, cooling with a tendency toward later ice break-up of 5 days/century, (3) 1770-1920, warming with a tendency toward earlier ice break-up of 15 days/century, and (4) 1920-1990, *cooling with a tendency toward later ice break-up of 12 days/century*.

On the other hand, in a study of the Nordic Seas (the Greenland, Iceland, Norwegian, Barents and Western Kara Seas), Vinje (2001) determined that "the extent of ice in the Nordic Seas measured in April has decreased by 33% over the past 135 years." He notes, however, that "nearly half of this reduction is observed over the period 1860-1900," and we note, in this regard, that the first half of this sea-ice decline occurred over a period of time when the atmosphere's CO_2 concentration rose by only 7 ppm, whereas the second half of the sea-ice decline occurred over a period of time when the air's CO_2 concentration rose by more than 70 ppm. This observation clearly suggests that if the historical rise in the air's CO_2 content has been responsible for the historical decrease in sea-ice extent, its impact over the last century has *declined* to *less than a tenth* of what its impact was over the preceding four decades, which in turn suggests that the increase in the air's CO_2 content over the past 135 years has likely had nothing whatsoever to do with the concomitant decline in sea-ice cover.

In a similar study of the Kara, Laptev, East Siberian and Chuckchi Seas, based on newly available long-term Russian observations, Polyakov *et al*. (2002) found "smaller than expected" trends in sea ice cover that, in their words, "do not support the hypothesized polar amplification of global warming." Likewise, in a second study published the following year, Polyakov *et al*. (2003) report that "over the entire Siberian marginal-ice zone the century-long trend is only -0.5% per decade," while "in the Kara, Laptev, East Siberian, and Chukchi Seas the ice extent trends are not large either: -1.1%, -0.4%, +0.3% and -1.0% per decade, respectively." Moreover, they say that "these trends, except for the Chukchi Sea, are not statistically significant," which observations tend to discredit climate model *qualitative* predictions of *amplified warming in earth's polar regions* in response to increases in the air's CO_2 content, which in turn tends to discredit their *quantitative* predictions of CO_2-induced global warming.

In another study, Divine and Dick (2006) used historical April through August ice observations made in the Nordic Seas - comprised of the Iceland, Greenland, Norwegian and Barents Seas, extending from 30°W to 70°E - to construct time series of ice-edge position anomalies spanning the period 1750-2002, which they analyzed for evidence of long-term trend and oscillatory behavior. The authors report that "evidence was found of oscillations in ice cover with periods of about 60 to 80 years and 20 to 30 years, superimposed on a continuous negative trend," which observations are indicative of a "persistent ice retreat since the second half of the 19th century" that began well before anthropogenic CO_2 emissions could have had much of an effect on earth's climate.

Noting that the last cold period observed in the Arctic occurred at the end of the 1960s, the two Norwegian researchers say their results suggest that "the Arctic ice pack is now at the periodical apogee of the low-frequency variability," and that "this could explain the strong negative trend in ice extent during the last decades as a possible superposition of natural low frequency variability and greenhouse gas induced warming of the last decades." *However*, as they immediately caution, "a similar shrinkage of ice cover was observed in the 1920s-1930s, during the previous warm phase of the low frequency oscillation, when any anthropogenic influence is believed to have still been negligible." They suggest, therefore, "that during decades to come ... the retreat of ice cover may change to an expansion."

In light of this litany of findings, it is difficult to accept the alarmist position that Northern Hemispheric sea ice is rapidly disintegrating in response to CO_2-induced global warming. Rather, the oscillatory behavior observed in so many of the sea ice studies suggests, in the words of Parkinson (2000), "the possibility of close connections between the sea ice cover and major oscillatory patterns in the atmosphere and oceans," including connections with: "(1) the North Atlantic Oscillation (e.g., Hurrell and van Loon, 1997; Johannessen *et al*., 1999; Kwok and Rothrock, 1999; Deser *et al*., 2000; Kwok, 2000, Vinje, 2001) and the spatially broader Arctic Oscillation (e.g., Deser *et al*., 2000; Wang and Ikeda, 2000); (2) the Arctic Ocean Oscillation (Polyakov *et al*., 1999; Proshutinsky *et al*., 1999); (3) a 'see-saw' in winter temperatures between Greenland and northern Europe (Rogers and van Loon, 1979); and (4) an interdecadal Arctic climate cycle (Mysak *et al*., 1990; Mysak and Power, 1992)." The likelihood that Arctic sea ice trends are the product of such natural oscillations, Parkinson continues, "provides a strong rationale for considerable caution when extrapolating into the future the widely reported decreases in the Arctic ice cover over the past few decades or when attributing the decreases primarily to global warming," a caution with which we heartily agree.

One final study of note that should be mentioned here is that of Bamber *et al*. (2004), who used high-accuracy ice-surface elevation measurements (Krabill *et al*., 2000) of the largest ice cap in the Eurasian Arctic -- Austfonna, on the island of Nordaustlandet in northeastern Svalbard -- to evaluate ice cap elevation changes between 1996 and 2002. They determined that the central and highest-altitude area of the ice cap, which comprises 15% of its total area, "increased in elevation by an average of 50 cm per year between 1996 and 2002," while "to the northeast of this region, thickening of about 10 cm per year was also observed." They further note that the highest of these growth rates represents "as much as a 40% increase in accumulation rate (Pinglot *et al*., 2001)."

Based on the ancillary sea-ice and meteorological data they analyzed, Bamber *et al*. concluded that the best explanation for the dramatic increase in ice cap growth over the six-year study period was a large increase in precipitation caused by a concomitant reduction in sea-ice cover in this sector of the Arctic. Their way of characterizing this phenomenon is simply to say that it represents the transference of ice from the top of the sea (in this case, the Barents Sea) to the top of the adjacent land (in this case, the Austfonna ice cap). And as what has been observed to date is but the *beginning* of the phenomenon, which will become even stronger in the absence of nearby sea-ice, "projected changes in Arctic sea-ice cover," as they say in the concluding sentence of their paper, "will have a significant impact on the mass-balance of land ice around the Arctic Basin over at least the next 50 years," which result, we might add, may well be far, far different from what the world's climate alarmists are currently anticipating.

Yes, the tales told by Arctic sea ice behavior are many and varied, as well as incomplete and even contradictory in some instances. It will thus be a very long time indeed before we can accurately decipher the grand message they contain, if there even is a grand message, which is by no means certain.

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

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4.2.2.2. Thickness

Based on analyses of submarine sonar data, Rothrock *et al*. (1999) and Wadhams and Davis (2000) suggested that Arctic sea ice had thinned by nearly 50% over the prior few decades. Their reports were widely cited by both the Intergovernmental Panel on Climate Change (IPCC: Houghton *et al*., 2001) and by the popular media, who at the time of the publications' appearance were whipped into a frenzy by climate-alarmist claims that the sea-ice thinning was caused by global warming that had been induced by anthropogenic CO_2 emissions.

So how has this contention withstood the test of time, albeit of but a few short years' duration? The first hint of an answer appeared essentially simultaneously with the publication of the ominous reports, when Johannessen *et al*. (1999) used surface-based measurements to derive variations in area-averaged Arctic sea-ice thickness from 1978 to 1991. They, too, detected a downward trend in this parameter. However, in carefully scrutinizing their data, it can be seen that the decline in sea-ice thickness did not occur smoothly over the period of study. In fact, essentially all of the drop occurred rather abruptly over a single period of not more than three years (1987/88-1990/91) and possibly only one year (1989/90-1990/91).

The next chapter in the complex detective story occurred two years later, when Winsor (2001) analyzed a much more comprehensive set of Arctic sea-ice data that had been obtained from six submarine cruises conducted between 1991 and 1997 that had covered the central Arctic Basin from 76° N to 90° N, as well as two areas that had been particularly densely sampled, one centered around the North Pole (>87° N) and one in the central part of the Beaufort Sea (centered at approximately 76° N, 145°W). The transect data across the entire Arctic Basin revealed that the mean Arctic sea-ice thickness had remained "almost constant" over the period of study. Data from the North Pole also showed little variability, and a linear regression of the data revealed a "slight increasing trend for the whole period." As for the Beaufort Sea region, annual variability in sea ice thickness was greater than at the North Pole; but once again, in Winsor's words, "no significant trend" in mean sea-ice thickness was found. Combining the North Pole results with the results of an earlier study, Winsor thus concluded that "mean ice thickness has remained on a near-constant level around the North Pole from 1986 to 1997."

The following year, Holloway and Sou (2002) explored "how observations, theory, and modeling work together to clarify perceived changes to Arctic sea ice," incorporating data from "the atmosphere, rivers, and ocean along with dynamics expressed in an ocean-ice-snow model." On the basis of a number of different data-fed model runs, they found that for the last half of the past century, "no linear trend [in Arctic sea ice volume] over 50 years is appropriate," noting that their results indicated "increasing volume to the mid-1960s, decadal variability without significant trend from the mid-1960s to the mid-1980s, then a loss of volume from the mid-1980s to the mid-1990s." The net effect of this behavior, in their words, was that "the volume estimated in 2000 is close to the volume estimated in 1950." Hence, they suggested that the initial inferred rapid thinning of Arctic sea ice was, as they put it, "unlikely," due to problems arising from under sampling. They also reported that "varying winds that readily redistribute Arctic ice create a recurring pattern whereby ice shifts between the central Arctic and peripheral regions, especially in the Canadian sector," and that the "timing and tracks of the submarine surveys missed this dominant mode of variability."

In the same year, Polyakov *et al*. (2002) employed newly available long-term Russian fast-ice data obtained from the Kara, Laptev, East Siberian and Chuckchi Seas to investigate trends and variability in the Arctic environment poleward of 62°N. This study revealed that fast-ice thickness trends in the different seas were "relatively small, positive or negative in sign at different locations, and not statistically significant at the 95% level." A year later, these results were reconfirmed by Polyakov *et al*. (2003), who reported that the available fast-ice records "do not show a significant trend," while noting that "in the Kara and Chukchi Seas trends are positive, and in the Laptev and East Siberian Seas trends are negative," but stating that "these trends are not statistically significant at the 95% confidence level."

The following year, Laxon *et al*. (2003) used an eight-year time series (1993-2001) of Arctic sea-ice thickness data derived from measurements of ice freeboard made by radar altimeters carried aboard ERS-1 and 2 satellites to determine the mean thickness and variability of Arctic sea ice between latitudes 65 and 81.5°N, which region covers the entire circumference of the Arctic Ocean, including the Beaufort, Chukchi, East Siberian, Kara, Laptev, Barents and Greenland Seas. These real-world observations served a number of purposes: (1) they revealed "an interannual variability in ice thickness at higher frequency, and of greater amplitude, than simulated by regional Arctic models," (2) they undermined "the conclusion from numerical models that changes in ice thickness occur on much longer timescales than changes in ice extent," and (3) they showed that "sea ice mass can change by up to 16% within one year," which finding "contrasts with the concept of a slowly dwindling ice pack, produced by greenhouse warming." Laxon *et al*. thus concluded that "errors are present in current simulations of Arctic sea ice," stating in their closing sentence that "until models properly reproduce the observed high-frequency, and thermodynamically driven, variability in sea ice thickness, simulations of both recent, and future, changes in Arctic ice cover will be open to question."

Next, based on monthly fields of ice motion obtained from the International Arctic Buoy Program, Pfirman *et al*. (2004) analyzed Arctic sea-ice drift dynamics from 1979-1997, using a Lagrangian perspective that "shows the complexities of ice drift response to variations in atmospheric conditions." This analysis indicated, in their words, that "large amounts of sea ice form over shallow Arctic shelves, are transported across the central basin and are exported primarily through Fram Strait and, to lesser degrees, the Barents Sea and Canadian Archipelago," consistent with the observations of several other investigators. They also determined that within the central Arctic, ice travel times averaged 4.0 years from 1984-85 through 1988-89, but only 3.0 years from 1990-91 through 1996-97. This enhanced rate of export of old ice to Fram Strait from the Beaufort Gyre over the latter period decreased the fraction of thick ridged ice within the central basin of the Arctic, and was deemed by Pfirman *et al*. to be responsible for some of the sea-ice thinning observed between the 1980s and 1990s. They also note that the rapid change in ice dynamics that occurred between 1988 and 1990 was "in response to a weakening of the Beaufort high pressure system and a strengthening of the European Arctic low (a shift from lower North Atlantic Oscillation/Arctic Oscillation to higher NAO/OA index) [Walsh *et al*., 1996; Proshutinsky and Johnson, 1997; Kwok, 2000; Zhang *et al*., 2000; Rigor *et al*., 2002]."

Lastly, in a paper on landfast ice in Canada's Hudson Bay, Gagnon and Gough (2006) cite nine different studies of sea-ice cover, duration and thickness in the Northern Hemisphere, noting that the Hudson Bay region "has been omitted from those studies with the exception of Parkinson *et al*. (1999)," which makes one wonder *why*. For 13 stations located on the shores of Hudson Bay (7) and surrounding nearby lakes (6), Gagnon and Gough then analyzed long-term weekly measurements of ice thickness and associated weather conditions that began and ended, in the mean, in 1963 and 1993, respectively.

Results of the study revealed that a "statistically significant thickening of the ice cover over time was detected on the western side of Hudson Bay, while a slight thinning *lacking statistical significance* [our italics] was observed on the eastern side." This asymmetry, in their words, was "related to the variability of air temperature, snow depth, and the dates of ice freeze-up and break-up," with "increasing maximum ice thickness at a number of stations" being "correlated to earlier freeze-up due to negative temperature trends in autumn," and with high snow accumulation being associated with low ice thickness, "because the snow cover insulates the ice surface, reducing heat conduction and thereby ice growth." Noting that their findings "are in contrast to the projections from general circulation models, and to the reduction in sea-ice extent and thickness observed in other regions of the Arctic," Gagnon and Gough say "this contradiction must be addressed in regional climate change impact assessments," rather, we would add, than simply being *ignored*.

These observations suggest that much of the reported thinning of Arctic sea ice that occurred in the 1990s -- *if real*, as per Winsor (2001) -- was *not* the result of CO_2-induced global warming, as claimed at the time by many alarmists. Rather, it was a natural consequence of changes in ice dynamics caused by an atmospheric *regime shift*, of which there have been several in decades past and will likely be several in decades to come, totally irrespective of past or future changes in the air's CO_2 content. Whether *any* portion of possible past sea ice thinning was due to global warming is consequently still impossible to know, for temporal variability in Arctic sea-ice behavior is simply too great to allow such a small and slowly-developing signal to be detected yet. In describing an earlier regime shift, for example, Dumas *et al*. (2003) noted that "a sharp decrease in ice thickness of roughly 0.6 m over 4 years (1970-74) [was] followed by an abrupt increase of roughly 0.8 m over 2 years (1974-76)."

In view of these several observations, it will likely be a number of years before anything definitive can be said about CO_2-induced global warming on the basis of the thickness of Arctic sea-ice, other than that its impact on sea-ice thickness is much too small to be detected at the present time.

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

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4.3. Precipitation Trends

In spite of the fact that GCMs have failed to accurately reproduce observed patterns and totals of precipitation (Lebel *et al*., 2000), model predictions of imminent CO_2-induced global warming often suggest that this phenomenon should lead to increases in rainfall amounts and intensities. Hence, many scientists are examining historical precipitation records in an effort to determine how temperature changes of the past millennium have impacted these aspects of earth's hydrologic cycle. In this section, we review what some of them have learned about rainfall across the globe, starting with Africa.

Additional information on this subject, including reviews on precipitation topics not discussed here, can be found at http://www.co2science.org/subject/p/subject_p.php.

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4.3.1. Africa

Beginning in southern Africa, Richard *et al*. (2001) analyzed summer (Jan-Mar) rainfall totals over the period 1900-1998, finding that interannual variability was higher for the periods 1900-1933 and 1970-1998, but lower for the period 1934-1969. The strongest rainfall anomalies (greater than two standard deviations) were observed at the beginning of the century. However, the authors conclude there were "no significant changes in the January-March rainfall totals," nor any evidence of "abrupt shifts during the 20th century," suggesting that rainfall trends in southern Africa do not appear to have been influenced by CO_2-induced - or any other type of - global warming.

Moving to the equatorial region of East Africa, Nicholson and Yin (2001) report there have been "two starkly contrasting climatic episodes" since the late 1700s. The first, which began sometime prior to 1800, was characterized by "drought and desiccation." Extremely low lake levels were the norm, as drought reached its extreme during the 1820s and 1830s. In the mid to latter part of the 1800s, however, the drought began to weaken and floods became "continually high," but by the turn of the century lake levels began to fall as mild drought conditions returned. The drought did not last long, however, and the latter half of the 20th Century has seen an enhanced hydrologic cycle with a return of some lake levels to the high stands of the mid to late 1800s.

Verschuren *et al*. (2000) also examined hydrologic conditions in equatorial East Africa, but over a much longer time scale, i.e., a full thousand years. They report the region was significantly drier than it is today during the Medieval Warm Period from AD 1000 to 1270, while it was relatively wet during the Little Ice Age from AD 1270 to 1850. However, this latter period was interrupted by three episodes of prolonged dryness: 1390-1420, 1560-1625 and 1760-1840. These "episodes of persistent aridity," according to the authors, were "more severe than any recorded drought of the twentieth century."

The dry episode of the late 18th / early 19th centuries recorded in Eastern Africa has also been identified in Western Africa. In analyzing the climate of the past two centuries, Nicholson (2001) reports that the most significant climatic change that has occurred "has been a long-term reduction in rainfall in the semi-arid regions of West Africa," which has been "on the order of 20 to 40% in parts of the Sahel." There have been, she says, "three decades of protracted aridity," and "nearly all of Africa has been affected ... particularly since the 1980s." However, she goes on to note that "the rainfall conditions over Africa during the last 2 to 3 decades are not unprecedented," and that "a similar dry episode prevailed during most of the first half of the 19th century."

The importance of these findings is best summarized by Nicholson herself, when she states that "the 3 decades of dry conditions evidenced in the Sahel are not in themselves evidence of irreversible global change." And especially, we would add, are they not evidence of global warming-induced change. Why not (to both points)? Because a longer historical perspective of the type we are constantly striving to obtain clearly indicates, in the first instance, that an even longer period of similar dry conditions occurred between 1800 and 1850. And in the second instance, this remarkable dry period occurred when the earth was still in the clutches of the Little Ice Age, a period of cold that is without precedent in at least the last 6500 years ... *even in Africa* (Lee-Thorp *et al*., 2001). Hence, there is no reason to think that the past two- to three-decade Sahelian drought is in any way unusual or that it was caused by the putative higher temperatures of that period. Simply put, like many other things, *droughts happen*.

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

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4.3.2. Arctic

Rawlins *et al*. (2006) state that "warming is predicted to enhance atmospheric moisture storage resulting in increased net precipitation," citing as the basis for this statement the Arctic Climate Impact Assessment (2005). Likewise, Peterson *et al*. (2002) have written that "both theoretical arguments and models suggest that net high-latitude precipitation increases in proportion to increases in mean hemispheric temperature," citing the works of Manaabe and Stouffer (1994) and Rahmstorf and Ganopolski (1999). Do real-world data bear them out? In the paragraphs that follow, we evaluate this question in light of the results of three studies that come to bear upon it.

Curtis *et al*. (1998) examined a number of climatic variables at two first-order Arctic weather stations (Barrow and Barter Island, Alaska) that began in 1949, finding that both the frequency and mean intensity of precipitation at these two locations decreased over the period of record. Contemporaneously, they report that temperatures in the western Arctic increased, but that "the observed mean increase varies strongly from month-to-month making it difficult to explain the annual trend solely on the basis of an anthropogenic effect resulting from the increase in greenhouse gases in the atmosphere." Be that as it may, the four researchers concluded that the theoretical model-based assumption that "increased temperature leads to high precipitation ... is not valid," at least for the part of the western Arctic that was the focus of their analysis.

Lamoureux (2000) analyzed varved lake sediments obtained from Nicolay Lake, Cornwall Island, Nunavut, Canada, which were compared with rainfall events recorded at a nearby weather station over the period 1948-1978 and thereby used to reconstruct a rainfall history for the surrounding region over the 487-year period from 1500 to 1987. The results were suggestive of a small, but statistically insignificant, increase in rainfall over the course of the record. However, *heavy* rainfall was most frequent during the 17th and 19th centuries, which were the *coldest* periods of the past 400 years in the Canadian High Arctic, as well as the Arctic as a whole. In addition, Lamoureux found that "more frequent extremes and increased variance in yield occurred during the 17th and 19th centuries, likely due to increased occurrences of cool, *wet* [our italics] synoptic types during the *coldest* [our italics] periods of the *Little Ice Age* [our italics]." Consequently, the results of this study also contradict the story promulgated by climate alarmists relative to the effects of global warming on extreme weather events and weather variability, both of which are typically claimed to increase with an increase in air temperature. Here, however, in a part of the planet predicted to be most impacted by CO_2-induced global warming -- the Canadian High Arctic -- a warming of the climate is demonstrated to *reduce* weather extremes related to precipitation.

Most recently, Rawlins *et al*. (2006) calculated trends in the spatially-averaged water equivalent of annual rainfall and snowfall across the six largest Eurasian drainage basins that feed major rivers that deliver water to the Arctic Ocean for the period 1936-1999, over which time interval climate alarmists claim the globe's mean temperature rose to a level -- and at a rate -- that was *unprecedented over the past two millennia*. Their results indicated that annual rainfall across the total area of the six basins decreased consistently and significantly over the 64-year period. Annual snowfall, on the other hand, exhibited "a strongly significant increase," but only "until the late 1950s." Thereafter, it exhibited "a moderately significant decrease," so that "no significant change [was] determined in Eurasian-basin snowfall over the entire 64 year period." The researchers' bottom-line finding, therefore, was that annual *total* precipitation (including both rainfall and snowfall) *decreased* over the period of their study; and they note that this finding is "consistent with the reported (Berezovskaya *et al*., 2004) decline in total precipitation."

In light of the findings reviewed above, either (1) the theoretical arguments and model predictions that suggest that "high-latitude precipitation increases in proportion to increases in mean hemispheric temperature" are not incredibly robust, or (2) late 20th-century temperatures may not have been much warmer than those of the mid-1930s and 40s, or (3) both of the above, any or all of which choices fail to provide support for the standard alarmist scenario of catastrophic CO_2-induced global warming and its many conjectured negative planetary impacts.

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

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4.3.3. Asia

Kripalani *et al*. (2003) note that globally-averaged temperatures are projected to rise under all scenarios of future energy use, according to the IPCC, leading to "increased variability and strength of the Asian monsoon." Consequently, to see if there is any sign of such a precipitation response in real-world measurements, they examined Indian monsoon rainfall using observational data for the period 1871-2001 that were obtained from 306 stations distributed across the country. In doing so, they discovered decadal variations running throughout the record that reveal "distinct alternate epochs of above and below normal rainfall," which epochs "tend to last for about three decades." In addition, they report "there is no clear evidence to suggest that the strength and variability of the Indian Monsoon Rainfall (IMR) nor the epochal changes are affected by the global warming." They also report that "studies by several authors in India have shown that there is no statistically significant trend in IMR for the country as a whole." Last of all, they report that "Singh (2001) investigated the long term trends in the frequency of cyclonic disturbances over the Bay of Bengal and the Arabian Sea using 100-year (1890-1999) data and found significant *decreasing* trends [our italics]." As a result, Kripalani *et al*. conclude that "there seem[s] to be no support for the intensification of the monsoon nor any support for the increased hydrological cycle as hypothesized by [the] greenhouse warming scenario in model simulations." In addition, they say that "the analysis of observed data for the 131-year period (1871-2001) suggests no clear role of global warming in the variability of monsoon rainfall over India," much as Kripalani and Kulkarni (2001) had concluded two years earlier. Hence, it is *doubly* clear that the climate models appear to have struck out with respect to both of their Asian monsoon-related projections.

Kanae *et al*. (2004) also note that both the number and intensity of heavy precipitation events are projected to increase in a warming world, according to the IPCC. Hence, they investigate this climate-model-derived hypothesis with digitalized hourly precipitation data recorded at the Tokyo Observatory of the Japan Meteorological Agency for the period 1890-1999. Within this context, they report that "many hourly heavy precipitation events (above 20 mm/hour) occurred in the 1990s compared with the 1970s and the 1980s," and that against that backdrop, "the 1990s seems to be unprecedented." However, they note that "hourly heavy precipitation around the 1940s is even stronger/more frequent than in the 1990s." In fact, their plots of maximum hourly precipitation and the number of extreme hourly precipitation events rise fairly regularly from the 1890s to peak in the 1940s, after which declines set in that bottom out in the 1970s and then reverse to rise to endpoints in the 1990s that *are not yet as high as the peaks of the 1940s*.

Taking a somewhat longer view of the subject, Pederson *et al*. (2001) used tree-ring chronologies from northeastern Mongolia to reconstruct annual precipitation and streamflow histories for the period 1651-1995. Analyses of both standard deviations and five-year intervals of extreme wet and dry periods of this record revealed that "variations over the recent period of instrumental data are not unusual relative to the prior record." The authors do state, however, that the reconstructions "appear to show more frequent extended wet periods in more recent decades," but they say this observation "does not demonstrate unequivocal evidence of an increase in precipitation as suggested by some climate models." In addition, they report that spectral analysis of the data revealed significant periodicities around 12 and 20-24 years, suggesting, in their words, "possible evidence for solar influences in these reconstructions for northeastern Mongolia."

Going back even further in time, Touchan *et al*. (2003) developed two reconstructions of spring (May-June) precipitation for southwestern Turkey from tree-ring width measurements, one of which extended from 1776 to 1998 and one from 1339 to 1998. These reconstructions, in their words, "show clear evidence of multi-year to decadal variations in spring precipitation," but they report that "dry periods of 1-2 years were well distributed throughout the record" and that the same was true of wet periods of 1-2 years' duration. With respect to more extreme events, however, the period that preceded the Industrial Revolution stood out. They say, for example, that "all of the wettest 5-year periods occurred prior to 1756," while the longest period of reconstructed spring drought was the four-year period 1476-79, and the single driest spring was 1746. Hence, it is clear that Turkey's greatest precipitation extremes occurred *prior* to the Modern Warm Period, which is just the *opposite* of what climate alarmists typically claim about extreme weather and its response to global warming.

Looking *much* further back in time (from 9600 to 6100 years ago) were Neff *et al*. (2001), who explored the relationship between a ^{14}C tree-ring record and a $\delta^{18}O$ proxy record of monsoon rainfall intensity as recorded in calcite $\delta^{18}O$ data obtained from a stalagmite in northern Oman. They found that the correlation between the two data sets was "extremely strong," and that a spectral analysis of the data revealed statistically significant periodicities centered on 779, 205, 134 and 87 years for the $\delta^{18}O$ record and periodicities of 206, 148, 126, 89, 26 and 10.4 years for the ^{14}C record. Consequently, because variations in ^{14}C tree-ring records are generally attributed to variations in solar activity, and because of the ^{14}C record's strong correlation with the $\delta^{18}O$ record, as well as the closely corresponding results of their spectral analyses, Neff *et al*. conclude there is "solid evidence" that both signals are responding to solar forcing.

In conclusion, the evidence reviewed here provides absolutely no support for the point of view that precipitation in a warming world becomes more variable and intense. In fact, in some cases it tends to suggest just the opposite, and provides support for the proposition that precipitation responds more to cyclical variations in solar activity than to anything else.

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

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4.3.4. Europe

4.3.4.1. Central

Koning and Franses (2005) conducted a detailed analysis of a century of daily precipitation data that had been acquired at the de Bilt meteorological station in the Netherlands. Using what they call "robust nonparametric techniques," they found that the cumulative distribution function of annual maximum precipitation levels remained constant throughout the period 1906-2002, leading them to conclude that "precipitation levels are not getting higher." In addition, they report that similar analyses they performed for the Netherlands' five other meteorological stations "did not find qualitatively different results."

Moving eastward, and extending the temporal domain of study from one century to five, Wilson *et al*. (2005) developed two versions of a March-August precipitation chronology based on living and historical tree-ring widths obtained from the Bavarian Forest of southeast Germany for the period 1456-2001. The first version, standardized with a fixed 80-year spline function (SPL), was designed to retain decadal and higher frequency variations, while the second version used regional curve standardization (RCS) to retain lower frequency variations. Their efforts revealed significant yearly and decadal variability in the SPL chronology; but there did not appear to be any trend toward either wetter or drier conditions over the 500-year period. The RCS reconstruction, on the other hand, better captured lower frequency variation, suggesting that March-August precipitation was substantially greater than the long-term average during the periods 1730-1810 and 1870-2000 and drier than the long-term average during the periods 1500-1560, 1610-1730 and 1810-1870. Once again, however, there was little evidence of a long-term trend.

Moving still further east in Central Europe, and covering a full millennium and a half, Solomina *et al*. (2005) derived the first tree-ring reconstruction of spring (April-July) precipitation for the Crimean peninsula, located on the northern coast of the Black Sea in the Ukraine, for the period 1620-2002, after which they utilized this chronology to correctly date and correlate with an earlier precipitation reconstruction derived from a sediment core taken in 1931 from nearby Saki Lake, thus ending up with a proxy precipitation record for the region that stretched all the way back to AD 500. In describing their findings, Solomina *et al*. say that no trend in precipitation was evident over the period 1896-1988 in an instrumental record obtained at a location adjacent to the tree-sampling site. Also, the reconstructed precipitation values from the tree-ring series revealed year-to-year and decadal variability, but remained "near-average with relatively few extreme values" from about the middle 1700s to the early 1800s and again since about 1920. The most notable anomaly of the 1500-year reconstruction was an "extremely wet" period that occurred between AD 1050 and 1250, which Solomina *et al*. describe as broadly coinciding with the Medieval Warm Epoch, when humidity was higher than during the instrumental era.

The results of these several analysis demonstrate that over the period of 20th-century global warming -- which climate alarmists claim was *unprecedented over the past two millennia or more* -- the climate-model-based expectation of enhanced precipitation was not observed in Central Europe. Of course, Central Europe represents but a small portion of the entire planet. Nevertheless, for a warming that was supposedly so extreme, one would have expected to have seen *something* along the lines of what the alarmists have claimed would be the case ... if they were correct. *But we don't!* And perhaps the reason *why* we don't see what they predict is that earth's climate is likely not yet as warm as it was during the Medieval Warm Period, when the data of Solomina *et al*. suggest that the region they studied *was* distinctly wetter than it was both before and after that time, and when, of course, the air's CO_2 concentration was fully 100 ppm *less* than it is today.

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

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4.3.4.2. Mediterranean

Starting at the western extreme of the continent, Rodrigo *et al*. (2001) used a variety of documentary data to reconstruct seasonal rainfall in Andalusia (southern Spain) from 1501 to 1997, after which they developed a relationship between seasonal rainfall and the North Atlantic Oscillation (NAO) over the period 1851-1997, which they used to reconstruct a history of the NAO from 1501 to 1997. This work revealed that the NAO influence on climate is stronger in winter than in other seasons of the year in Andalusia, explaining 40% of the total variance in precipitation; and Rodrigo *et al*. make a point of noting that "the recent positive temperature anomalies over western Europe and recent dry [*not wet*] winter conditions over southern Europe and the Mediterranean are strongly related to the persistent and exceptionally strong positive phase of the NAO index since the early 1980s," as opposed to an intensification of global warming.

Also working in the Andalusia region of southern Spain, Sousa and Garcia-Murillo (2003) studied proxy indicators of climatic change in Doñana Natural Park over a period of several hundred years, comparing their results with those of other such studies conducted in neighboring regions. This work revealed that the Little Ice Age (LIA) was by no means uniform in their region of study, as it included both wetter and drier periods. Nevertheless, they cite Rodrigo *et al*. (2000) as indicating that "the LIA was characterized in the southern Iberian Peninsula by increased rainfall," and they cite Grove (2001) as indicating that "climatic conditions inducing the LIA glacier advances [of Northern Europe] were also responsible for an increase in flooding frequency and sedimentation in Mediterranean Europe." Sousa and Garcia-Murillo's work complements these findings by indicating "an aridization of the climatic conditions after the last peak of the LIA (1830-1870)," which suggests that much of Europe became drier, not wetter, as the earth recovered from the global chill of the Little Ice Age.

Moving eastward into Italy, Crisci *et al*. (2002) analyzed rainfall data collected from 81 gauges spread throughout the Tuscany region for three different periods: (1) from the beginning of each record through 1994, (2) the shorter 1951-1994 period, and (3) the still-shorter 1970-1994 period. For each of these periods, trends were derived for extreme rainfall durations of 1, 3, 6, 12 and 24 hours. This work revealed that for the period 1970-1994, the majority of all stations exhibited no trends in extreme rainfall at any of the durations tested; while four had positive trends at all durations and none had negative trends at all durations. For the longer 1951-1994 period, the majority of all stations exhibited no trends in extreme rainfall at any of the durations tested; while none had positive trends at all durations and only one had negative trends at all durations. For the still-longer complete period of record, the majority of all stations again continued to exhibit no trends in extreme rainfall at any of the durations tested; while none had positive trends at all durations and only one had negative trends at all durations, revealing no impact of 20th-century global warming one way or the other.

Working in northern Italy, Tomozeiu *et al*. (2002) performed a series of statistical tests to investigate the nature and potential causes of trends in winter (Dec-Feb) mean precipitation recorded at forty stations over the period 1960-1995. This work revealed that nearly all of the stations experienced significant *decreases* in winter precipitation over the 35-year period of study; and by subjecting the data to a Pettitt test, they detected a significant downward shift at all stations around 1985. An Empirical Orthogonal Function analysis was also performed on the precipitation data, revealing a principal component that represented a common large-scale process that was likely responsible for the phenomenon. Strong correlation between this component and the North Atlantic Oscillation (NAO) suggested, in their words, that the changes in winter precipitation around 1985 "could be due to an intensification of the positive phase of the NAO." In this case, therefore, there was not only no *increase* in precipitation over the period of time when climate alarmists claim the planet warmed at a rate that was *unprecedented over the past two millennia*, there was an actual *decrease*, which not only had nothing to do with global warming but was more likely the result of a simple regime shift of the NAO.

Working in the eastern Basilicata region of southern Italy, where they concentrated on characterizing trends in extreme rainfall events, as well as resultant flood events and landslide events, Clark and Rendell (2006) analyzed 50 years of rainfall records (1951-2000). This work indicated, in their words, that "the frequency of extreme rainfall events in this area declined by more than 50% in the 1990s compared to the 1950s." In addition, they report that "impact frequency also decreased, with landslide-event frequency changing from 1.6/year in the period 1955-1962 to 0.3/year from 1985 to 2005, while flood frequency peaked at 1.0/year in the late 1970s before declining to less than 0.2/year from 1990." Hence, they concluded that if the climate-driven changes they observed over the latter part of the 20th century continue, "the landscape of southern Italy and the west-central Mediterranean will become increasingly stable," or as they say in their concluding paragraph, "increased land-surface stability will be the result."

Continuing westward to Bulgaria, Alexandrov *et al*. (2004) analyzed a number of 20th-century data sets from throughout the country, finding "a decreasing trend in annual and especially summer precipitation from the end of the 1970s" and that "variations of annual precipitation in Bulgaria showed an overall decrease." In addition, they report that the region stretching from the Mediterranean into European Russia and the Ukraine "has experienced decreases in precipitation by as much as 20% in some areas."

Last of all, based on analyses of tree-ring width data and their connection to large-scale atmospheric circulation, Touchan *et al*. (2005) developed summer (May-August) precipitation reconstructions for several parts of the eastern Mediterranean region, including Turkey, Syria, Lebanon, Cyprus and Greece, which extend back in time as much as 600 years. Over this period, they found that May-August precipitation varied on multi-annual and decadal timescales, but that on the whole there were no long-term trends. The longest dry period occurred in the late 16th century (1591-1595), while there were two extreme wet periods: 1601-1605 and 1751-1755. In addition, both extreme wet and dry precipitation events were found to be more variable over the intervals 1520-1590, 1650-1670 and 1850-1930, indicating that as the globe experienced the supposedly unprecedented warming of the last decades of the 20th century, May-August precipitation in the eastern Mediterranean region actually become *less* variable than it had been in the earlier part of the century.

In conclusion, the story told by these several studies of precipitation characteristics of Mediterranean Europe is vastly different from that which is routinely claimed for the planet as a whole by the world's climate alarmists.

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

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4.3.4.3. Northern

Out in the middle of the North Atlantic Ocean in Iceland, Hanna *et al*. (2004) analyzed variations in several climatic variables, including precipitation, over the past century in an effort to determine if there is "possible evidence of recent climatic changes" in that cold island nation. For the period 1923-2002, precipitation appeared to have increased slightly, although they questioned the veracity of the trend, citing several biases that may have corrupted the data base.

Back on the mainland, Linderholm and Molin (2005) analyzed two independent precipitation proxies, one derived from tree-ring data and one from a farmer's diary, to produce a 250-year record of summer (June-August) precipitation in east central Sweden. This work revealed there had been a high degree of variability in summer precipitation on inter-annual to decadal time scales throughout the record. Over the past century of supposedly unprecedented global warming, however, precipitation was found to have exhibited *less* variability than it did during the 150 years that preceded it.

Finally, in a study covering the longest time span of all, Linderholm and Chen (2005) derived a 500-year winter (September-April) precipitation chronology from tree-ring data obtained within the northern boreal forest zone of west-central Scandinavia in an effort to better understand historic precipitation variability within this region. The reconstructed chronology they developed showed considerable variability, with the exception of a fairly stable period of above-average precipitation between AD 1730 and 1790. Additionally, above average winter precipitation was found to have occurred in 1520-1561, 1626-1647, 1670-1695, 1732-1851, 1872-1892 and 1959 to the present, with the highest values reported in the early to mid-1500s; while below average winter precipitation was observed during 1504-1520, 1562-1625, 1648-1669, 1696-1731, 1852-1871, and 1893-1958, with the lowest values occurring at the beginning of the record and the beginning of the 17th century. These findings thus demonstrated that non-CO_2-forced wetter and drier conditions than those of the present have occurred repeatedly within this region throughout the past five centuries, and that similar extreme conditions may therefore be expected to *naturally* recur in the future.

In considering these diverse observations from Northern Europe, it is clear they provide no support whatsoever for alarmist claims of imminent changes in precipitation characteristics outside the bounds of historic variability.

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

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4.3.5. United States

Climate models typically suggest that global warming will adversely affect water resources via changes in rainfall amounts and intensities. As noted by Kunkel (2003), for example, "several studies have argued that increasing greenhouse gas concentrations will result in an increase of heavy precipitation (Cubasch *et al*., 2001; Yonetani and Gordon, 2001; Kharin and Zwiers, 2000; Zwiers and Kharin, 1998; Trenberth, 1998)." Consequently, in an effort to either substantiate or reject this hypothesis, numerous scientists are examining historical and proxy precipitation records to see what effect the temperature increase of the Little Ice Age-to-Modern Warm Period transition might have had on earth's hydrologic cycle. In this section, we review what several researchers have learned in this regard about precipitation in the heart of North America, i.e., the United States, as they have sought to determine if there have been any dangerous increases in the intensity and frequency of extreme precipitation events in this particular part of the world.

Molnar and Ramirez (2001) conducted a detailed watershed-based analysis of precipitation and streamflow trends for the period 1948-97 in the semiarid region of the Rio Puerco Basin of New Mexico. They found, in their words, that "at the annual timescale, a statistically significant increasing trend in precipitation in the basin was detected." This trend was driven primarily by an increase in the number of rainy days in the moderate rainfall intensity range, with essentially no change being observed at the high-intensity end of the spectrum. In the case of streamflow, however, there was *no* trend at the annual timescale; but monthly totals *increased* in *low*-flow months and *decreased* in *high*-flow months.

What are the implications of these observations? Increasing precipitation in a semiarid region sounds like a huge plus to us; and having most of that increase in the moderate rainfall intensity range also sounds like a plus. Increasing streamflow in *low*-flow months sounds good as well, as does decreasing streamflow in *high*-flow months. In fact, what more could one possibly desire in terms of changes in precipitation? ... especially in a world that climate alarmists claim is supposed to be experiencing more extreme weather events and increases in both floods and droughts?

We once thought that this prediction was a clever ploy on the part of the world's climate alarmists, i.e., that by predicting more warming-induced floods and droughts *at one and the same time*, they were making sure there was no way they could possibly miss in their predictions of CO_2-induced calamities. It would appear, however, that we were *wrong* in that assumption: *they did miss*!

In a much colder part of the country, Cowles *et al*. (2002) analyzed *snow water equivalent* (SWE) data obtained from four different measuring systems -- snow courses, snow telemetry, aerial markers and airborne gamma radiation -- at more than 2000 sites in the eleven westernmost states over the period 1910-1998. This work revealed that the long-term SWE trend of this entire region was *negative*, but with some significant within-region differences. In the northern Rocky Mountains and Cascades of the Pacific Northwest, for example, the trend was decidedly negative, with SWE decreasing at a rate of 0.1 to 0.2 inches per year. In the intermountain region and southern Rockies, however, there was *no* change in SWE with time. Cowles *et al*. additionally note that their results "reinforce more tenuous conclusions made by previous authors," citing Chagnon *et al*. (1993) and McCabe and Legates (1995), who studied snow course data from 1951-1985 and 1948-1987, respectively, at 275 and 311 sites. They too found a decreasing trend in SWE at most sites in the Pacific Northwest but more ambiguity in the southern Rockies.

These findings are particularly interesting in light of the fact that nearly all climate models suggest the planet's hydrologic cycle will be *enhanced* in a warming world and that precipitation will *increase*. This prediction is especially applicable to the Pacific Northwest of the United States, where Kusnierczyk and Ettl (2002) report that climate models predict "increasingly warm and wet winters," as do Leung and Wigmosta (1999). Over the period of Cowles *et al*.'s study, however, when there was well-documented worldwide warming, precipitation that fell and accumulated as snow in the western USA did not respond as predicted. In fact, over the Pacific Northwest, it did just the *opposite*.

Garbrecht and Rossel (2002) used state divisional monthly precipitation data from the US National Climatic Data Center to investigate the nature of precipitation throughout the US Great Plains from January 1895 through December 1999, finding that regions in the central and southern Great Plains experienced above-average precipitation over the last two decades of the 20th century. This 20-year span of time was the longest and most intense wet period of the entire 105 years of record, and was primarily the result of a reduction in the number of dry years and an increase in the number of wet years. What made it even better was the fact that the number of *very* wet years, in the words of the authors, "did not increase as much and even showed a decrease for many regions." The northern and northwestern Great Plains also experienced a precipitation increase at the end of this 105-year interval, but it was primarily confined to the final decade of the 20th century; and again, as Garbrecht and Rossel report, "fewer dry years over the last 10 years, as opposed to an increase in very wet years, were the leading cause of the observed wet conditions."

It is interesting to note, in this regard, that during the period of time described by the alarmists as having been host to the most dramatic global warming of the past two *millennia*, which according to them should have resulted in devastating droughts and floods, the Great Plains of the United States, like the Rio Puerco Basin of New Mexico, actually experienced the best of both water-resource worlds. Overall, conditions got wetter, which means less drought; while the constancy - or even *decline* - in the number of *very* wet years tended to mitigate against floods. What could possibly be better? It looks like the new Modern Warm Period is going to eventually be classified as another Little Climatic *Optimum*!

Taking a look at the entire conterminous United States from 1895-1999, McCabe and Wolock (2002) evaluated and analyzed (1) values of annual precipitation minus annual potential evapotranspiration, (2) surplus water that eventually becomes streamflow, and (3) the water deficit that must be supplied by irrigation to grow vegetation at an optimum rate. Their work revealed that for the country as a whole, there was a statistically significant increase in the first two of these three parameters, while for the third there was no change. In describing the significance of these findings, McCabe and Wolock say "there is concern that increasing concentrations of atmospheric carbon dioxide and other radiatively active gases may cause global warming and ... adversely affect water resources." The results of their analyses, however, reveal that over the past century of significant (but neither unusual nor unnatural) global warming, just the *opposite* has occurred, at least within the conterminous United States: moisture has become *more* available, while there has been no change in the amount of water required for optimum plant growth.

Also studying the conterminous United States were Kunkel *et al*. (2003), who analyzed a new data base of daily precipitation observations for the period 1895-2000. This effort indicated, in their words, that "heavy precipitation frequencies were relatively high during the late 19th/early 20th centuries, decreasing to a minimum in the 1920s and 30s, followed by a general increase into the 1990s." More specifically, they note that "for 1-day duration events, frequencies during 1895-1905 are comparable in magnitude to frequencies in the 1980s and 1990s," while "for 5- and 10-day duration events, frequencies during 1895-1905 are only slightly smaller than late 20th century values."

In commenting on these findings, Kunkel *et al*. note that since enhanced greenhouse gas forcing of the climate system was very small in the early years of this record, the elevated extreme precipitation frequencies of that time "were most likely a consequence of naturally forced variability," which further suggests, in their words, "the possibility that natural variability could be an important contributor to the recent increases." This is also the conclusion of Kunkel (2003), who in a review of this and other pertinent studies states that frequencies of extreme precipitation events in the United States in the late 1800s and early 1900s "were about as high as in the 1980s/1990s." Consequently, he too concludes that "natural variability in the frequency of precipitation extremes is quite large on decadal time scales and cannot be discounted as the cause or one of the causes of the recent increases."

Working with proxy data that extend much further back in time, Haston and Michaelsen (1997) developed a 400-year history of precipitation for 29 stations in coastal and near-interior California between San Francisco Bay and the U.S.-Mexican border using tree-ring chronologies. Their research revealed that although region-wide precipitation during the 20th century was higher than what was experienced during the preceding three centuries, it was also "less variable compared to other periods in the past," both of which characteristics are huge positive developments for both man and nature in this important region of California.

In a similar study, Gray *et al*. (2003) examined fifteen tree ring-width series that had been used in previous reconstructions of drought for evidence of low-frequency variation in precipitation in five regional composite chronologies pertaining to the central and southern Rocky Mountains. In describing what they found, they say that "strong multidecadal phasing of moisture variation was present in all regions during the late 16th century megadrought," and that "oscillatory modes in the 30-70 year domain persisted until the mid-19th century in two regions, and wet-dry cycles were apparently synchronous at some sites until the 1950s drought." They also note that "severe drought conditions across consecutive seasons and years in the central and southern Rockies may ensue from coupling of the cold phase PDO [Pacific Decadal Oscillation] with the warm phase AMO [Atlantic Multidecadal Oscillation] (Cayan *et al*., 1998; Barlow *et al*., 2001; Enfield *et al*., 2001)," something they envision happening in both the severe drought of the 1950s and the late 16th-century megadrought. Hence, there is no particular reason to associate any of the wetter or drier periods of the 20th century with global warming, for both conditions appear to be naturally recurring products of various climate "regime shifts" in the Pacific and Atlantic Oceans that are independent of the mean thermal state of the planet.

Going back even further in time, Ni *et al*. (2002) developed a 1000-year history of cool-season (November-April) precipitation for each climate division in Arizona and New Mexico from a network of 19 tree-ring chronologies. With respect to drought, they found that "sustained dry periods comparable to the 1950s drought" occurred in "the late 1000s, the mid 1100s, 1570-97, 1664-70, the 1740s, the 1770s, and the late 1800s." They also note that the 1950s drought "was large in scale and severity, but it only lasted from approximately 1950 to 1956," whereas the 16th century megadrought lasted more than four times longer. With respect to the opposite of drought, Ni *et al*. report that several wet periods comparable to the wet conditions seen in the early 1900s and after 1976 occurred in "1108-20, 1195-1204, 1330-45, the 1610s, and the early 1800s." They also note that "the most persistent and extreme wet interval occurred in the 1330s."

Speaking of the *causes* of the different precipitation extremes, Ni *et al*. say that "the 1950s drought corresponds to La Niña/-PDO [Pacific Decadal Oscillation] and the opposite polarity [+PDO] corresponds to the post-1976 wet period," which leads them to hypothesize that "the prominent shifts seen in the 1000 year reconstructions in Arizona and New Mexico may also be linked to strong shifts of the coupled ENSO-PDO system." For the particular part of the world covered by their study, therefore, there appears to be nothing unusual about the extremes of both wetness and dryness experienced during the 20th century.

In another equally long study, but on the opposite side of the country, Cronin *et al*. (2000) measured and analyzed salinity gradients across sediment cores extracted from Chesapeake Bay, the largest estuary in the United Sates, in an effort to examine precipitation variability in the surrounding watershed over the past 1000 years. They found a high degree of decadal and multidecadal variability between wet and dry conditions throughout the record, where regional precipitation totals fluctuated between 25 to 30%, often in "extremely rapid [shifts] occurring over about a decade." Precipitation over the last two centuries, however, was on average greater than what it was during the previous eight centuries, with the exception of the Medieval Warm Period (AD 1250-1350), when the climate was judged to have been "extremely wet." In addition, it was determined that this region, like the southwestern United States, had experienced several "mega-droughts," lasting from 60-70 years in length, some of which Cronin *et al*. describe as being "more severe than twentieth century droughts."

Also like the study of Ni *et al*., Cronin *et al*.'s work reveals nothing unusual about precipitation during the 20th century, the latter two decades of which climate alarmists adamantly claim comprise the warmest such period of the past *two millennia*. It indicates, for example, that both wetter and drier intervals occurred repeatedly in the past in the Chesapeake Bay watershed; and there is no reason not to believe they will occur in the future ... with or without any further global warming. Consequently, there is no basis in real-world data for predicting warming-induced droughts and floods in this and other parts of the world.

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

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4.3.6. Canada and Mexico

Kunkel (2003) reports that "several studies have argued that increasing greenhouse gas concentrations will result in an increase of heavy precipitation (Cubasch *et al*., 2001; Yonetani and Gordon, 2001; Kharin and Zwiers, 2000; Zwiers and Kharin, 1998; Trenberth, 1998)." Consequently, Kunkel looked for such a signal in precipitation data from Canada that covered much of the past century. His search, however, was in vain, as the data indicated, in his words, that "there has been no discernible trend in the frequency of the most extreme events in Canada."

Zhang *et al*. (2001) also studied the temporal characteristics of heavy precipitation events across Canada, using what they describe as "the most homogeneous long-term dataset currently available for Canadian daily precipitation." Their efforts revealed that decadal-scale variability was a dominant feature of both the frequency and intensity of the annual number of extreme precipitation events, but they found "no evidence of any significant long-term changes." When the annual data were divided into seasonal data, however, an increasing trend in the number of extreme autumn *snowfall* events was noted; and an investigation into precipitation totals (extreme plus non-extreme events) revealed a slightly increasing trend that was attributed to increases in the number of *non-heavy* precipitation events. Zhang *et al*.'s overall conclusion, therefore, was that "increases in the concentration of atmospheric greenhouse gases during the twentieth century have not been associated with a generalized increase in extreme precipitation over Canada."

Taking a longer view of the subject was Lamoureux (2000), who analyzed varved lake sediments obtained from Nicolay Lake, Cornwall Island, Nunavut, Canada, and compared the results with rainfall events recorded at a nearby weather station over the period 1948-1978, which comparison enabled the reconstruction of a rainfall history for the location over the 487-year period from 1500 to 1987. This history was suggestive of a small, but statistically insignificant, increase in total rainfall over the course of the record. *Heavy* rainfall was most frequent during the 17th and 19th centuries, which were the *coldest* periods of the past 400 years in the Canadian High Arctic, as well as the Arctic as a whole. In addition, Lamoureux says that "more frequent extremes and increased variance in yield occurred during the 17th and 19th centuries, likely due to increased occurrences of cool, wet synoptic types during the coldest periods of the Little Ice Age."

This study, like the others discussed above, contradicts the climate-alarmist claim that extreme precipitation events become more frequent and more severe with increasing temperature. Here in the Canadian High Arctic, in a part of the planet predicted to be most impacted by CO_2-induced global warming, rising temperatures have been shown to *reduce* precipitation extremes, even in the face of a slight increase in total precipitation.

South of the United States, Diaz *et al*. (2002) created a 346-year history of winter-spring (November-April) precipitation for the Mexican state of Chihuahua, based on earlywood width chronologies of over 300 Douglas fir trees growing at four locations along the western and southern borders of Chihuahua and at two locations in the United States just above Chihuahua's northeast border. This exercise revealed, in their words, that "three of the 5 worst winter-spring drought years in the past three-and-a-half centuries are estimated to have occurred during the 20th century." Although this fact makes it *sound* like the 20th century was highly anomalous in this regard, *it was not*; for two of those three worst drought years occurred during a decadal period of average to slightly-above-average precipitation, so the three years were *not* representative of long-term droughty conditions.

Diaz *et al*. additionally report that "the longest drought indicated by the smoothed reconstruction lasted 17 years (1948-1964)," which again makes the 20th century look unusual in this regard. However, for several of the years of that interval, precipitation values were only *slightly* below normal; and there were four very similar dry periods interspersed throughout the preceding two and a half centuries: one in the late 1850s and early 1860s, one in the late 1790s and early 1800s, one in the late 1720s and early 1730s, and one in the late 1660s and early 1670s.

With respect to the 20th century alone, there was a long period of high winter-spring precipitation that stretched from 1905 to 1932; and following the major drought of the 1950s, precipitation remained at, or just slightly above, normal for the remainder of the record. Finally, with respect to the entire 346 years, *there was no long-term trend in the data, nor was there any evidence of a significant departure from that trend over the course of the 20th century*. Consequently, Chihuahua's precipitation history did not differ in any substantial way during the 20th century from what it was over the prior *quarter of a millennium*, suggesting that neither 20th-century anthropogenic CO_2 emissions nor 20th-century warming - whether natural or human-induced - significantly impacted precipitation in that part of North America.

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

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4.3.7. Global

Huntington (2006) notes there is "a theoretical expectation that climate warming will result in increases in evaporation and precipitation, leading to the hypothesis that one of the major consequences will be an intensification (or acceleration) of the water cycle (DelGenio *et al*., 1991; Loaciga *et al*., 1996; Trenberth, 1999; Held and Soden, 2000; Arnell *et al*., 2001)," and in reviewing the scientific literature on *precipitation*, he concludes that on a globally averaged basis, "precipitation over land increased by about 2% over the period 1900-1998 (Dai *et al*., 1997; Hulme *et al*., 1998)."

New *et al*. (2001) also reviewed several global precipitation data sets, analyzing the information they contain to obtain a picture of precipitation *patterns* over the 20th century. In their case, they determined that precipitation over the land area of the globe was mostly below the century-long mean over the first decade and a half of the record, but that it increased from 1901 to the mid-1950s, whereupon it remained above the century-long mean until the 1970s, after which it declined by about the same amount to 1992 (taking it well below the century-long mean), whereupon it recovered and edged upward towards the century mean. Hence, for the entire century, there was indeed a *slight* increase in global land area precipitation; but *since 1915* there was essentially *no net change*.

For the *oceanic* portion of the world between 30°N and 30°S, however, the record of which begins in 1920, there *was* a discernable change in precipitation over the course of the record; however, it was an overall *decrease* of about 0.3% per decade. Hence, *for the world as a whole*, which is 70% covered by water, there may well have been a slight *decrease* in precipitation since about 1917 or 18.

Concentrating on the last half of the 20th century, Neng *et al*. (2002) analyzed data from 1948 to 2000 in a quest to determine the effect of warm ENSO years on annual precipitation over the land area of the globe. In doing so, they found that some regions experienced *more* rainfall in warm ENSO years, while others experienced *less*. However, in the words of the researchers, "in warm event years, the land area where the annual rainfall was reduced is *far greater* [our italics] than that where the annual rainfall was increased, and the reduction is *more significant* [our italics] than the increase." Consequently, whereas state-of-the-art climate models nearly always ***pre***dict more precipitation in a warming world, the data of Neng *et al*.'s study ***de***pict just the *opposite* effect over the land area of the globe. Hence, with respect to one of the most basic of all climate-model predictions, there appears to be a total lack of vindication in the real world, where it really counts.

Most recently - and noting that "the Global Precipitation Climatology Project (GPCP) has produced merged satellite and in situ global precipitation estimates, with a record length now over 26 years beginning 1979 (Huffman *et al*., 1997; Adler *et al*., 2003)" - Smith *et al*. (2006) used empirical orthogonal function (EOF) analysis to study annual GPCP-derived precipitation variations over the period of record. In doing so, they found that the first three EOFs accounted for 52% of the observed variance in the precipitation data. Mode 1 was associated with mature ENSO conditions and correlated strongly with the Southern Oscillation Index, while Mode 2 was associated with the strong warm ENSO episodes of 1982/83 and 1997/98. Mode 3, on the other hand, was uncorrelated with ENSO but was associated with tropical trend-like changes that were correlated with interdecadal warming of tropical sea surface temperatures.

Globally, Smith *et al*. report that "the mode 3 variations average to near zero, so this mode does not represent any net change in the amount of precipitation over the analysis period." Consequently, over the period 1979-2004, when alarmists claim the world warmed at a rate and to a degree that was *unprecedented over the past two millennia*, Smith *et al*. found that most of the precipitation variations in their global data set were "associated with ENSO and have no trend." As for the variations that were *not* associated with ENSO and that *did* exhibit trends, they say that the trends were associated "with increased tropical precipitation over the Pacific and Indian Oceans associated with local warming of the sea." However, they note that this increased precipitation was "balanced by decreased precipitation in other regions," so that "the global average change [was] near zero."

Over the earth as a whole, therefore, it would appear from Smith *et al.*'s study, as well as from the other studies described above, that one of the major theoretical expectations of the climate modeling community remains unfulfilled, even under the supposedly highly favorable thermal conditions of the last quarter-century, which observation suggests that their other major theoretical expectation, i.e., catastrophic CO_2-induced global warming, will likely remain unfulfilled too.

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

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4.4. Streamflow

Model projections suggest that CO_2-induced global warming will adversely impact earth's water resources by inducing large changes in global streamflow characteristics. As a result, many scientists are examining proxy streamflow records in an effort to determine how temperature changes of the 20th century may or may not have impacted this aspect of the planet's hydrologic cycle. We here review such findings for North America and Eurasia, seeking to discover if there have indeed been any 20th-century changes in streamflow regimes that might reasonably have been caused by 20th-century changes in air temperature and atmospheric CO_2 concentration, which latter changes are frequently characterized as having been unprecedented (or nearly so) over *the past thousand years*. We begin with a study of records from Eurasia.

Additional information on this topic, including reviews on streamflow not discussed here, can be found at http://www.co2science.org/subject/s/subject_s.php under the heading Streamflow.

4.4.1. Eurasia

Pederson *et al*. (2001) used tree-ring chronologies from northeastern Mongolia to develop annual precipitation and streamflow histories for the period 1651-1995. This work revealed, with respect to both standard deviations and 5-year intervals of extreme wet and dry periods, that "variations over the recent period of instrumental data are not unusual relative to the prior record," although they say that the reconstructions "appear to show more frequent extended wet periods in more recent decades." Nevertheless, they state that this observation "does not demonstrate unequivocal evidence of an increase in precipitation as suggested by some climate models." Spectral analysis of the data also revealed significant periodicities of 12 and 20-24 years, suggesting, in the researchers' words, "possible evidence for solar influences in these reconstructions for northeastern Mongolia."

Working in another part of the same region, Davi *et al*. (2006) report that "absolutely dated tree-ring-width chronologies from five sampling sites in west-central Mongolia were used in precipitation models and an individual model was made using the longest of the five tree-ring records (1340-2002)," which effort led to a reconstruction of streamflow that extended from 1637 to 1997. In analyzing these data, the four researchers discovered there was "much wider variation in the long-term tree-ring record than in the limited record of measured precipitation," which for the region they studied covered the period from 1937 to 2003. In addition, they report their streamflow history indicates that "the wettest 5-year period was 1764-68 and the driest period was 1854-58," while "the most extended wet period [was] 1794-1802 and ... extended dry period [was] 1778-83." For this part of Mongolia, therefore - which the researchers say "is representative of the central Asian region" - there is no support to be found for the climate-alarmist contention that the "unprecedented" warming of the 20th century has led to increased variability in precipitation and streamflow.

Pekarova *et al*. (2003) analyzed the annual discharge rates of selected large rivers of the world for recurring cycles of wet and dry periods. For those rivers with sufficiently long and accurate data series, they also derived long-term discharge rate *trends*. This latter analysis, however, did not show "any significant trend change in long-term discharge series (1810-1990) in representative European rivers," including the Goeta, Rhine, Neman, Loire, Wesaer, Danube, Elbe, Oder, Vistule, Rhone and Po. These latter observations are most interesting, for they indicate that even over the 180-year time period that saw the demise of the Little Ice Age and the ushering in of the Current Warm Period, there were no long-term trends in the discharge rates of the major rivers of Europe.

In another study, Hisdal *et al*. (2001) performed a series of statistical analyses on more than 600 daily streamflow records from the European Water Archive to examine trends in the severity, duration and frequency of drought over the following four time periods: 1962-1990, 1962-1995, 1930-1995, and 1911-1995. This protocol indicated that "despite several reports on recent droughts in Europe, there is no clear indication that streamflow drought conditions in Europe have generally become more severe or frequent in the time periods studied." Quite to the contrary, they report discovering that the number of trends pointing towards decreasing streamflow deficits or fewer drought events exceeded the number of trends pointing towards increasing drought deficits or more drought events.

Looking back towards Asia, Cluis and Laberge (2001) utilized streamflow records stored in the databank of the Global Runoff Data Center at the Federal Institute of Hydrology in Koblenz (Germany) to see if there were any recent changes in river runoff of the type predicted by IPCC scenarios of global warming, such as increased streamflow and increases in streamflow variability that would lead to more floods and droughts. *Spatially*, their study encompassed 78 rivers said to be "geographically distributed throughout the whole Asia-Pacific region," while *temporally* the mean start and end dates of the river flow records were 1936 ± 5 years and 1988 ± 1 year.

As a result of their analyses, the two researchers determined that *mean* river discharges were unchanged in 67% of the cases investigated; and where trends did exist 69% of them were downward. Likewise, *maximum* river discharges were unchanged in 77% of the cases investigated; and where trends did exist 72% of them were downward. *Minimum* river discharges, on the other hand, were unchanged in 53% of the cases investigated; while where trends did exist 62% of them were *upward*.

With respect to the implications of these findings, we note that in the case of *mean* river discharge, the empirical observations go doubly against climate-alarmist predictions, i.e., most rivers show no change in flow volume, while most of those that do show changes exhibit decreases. In the case of *maximum* river discharge, the empirical observations also go doubly against climate-alarmist predictions, i.e., most rivers show no change in flow volume, while most of those that do exhibit changes show decreases, indicative of the likelihood of *less flooding*. Finally, in the case of *minimum* river discharge, the empirical observations once again go doubly against climate alarmist predictions, i.e., most rivers show no change in flow volume, while most of those that do exhibit changes show increases, indicative of the likelihood of *less drought*. Consequently, out of six possible metrics related to streamflow trends, all six exhibit changes that are contrary to IPCC-promoted scenarios of climate change.

In another study, MacDonald *et al*. (2007) used "tree ring records from a network of sites extending across northern Eurasia to provide reconstructions [extending back to AD 1800] of annual discharge for the October to September water year for the major Eurasian rivers entering the Arctic Ocean (S. Dvina, Pechora, Ob', Yenisey, Lena, and Kolyma)." Results indicated that annual discharges of the mid to late 20th century previously reported are not significantly greater than discharges experienced over the preceding 200 years, and "are thus still within the range of long-term natural variability." In addition, they say their "longer-term discharge records do not indicate a consistent positive significant correlation between discharge [and] Siberian temperature." In fact, they report there are actually weak *negative* correlations between discharge and temperature on some of the rivers over the period of their study.

In a contemporaneous study, Smith *et al*. (2007) present "a first analysis of a new data set of daily discharge records from 138 small to medium-sized unregulated rivers in northern Eurasia," focusing on providing "a first continental-scale assessment of low-flow trends since the 1930s." Results indicate that "a clear result of this analysis is that, on balance, the monthly minimum values of daily discharge, or 'low flows,' have risen in northern Eurasia during the 20th century," adding that "from 12 unusually complete records from 1935-2002 we see that the minimum flow increases are greatest since ~1985."

From the things discovered by Smith *et al*., therefore, it is clear that over much of northern Eurasia, predictions of more drought seem rather off the mark, as daily low flows of the majority of northern Eurasian rivers have been *increasing*. Moreover, in the words of the five researchers, they have been increasing "in summer as well as winter and in non-permafrost as well as permafrost terrain," with the greatest increases occurring "since ~1985," when the world experienced what climate alarmists typically describe as a warming that was *unprecedented* over the past one to two *millennia*.

Writing about the Qinghai-Tibet Plateau, where they conducted their streamflow study, Cao *et al*. (2006) note that "both theoretical arguments and models suggest that net high-latitude precipitation increases in proportion to increases in mean hemispheric temperature (Houghton *et al*., 2001; Rahmstorf and Ganopolski, 1999; Bruce *et al*., 2002)," stating that in these scenarios "under global warming, mainly in the middle and west regions of northwest China, precipitation increases significantly," so that "some researchers [have] even advanced the issue of [a] climatic shift from warm-dry to warm-wet in northwest China (Shi, 2003)," with the ultimate expectation that total river discharge within the region would significantly increase in response to global warming.

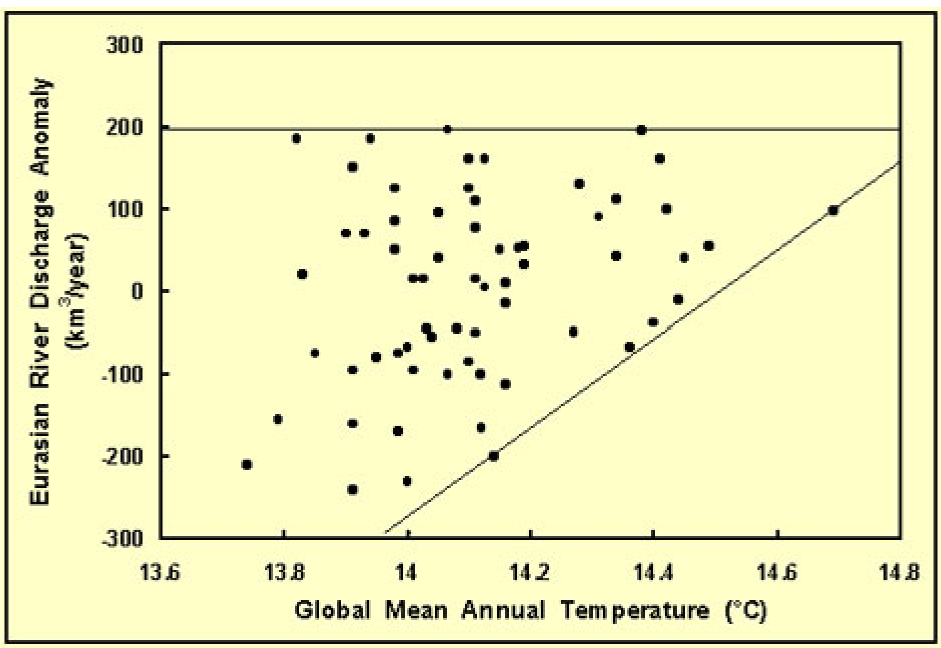
As a test of these climate-model predictions, Cao *et al*. analyzed annual discharge data for five large rivers of the Qinghai-Tibet Plateau over the period 1956-2000, using the Mann-Kendall nonparametric trend test; and in doing so, they found that over the period of their study, "river discharges in the Qinghai-Tibet Plateau, in general, have no obvious change with the increase of the Northern Hemisphere surface air temperature." Hence, because they could detect, in their words, "no increase in the stream discharge in the Qinghai-Tibet Plateau with global warming," Cao *et al*. concluded that their real-world findings are not "in accordance with the anticipated ideas" that led them to conduct their study. Indeed, the disconnect between streamflow and global warming in this and many other studies argues strongly against either (1) the claimed *consequences* of global warming or (2) the claimed *large magnitude* of global warming or (3) *both* of these standard climate-alarmist claims.

Last of all, worried about the possibility that enhanced freshwater delivery to the Arctic ocean by increased river flow could shut down the ocean's thermohaline circulation, Peterson *et al*. (2002) plotted annual values of the combined discharge of the six largest Eurasian Arctic rivers (Yenisey, Lena, Ob', Pechora, Kolyma and Severnaya Dvina) - which drain about two-thirds of the Eurasian Arctic landmass - against the globe's mean annual surface air temperature (SAT), after which they ran a simple linear regression through the data and determined that the combined discharge of the six rivers seems to rise by about 212 km^3/year in response to a 1°C increase in mean global air temperature. Then, they calculated that for the high-end global warming predicted by the Intergovernmental Panel on Climate Change (IPCC) to occur by AD 2100, i.e., a temperature increase of 5.8°C, the warming-induced increase in freshwater discharge from the six rivers could rise by as much as 1260 km^3/year (we calculate 5.8°C x 212 km^3/year/°C = 1230 km^3/year), which represents a 70% increase over the mean discharge rate of the last several years.

The link between this conclusion and the postulated shutting down of the thermohaline circulation of the world's oceans resides in the *hypothesis* that the delivery of such a large addition of freshwater to the North Atlantic Ocean may slow - or even *stop* - that location's production of new deep water, which constitutes one of the driving forces of the great oceanic "conveyor belt." Although still discussed, this scenario is currently not as highly regarded as it was when Peterson *et al*. conducted their research, for a number of reasons, one that we have highlighted being the difficulty of accepting the tremendous extrapolation Peterson *et al*. make in extending their Arctic freshwater discharge vs. SAT relationship to the great length that is implied by the IPCC's predicted high-end warming of 5.8°C over the remainder of the current century.

Consider, for example, that "over the period of the discharge record, global SAT increased by [only] 0.4°C," according to Peterson *et al*. Do you think it reasonable to extend the relationship they derived across that small temperature range fully *fourteen and a half times further*? We surely don't, nor should any other rational person.

Consider also the Eurasian river discharge anomaly vs. global SAT plot of Peterson *et al*. (their Figure 4), which we have replotted in the figure below. Enclosing their data with simple straight-line upper and lower bounds, it can be seen that *the upper bound of the data does not change over the entire range of global SAT variability*, suggesting the very real possibility that the upper bound corresponds to a maximum Eurasian river discharge rate that cannot be exceeded in the real world under its current geographic and climatic configuration. The lower bound, on the other hand, rises so rapidly with increasing global SAT that *the two bounds intersect less than two-tenths of a degree above the warmest of Peterson et al.'s 63 data points*, suggesting that 0.2°C beyond the temperature of their warmest data point may be all the further any relationship derived from their data may validly be extrapolated.



Annual Eurasian Arctic river discharge anomaly vs. annual global surface air temperature (SAT) over the period 1936 to 1999. Adapted from Peterson et al. *(2002)*.

In considering these observations, plus the findings of the other papers reviewed in this section, real-world data do not support the hydrologic negativism climate alarmists associate with both real-world and simulated global warming in Eurasia.

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

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4.4.2. North America

Brown *et al*. (1999) studied siliciclastic sediment grain size, planktonic foraminiferal and pteropod relative frequencies, and the carbon and oxygen isotopic compositions of two species of planktonic foraminifera in cored sequences of hemipelagic muds deposited over the past 5300 years in the northern Gulf of Mexico for evidence of variations in Mississippi River outflow characteristics over this time period. The results of their research indicated the occurrence of large *megafloods* - which they describe as having been "almost certainly larger than historical floods in the Mississippi watershed" - at 4700, 3500, 3000, 2500, 2000, 1200 and 300 years before present. These fluvial events, in their estimation, were likely "episodes of multidecadal duration," spawned by an export of extremely moist gulf air to midcontinental North America that was driven by naturally-occurring same-time-scale oscillations in Gulf of Mexico ocean currents.

Think what would happen *if*, in the words of the three researchers, the United States began to experience a *multidecadal episode* of "historically unprecedented precipitation and flooding in the Mississippi watershed." Before it was even in full-swing, the IPCC-inspired media would probably have driven the U.S. Senate to unanimous ratification of a dozen Kyoto protocols. But would they have been right to do so? Such an occurrence of "historically unprecedented" extreme weather sure sounds like what the climate models are predicting to occur as a consequence of the ongoing rise in the air's CO_2 content; but it is clear that these particular extreme events were in no way related to variations in atmospheric CO_2 concentration, as they occurred over a period of near-constancy in this atmospheric property. And if it's happened before, it can happen again. How easy it would be, therefore, to make a monumental mistake in our stewardship of the planet! Brown *et al*.'s study thus reminds us that we must not to rush to judgment in matters of such great importance.

Hidalgo *et al*. (2000) used a form of principal components analysis to reconstruct a history of streamflow in the Upper Colorado River Basin from information obtained from tree-ring data, after which they compared their results with the streamflow reconstruction of Stockton and Jacoby (1976). In doing so, they found their results were similar to those of the earlier 1976 study, but that their newer reconstruction responded with better fidelity to periods of below-average streamflow or regional drought. Hence, it was easier for them to see there had been "a near-centennial return period of extreme drought events in this region," going all the way back to the early 1500s, providing another demonstration of the cyclical nature of climate.

Also of great importance, Hidalgo *et al*.'s work provided additional evidence for the existence of past droughts that surpassed the worst of the 20th century. Consequently, it would not be surprising to see such a drought occur again; and if it lasted as long as such droughts have lasted in the past, it would likely be claimed by climate alarmists to have been caused by CO_2-induced global warming. However, such need not be the case, since the most severe droughts of the past 500 years occurred at times when the air temperature and atmospheric CO_2 concentration were *much* lower than they are today; and, hence, they could just as easily occur now without any help from rising air temperatures and CO_2 concentrations as they did then.

Working in the same general area a few years later, Woodhouse *et al*. (2006) generated updated proxy reconstructions of water-year streamflow for four key streamflow gauges in the Upper Colorado River Basin (Green River at Green River, Utah; Colorado near Cisco, Utah; San Juan near Bluff, Utah; and Colorado at Lees Ferry, Arizona), "using an expanded tree-ring network and longer calibration records than in previous efforts." By these means they determined that the major drought of 2000-2004, "as measured by 5-year running means of water-year total flow at Lees Ferry ... is not without precedence in the tree ring record," and that "average reconstructed annual flow for the period 1844-1848 was lower." They also report that "two additional periods, in the early 1500s and early 1600s, have a 25% or greater chance of being as dry as 1999-2004," and that six other periods "have a 10% or greater chance of being drier." In addition, their work revealed that "longer duration droughts have occurred in the past," and that "the Lees Ferry reconstruction contains one sequence each of six, eight, and eleven consecutive years with flows below the 1906-1995 average."

"Overall," in the words of the three researchers, "these analyses demonstrate that severe, sustained droughts are a defining feature of Upper Colorado River hydroclimate." In fact, they conclude that "droughts more severe than any 20th to 21st century event occurred in the past," meaning the preceding few centuries. Interestingly, this finding is just the *opposite* of what climate alarmists would have one believe, i.e., that global warming brings with it more frequent and longer-lasting droughts of much greater severity. In stark contrast to this climate-model-based claim, the real-world record of the USA's Upper Colorado River Basin suggests that such droughts were more strongly associated with the much colder temperatures of the Little Ice Age.

Expanding the scope of investigation just a bit, and noting that "paleoclimatic studies indicate that the natural variability in 20th century [streamflow] gage records is likely only a subset of the full range of natural variability," while citing in support of this statement the studies of Stockton and Jacoby (1976), Smith and Stockton (1981), Meko *et al*. (2001) and Woodhouse (2001), Woodhouse and Lukas (2006) developed "a network of 14 annual streamflow reconstructions, 300-600 years long, for gages in the Upper Colorado and South Platte River basins in Colorado generated from new and existing tree-ring chronologies." The results indicated, as they describe it, that "the 20th century gage record does not fully represent the range of streamflow characteristics seen in the prior two to five centuries." Of greatest significance, in this regard, was probably the fact that "multi-year drought events more severe than the 1950s drought have occurred," and that "the greatest frequency of extreme low flow events occurred in the 19th century," with a "clustering of extreme event years in the 1840s and 1850s."

These findings are of great importance to water resource planners. In addition, they provide a huge "security net" for climate-alarmists who predict the occurrence of both extreme droughts *and* floods in response to anthropogenic-produced increases in air temperature. This "assurance of fulfillment" of their prophetic pronouncements arises from the fact that historic streamflow variability is "only a subset of the full range of natural variability." This being the case, it can be appreciated that predictions of abnormal perturbations (relative to the past hundred or so years) of both wet and dry conditions likely *will* see fulfillment sometime in the future ... *but it need not be due to CO_2-induced global warming*, for atmospheric CO_2 concentration and air temperature were both significantly lower than they are now - and will be throughout the 21th century - during the prior centuries of the Little Ice Age, when the greater *natural* variability in streamflow detected by Woodhouse and others occurred.

Working in an adjacent region of the western United States, Carson and Munroe (2005) used tree-ring data collected by Stockton and Jacoby (1976) from the Uinta Mountains of Utah to reconstruct mean annual discharge in the Ashley Creek watershed for the period 1637 to 1970. As a result of their efforts, significant persistent departures from the long-term mean were noted throughout the 334-year record of reconstructed streamflow. The periods 1637-1691 and 1741-1897 experienced reduced numbers of extremely large flows and increased numbers of extremely small flows, indicative of persistent drought or near-drought conditions. In contrast, there was an overall abundance of extremely large flows and relatively few extremely small flows during the periods 1692-1740 and 1898-1945, indicative of wetter conditions. These results provide yet another indication of the cyclical nature of climate. In addition, they provide still more evidence for the existence of past periods of extreme wetness and dryness with accompanying floods and droughts, when both air temperatures and atmospheric CO_2 concentrations were much lower than they were throughout the bulk of the 20th century.

Lins and Slack (1999) analyzed secular trends in streamflow for 395 climate-sensitive stream gage stations (including data from more than 1500 individual gages) located throughout the conterminous United States, some of which stations possessed data sets stretching all the way back to 1914. In doing so, they found many more up-trends than down-trends in streamflow nationally, with slight decreases "only in parts of the Pacific Northwest and the Southeast." These and other of their findings, as they describe them, indicate "the conterminous U.S. is getting wetter, *but less extreme* [our italics]," and it is difficult to conceive of a better result. As the world has warmed over the past century, the United States has gotten wetter in the mean, but less variable at the extremes, where floods and droughts occur.

Also studying the conterminous United States were McCabe and Wolock (2002), who for the period 1895-1999 evaluated (1) precipitation minus annual potential evapotranspiration, (2) the surplus water that eventually becomes streamflow, and (3) the water deficit that must be supplied by irrigation to grow vegetation at an optimum rate. This exercise revealed there was a statistically significant *increase* in the first two of these parameters, while for the third there was *no change*, indicative of the fact that over the period of time climate alarmists describe as having witnessed a global warming that was *unprecedented* over the past one to two *millennia* (which they claim is leading to catastrophic moisture-related consequences for agriculture), water has actually become *more* available within the conterminous United States, and there has been *no increase* in the amount of water required for optimum plant growth.

Knox (2001) studied how conversion of the U.S. Upper Mississippi River Valley from prairie and forest to crop and pasture land by settlers in the early 1800s influenced subsequent watershed runoff and soil erosion rates. Initially, the conversion of the region's natural landscape to primarily agricultural use boosted surface erosion rates to values three to eight times greater than those characteristic of pre-settlement times. In addition, the land-use conversion increased peak discharges from high-frequency floods by 200 to 400%. Since the late 1930s, however, surface runoff has been decreasing; but the decrease "is not associated with climatic causes," according to Knox, who reports that "an analysis of temporal variation in storm magnitudes for the same period showed no statistically significant trend."

Other notable findings of Knox's study include the observation that since the 1940s and early 1950s, the magnitudes of the largest daily flows have been decreasing at the same time that the magnitude of the average daily baseflow has been increasing, indicating a trend toward fewer flood *and* drought conditions. Once again, therefore, we have a situation where global warming has coincided with a streamflow trend that is leading to the best of all possible worlds, i.e., one of greater water availability, but with fewer and smaller floods and droughts.

Molnar and Ramirez (2001) conducted a detailed watershed-based analysis of precipitation and streamflow trends for the period 1948-97 in a semiarid region of the southwestern United States, the Rio Puerco Basin of New Mexico. "At the annual timescale," as they describe it, "a statistically significant increasing trend in precipitation in the basin was detected." This trend was driven primarily by an increase in the number of rainy days in the moderate rainfall intensity range, with essentially no change at the high-intensity end of the spectrum. In the case of streamflow, however, there was no trend at the annual timescale; but monthly totals *increased* in *low*-flow months and *decreased* in *high*-flow months.

What are the implications of these findings? Increasing precipitation in a semiarid region sounds like a plus to us. Having most of the increase in the moderate rainfall intensity range also sounds like a plus. Increasing streamflow in normally low-flow months sounds good as well, as does decreasing streamflow in high-flow months. In fact, what more could one possibly want in terms of changes in precipitation and streamflow? ... especially in a world that according to the anti-CO_2 forces of the planet is supposed to be experiencing more extreme weather events and increases in floods and droughts? We once thought that by predicting both more floods and more droughts at one and the same time in response to global warming, climate alarmists were making sure they could not be proven wrong in their predictions of CO_2-induced water-related calamities. In reviewing what nature reveals about the matter, however, it seems we erred in this assumption; they can be wrong on both counts, and they oftentimes are.

Shifting to a study of *snowmelt runoff* (SMR), McCabe and Clark (2005) note that most prior studies of this phenomenon in the western United States have depended on *trend analyses* to identify changes in timing, but they indicate that "trend analyses are unable to determine if a trend is gradual or a step change." This fact is crucial, they say, because when "changes in SMR timing have been identified by linear trends, there is a tendency to attribute these changes to global warming because of large correlations between linear trends in SMR timing and the increasing trend in global temperature." Therefore, using daily streamflow data for 84 stations in the western U.S., each with complete water-year information for the period 1950-2003, they conducted a number of analyses that enabled them to determine each station's mean streamflow trend over the last half century, as well as any *stepwise changes* that may have occurred in each data series.

As others before them had previously learned, the two researchers found that "the timing of SMR for many rivers in the western United States has shifted to earlier in the snowmelt season." However, they discovered that "the shift to earlier SMR has not been a gradual trend, but appears to have occurred as a step change during the mid-1980s," which shift was "related to a regional step increase in April-July temperatures during the mid-1980s." As a result, and after discussing various other possible reasons for what they had discovered, McCabe and Clark concluded that "the observed change in the timing of SMR in the western United States is a regional response to natural climatic variability and may not be related to global trends in temperature."

Over in Minnesota, Novotny and Stefan (2006) analyzed streamflow records (extending up to the year 2002, with lengths ranging from 53 to 101 years) obtained from 36 gauging stations in five major river basins of the state, deriving histories of seven annual streamflow statistics: "mean annual flow, 7-day low flow in winter, 7-day low flow in summer, peak flow due to snow melt runoff, peak flow due to rainfall, as well as high and extreme flow days (number of days with flow rates greater than the mean plus one or two standard deviations, respectively)." In doing so, they found significant trends in each of the seven streamflow statistics throughout the state, but that in most cases "the trends are not monotonic but periodic," and they determined, as might have been expected, that "the mean annual stream flow changes are well correlated with total annual precipitation changes."

Most significantly, they found that *peak flood flows due to snowmelt runoff* "are not changing at a significant rate throughout the state," but that 7-day low flows or *base flows* are "increasing in the Red River of the North, Minnesota River and Mississippi River basins during both the summer and winter," that the "low flows are changing at a significant rate in a significant number of stations and at the highest rates in the past 20 years," and that "this finding matches results of other studies which found low flows increasing in the upper Midwest region including Minnesota (Lins and Slack, 1999; Douglas *et al*., 2000)."

With respect to the ramifications of their findings, the two researchers write than "an increase in mean annual streamflow in Minnesota would be welcome," as "it could provide more aquatic habitat, better water quality, and more recreational opportunities, among other benefits."

Likewise, they say that "water quality and aquatic ecosystems should benefit from increases in low flows in both the summer and winter, since water quality stresses are usually largest during low flow periods." In addition, they say "other good news is that spring floods (from snowmelt), the largest floods in Minnesota, have not been increasing significantly." Clearly, therefore, even in the fabled "Land of Ten Thousand Lakes," increasing base flows of rivers and streams are tending to *enhance* the environment, in response to - or in spite of (take your pick) - the supposedly unprecedented increases in air temperature and atmospheric CO_2 concentration that have been experienced concurrently.

In a study that covered parts of two countries, Rood *et al*. (2005) performed an empirical analysis of streamflow trends for rivers fed by relatively pristine watersheds in the central Rocky Mountain Region of North America that extends from Wyoming in the United States through British Columbia in Canada. In doing so, they applied both parametric and non-parametric statistical analyses to assess nearly a century of annual discharge (ending about 2002) along 31 river reaches that drain this part of North America. These analyses revealed that river flows in this region *declined* over the past century by an average of 0.22% per year, with four of them exhibiting recent decline rates exceeding 0.5% per year. This finding, in the words of Rood *et al*., "contrasts with the many current climate change predictions that [this specific] region will become warmer and wetter in the near-future." Once again, therefore, the models appear to have gotten it all wrong for a large portion of North America.

Working entirely in Canada, where about three quarters of the country is drained by rivers that discharge their water into the Arctic and North Atlantic Oceans, Déry and Wood (2005) analyzed hydrometric data from 64 northern Canadian rivers that drain more than half of the country's landmass for the period 1964-2003. Then, after assessing both variability and trends, they explored the influence of large-scale teleconnections as possible drivers of the trends they detected. This work indicated there was a statistically significant mean decline of approximately10% in the discharge rates of the 64 rivers over the four decades of their study, which was nearly identical to the decline in precipitation falling over northern Canada between 1964 and 2000. These facts led the two scientists to conclude that the changes in river discharge they observed were driven "primarily by precipitation rather than evapotranspiration." As for the *cause* of the precipitation/river discharge decline, statistically significant links were found between the decline and the Arctic Oscillation, the El Niño/Southern Oscillation and the Pacific Decadal Oscillation. Consequently, the results of this study indicate there is nothing unusual about the four-decade-long trends in northern Canada river discharge rates, which means there is nothing in these trends that would suggest a global warming impact. If anything, the results argue *against* the worrisome climate-alarmist notion, for state-of-the-art climate models generally suggest that global warming will *enhance* river discharge rates due to an intensified hydrologic cycle. The trends observed here, however, are just the *opposite*; and it would appear they are the products of natural variations in natural phenomena.

Also in Canada Campbell (2002) analyzed the grain sizes of sediment cores obtained from Pine Lake, Alberta, to provide a non-vegetation-based high-resolution record of climate variability for this part of North America over the past 4000 years. This research effort revealed the existence of periods of both increasing and decreasing grain size (a proxy for moisture availability) throughout the 4000-year record at decadal, centennial and millennial time scales. The most predominant departures included 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). In addition, a standardized median grain-size history revealed that the highest rates of stream discharge during the past 4000 years occurred during the Little Ice Age approximately 300-350 years ago. During this time, grain sizes were about 2.5 standard deviations above the 4000-year mean. In contrast, the lowest rates of streamflow were observed around AD 1100, when median grain sizes were nearly 2 standard deviations below the 4000-year mean, while most recently, grain size over the past 150 years has generally remained above average.

The Pine Lake sediment record convincingly demonstrates the reality of the non-CO_2-induced millennial-scale climatic oscillation that has alternately brought several-century-long periods of dryness and wetness to the southern Alberta region of North America during concomitant periods of relative global warmth and coolness, respectively, revealing a relationship that was not evident in the prior streamflow studies reviewed here that did not stretch all the way back in time to the Medieval Warm Period. It also demonstrates there is nothing unusual about the region's current moisture status, which suggests that the planet may still have a bit of warming to do before the Current Warm Period is fully developed.

In a final study from Canada, St. George (2007) begins by noting that the study of Burn (1994) suggested that a doubling of the air's CO_2 content could increase the severity and frequency of droughts in the prairie provinces of Canada (Alberta, Saskatchewan, Manitoba), but that results from an ensemble of climate models suggest that runoff in the Winnipeg River region of southern Manitoba, as well as runoff in central and northern Manitoba, could increase 20-30% by the middle of the 21st century (Milly *et al*., 2005). To help resolve this dichotomy, St. George obtained daily and monthly streamflow data from nine gauge stations within the Winnipeg River watershed from the Water Survey of Canada's HYDAT data archive, plus precipitation and temperature data from Environment Canada's Adjusted Historical Canadian Climate Data archive, and analyzed them for trends over the period 1924-2003.

This work revealed, in the words of St. George, that "mean annual flows have increased by 58% since 1924 ... with winter streamflow going up by 60-110%," primarily because of "increases in precipitation during summer and autumn." In addition, he notes that similar "changes in annual and winter streamflow are observed in records from both regulated and unregulated portions of the watershed, which point to an underlying cause related to climate." Countering these positive findings, however, St. George says there are "reports of declining flow for many rivers in the adjacent Canadian prairies," citing the studies of Westmacott and Burn (1997), Yulianti and Burn (1998), Dery and Wood (2005) and Rood *et al*. (2005). Consequently, just as there are conflicting predictions about the *future* water status of portions of the Prairie Provinces of Canada, especially in Manitoba, so too are there conflicting reports about *past* streamflow trends in this region. Hence, it's anybody's guess as to what will actually occur in the years and decades ahead, although based on the observed trends he discovered, St. George believes "the potential threats to water supply faced by the Canadian Prairie Provinces over the next few decades will not include decreasing streamflow in the Winnipeg River basin."

In concluding this subsection, we report on the recent *global* study of Milliman *et al*. (2008), who computed temporal discharge trends for 137 rivers over the last half of the 20th century that provide what they call a "reasonable global representation," as their combined drainage basins represent about 55% of the land area draining into the global ocean. In the words of the five researchers, "between 1951 and 2000 cumulative discharge for the 137 rivers remained statistically unchanged." In addition, they report that "global on-land precipitation between 1951 and 2000 remained statistically unchanged." Then, in a simple and straightforward conclusion, Milliman *et al*. write that "neither discharge nor precipitation changed significantly over the last half of the 20th century, offering little support to a global intensification of the hydrological cycle," such as is generally claimed to be a consequence of CO_2-induced global warming.

Thus, we note there appear to be few real-world data that provide any significant support for the contention that CO_2-induced global warming will lead to more frequent and/or more severe increases and decreases in streamflow that result in, or are indicative of, more frequent and/or more severe floods and droughts. In fact, in the vast majority of cases, observed trends appear to be just the *opposite* of what is predicted to occur. Not only are real-world observations nearly all *not undesirable*, they are *positive*, and typically *extremely* so.

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

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4.5. Greenland

A long succession of climate models has consistently predicted that CO_2-induced global warming should be significantly amplified in earth's polar regions and that the first signs of humanity's expected impact on the world's weather should thus be manifest there. In consequence of such warming, the models further predict the rapid disintegration of the Greenland Ice sheet and subsequent raising of global sea level on the order of 7 feet. But how valid are such claims? Is the so-called unprecedented warmth of the past two millennia exerting a notable influence on the Greenland ice sheet? We answer such questions in the subsections below, citing numerous scientific studies.

Additional information on this topic, including reviews on Greenland not discussed here, can be found at http://www.co2science.org/subject/g/subject_g.php under the heading Greenland.

4.5.1. Temperature History

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 group of seven scientists reports that "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 last 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. Indeed, Bard forcefully states that "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 [our italics]," which is a particularly important point, seeing that 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 but 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 actually provides an effective "insurance policy" against abrupt climate change; for 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. Hence, and in light of the fact that the four preceding interglacials basked in temperatures fully 2°C *warmer* than those of the current interglacial (Petit *et al*., 1999) without suffering any adverse climatic consequences, humanity would be wise to not surrender the *true* environmental insurance policy we worked so hard to put in place by depositing the excess CO_2 we produced over the course of the Industrial Revolution into the atmosphere, where it clearly does both the climate and the biosphere great good.

Focusing on the more pertinent period of the current interglacial or Holocene, we next consider a number of papers that come to bear upon the reality of the Medieval Warm Period and Little Ice Age: two well-known multi-century periods of significant climatic aberration, whose existence the world's climate alarmists simply refuse to acknowledge. And why do they refuse to acknowledge them? Because 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-Modern 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 entitled "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; and 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 20th 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 1100 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 1100 to 700 years BP than it was over the 20th 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 1300-900 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." Last of all, 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.

Many more details of this incredible 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 3200 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. Furthermore, 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. Hence, since the peak warmth of the Medieval Warm Period was caused by something quite apart from elevated levels of atmospheric CO_2, or any other greenhouse gas, for that matter, there is no reason to not believe that a return engagement of that same factor or group of factors is responsible for the even *lesser* warmth of today.

Concentrating finally on the 20th 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 data sets (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 that 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-20th-century cooling on Greenland. Based on mean monthly temperatures of 37 Arctic and 7 sub-Arctic stations, as well as temperature anomalies of 30 grid-boxes from the updated data set of Jones, for example, Przybylak (2001) 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 1300 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 that temperatures there actually cooled at a rate of 0.15 ± 0.03°C per decade during the past 75 years.

Concluding our discussion of this final aspect of Greenland's temperature history, we note that 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 ... and cooled *significantly*.

At the *start* of the 20th century, however, Greenland was warming, as it emerged, along with the rest of the world, from the depths of the Little Ice Age. What is more, 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 fact, 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 thus 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."

In further contemplating the results of the study of Chylek *et al*., it is clear that the entire history of anthropogenic CO_2 emissions since the inception of the Industrial Revolution has had *no discernable impact* on Greenland air temperatures. Hence, it can readily be appreciated that there is absolutely no substance to the claim that Greenland provides evidence for an impending CO_2-induced warming of *any* magnitude. What these many studies of the temperature history of Greenland do depict is 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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4.5.2. Contribution to Sea Level

Studies of the growth and decay of polar ice sheets are of great importance because of the relationships of these phenomena to global warming and the impacts they can have on sea level. In this section, therefore, we review a number of such studies that pertain to the Greenland Ice Sheet.

In the 24 March 2006 issue of *Science*, a number of commentaries heralded accelerating discharges of glacial ice from Greenland and Antarctica, while dispensing dire warnings of an imminent large, rapid and accelerating sea-level rise (Bindschadler, 2006; Joughin, 2006; Kerr, 2006; Kennedy and Hanson, 2006). This distressing news was based largely on three reports published in the same issue (Ekstrom *et al*., 2006; Otto-Bliesner *et al*., 2006; Overpeck *et al*., 2006), wherein the unnerving phenomena were attributed to anthropogenic-induced global warming, which is widely claimed to be due primarily to increases in the air's CO_2 content that are believed to be driven by the burning of ever increasing quantities of fossil fuels such as coal, gas and oil. But does all of this make any sense?

Consider the report of Ekstrom *et al*., who studied "glacial earthquakes" caused by sudden sliding motions of glaciers on Greenland. Over the period Jan 1993 to Oct 2005, they determined that (1) *all* of the best-recorded quakes were associated with major outlet glaciers on the east and west coasts of Greenland between approximately 65 and 76°N latitude, (2) "a clear increase in the number of events is seen starting in 2002," and (3) "to date in 2005, twice as many events have been detected as in any year before 2002."

With respect to the *reason* for the recent increase in glacial activity on Greenland, Clayton Sandell of ABC News (23 March 2006) quoted Ekstrom as saying "I think it is very hard not to associate this with global warming," which sentiment appears to be shared by almost all of the authors of the seven *Science* articles. Unwilling to join in that conclusion, however, was Joughin, who in the very same issue presented histories of summer temperature at four coastal Greenland stations located within the same latitude range as the sites of the glacial earthquakes, which histories suggest that it was warmer in this region back in the 1930s than it was over the period of Ekstrom *et al*.'s analysis.

Based on these data, Joughin concluded that the recent warming in Greenland "is too short to determine whether it is an anthropogenic effect or natural variability," a position that is supported - and in some cases even more rigorously - by numerous scientists who have researched the issue, as noted in the following brief synopses of some of their studies.

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 data sets (Parker *et al*., 1995; Rayner *et al*., 1996; Kalnay *et al*., 1996). Their analyses revealed that 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. In addition, it was determined that the cooling was "significantly inversely correlated with an increased phase of the North Atlantic Oscillation over the past few decades."

In an even broader study based on mean monthly temperatures of 37 Arctic and 7 sub-Arctic stations, as well as temperature anomalies of 30 grid-boxes from the updated data set of Jones, Przybylak (2000) found that (1) "in the Arctic, the highest temperatures since the beginning of instrumental observation occurred clearly in the 1930s," (2) "even in the 1950s the temperature was higher than in the last 10 years," (3) "since the mid-1970s, the annual temperature shows no clear trend," and (4) "the level of temperature in Greenland in the last 10-20 years is similar to that observed in the 19th century." These findings led him to conclude that the meteorological record "shows that the observed variations in air temperature in the real Arctic are in many aspects not consistent with the projected climatic changes computed by climatic models for the enhanced greenhouse effect," because, in his words, "the temperature predictions produced by numerical climate models significantly differ from those actually observed."

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 1300 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 fact, they report that observational evidence from Jan Mayen Island indicates that temperatures there actually cooled at a rate of 0.15 ± 0.03°C per decade throughout the prior *75 years*.

More recently, 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 then-current coastal temperatures were "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."

At the *start* of the 20th century, however, Greenland *was* warming, as it emerged, along with the rest of the world, from the depths of the Little Ice Age. What is more, 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 fact, 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."

In light of these several real-world observations, it is clear that the recent upswing in glacial activity on Greenland likely has had nothing to do with anthropogenic-induced global warming, as temperatures there have yet to rise either as *fast* or as *high* as they did during the great warming of the 1920s, which was clearly a *natural* phenomenon. It is also important to recognize the fact that coastal glacial discharge represents only *half* of the equation relating to sea level change, the other half being inland ice accumulation derived from precipitation; and when the mass balance of the *entire* Greenland ice sheet was recently assessed via satellite radar altimetry, quite a different result was obtained than that suggested by the seven *Science* papers of 24 March.

Zwally *et al*. (2005), for example, found that although "the Greenland ice sheet is thinning at the margins," it is "growing inland with a small overall mass gain." In fact, for the 11-year period 1992-2003, Johannessen *et al*. (2005) found that "below 1500 meters, the elevation-change rate is [a negative] 2.0 ± 0.9 cm/year, in qualitative agreement with reported thinning in the ice-sheet margins," but that "an increase of 6.4 ± 0.2 cm/year is found in the vast interior areas above 1500 meters." Spatially averaged over the bulk of the ice sheet, the net result, according to the latter researchers, was a mean increase of 5.4 ± 0.2 cm/year, "or ~60 cm over 11 years, or ~54 cm when corrected for isostatic uplift." Consequently, the Greenland ice sheet would appear to have experienced no net loss of mass over the last decade for which data are available. Quite to the contrary, in fact, it was likely host to a net *accumulation* of ice, which Zwally *et al*. found to be producing a 0.03 ± 0.01 mm/year *decline* in sea-level.

In an attempt to downplay the significance of these inconvenient findings, Kerr quoted Zwally as saying he believes that "right now" the Greenland ice sheet is experiencing a net loss of mass. Why? Kerr says Zwally's belief is "based on his gut feeling about the most recent radar and laser observations." Fair enough. But *gut feelings* are a poor substitute for comprehensive real-world measurements; and even if the things that Zwally's intestines were telling him are ultimately found to be correct, their confirmation would only demonstrate just how rapidly the Greenland environment can change. Also, we would have to wait and see how long the mass losses prevailed in order to assess their significance within the context of the CO_2-induced global warming debate. For the present and immediate future, therefore, we have no choice but to stick with what existent data and analyses suggest, i.e., that *cumulatively since the early 1990s* and *conservatively* (since the balance is likely still positive), there has been no net loss of mass from the Greenland ice sheet.

Nevertheless, many continue to hold to the view that the Greenland Ice Sheet is teetering on the verge of extinction, that it will melt rapidly and all but "slip-sliding away" into the ocean, where its unleashed water will raise global sea levels to heights that will radically alter continental coastlines and submerge major cities. The recent study of Eldrett *et al*. (2007), however, provides further new evidence that such an alarmist view of the matter is poles away from the truth.

The five researchers from the School of Ocean and Earth Science of the National Oceanography Centre of the University of Southampton in the UK report they "have generated a new stratigraphy for three key Deep Sea Drilling Project/Ocean Drilling Program sites by calibrating dinocyst events to the geomagnetic polarity timescale." In doing so, they say their detailed core observations revealed evidence for "extensive ice-rafted debris, including macroscopic dropstones, in late Eocene to early Oligocene sediments from the Norwegian-Greenland Sea that were deposited between about 38 and 30 million years ago." They further report that their data "indicate sediment rafting by glacial ice, rather than sea ice, and point to East Greenland as the likely source," and they conclude that their data thus suggest "the existence of (at least) isolated glaciers on Greenland about 20 million years earlier than previously documented." What is particularly interesting about this finding, as Eldrett *et al*. describe it, is that it indicates the presence of glacial ice on Greenland "at a time when temperatures and atmospheric carbon dioxide concentrations were substantially higher." How much higher? According to graphs the researchers present, ocean bottom-water temperatures were 5-8°C warmer, while atmospheric CO_2 concentrations were as much as *four times greater than they are today*.

The problem these observations provide for those who hold to the view that global warming will melt the Greenland ice sheet, to quote Eldrett *et al*., is that "palaeoclimate model experiments generate substantial ice sheets in the Northern Hemisphere for the Eocene only in runs where carbon dioxide levels are lower (approaching the pre-anthropogenic level) than suggested by proxy records," which records indicate atmospheric CO_2 concentrations fully *two to seven times greater than the pre-anthropogenic level* during the time of the newly-detected ice sheets.

"Regardless," as the researchers say, their data "provide the first stratigraphically extensive evidence for the existence of continental ice in the Northern Hemisphere during the Palaeogene," which "is about 20 million years earlier than previously documented, at a time when global deep water temperatures and, by extension, surface water temperatures at high latitude, were much warmer." Therefore - and also "by extension" - there is great reason to not only *doubt*, but to *reject out-of-hand*, scare stories of sea levels rapidly rising tens of feet in response to a predicted rapid demise of the Greenland Ice Sheet, which is seen by the alarmists as occurring in response to a warming of the planet that may be pushing it perilously close to a high-temperature "tipping point," for we now have evidence of a *much* warmer period of time that *failed* to bring about such a catastrophic consequence.

Other evidence that contradicts climate-alarmist contentions of the impending demise of the Greenland Ice Sheet has been around for several years. Cuffey and Marshall (2000), for example, reevaluated previous estimates of the Greenland Ice Sheet's contribution to sea level rise during the last interglacial (a rise of one to two meters), based on a recalibration of oxygen-isotope-derived temperatures from central Greenland ice cores. The results of their analysis suggested that the Greenland Ice Sheet was much smaller during the last interglacial than had previously been thought, with melting of the ice sheet contributing somewhere between four and five and a half meters to sea level rise. Although these results suggest that wastage of the Greenland Ice Sheet could potentially raise sea levels considerably more than had previously been believed, Hvidberg (2000) put a positive spin on the subject by stating that "high sea levels during the last interglacial should not be interpreted as evidence for extensive melting of the West Antarctic Ice Sheet, and so challenges the hypothesis that the West Antarctic is particularly sensitive to climate change," which is *good* news, as West Antarctica presents a much greater threat to global sea level rise than does Greenland. Also, whereas the possibility exists that sea levels in the present interglacial could yet rise to the heights of those of the last interglacial as a result of a major shrinking of the Greenland Ice Sheet, Cuffey and Marshall estimate that the ice sheet's widespread melting during the prior interglacial took place over the course of a few *millennia*, as opposed to the *decades* that could be counted on one's hands and toes that are suggested by alarmist scaremongering.

Continuing, Krabill *et al*. (2000) used data obtained from aircraft laser-altimeter surveys over northern Greenland in 1994 and 1999, together with previously reported data from southern Greenland, to evaluate the mass balance of the Greenland Ice Sheet. Above an elevation of 2000 meters they found areas of both thinning and thickening; and these phenomena nearly balanced each other, so that in the south there was a net thinning of 11 ± 7 mm/year, while in the north there was a net thickening of 14 ± 7 mm/year. Altogether, the entire region exhibited a net thickening of 5 ± 5 mm/year; but in correcting for bedrock uplift, which averaged 4 mm/year in the south and 5 mm/year in the north, the average thickening rate decreased to *practically nothing*. In fact, the word used by Krabill *et al*. to describe the net balance was "zero."

At lower elevations, thinning was found to predominate along approximately 70% of the coast. Here, however, flight lines were few and far between, so few and far between, in fact, that the researchers said that "in order to extend our estimates to the edge of the ice sheet in areas not bounded by our surveys, we *calculated* [our italics] a *hypothetical* [our italics] thinning rate on the basis of the coastal positive degree day anomalies." Then, they *interpolated* between this calculated coastal thinning rate and the nearest observed elevation changes to obtain their final answer: a total net reduction in ice volume of 51 km^3/year.

Unfortunately, it is hard to know what *estimates* derived from *interpolations* based on *calculations* of a *hypothetical* thinning rate mean. Hence, we question their significance; and, in fact, the commentary of the researchers themselves tends to do the same. They note, for example, that they do not have a "satisfactory explanation" for the "widespread thinning at elevations below 2000 m," which suggests, to us at least, that the reason this phenomenon is unexplainable is that it may not be real. Furthermore, they note that even if the thinning was real, it could not be due to global or regional warming; for they report that Greenland temperature records indicate "the 1980s and early 1990s were about half a degree cooler than the 96-year mean."

After discussing some other factors that could possibly be involved, Krabill *et al*. state they are left with changes in ice dynamics as the most likely cause of the hypothetical ice sheet thinning. But they admit in their final sentence that "we have no evidence for such changes, and we cannot explain why they should apply to many glaciers in different parts of Greenland." Hence, it would seem that the logical thing to do is admit that this study resolves almost nothing about the mass balance of the coastal regions of the Greenland Ice Sheet, and that it resolves *absolutely* nothing about the subject of global warming and its effect or non-effect upon this hypothetical phenomenon.

In a preliminary step required to better understand the relationship of glacier dynamics to climate change in West Greenland, Taurisano *et al*. (2004) described the temperature trends of the Nuuk fjord area during the last century. This analysis 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." Last of all, they report there was no significant trend in annual precipitation.

In their concluding discussion, Taurisano *et al*. remark that the temperature data they studied "reveal a pattern which is common to most other stations in Greenland." Hence, we can be thankful that whatever the rest of the Northern Hemisphere may be doing, *the part that holds the lion's share of the hemisphere's ice has been cooling for the past half-century*, and at a very significant rate, making it ever more unlikely that its horde of frozen water will be released to the world's oceans to raise havoc with global sea level any time soon. In addition, because the annual number of snowfall days over much of Greenland has increased so dramatically over the same time period, it is possible that enhanced accumulation of snow on its huge ice sheet may be compensating for the melting of many of the world's mountain glaciers and keeping global sea level in check for this reason too. Last of all, Greenland's temperature trend of the past half-century has been just the *opposite* - and strikingly so - of that which is claimed for the Northern Hemisphere and the world by the IPCC and its climate-alarmist friends. Furthermore, as Greenland contributes significantly to the land area of the Arctic, it presents these folks with a *double* problem, as they have historically claimed that high northern latitudes should be the first to exhibit convincing evidence of CO_2-induced global warming.

In a study with a negative take on the issue, Rignot and Kanagaratnam (2005) used satellite radar interferometry observations of Greenland to detect what they described as "widespread glacier acceleration." Calculating that this phenomenon had led to a doubling of the ice sheet mass deficit in the last decade and, therefore, a comparable increase in Greenland's contribution to rising sea levels, they went on to claim that "as more glaciers accelerate ... the contribution of Greenland to sea-level rise will continue to increase."

With respect to these contentions, we have no problem with what the two researchers have *observed* with respect to Greenland's glaciers; but we feel compelled to note that what they have *calculated* with respect to the mass balance of Greenland's Ice Sheet and what they say it implies about sea level are diametrically opposed to the story told by other more inclusive real-world data. One reason for this discrepancy is that instead of relying on *measurements* for this evaluation, Rignot and Kanagaratnam relied on the *calculations* of Hanna *et al*. (2005), who used *meteorological models* "to retrieve annual accumulation, runoff, and surface mass balance." When actual *measurements* of the ice sheet via satellite radar altimetry are employed, for example, a decidedly different perspective is obtained, as indicated by the work of Zwally *et al*. (2005) and Johannessen *et al*. (2005), which we cited earlier in this Summary. Consequently, and in direct contradiction of the claim of Rignot and Kanagaratnam, Greenland would appear to have experienced no ice sheet mass deficit in the last decade. Quite to the contrary, in fact, it has likely been host to a net *accumulation* of ice, which Zwally *et al*. estimate to be contributing a negative 0.03 ± 0.01 mm/year to sea-level change. As a result, the net accumulation of ice on Greenland over the past decade or more may well have been ever so slightly *lowering* global sea level.

Yet in spite of all the real-world evidence that supports this positive perspective, climate alarmists such as Al Gore continue to claim that *if Greenland melted or broke up and slipped into the sea .. sea levels worldwide would increase by between 18 and 20 feet* (Gore, 2006). Quoting politicians like the UK's Sir David King, who says "the maps of the world will have to be redrawn," Gore conveys the impression that the occurrence of this hypothetical scenario is something we could expect to witness in the very near future. And to make this point even more poignant, Gore illustrates in his *An Inconvenient Truth* book what would likely happen to Florida, San Francisco Bay, the Netherlands, Beijing, Shanghai, Calcutta, Bangladesh and Manhattan if this were to occur, suggesting that we should begin combating now what he implies is a *serious threat* commensurate with other major present-day concerns. The perspective provided by real-world science, however, is something far different, as the materials we have reviewed above clearly demonstrate, and as the findings of yet another analysis of the subject indicate as well.

In the 16 March 2007 issue of *Science*, which highlights the current status of polar-region science at the start of the International Polar Year, Shepherd and Wingham (2007) review what is known about sea-level contributions arising from wastage of the Antarctic and Greenland Ice Sheets, concentrating on the results of 14 satellite-based estimates of the imbalances of the polar ice sheets that have been derived since 1998. These studies have been of three major types - standard mass budget analyses, altimetry measurements of ice-sheet volume changes, and measurements of the ice sheets' changing gravitational attraction - and they have yielded a diversity of values, ranging from a sea-level-rise-equivalent of 1.0 mm/year to a sea-level-*fall*-equivalent of 0.15 mm/year.

Of these three approaches, the results of the latter technique, according to Shepherd and Wingham, "are more negative than those provided by mass budget or altimetry." Why? Because, in their words, the gravity-based technique "is new, and [1] a consensus about the measurement errors has yet to emerge, [2] the correction for postglacial rebound is uncertain, [3] contamination from ocean and atmosphere mass changes is possible, and [4] the results depend on the method used to reduce the data." In addition, they say that (5) the Gravity Recovery and Climate Experiment (GRACE) record is only three years long, and that (6) it is thus particularly sensitive to short-term fluctuations in ice sheet behavior that may not be indicative of what is occurring over a much longer timeframe. Even including these likely-inflated results, however, the two researchers conclude that the current "best estimate" of the contribution of polar ice wastage (from both Greenland *and* Antarctica) to global sea level change is a rise of

0.35 millimeters per year, which over a *century* amounts to only 35 millimeters *or* - to better compare it to the 20-foot rise described by Gore - *a little less than an inch and a half*.

Yet even this unimpressive sea level increase may be way too large, for although two of Greenland's largest outlet glaciers doubled their rates of mass loss in less than a year in 2004 - causing climate alarmists to claim the Greenland Ice Sheet was responding much more rapidly to global warming than anyone had ever expected - Howat *et al*. (2007) report that the two glaciers' rates of mass loss "decreased in 2006 to near the previous rates." And these observations, in their words, "suggest that special care must be taken in how mass-balance estimates are evaluated, particularly when extrapolating into the future, because short-term spikes could yield erroneous long-term trends."

In light of these many observations, we feel it should be obvious that much more is often implied about the future behavior of the Greenland Ice Sheet and its impact on global sea level than is scientifically justified. In fact, *vastly* more than is justified is often implied.

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

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4.6. Antarctica

Additional information on this topic, including reviews on Antarctica not discussed in this section, can be found at http://www.co2science.org/subject/a/subject_a.php under the heading Antarctica.

4.6.1.Temperature

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;

and many jumped on the global warming bandwagon, saying the gross CO_2-temperature 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, the bottom began to fall out of the poorly constructed bandwagon, as the evidentiary glue that held it together began to weaken. Advances in ice-coring instrumentation and techniques had improved considerably, and newer studies with finer temporal resolution began to reveal that, if anything, increases (decreases) in air temperature drive increases (decreases) in atmospheric CO_2 content, and not vice versa [see Indermuhle *et al*. (2000), Monnin *et al*. (2001)]. Thus, a severe blow was dealt to the climate-alarmist community, as a major tenant of the CO_2-induced global warming hypothesis was shown to be contradicted by real-world observations.

The most recent of these studies (Caillon *et al*., 2003) demonstrates that during Glacial Termination III, "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."

In spite of this admission, Caillon *et al*., and many others, hold to the view that the subsequent increase in atmospheric CO_2 -- which is believed to be due to warming-induced CO_2 outgassing from the world's oceans -- serves to amplify the warming that is caused by whatever prompts the temperature to rise in the first place. This belief, however, is founded on unproven assumptions about the strength of CO_2-induced warming; and it is applied without any regard for biologically-induced negative climate feedbacks that may occur in response to atmospheric CO_2 enrichment [see the Chapter on Feedback Factors in this report].

A second major blow to the CO_2-induced global warming hypothesis comes from the instrumental temperature record of the more recent past. This second setback is manifested in 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 tell a radically different story.

Doran *et al*. (2002), for example, examined temperature trends in the McMurdo Dry Valleys of Antarctica over the period 1986 to 2000, reporting a phenomenal 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.

In another study, Comiso (2000) assembled and analyzed Antarctic temperature data obtained from 21 surface stations and from infrared satellites operating since 1979. They found that for all of Antarctica, temperatures had declined by 0.08°C and 0.42°C per decade, respectively, when assessed via these two data sets. And in yet another study, 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?

No. According to Vaughan *et al*. (2001), "rapid *regional* warming [our italics]" has led to the loss of seven ice shelves in this region during the past 50 years. However, they note that sediment cores from 6000 to 1900 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 for climate alarmists to cite the 20th 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.

This 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. Hence, it is getting ever more difficult for climate alarmists to continue claiming that these several-hundred-year cold and warm periods were confined to lands bordering the North Atlantic Ocean. They clearly were *global*; and they clearly demonstrate the reality of the likely solar-induced millennial-scale climatic oscillation that is manifest in the post-1850 warming of the world that climate alarmists misconstrue as having been caused by the concomitant rise in the air's CO_2 content.

Further evidence that the Antarctic as a whole is in the midst of a cooling trend comes from the study of 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 last 18 years has been an equatorward expansion of 0.011 degree of latitude per year.

When all is said and done, therefore, 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 when it comes to representing reality.

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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4.6.2. Contribution to Sea Level

Vaughn *et al*. (1999) used more than 1800 published and unpublished *in situ* measurements of the surface mass balance of Antarctica to produce an assessment of yearly ice accumulation over the continent. Their results indicated that the "total net surface mass balance for the conterminous grounded ice sheet is 1811 Gton yr^{-1} (149 kg m^{-2} yr^{-1}) and for the entire ice sheet including ice shelves and embedded ice rises, 2288 Gton yr^{-1} (166 kg m^{-2} yr^{-1})." These values, in their words, "are around 18% and 7% higher than the estimates widely adopted at present [1999]," which were derived about 15 years earlier. Hence, they suggest that net icefall on Antarctica may well have increased somewhat over that prior decade and a half. Nevertheless, because of uncertainties in the various numbers, Vaughn *et al*. say "we are still unable to determine even the sign of the contribution of the Antarctic Ice Sheet to recent sea level change," which suggests the Antarctic canary has not a clarity of mind on the matter and is somewhat befuddled.

In another review of the subject that was published about the same time, Reeh (1999) found a broad consensus for the conclusion that a 1°C warming would create but little net change in mean global sea level; for Greenland's contribution would be a sea level rise on the order of 0.30 to 0.77 millimeters per year, while *Antarctica's contribution would be a fall on the order of 0.20 to 0.70 millimeters per year*, which also suggests the Antarctic canary is rather confused.
The following year, Wild and Ohmura (2000) studied the mass balance of Antarctica using two general circulation models developed at the Max Plank Institute for Meteorology in Hamburg, Germany: the older ECHAM3 and the new and improved ECHAM4. Under a doubled atmospheric CO_2 scenario, the two models were in close agreement in their mass balance projections, with both of them predicting *increases in ice sheet growth*, indicative of *decreases in sea level*, which by this time had the Antarctic canary really bewildered.

Two years later, van der Veen (2002) addressed the problem again, noting that "for purposes of formulating policies, some of which could be unpopular or costly, it is imperative that probability density functions be derived for predicted values such as sea level rise," further stating that with "greater societal relevance comes increased responsibility for geophysical modelers to demonstrate convincingly the veracity of their models to accurately predict future evolution of the earth's natural system or particular components thereof." In stepping forward to perform this task with respect to sea level change, however, he was forced to conclude that "the validity of the parameterizations used by [various] glaciological modeling studies to estimate changes in surface accumulation and ablation under changing climate conditions has not been convincingly demonstrated." Van der Veen calculated, for example, that uncertainties in model parameters are sufficiently great to yield a 95% confidence range of projected meltwater contributions from Greenland and Antarctica that encompass global sea-level *lowering* as well as rise by 2100 A.D. for low, middle and high warming scenarios. Hence, even for the *worst* of the IPCC warming projections, there could well be little to no change in mean global sea level due to the likely rise in the air's CO_2 content that may occur over the rest of this century. As a result, van der Veen concludes that the confidence level that can be placed in current ice sheet mass balance models "is quite low." Paraphrasing an earlier assessment of the subject, in fact, he says that today's best models "currently reside on the lower rungs of the ladder of excellence" and that "considerable improvements are needed before accurate assessments of future sea-level change can be made," once again leaving the Antarctic canary little to do but wring its wings in frustration.

Last of all, Wadhams and Munk (2004) attempted "an independent estimate of eustatic sea level rise based on the measured freshening of the global ocean, and with attention to the contribution from melting of sea ice (which affects freshening but not sea level)," reporting that their analysis produces "a eustatic rise of only 0.6 mm/year" and that when a steric contribution of 0.5 mm/year is added to the eustatic component, "a total of 1.1 mm/year, somewhat less than IPCC estimates," is the final result. Perhaps the most interesting finding of their analysis, however, is that the continental run-off which is "allowed," after subtracting the effect of sea ice melt, "is considerably lower than current estimates of sub-polar glacial retreat, suggesting a negative contribution from polar ice sheets (Antarctica plus Greenland) or from other non-glacial processes." In this regard, they assert "we do not have good estimates of the mass balance of the Antarctic ice sheet, which could make a much larger positive *or negative* [our italics] contribution."

The bottom line of Wadhams and Munk's analysis, as well as those of the other studies we have reviewed, clearly suggests - in fact *states* - there is considerable uncertainty associated with a number of basic parameters that are related to the water balance of the world's oceans and the meltwater contribution of Antarctica; and until these uncertainties are satisfactorily resolved, we - like the Antarctic canary - cannot be confident that we know what is happening at the bottom of the world in terms of phenomena related to the vertical displacement of the upper surface of the world's oceans. In fact, we haven't really a clue.

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

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4.6.3. West Antarctic Ice Sheet

Additional information on this topic, including reviews the West Antarctic Ice Sheet not discussed here, can be found at http://www.co2science.org/subject/w/subject_w.php under the heading West Antarctic Ice Sheet.

4.6.3.1. Collapse and Disintegration

The West Antarctic Ice Sheet (WAIS) is often described as the world's most *unstable* large ice sheet. As Hillenbrand *et al*. (2002) report, "it was speculated, from observed fast grounding-line retreat and thinning of a glacier in Pine Island Bay (Rignot, 1998; Shepherd *et al*., 2001), from the timing of late Pleistocene-Holocene deglaciation in the Ross Sea (Bindschadler, 1998; Conway *et al*., 1999), and from predicted activity of ice-stream drainage in response to presumed future global warming (Oppenheimer, 1998), that the WAIS may disappear in the future, causing the sea-level to rise at a rate of 1 to 10 mm/year (Bindschadler, 1998; Oppenheimer, 1998)." Hence, it is important to keep an eye on what is written about the subject in the scientific literature, which is what we do as ever more pertinent papers are published, the findings of a number of which we review in this section as they pertain to potential WAIS collapse and disintegration.

Cofaigh *et al*. (2001) analyzed five sediment cores from the continental rise west of the Antarctic Peninsula and six from the Weddell and Scotia Seas for their ice rafted debris (IRD) content, in an attempt to see if there are Antarctic analogues of the Heinrich layers of the North Atlantic Ocean, which testify of the repeated collapse of the eastern margin of the Laurentide Ice Sheet and the concomitant massive discharge of icebergs. If such IRD layers exist around Antarctica, the researchers reasoned, they would be evidence of "periodic, widespread catastrophic collapse of basins within the Antarctic Ice Sheet," which could obviously occur again. However, after carefully studying their data, they concluded that "the ice sheet over the Antarctic Peninsula did not undergo widespread catastrophic collapse along its western margin during the late Quaternary," and they say this evidence "argues against pervasive, rapid ice-sheet collapse around the Weddell embayment over the last few glacial cycles." And if there was no dramatic break-up of the WAIS over the last few glacial cycles, there's a very good chance there will be none before the current interglacial ends, especially since the data of Petit *et al*. (1999) indicate that the peak temperatures of each of the previous four intergalcials were warmer than the peak temperature of the current interglacial ... and by an average of more than 2°C.

Hillenbrand *et al*. (2002) studied the nature and history of glaciomarine deposits contained in sediment cores recovered from the West Antarctic continental margin in the Amundsen Sea to "test hypotheses of past disintegration of the WAIS." In doing so, they found that all proxies regarded as sensitive to a WAIS collapse changed markedly during the global climatic cycles of the past 1.8 million years, but that they "do not confirm a complete disintegration of the WAIS during the Pleistocene" at a place where "dramatic environmental changes linked to such an event should be documented." In fact, they say their results "suggest relative stability rather than instability of the WAIS during the Pleistocene climatic cycles," and they note that this conclusion is "consistent with only a minor reduction of the WAIS during the last interglacial period," citing the work of Huybrechts (1990), Cuffey and Marshall (2000) and Huybrechts (2002).

In another paper that addresses the subject of possible WAIS collapse, O'Neill and Oppenheimer (2002) say the ice sheet "may have disintegrated in the past during periods only modestly warmer (~2°C global mean) than today," and they thus claim that setting "a limit of 2°C above the 1990 global average temperature" -- above which the mean temperature of the globe should not be allowed to rise -- "is justified." If the truth be told, however, a 2°C warming of the globe would likely have *little to no impact* on the stability of the WAIS.

As we have already noted, for example, the average Antarctic peak temperature of all four of the world's prior interglacials was *at least* 2°C greater than the Antarctic peak temperature of the current interglacial; yet, in the words of the scientists who developed the pertinent temperature record (Petit *et al*., 1999), the evidence contained in the core "makes it unlikely that the West Antarctic ice sheet collapsed during the past 420,000 years," which is pretty much the same conclusion that was drawn by Cofaigh *et al*. In addition, we know from the Vostok ice core record that the peak Antarctic temperature of the most *recent* prior interglacial was fully *3°C* warmer than the peak Antarctic temperature of the interglacial in which we presently live, yet the WAIS *still* did not disintegrate during that prior time of elevated warmth. Furthermore, we know that throughout the long central portion of the current interglacial (when the most recent peak Antarctic temperature was reached), it was *much* warmer than it was in 1990, which is the year from which O'Neill and Oppenheimer's critical 2°C warming increment is measured; and this fact raises the 3°C temperature elevation of the last interglacial *relative to the global temperature of 1990* to something on the order of 4 or 5°C, for which, *again*, there was no evidence of even a *partial* WAIS disintegration.

Finally, and in spite of the current interglacial's *current* relative *coolness*, the Vostok ice core data indicate that the current interglacial has been *by far* the longest stable warm period of the entire 420,000-year record, which suggests we are probably long overdue for the next ice age to begin, and that we may not have the "5 to 50 centuries" that O'Neill and Oppenheimer suggest could be needed to bring about the WAIS disintegration subsequent to the attainment of whatever temperature in excess of 4 or 5°C above the current global mean would be needed to initiate the process. In conclusion, therefore, it would appear that the climate-alarmist vision of impending WAIS collapse and disintegration is does not match with reality.

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

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4.6.3.2. Dynamics

For quite some time now, alarmists have obsessed over what they contend will be the imminent demise of the West Antarctic Ice Sheet (WAIS) if human-induced CO_2 emissions are not dramatically reduced. As Al Gore (2006) has phrased it, if "half of Antarctica melted or broke up and slipped into the sea, sea levels worldwide would increase by between 18 and 20 feet." But is this really about to happen? In what follows, we briefly review the findings of a number of studies of the dynamics of various components of the WAIS and what they suggest about the subject.

Writing in the journal *Science* were Bindschadler and Vornberger (1998), who utilized satellite imagery taken since 1963 to examine spatial and temporal changes of Ice Stream B, which flows into the Ross Ice Shelf. The data indicated that since that time, the ice stream's width had increased by nearly 4 kilometers, at a rate that was, in their words, an "order of magnitude faster than models have predicted." However, they reported that the *flow speed* of the ice stream had *decreased* over this time period by about 50 percent, noting that "such high rates of change in velocity greatly complicate the calculation of mass balance of the ice sheet," and that such changes "do not resolve the overriding question of the stability of the West Antarctic Ice Sheet."

Bindschadler (1998) reviewed what was known about the WAIS for *Science* and analyzed its historical retreat in terms of its grounding line and ice front. This work revealed that from the time of the Last Glacial Maximum to the present, the retreat of the WAIS's grounding line had been faster than that of its ice front, which resulted in an expanding Ross Ice Shelf. In fact, Bindschadler reported that "the ice front now appears to be nearly stable," although its grounding line appeared to be retreating at a rate that suggested complete dissolution of the WAIS in another 4,000 to 7,000 years. Such a retreat would indeed result in a sustained sea level rise of 8 to 13 cm per century. However, even the smallest of these sea level rates-of-rise would require, according to Bindschadler, "a large negative mass balance for all of West Antarctica," and there were no broad-based data to support that scenario.

Switching from *Science* to *Nature*, Oppenheimer (1998) reviewed 122 studies that dealt with the stability of the WAIS and its effects on global sea level, concluding that "human-induced climate change may play a significant role in controlling the long-term stability of the West Antarctic Ice Sheet and in determining its contribution to sea-level change in the near future." Other of his statements, however, seemed to detract from this conclusion. He noted, for example, that the Intergovernmental Panel on Climate Change (IPCC) "estimated a zero Antarctic contribution to sea-level rise over the past century, and projected a small negative (about -1 cm) contribution for the twenty-first century." Furthermore, with respect to potential anthropogenic modification of the state and behavior of the atmosphere and ocean above and around Antarctica, he acknowledged that "measurements are too sparse to enable the observed changes to be attributed to any such [human-induced] global warming." And in the case of sea-ice extent, he admitted there appeared to not even be a modification; for he stated that "the IPCC assessment is that no trend has yet emerged."

Oppenheimer concluded his review with four scenarios of the future based upon various assumptions. One was that the WAIS will experience a sudden collapse that causes a 4-6 m sea-level rise within the coming century. However, he stated that this scenario "may be put aside for the moment, because no convincing model of it has been presented." A second scenario had the WAIS gradually disintegrating and contributing to a slow sea-level rise over two centuries, followed by a more rapid disintegration over the following 50 to 200 years. Once again, however, he noted that "progress on understanding [the] WAIS over the past two decades has enabled us to lower the relative likelihood of [this] scenario."

In another scenario, the WAIS takes 500-700 years to disappear, as it raises sea-level by 60-120 cm per century. Oppenheimer assesses the relative likelihood of this scenario to be the highest of all, "but with low confidence," as he puts it. Last of all is what occurs if ice streams slow, as a result of internal ice sheet readjustments, and the discharge of grounded ice decreases, which could well happen, even if ice shelves thin and major fast-moving glaciers do not slow. In such a situation, he notes that "the Antarctic contribution to sea-level rise turns increasingly negative," i.e., sea level *falls*. And in commenting upon the suite of scenarios just described, Oppenheimer emphatically states that "it is not possible to place high confidence in any specific prediction about the future of WAIS."

Also writing in *Nature*, Bell *et al*. (1998) used aerogeophysical data to investigate processes that govern fast moving ice streams on the WAIS. In conjunction with various models, these data suggested a close correlation between the margins of various ice streams and the underlying sedimentary basins, which appeared to act as lubricants for the overlying ice. As a result, the seven scientists suggested that the positions of ice-stream margins and their onsets were controlled by features of the underlying sedimentary basins; and they concluded that "geological structures beneath the West Antarctic Ice Sheet have the potential to dictate the evolution of the dynamic ice system, modulating the influence of changes in the global climate system," although their work did not indicate what effect, if any, a modest rise in near-surface air temperature might have on this phenomenon.

Returning to *Science*, Rignot (1998) reported on satellite radar measurements of the grounding line of Pine Island Glacier from 1992 to 1996, which were studied to determine whether or not this major ice stream in remote West Antarctica was advancing or retreating. The data indicated that the glacier's grounding line had retreated inland at a rate of 1.2 ± 0.3 kilometers per year over the four-year period of the study; and Rignot suggested that this retreat may have been the result of a slight increase in ocean water temperature. Because the study had utilized only four years of data, however, questions concerning the long-term stability of the WAIS, in the words of the researcher, "cannot be answered at present." In addition, although the glacier's grounding line had been found to be retreating, subsequent satellite images suggested that the location of the ice front had remained stable.

Finally advancing from 1998 to 1999, but still publishing in the journal *Science*, Conway *et al*. (1999) examined previously reported research, while conducting some of their own, dealing with the retreat of the WAIS since its maximum glacial extent some 20,000 years ago. In doing so, they determined that the ice sheet's grounding line remained near its maximum extent until about 10,000 years ago, whereupon it began to retreat at a rate of about 120 meters per year. This work also indicated that at the end of the 20th century it was retreating at about the same rate, which suggests that if it continues to behave as it has in the past, complete deglaciation of the WAIS will occur in about 7000 years. The researchers thus concluded that the modern-day grounding-line retreat of the WAIS is part of an ongoing recession that has been underway since the early to mid-Holocene; and that "it is not a consequence of anthropogenic warming or recent sea level rise." Consequently, climate alarmists who claim that CO_2-induced global warming is responsible for every inch of WAIS retreat, as well as every iceberg that breaks free of the ice sheet, are not justified in making such claims.

Stepping another year into the future, Stenoien and Bentley (2000) mapped the catchment region of Pine Island Glacier using radar altimetry and synthetic aperture radar interferometry, which they used to develop a velocity map that revealed a system of tributaries that channel ice from the catchment area into the fast-flowing glacier. Then, by combining the velocity data with information on ice thickness and snow accumulation rates, they were able to calculate, within an uncertainty of 30%, that the mass balance of the catchment region was not significantly different from zero.

One year later, Shepherd *et al*. (2001) used satellite altimetry and interferometry to determine the rate of change of the ice thickness of the entire Pine Island Glacier drainage basin between 1992 and 1999. This work revealed that the grounded glacier thinned by up to 1.6 meters per year between 1992 and 1999. Of this phenomenon, the researchers wrote that "the thinning cannot be explained by short-term variability in accumulation and must result from glacier dynamics," and since glacier dynamics typically respond to phenomena operating on time scales of hundreds to thousands of years, this observation would argue *against* 20th-century warming being a primary cause of the thinning. Shepherd *et al*. additionally say they could "detect no change in the rate of ice thinning across the glacier over a 7-year period," which also suggests that a long-term phenomenon of considerable inertia must be at work in this particular situation.

But what if the rate of glacier thinning, which *sounds* pretty dramatic, were to continue unabated? The researchers state that "if the trunk continues to lose mass at the present rate it will be entirely afloat within 600 years." And if that happens, they say they "estimate the net contribution to eustatic sea level to be 6 mm," which means that over each century of the foreseeable future, we could expect global sea level to rise by about one millimeter, or about the thickness of a paper clip.

Publishing in same year were Pudsey and Evans (2001), who studied ice-rafted debris obtained from four cores in Prince Gustav Channel, which until 1995 was covered by floating ice shelves. Their efforts indicated that the ice shelves had also retreated in mid-Holocene time, but that, in their words, "colder conditions after about 1.9 ka allowed the ice shelf to reform." Although they thus concluded that the ice shelves are sensitive indicators of *regional* climate change, they were careful to state that "we should not view the recent decay as an unequivocal indicator of anthropogenic climate change." Indeed, the disappearance of the ice shelves was *not unique*; it had happened before without our help, and it could well have happened again on its own. In fact, the breakup of the Prince Gustav Channel ice shelves was likely nothing more than the culmination of the Antarctic Peninsula's *natural recovery* from the cold conditions of Little Ice Age, as has been observed in many places throughout the Northern Hemisphere and several parts of the Southern Hemisphere as well.

Taking another step into the future, Raymond (2002) presented a brief appraisal of the status of the world's major ice sheets. His primary conclusions relative to the WAIS were that (1) "substantial melting on the upper surface of WAIS would occur only with considerable atmospheric warming," (2) of the three major WAIS drainages, the ice streams that drain northward to the Amundsen Sea have accelerated, widened and thinned "over substantial distances back into the ice sheet," but that "the eastward drainage toward the Weddell Sea is close to mass balance." And (3) of the westward drainage into the Ross Ice Shelf, "over the last few centuries, margins of active ice streams migrated inward and outward," while the "overall mass balance has changed from loss to gain," as "a currently active ice stream (Whillans) has slowed by about 20% over recent decades."

In a summary statement that takes account of these observations, Raymond says that "the total mass of today's ice sheets is changing only slowly, and even with climate warming increases in snowfall should compensate for additional melting," such as might possibly occur for the WAIS if the planet's temperature continues its post-Little Ice Age rebound.

Fast-forward another year and Stone *et al*. (2003) -- working on western Marie Byrd Land -- report how they determined cosmogenic ^{10}Be exposure dates of glacially-transported cobbles in elevation transects on seven peaks of the Ford Ranges between the ice sheet's present grounding line and the Clark Mountains some 80 km inland. Based on these ages and the elevations at which the cobbles were found, they reconstructed a history of ice-sheet thinning over the past 10,000-plus years. This history showed, in their words, that "the exposed rock in the Ford Ranges, up to 700 m above the present ice surface, was deglaciated within the past 11,000 years," and that "several lines of evidence suggest that the maximum ice sheet stood considerably higher than this."

Stone *et al*. additionally report that the consistency of the exposure age versus elevation trends of their data "indicates steady deglaciation since the first of these peaks emerged from the ice sheet some time before 10,400 years ago," and that the mass balance of the region "has been negative throughout the Holocene." The researchers also say their results "add to the evidence that West Antarctic deglaciation continued long after the disappearance of the Northern Hemisphere ice sheets and may still be under way," noting that the ice sheet in Marie Byrd Land "shows the same pattern of steady Holocene deglaciation as the marine ice sheet in the Ross Sea," where ice "has thinned and retreated since 7000 years ago," adding that "there is strong evidence that the limit of grounded ice in both regions -- and in Pine Island Bay -- is still receding."

As long contended by scientists who disagree with climate-alarmist claims that we are witnessing the CO_2-induced "early stages of rapid ice sheet collapse, with potential near-term impacts on the world's coastlines" -- as described by Ackert (2003) -- the work of Stone *et al*. convincingly demonstrates that the current thinning and retreat of the WAIS are merely manifestations of a slow but steady deglaciation that has been going on and on and on, ever since the beginning-of-the-end of the last great ice age. This phenomenon is unabashedly used by climate alarmists to scare people into believing anthropogenic CO_2 emissions are rapidly leading to the demise of the WAIS; but Stone *et al*. say something quite different, i.e., that "the pattern of recent change is consistent with the idea that thinning of the WAIS over the past few thousand years is continuing," while Ackert makes the point even plainer, when he says that "recent ice sheet dynamics appear to be dominated by the ongoing response to deglacial forcing thousands of years ago, rather than by a recent anthropogenic warming or sea level rise."

In conclusion, the massive ice repository that is the West Antarctic Ice Sheet is *not* "slip-sliding away" and about to redefine the world's coastlines in response to rising sea levels, as contended by folks such as Al Gore and James Hansen. It seems to be behaving quite nicely, just as it has for thousands of prior years.

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

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4.6.3.3. Mass Balance

Is the West Antarctic Ice Sheet (WAIS) growing or shrinking? In what follows, we briefly review the findings of several researchers who have focused their attention on the *mass balance* of the WAIS.

Anderson and Andrews (1999) analyzed grain size and foraminiferal contents of radiometrically-dated sediment cores collected from the eastern Weddell Sea continental shelf and the western Weddell Sea deep-sea floor in an attempt to better understand the behavior of both the East and West Antarctic ice sheets. In doing so, their data led them to conclude that "significant deglaciation of the Weddell Sea continental shelf took place prior to the last glacial maximum," and that the ice masses that border the Weddell Sea today "are more extensive than they were during the previous glacial minimum." Hence, they concluded "that the current interglacial setting is characterized by a more extensive ice margin and larger ice shelves than existed during the last glacial minimum, and that the modern West and East Antarctic ice sheets have not yet shrunk to their minimum." It is thus to be expected -- independent of what global air temperature may currently be doing, because of the great inertial forces at work over much longer time scales -- that the modern East and West Antarctic Ice Sheets may well continue to shrink and release more icebergs to the Southern Ocean over the coming years, decades and centuries, thereby slowly raising global sea level. Nothing man has done is responsible for these phenomena, however; and nothing man can do will impact them in any way.

Also studying the combined ice sheets of both East and West Antarctica were Wingham *et al*. (1998), who used satellite radar altimeter measurements from 1992 to 1996 to estimate the rate of change of the thickness of nearly two thirds of the grounded portion of the entire Antarctic Ice Sheet, while using snowfall variability data obtained from ice cores to ultimately calculate the mass balance of the interior of the continental ice sheet over the past century. Their results showed that, *at most*, the interior of the Antarctic Ice Sheet has been "only a modest source or sink of sea-level mass this century." As a result, Wingham *et al*. concluded that "a large century-scale imbalance for the Antarctic interior is unlikely," noting that this conclusion is in harmony with a body of relative sea-level and geodetic evidence "supporting the notion that the grounded ice has been in balance at the millennial scale." This full set of findings thus suggests that both portions of the Antarctic Ice Sheet may be rather impervious to climate changes of the magnitude characteristic of the Medieval Warm Period and Little Ice Age, which is the type of change most likely to occur -- if there is any change at all -- in response to the ongoing rise in the air's CO_2 content.

In another study of all of Antarctica, Vaughn *et al*. (1999) used more than 1800 published and unpublished measurements of the surface mass balance of the continent to produce an updated assessment of yearly ice accumulation. Their results indicated that the "total net surface mass balance for the conterminous grounded ice sheet is 1811 Gton yr^{-1} (149 kg m^{-2} yr^{-1}) and for the entire ice sheet including ice shelves and embedded ice rises, 2288 Gton yr^{-1} (166 kg m^{-2} yr^{-1})." Since Vaughn *et al*. say "these values are around 18% and 7% higher than the estimates widely adopted at present," which were derived about 1985, they would seem to suggest that net icefall on Antarctica may well have been somewhat greater near the end of the 20th century than what was believed to have been the case a decade and a half earlier. Nevertheless, because of uncertainties in these numbers, as well as in those representing the total mass of ice lost from the ice sheet and ice shelves, the authors note that "we are still unable to determine even the sign of the contribution of the Antarctic Ice Sheet to recent sea level change."

A year later, Stenoien and Bentley (2000) mapped the catchment region of West Antarctica's Pine Island Glacier, using radar altimetry and synthetic aperture radar interferometry. These data were used to develop a velocity map that revealed a system of tributaries that channeled ice from the catchment area into the fast-flowing glacier; and by combining the velocity data with information on ice thickness and snow accumulation rates, the two researchers were able to calculate an approximate mass balance for the glacier. Within an uncertainty of 30%, it was thereby determined that the mass balance of the catchment region was not significantly different from zero.

After three more years, Davis and Ferguson (2004) evaluated elevation changes of the entire Antarctic ice sheet over the five-year period June 1995 to April 2000, based on more than 123 *million* elevation change measurements made by the European Space Agency's European Remote Sensing 2 satellite radar altimeter. In doing so, they determined that the east Antarctic ice sheet had a five-year trend of 1.0 ± 0.6 cm/year, that the west Antarctic ice sheet had a five-year trend of -3.6 ± 1.0 cm/year, and that the entire Antarctic continent (north of 81.6°S) had a five-year trend of 0.4 ± 0.4 cm/year. In addition, the Pine Island, Thwaites, DeVicq and Land glaciers of West Antarctica exhibited five-year trends ranging from - 26 to - 135 cm/year.

In discussing their findings, Davis and Ferguson noted that the strongly negative trends of the coastal glacier outlets "suggest that the basin results are due to dynamic changes in glacier flow," and that recent observations "indicate strong basal melting, caused by ocean temperature increases, is occurring at the grounding lines of these outlet glaciers." Hence, they concluded "there is good evidence that the strongly negative trends at these outlet glaciers, the mass balance of the corresponding drainage basins, and the overall mass balance of the west Antarctic ice sheet may be related to increased basal melting caused by ocean temperature increases." Nevertheless, driven by the significantly positive trend of the much larger east Antarctic ice sheet, the ice volume of the entire continent grew ever larger over the last five years of the 20th century, the majority of which increase, according to Davis and Ferguson, was due to increased snowfall.

One year later, in an Editorial Essay published in the journal *Climatic Change*, Oppenheimer and Alley (2005) discussed "the degree to which warming can affect the rate of ice loss by altering the mass balance between precipitation rates on the one hand, and melting and ice discharge to the ocean through ice streams on the other," with respect to the WAIS and Greenland Ice Sheet (GIS). After a brief overview of the topic, they noted that "the key questions with respect to both WAIS and GIS are: What processes limit ice velocity, and how much can warming affect those processes?" In answer to these questions, they said that "no consensus has emerged about these issues nor, consequently, about the fate of either ice sheet, a state of affairs reflecting the weakness of current models and uncertainty in paleoclimatic reconstructions."

After a cursory review of the science related to these two key questions, Oppenheimer and Alley say their review "leads to a multitude of questions with respect to the basic science of the ice sheets," which we list below. However, instead of listing them in their original question form, we post them in the form of statements that address what *we do not know* about the various sub-topics mentioned, which is obviously what prompts the questions in the first place and validates the content of the statements.

(1) *We do not know* if the apparent response of glaciers and ice streams to surface melting and melting at their termini (e.g., ice shelves) could occur more generally over the ice sheets.
(2) *We do not know* if dynamical responses are likely to continue for centuries and propagate further inland or if it is more likely that they will be damped over time.
(3) *We do not know* if surface melting could cause rapid collapse of the Ross or Filchner-Ronne ice shelves, as occurred for the smaller Larsen ice shelf.
(4) *We do not know* if ice sheets made a significant net contribution to sea level rise over the past several decades.
(5) *We do not know* what might be useful paleoclimate analogs for sea level and ice sheet behavior in a warmer world.
(6) *We do not know* the reliability of Antarctic and Southern Ocean temperatures (and polar amplification) that are projected by current GCMs, nor do we know why they differ so widely among models, nor how these differences might be resolved.
(7) *We do not know* the prospects for expanding measurements and improving models of ice sheets nor the timescales involved.
(8) *We do not know* if current uncertainties in future ice sheet behavior can be expressed quantitatively.
(9) *We do not know* what would be useful early warning signs of impending ice sheet disintegration nor when these might be detectable.
(10) *We do not know*, given current uncertainties, if our present understanding of the vulnerability of either the WAIS or GIS is potentially useful in defining "dangerous anthropogenic interference" with earth's climate system.
(11) *We do not know* if the concept of a threshold temperature is useful.
(12) *We do not know* if either ice sheet seems more vulnerable and thus may provide a more immediate measure of climate "danger" and a more pressing target for research.
(13) *We do not know* if any of the various temperatures proposed in the literature as demarking danger of disintegration for one or the other ice sheet are useful in contributing to a better understanding of "dangerous anthropogenic interference."
(14) *We do not know* on what timescale future learning might affect the answers to these questions.

In concluding their essay, Oppenheimer and Alley describe this list of deficiencies in our knowledge of things related to the WAIS as "gaping holes in our understanding" that "will not be closed unless governments provide adequate resources for research," which seem just a bit self-serving. More importantly, however, they state that "if emissions of the greenhouse gases are not reduced while uncertainties are being resolved, there is a risk of making ice-sheet disintegration nearly inevitable."

Clearly, there is a chance -- be it ever so small -- that almost anything *could* occur. But how *probable* are such high-risk phenomena? To claim, as Oppenheimer and Alley do, that ice-sheet disintegration is *nearly inevitable* if emissions of greenhouse gases are not reduced, is *incredibly illogical*, especially in light of the existence of what they say are "gaping holes in our understanding," as enumerated in the above list. In fact, given the degree of deficiency in our knowledge of the matter, it is perhaps as likely as not that a continuation of the planet's recovery from the relative cold of the Little Ice Age could actually lead to a *buildup* of polar ice; but there is no way *we* would ever say that that outcome is "nearly inevitable."

The following year also saw the publication of a paper that had little to recommend its main conclusions. Velicogna and Wahr (2006) used measurements of time-variable gravity from the Gravity Recovery and Climate Experiment (GRACE) satellites to determine mass variations of the Antarctic ice sheet for the 34 months between April 2002 and August 2005. When all was said and done -- which included a lot of dubious approximations -- the two researchers concluded that "the ice sheet mass decreased significantly, at a rate of 152 ± 80 km^3/year of ice, equivalent to 0.4 ± 0.2 mm/year of global sea level rise," all of which mass loss came from the WAIS, since they calculated that the East Antarctic Ice Sheet mass balance was 0 ± 56 km^3/year.

What these results imply about the real world is highly dependent upon their ability to truly represent what they presume to describe; and in this regard Velicogna and Wahr say there is "geophysical contamination ... caused by signals outside Antarctica," including "continental hydrology ... and ocean mass variability." The first of these confounding factors, according to them, "is *estimated* [our italics] using monthly, global water storage fields from the Global Land Data Assimilation system," while "the ocean contamination is *estimated* [our italics] using a JPL version of the Estimating Circulation and Climate of the Ocean (ECCO) *general circulation model* [our italics]."

In addition to these problems, the two researchers note that the GRACE mass solutions "do not reveal whether a gravity variation over Antarctica is caused by a change in snow and ice on the surface, a change in atmospheric mass above Antarctica, or post-glacial rebound (PGR: the viscoelastic response of the solid Earth to glacial unloading over the last several thousand years)."

To adjust for the confounding effect of the variable atmospheric mass above Antarctica, Velicogna and Wahr utilized European Centre for Medium-Range Weather Forecasts (ECMWF) meteorological fields, but they acknowledge that "there are errors in those fields," so they "*estimate* [our italics] the secular component of those errors by finding monthly differences between meteorological fields from ECMWF and from the National Centers for Environmental Prediction."

With respect to post-glacial rebound, Velicogna and Wahr say "there are two important sources of error in PGR estimates: the ice history and Earth's viscosity profile." To deal with this problem, they "*estimate* [our italics] the PGR contribution and its uncertainties using *two* ice history *models* [our italics]."

All of these estimates and adjustments are convoluted and complex, as well as highly dependent upon various *models*. In addition, the estimates and adjustments do not deal with miniscule effects, as Velicogna and Wahr acknowledge that "the PGR contribution is much larger than the uncorrected GRACE trend." In fact, their calculations indicate that the PGR contribution exceeds that of the signal being sought *by nearly a factor of five!!!* And they are forced to admit that "a significant ice mass trend does not appear until the PGR contribution is removed."

In light of the latter *humungous* confounding problem, Velicogna and Wahr rightly state in their concluding paragraph that "the main disadvantage of GRACE is that it is more sensitive than other techniques to PGR." In fact, considering the many other adjustments they had to make, based upon *estimations* utilizing *multiple models* and *databases with errors* that had to be *further estimated*, we are led to totally discount the significance of their final result, particularly in light of the additional fact that it did not even cover a full three-year period. *Much* more likely to be *much* more representative of the truth with respect to the WAIS's mass balance are the findings of Zwally *et al*. (2005), who determined Antarctica's contribution to mean global sea level over a recent *nine*-year period to be only 0.08 mm/year compared to the five-times-greater value of 0.4 mm/year calculated by Velcogna and Wahr.

In a contemporaneous study, van de Berg *et al*. (2006) compared results of model-simulated Antarctic *surface mass balance* (SMB) -- which they derived from a regional atmospheric climate model for the time period 1980 to 2004 that used ERA-40 fields as lateral forcings -- with "all available SMB *observations* [our italics] from Antarctica (N=1900)" in a *recalibration process* that ultimately allowed them "to construct a best estimate of contemporary Antarctic SMB," where the many real-world observations employed in this process came from the studies of Vaughan *et al*. (1999), van den Broeke *et al*. (1999), Frezzotti *et al*. (2004), Karlof *et al*. (2000), Kaspari *et al*. (2004), Magand *et al*. (2004), Oerter *et al*. (1999, 2000), Smith *et al*. (2002) and Turner *et al*. (2002), which observations were derived by a number of different measurement techniques -- including stake arrays, bomb horizons and chemical analyses of ice cores that covered time periods ranging from a few years to more than a century.

As a result of this effort, van de Berg *et al*. determined that "the SMB integrated over the grounded ice sheet (171 ± 3 mm per year) exceeds previous estimates by as much as 15%," with the largest differences between their results and those of others being "up to one meter per year higher in the coastal zones of East and West Antarctica," concluding that "support or falsification of this result can only be found in new SMB observations from poorly covered high accumulation regions in coastal Antarctica." Consequently, until such time as pertinent new data might indicate otherwise, we have little reason to believe anything much different from what they have determined, i.e., that Antarctica's grounded ice sheet has been steadily growing for the past quarter-century.

In the very same year, Wingham *et al*. (2006) "analyzed 1.2 x 10^8 European remote sensing satellite altimeter echoes to determine the changes in volume of the Antarctic ice sheet from 1992 to 2003," which survey, in their words, "covers 85% of the East Antarctic ice sheet and 51% of the West Antarctic ice sheet," which together comprise "72% of the grounded ice sheet." In doing so, they found that "overall, the data, corrected for isostatic rebound, show the ice sheet growing at 5 ± 1 mm per year." To calculate the ice sheet's change in *mass*, however, "requires knowledge of the density at which the volume changes have occurred," and when the researchers' best estimates of regional differences in this parameter were used, they found that "72% of the Antarctic ice sheet is gaining 27 ± 29 Gt per year, a sink of ocean mass sufficient to *lower* [their italics] global sea levels by 0.08 mm per year." This net *extraction* of water from the global ocean, according to Wingham *et al*., occurs because "mass gains from accumulating snow, particularly on the Antarctic Peninsula and within East Antarctica, exceed the ice dynamic mass loss from West Antarctica."

Also publishing in 2006, Ramillien *et al*. derived new estimates of the mass balances of the East and West Antarctic ice sheets from GRACE data for the period July 2002 to March 2005: a loss of 107 ± 23 km^3/year for West Antarctica and a gain of 67 ± 28 km^3/year for East Antarctica, which results yielded a net ice loss for the entire continent of only 40 km^3/year (which translates to a mean sea level rise of 0.11 mm/year), as opposed to the 152 km^3/year ice loss calculated by Velicogna and Wahr (which translates to a nearly four times larger mean sea level rise of 0.40 mm/year). Clearly, Ramillien *et al*.'s mean sea level rise is much less ominous than the much larger value calculated by Velicogna and Wahr; and it is of the same order of magnitude as the 0.08 mm/year Antarctic-induced mean sea level rise calculated by Zwally *et al*. (2005), which was derived from elevation changes based on *nine* years of satellite *radar altimetry data* obtained from the European Remote-sensing Satellites ERS-1 and -2. Even at that, the GRACE approach is still laden with a host of potential errors, as we noted in our discussion of the Velicogna and Wahr paper, and as both they and Ramillien *et al*. readily admit. In addition, as the latter researchers note in their closing paragraph, "the GRACE data time series is still very short and these results must be considered as preliminary since we cannot exclude that the apparent trends discussed in this study only reflect interannual fluctuations."

In yet another contemporary study, Remy and Frezzotti (2006) reviewed "the results given by three different ways of estimating mass balance, first by measuring the difference between mass input and output, second by monitoring the changing geometry of the continent, and third by modeling both the dynamic and climatic evolution of the continent." In describing their findings, the two researchers state that "the East Antarctica ice sheet is nowadays more or less in balance, while the West Antarctica ice sheet exhibits some changes likely to be related to climate change and is in negative balance." In addition, they report that "the current response of the Antarctica ice sheet is dominated by the background trend due to the retreat of the grounding line, leading to a sea-level rise of 0.4 mm/yr over the short-time scale," which they describe in terms of centuries. However, they note that "later, the precipitation increase will counterbalance this residual signal, leading to a thickening of the ice sheet and thus a decrease in sea level."

In one final study from 2006, van den Broeke *et al*. employed a regional atmospheric climate model (RACMO2), with snowdrift-related processes calculated offline, to calculate the flux of solid precipitation (Ps), surface sublimation (SU), sublimation from suspended (drifting/saltating) snow particles, horizontal snow drift transport, and surface melt (ME). In doing so, they found that "even without snowdrift-related processes, modeled (Ps-SU-ME) from RACMO2 strongly correlates with 1900 spatially weighted quality-controlled in situ SSMB *observations* [our italics]," which result they describe as "remarkable," given that the "model and observations are completely independent." Then, to deal with a remaining systematic elevation bias in the model results, they applied a set of empirical corrections (at 500-m intervals) that "largely eliminated" this final deviation from reality. And after analyzing all of the data-driven results for trends over the period 1980-2004, the four Dutch researchers report that "no trend is found in *any* [our italics] of the Antarctic SSMB components, nor in the size of ablation areas."

At long last, we finally move from 2006 to 2007, as we conclude with a brief review of the paper of Krinner *et al*. (2007), who used the LMDZ4 atmospheric general circulation model (Hourdin *et al*., 2006) to simulate Antarctic climate for the periods 1981-2000 (to test the model's ability to adequately simulate present conditions) and 2081-2100 (to see what the future might hold for the mass balance of the Antarctic Ice Sheet and its impact on global sea level). This work revealed, first of all, that "the simulated present-day surface mass balance is skilful on continental scales," which gave them confidence that their results for the end of the 21st century would be reasonably skilful as well. Of that latter period a full century from now, they determined that "the simulated Antarctic surface mass balance increases by 32 mm water equivalent per year," which corresponds "to a sea level decrease of 1.2 mm per year by the end of the twenty-first century," which would in turn "lead to a cumulated sea level decrease of about 6 cm." This result, in their words, occurs because the simulated temperature increase "leads to an increased moisture transport towards the interior of the continent because of the higher moisture holding capacity of warmer air," where the extra moisture falls as precipitation, causing the continent's ice sheet to grow.

The results of this study -- based on sea surface boundary conditions taken from IPCC Fourth Assessment Report simulations (Dufresne *et al*., 2005) that were carried out with the IPSL-CM4 coupled atmosphere-ocean general circulation model (Marti *et al*., 2005), of which the LMDZ4 model is the atmospheric component -- argue strongly against climate-alarmist predictions of future catastrophic sea level rise due to mass wastage of the Antarctic Ice Sheet caused by CO_2-induced global warming. In fact, they suggest just the *opposite*, i.e., that CO_2-induced global warming would tend to *buffer* the world against such an outcome. And that seems to be the message of most of the other major studies of the subject as well.

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

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4.6.3.4. Sea Level

How might the West Antarctic Ice Sheet influence global sea level as a result of global warming? Here, we here review what has been learned over the past decade by scientists who specialize in this particular field of research.

In a review of what was known about the West Antarctic Ice Sheet (WAIS) that was published in *Science* back in 1998, Bindschadler analyzed its historical retreat in terms of its grounding line and ice front. This work revealed that from the time of the Last Glacial Maximum to the present, the retreat of the ice sheet's grounding line had been faster than that of its ice front, which resulted in an expanding Ross Ice Shelf; and although Bindschadler wrote that "the ice front now appears to be nearly stable," there were indications that its grounding line was retreating at a rate that suggested complete dissolution of the WAIS in another 4,000 to 7,000 years. Such a retreat was calculated to result in a sustained sea level rise of 8-13 cm per century. However, even the smallest of these rates-of-rise would require, in Bindschadler's words, "a large negative mass balance for all of West Antarctica," and there were no broad-based data that supported that scenario.

A year later, Reeh (1999) reviewed what was known about the mass balances of both the Greenland and Antarctic ice sheets, concluding that the future contribution of the Greenland and Antarctic ice sheets to global sea level depends upon their *past* climate and dynamic histories as much as it does upon *future* climate. With respect to potential climate change, in fact, Reeh determined there was a broad consensus that the effect of a 1°C climatic warming on the Antarctic ice sheet would be a *fall* in global sea level on the order of 0.2 to 0.7 millimeters per year.

The following year, Cuffey and Marshall (2000) reevaluated previous model estimates of the Greenland ice sheet's contribution to sea level rise during the last interglacial, based on a recalibration of oxygen-isotope-derived temperatures from central Greenland ice cores. Their results suggested that the Greenland ice sheet was much smaller during the last interglacial than previously thought, with melting of the ice sheet contributing somewhere between four and five and a half meters to sea level rise. According to Hvidberg (2000), this finding suggests that "high sea levels during the last interglacial should not be interpreted as evidence for extensive melting of the West Antarctic Ice Sheet, and so challenges the hypothesis that the West Antarctic is particularly sensitive to climate change."

Jumping ahead five years, Oppenheimer and Alley (2005) discussed "the degree to which warming can affect the rate of ice loss by altering the mass balance between precipitation rates on the one hand, and melting and ice discharge to the ocean through ice streams on the other," with respect to both the West Antarctic and Greenland Ice Sheets. Their review of the subject led them to conclude that we simply do not know if these ice sheets had made a significant contribution to sea level rise over the past several decades.

One year later, however, the world was exposed to a far different view of the issue, when Velicogna and Wahr (2006) used measurements of time-variable gravity from the Gravity Recovery and Climate Experiment (GRACE) satellites to determine mass variations of the Antarctic ice sheet for the 34 months between April 2002 and August 2005. When all was said and done -- which included a lot of dubious approximations -- the two researchers concluded that "the ice sheet mass decreased significantly, at a rate of 152 ± 80 km^3/year of ice, equivalent to 0.4 ± 0.2 mm/year of global sea level rise," all of which mass loss came from the WAIS, since they calculated that the East Antarctic Ice Sheet mass balance was 0 ± 56 km^3/year. What these results imply about the real world is highly dependent upon their ability to truly represent what they presume to describe; and in this regard Velicogna and Wahr say there is "geophysical contamination ... caused by signals outside Antarctica," including "continental hydrology ... and ocean mass variability." The first of these confounding factors, according to them, "is *estimated* [our italics] using monthly, global water storage fields from the Global Land Data Assimilation system," while "the ocean contamination is *estimated* [our italics] using a version of the Estimating Circulation and Climate of the Ocean (ECCO) *general circulation model* [our italics]."

In addition to these problems, the two researchers note that the GRACE mass solutions "do not reveal whether a gravity variation over Antarctica is caused by a change in snow and ice on the surface, a change in atmospheric mass above Antarctica, or post-glacial rebound (PGR: the viscoelastic response of the solid Earth to glacial unloading over the last several thousand years)."

To adjust for the confounding effect of the variable atmospheric mass above Antarctica, Velicogna and Wahr utilized European Centre for Medium-Range Weather Forecasts (ECMWF) meteorological fields, but they acknowledge "there are errors in those fields," so they "*estimate* [our italics] the secular component of those errors by finding monthly differences between meteorological fields from ECMWF and from the National Centers for Environmental Prediction."

With respect to post-glacial rebound, the two researchers say "there are two important sources of error in PGR estimates: the ice history and Earth's viscosity profile." To deal with this problem, they "*estimate* [our italics] the PGR contribution and its uncertainties using *two* ice history *models* [our italics]."

All of these estimates and adjustments are convoluted and complex, as well as highly dependent upon various *models*. In addition, the estimates and adjustments do not deal with miniscule effects, as Velicogna and Wahr acknowledge that "the PGR contribution is much larger than the uncorrected GRACE trend." In fact, their calculations indicate that the PGR contribution exceeds that of the signal being sought *by nearly a factor of five!!!* And they are forced to admit that "a significant ice mass trend does not appear until the PGR contribution is removed."

In light of the latter *humungous* confounding problem, Velicogna and Wahr rightly state in their concluding paragraph that "the main disadvantage of GRACE is that it is more sensitive than other techniques to PGR." In fact, considering the many other adjustments they had to make, based upon *estimations* utilizing *multiple models* and *databases with errors* that had to be *further estimated*, we are led to totally discount the significance of their final result, particularly in light of the additional fact that it did not even cover a full three-year period. *Much* more likely to be *much* more representative of the truth with respect to the WAIS's mass balance are the findings of Zwally *et al*. (2005), who determined Antarctica's contribution to mean global sea level over a recent *nine*-year period to be only 0.08 mm/year compared to the five-times-greater value of 0.4 mm/year calculated by Velcogna and Wahr.

Skipping ahead one more year, Ramillien *et al*. (2006) also used GRACE data to derive estimates of the mass balances of the East and West Antarctic ice sheets for the period July 2002 to March 2005, obtaining a loss of 107 ± 23 km^3/year for West Antarctica and a gain of 67 ± 28 km^3/year for East Antarctica, which results yielded a net ice loss for the entire continent of only 40 km^3/year (which translates to a mean sea level rise of 0.11 mm/year), as opposed to the 152 km^3/year ice loss calculated by Velicogna and Wahr (which translates to a nearly four times larger mean sea level rise of 0.40 mm/year). Clearly, Ramillien *et al*.'s mean sea level rise is much less ominous than the much larger value calculated by Velicogna and Wahr; and it is of the same order of magnitude as the 0.08 mm/year Antarctic-induced mean sea level rise calculated by Zwally *et al*. (2005), which was derived from elevation changes based on nine years of satellite radar altimetry data obtained from the European Remote-sensing Satellites ERS-1 and -2. Even at that, the GRACE approach is still laden with a host of potential errors, as we noted in our discussion of the Velicogna and Wahr paper. In addition, as Ramillien *et al*. note in their closing paragraph, "the GRACE data time series is still very short and these results must be considered as preliminary since we cannot exclude that the apparent trends discussed in this study only reflect interannual fluctuations," which caveat also applies to the Velicogna and Wahr analysis.

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Last of all, we end once again with the study of Krinner *et al*. (2007), who used the LMDZ4 atmospheric general circulation model of Hourdin *et al*. (2006) to simulate Antarctic climate for the periods 1981-2000 (to test the model's ability to adequately simulate present conditions) and 2081-2100 (to see what the future might hold for the mass balance of the Antarctic Ice Sheet and its impact on global sea level). This work revealed, first of all, that "the simulated present-day surface mass balance is skilful on continental scales," which gave them confidence that their results for the end of the 21st century would be reasonably skilful as well. Of that latter period some 90 years from now, they determined that "the simulated Antarctic surface mass balance increases by 32 mm water equivalent per year," which corresponds "to a sea level *decrease* [our italics] of 1.2 mm per year by the end of the twenty-first century," which would in turn "lead to a cumulated sea level decrease of about 6 cm." This result, in their words, occurs because the simulated temperature increase "leads to an increased moisture transport towards the interior of the continent because of the higher moisture holding capacity of warmer air," where the extra moisture falls as precipitation, causing the continent's ice sheet to grow.

The results of this study -- based on sea surface boundary conditions taken from IPCC Fourth Assessment Report simulations (Dufresne *et al*., 2005) that were carried out with the IPSL-CM4 coupled atmosphere-ocean general circulation model (Marti *et al*., 2005), of which the LMDZ4 model is the atmospheric component -- argue strongly against climate-alarmist predictions of future catastrophic sea level rise due to mass wastage of the Antarctic Ice Sheet caused by CO_2-induced global warming. In fact, they suggest just the *opposite*, i.e., that CO_2-induced global warming would tend to *buffer* the world against such an outcome.

All in all, it would appear there has been very little change in global sea level due to wastage of the WAIS over the past few decades, and that there will probably be little change in both the near and far future. In fact, what wastage might occur along the coastal area of the ice sheet over the long term would likely be countered, or even *more* than countered, by greater inland snowfall. And in the case of the latter possibility, or *probability*, the entire Antarctic Ice Sheet could well compensate for any long-term wastage of the Greenland Ice Sheet that might occur, in terms of how these phenomena impact global sea level.

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

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4.7. Sea Level Rise

Periodically, individual scientists and groups of scientists analyze global sets of sea level data to see if there is any indication of a dramatic increase in the mean rate-of-rise of the global ocean surface in response to the supposedly unprecedented warming of the planet over the course of the 20th century, which climate alarmists claim should be accelerating sea level rise and leading to catastrophic coastal flooding around the world. What follows, then, is a brief summary of such findings as they have appeared in the peer-reviewed scientific literature over the past few years.

Cazenave *et al*. (2003) studied climate-related processes that cause variations in mean global sea level on interannual to decadal time scales, focusing on thermal expansion of the oceans and continental water mass balance. In doing so, they determined that the rate of thermal-induced sea level rise over the past 40 years was about 0.5 mm/year. From early 1993 to the end of the 20th century, however, analyses of TOPEX-Poseidon altimetry data and the global ocean temperature data of Levitus *et al*. (2000) yielded rates-of-rise that were approximately *six times greater* than the mean four-decade rate, which suggested to them that "an acceleration took place in the recent past, likely related to warming of the world ocean." However, as they alternatively note, "the recent rise may just correspond to the rising branch of a decadal oscillation." In addition, they say that "satellite altimetry and *in situ* temperature data have their own uncertainties and it is still difficult to affirm with certainty that sea level rise is indeed accelerating." In fact, they cite the work of Nerem and Mitchum (2001) as indicating that "about 20 years of satellite altimetry data would be necessary to detect, with these data alone, any acceleration in sea level rise."

Mörner (2004) provided a more expansive setting for his analysis of the subject by noting that "prior to 5000-6000 years before present, all sea level curves are dominated by a general rise in sea level in true glacial eustatic response to the melting of continental ice caps," but that "sea level records are now dominated by the irregular redistribution of water masses over the globe ... primarily driven by variations in ocean current intensity and in the atmospheric circulation system and maybe even in some deformation of the gravitational potential surface." With respect to the last 150 years, he reports that "the mean eustatic rise in sea level for the period 1850-1930 was [on] the order of 1.0-1.1 mm/year," but that "after 1930-40, this rise seems to have stopped (Pirazzoli *et al*., 1989; Mörner, 1973, 2000)." This stasis, in his words, "lasted, at least, up to the mid-60s." Thereafter, with the advent of the TOPEX/Poseidon mission, Mörner notes that "the record can be divided into three parts: (1) 1993-1996 with a clear trend of stability, (2) 1997-1998 with a high-amplitude rise and fall recording the ENSO event of these years and (3) 1998-2000 with an irregular record of no clear tendency." Most important of all, in his words, Mörner states "there is a total absence of any recent 'acceleration in sea level rise' as often claimed by IPCC and related groups," and, therefore, "there is no fear of any massive future flooding as claimed in most global warming scenarios."

Church *et al*. (2004) used TOPEX/Poseidon satellite altimeter data to estimate global empirical orthogonal functions, which they combined with historical tide gauge data, to estimate monthly distributions of large-scale sea level variability and change over the period 1950-2000. Their resultant "best estimate" of the rate of globally-averaged sea level rise over the last half of the 20th century was 1.8 ± 0.3 mm/year. In addition, they noted that "decadal variability in sea level is observed, but to date there is no detectable secular increase in the rate of sea level rise over the period 1950-2000." What is more, they reported that no increase in the rate of sea level rise has been detected for the *entire* 20th century, citing the work of Woodworth (1990) and Douglas (1992).

Cazenave and Nerem (2004) summarized what was known shortly after the turn of the century about past and then-current rates of sea level rise *because*, in their words, "determining the rate of sea level change over the last century is critically important in order to determine if the present-day rate of sea level change has changed appreciably," which, as we have noted, is something one would expect to have occurred if 20th-century global warming was truly as unprecedented as climate alarmists say it was, bringing the planet to a level of warmth they claim was unprecedented over the past two millennia and within less than a degree of the all-time high temperature of the last *million* or more years. What they learned in this endeavor was that "the geocentric rate of global mean sea level rise over the last decade (1993-2003) is now known to be very accurate, +2.8 ± 0.4 mm/year, as determined from TOPEX/Poseidon and Jason altimeter measurements," and that "this rate is significantly larger than the historical rate of sea level change measured by tide gauges during the past decades (in the range of 1-2 mm/year)."

However, as Cazenave and Nerem continue, "the altimetric rate could still be influenced by decadal variations of sea level unrelated to long-term climate change, such as the Pacific Decadal Oscillation, and thus a longer time series is needed to rule this out." They also noted that satellite altimetry had revealed a "non-uniform geographical distribution of sea level change, with some regions exhibiting trends about 10 times the global mean." In addition, they note that "for the past 50 years, sea level trends caused by change in ocean heat storage also show high regional variability," which fact "has led to questions about whether the rate of 20th-century sea level rise, based on poorly distributed historical tide gauges, is really representative of the true global mean." Consequently, and in spite of the many new instruments and techniques that are being used to search for a global warming signal in global sea level data, Cazenave and Nerem report that "these tools seem to have raised more questions than they have answered."

Noting that global climate *models* "show an increase in the rate of global average sea level rise during the 20th century," but that several prior studies (Douglas, 1991, 1992; Maul and Martin, 1993; Church *et al*., 2004; Holgate and Woodworth, 2004) had shown the *measured* rate of global sea level rise to have been rather stable over the past hundred years, White *et al*. (2005) conducted yet another analysis of the available data in an attempt to find the elusive predicted increase in the global sea level's rate of rise, comparing estimates of coastal and global averaged sea level for 1950 to 2000. When all was said and done, their results confirmed the earlier findings of "no significant increase in the rate of sea level rise during this 51-year period," i.e., over the last half of the 20th century, including its last two decades, which are especially demonized by climate alarmists for their supposedly unprecedented rate of temperature increase.

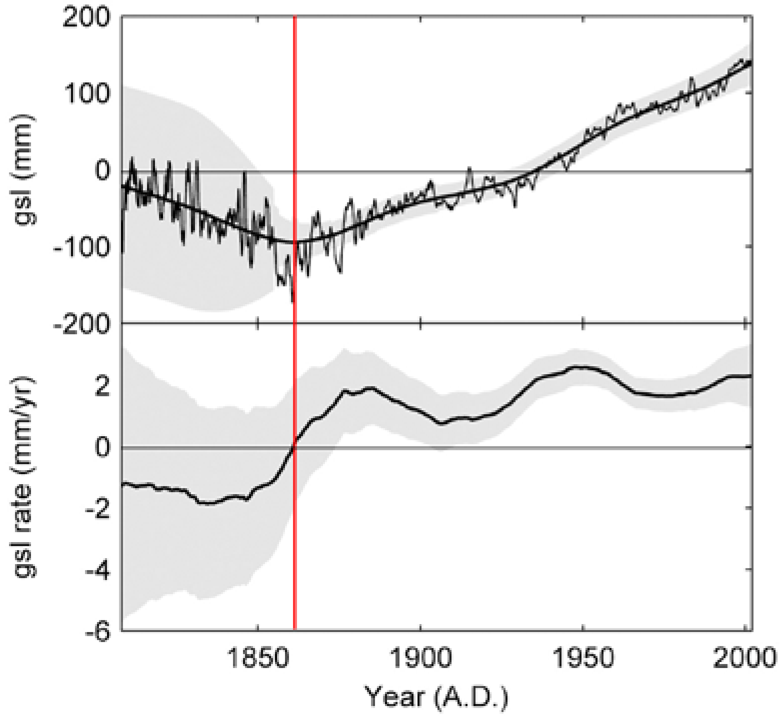
Lombard *et al*. (2005) investigated the *thermosteric* or temperature-induced sea-level change of the last 50 years using the global ocean temperature data of Levitus *et al*. (2000) and Ishii *et al*. (2003). This work revealed that thermosteric sea level variations are dominated by decadal oscillations of the planet's chief ocean-atmosphere climatic perturbations (El Niño-Southern Oscillation, Pacific Decadal Oscillation and North Atlantic Oscillation); and in terms of the global mean, as they describe it, thermosteric trends computed over 10-year windows "show large fluctuations in time, with positive values (in the range 1 to 1.5 mm/year for the decade centered on 1970) and negative values (-1 to -1.5 mm/year for the decade centered on 1980)." In the mean, however, and over the full half-century period Lombard *et al*. investigated, there was a net rise in sea level due to the thermal expansion of sea water, *but only because the record began at the bottom of a trough and ended at the top of a peak*. In between these two points, there were both higher and lower values, so that one cannot be sure what would be implied if earlier data were available or what will be implied as more data are acquired. Noting that sea level trends derived from TOPEX/Poseidon altimetry over 1993-2003 are "mainly caused by thermal expansion" and are thus "very likely a non-permanent feature," Lombard *et al*. thus concluded that "we simply cannot extrapolate sea level into the past or the future using satellite altimetry alone." Consequently, even the 50 years of global ocean temperature data we possess are insufficient to tell us much about the degree of global warming that may have occurred over the past half-century, as any long-term increase in global sea level that may have been caused by the temperature increase is absolutely *dwarfed* by decadal-scale variability.

Carton *et al*. (2005) introduced their study of the subject by noting that "recent altimeter observations indicate an increase in the rate of sea level rise during the past decade to 3.2 mm/year, well above the centennial estimate of 1.5-2 mm/year," noting further that "this apparent increase could have resulted from enhanced melting of continental ice," as climate alarmists often claim, "or from decadal changes in thermosteric and halosteric effects." Hence, they explored these opposing options "using the new eddy-permitting Simple Ocean Data Assimilation version 1.2 reanalysis of global temperature, salinity, and sea level spanning the period 1968-2001," and in doing so they determined that "the effect on global sea level rise of changing salinity is small except in subpolar regions." However, they found that warming-induced steric effects "are enough to explain much of the observed rate of increase in the rate of sea level rise in the last decade of the 20th century without need to invoke acceleration of melting of continental ice." And as determined by Lombard *et al*., as described in the preceding paragraph, the high thermosteric-induced rate-of-rise of global sea level over the past decade is likely "a non-permanent feature" of the global ocean's transient thermal behavior. Consequently, and in harmony with the findings of Levitus *et al*. (2005) and Volkov and van Aken (2005), Carton *et al*. found no need to invoke the melting of land-based glacial ice to explain the observed increase in global sea-level rise of the past decade.

Even more revealing was the globally-distributed sea level time series study of Jevrejeva *et al*. (2006), who analyzed information contained in the *Permanent Service for Mean Sea Level* database using a method based on Monte Carlo Singular Spectrum Analysis and removed 2- to 30-year quasi-periodic oscillations to derive nonlinear long-term trends for 12 large ocean regions, which they combined to produce the mean global sea level (gsl) and gsl rate-of-rise (gsl rate) curves depicted in the figure on the next page.

In discussing their findings, Jevrejeva *et al*. say they show that "global sea level rise is irregular and varies greatly over time," noting that "it is apparent that rates in the 1920-1945 period are likely to be as large as today's." In addition, they report that their "global sea level trend estimate of 2.4 ± 1.0 mm/year for the period from 1993 to 2000 matches the 2.6 ± 0.7 mm/year sea level rise found from TOPEX/Poseidon altimeter data." With respect to what the four researchers describe as "the discussion on whether sea level rise is accelerating," therefore, their results pretty much answer the question in the negative.

The observations described above make us wonder why late 20th-century global warming - which climate alarmists describe as having been *unprecedented over the past two millennia* - cannot be detected in global sea level data. We are even more intrigued about the matter in light of the fact that the effects of the warming that led to the demise of the Little Ice Age - which by climate-alarmist contention should have been considerably less dramatic than the warming of the late 20th century - are *readily* apparent to the right of the vertical red line in the above figure. Likewise, we are perplexed by the demonstrable *fact* that although the rising atmospheric CO_2 concentration - which climate alarmists claim is primarily responsible for the supposedly unprecedented global warming of the late 20th century - experienced a dramatic increase in its rate-of-rise just after 1950 (shifting from a 1900-1950 mean rate-of-rise of 0.33 ppm/year to a 1950-2000 mean rate-of-rise of 1.17 ppm/year), the mean global sea level rate-of-rise did not trend upwards after 1950, nor has it subsequently exceeded its 1950 rate-of-rise. These observations clearly indicate that something is drastically wrong with the warped world-view of the world's climate alarmists.



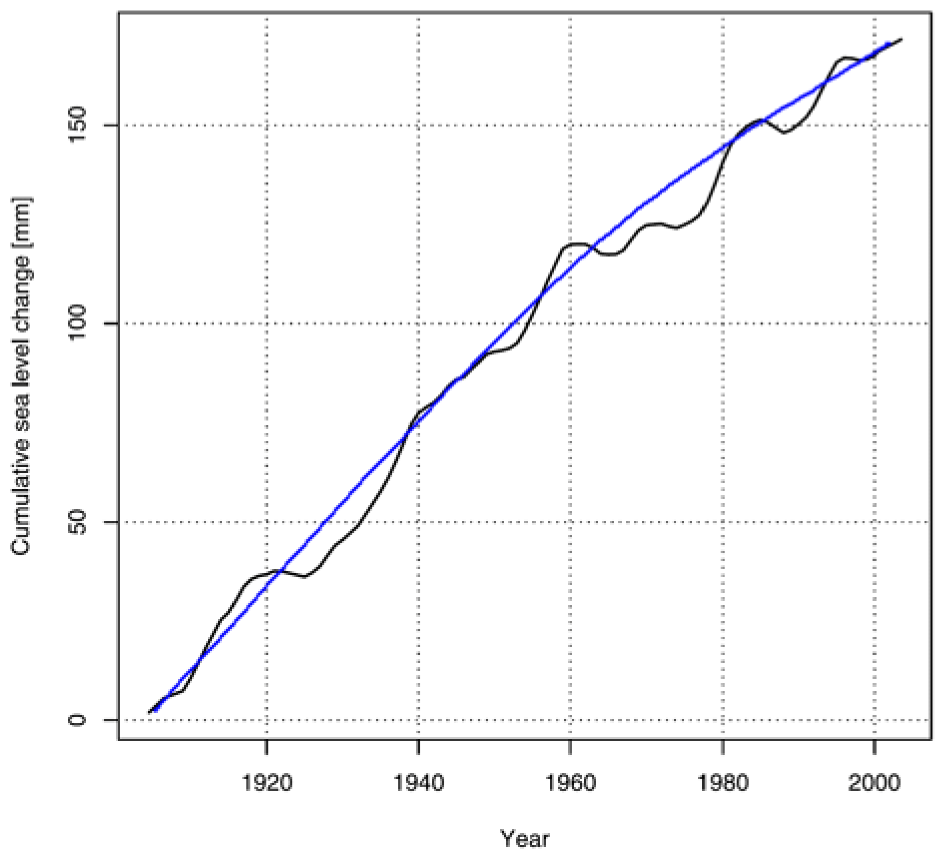
Mean global sea level (top), with shaded 95% confidence interval, and mean gsl rate-of-rise (bottom), with shaded standard error interval, adapted from Jevrejeva *et al*. (2006).

In concluding our examination of the peer-reviewed sea level science, we report the findings of the most recent study of Holgate (2007). In a previous paper, Holgate and Woodworth (2004) derived a mean global sea level history from 177 coastal tide gauge records that spanned the period 1955-1998; and in an attempt to extend that record back in time another half-century, Holgate chose nine much longer high-quality records from around the world (New York, Key West, San Diego, Balboa, Honolulu, Cascais, Newlyn, Trieste and Auckland) to see if their combined mean progression over the 1955-1998 period was similar enough to the concomitant mean sea level history of the 177 stations to employ the mean nine-station record as a reasonable representation of mean global sea level history for the much longer period stretching from 1904 to 2003.

In comparing the sea level histories derived from the two data sets, Holgate found that their mean rates-of-rise were indeed similar over the second half of the 20th century; and this observation thus implied, in Holgate's words, that "a few high quality records from around the world can be used to examine large spatial-scale decadal variability as well as many gauges from each region are able to [do]."

As a result of this finding, Holgate constructed the nine-station-derived wavering black line in the figure below as a reasonable best representation of the 1904-2003 mean global sea level history of the world, and based on that history calculated that the mean rate of global sea level rise was "larger in the early part of the last century (2.03 ± 0.35 mm/year 1904-1953), in comparison with the latter part (1.45 ± 0.34 mm/year 1954-2003)."

Another way of thinking about the century-long sea level history portrayed in the figure below is suggested by the blue curve we have fit to it, which indicates that mean global sea level may have been rising, in the mean, ever more slowly with the passage of time throughout the entire last hundred years, with a possible acceleration of that trend over the last few decades.



Cumulative increase in mean global sea level (1904-2003) derived from nine high-quality tide gauge records from around the world. Adapted from Holgate (2007).

In any event, and whichever way one looks at the findings of Holgate - either as two successive linear trends (representative of the mean rates-of-rise of the first and last halves of the 20th century) or as one longer continuous curve (such as we have drawn) - the nine select tide gauge records indicate that the mean rate of global sea level rise has *not* accelerated over the recent past (if anything, in fact, it's done just the *opposite*), when Mr. Gore and the climate alarmists have incessantly *claimed* that (1) the earth warmed to a degree that is unprecedented over many millennia, (2) the warming resulted in a net accelerated melting of the vast majority of the world's mountain glaciers and polar ice caps, and (3) global sea level rose at an ever increasing rate. The real-world data-based results of Holgate, as well as those of all of the other studies noted in this brief examination, clearly suggest that *all of these claims appear to be false*.

Additional information on this topic, including reviews on sea level not discussed here, can be found at http://www.co2science.org/subject/s/subject_s.php under the heading Sea Level.

4.8. 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.

4.8.1. Overview

It is frequently *claimed* that temperatures over the latter part of the 20th century were higher than those experienced at any other time over the past one to two millennia, based primarily on the work of Mann *et al*. (1998, 1999) and Mann and Jones (2003). Their reason for doing so is to use this *claim* to support the related *claim* that anthropogenic CO_2 emissions from the burning of fossil fuels have caused dramatic global warming, which if allowed to continue will produce a number of catastrophic consequences. However, one can disprove the first of these claims, so as to remove support for the second, by demonstrating that about 1000 years ago, when there was approximately 25% *less* CO_2 in the atmosphere than there is currently, temperatures throughout the entire world were equally as high as (or even *higher* than) they were over the latter part of the 20th century – and such a project has actually been conducted. This real-world data-based *fact*, as evidenced in the material below, conclusively demonstrates there is nothing unnatural about the planet's current level of warmth, and that it is likely caused by the recurrence of whatever cyclical phenomenon created the equal or even *greater* warmth of the Medieval Warm Period (MWP).

4.8.1.1. Was There a Global MWP?

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

In likely the largest synthesis of MWP research articles in the world, *CO_2 Science* (http://www.co2science.org/data/mwp/mwpp.php) has highlighted a different MWP study each week on its website for the past couple of years, documenting the global nature of this warm-temperature era. To date, they have analyzed approximately 200 research papers, demonstrating the reality of this natural climatic fluctuation.

Figure 1 below illustrates the spatial distribution of the proxy climate studies analyzed by *CO_2 Science* according to three different categories. The first of these categories, denoted by the red squares, is comprised of 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). The second category is comprised of 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 (blue circles). The third category is comprised of studies where the MWP was evident in the study's data, but where the data did not provide a means by which the warmth of the MWP could be compared with that of the CWP (green triangles). This third category may seem rather innocuous, but such studies contradict the climate-alarmist claim that the MWP, if it occurred at all, was only a *regional* phenomenon experienced by lands significantly influenced by the North Atlantic Ocean. This category also includes studies that are based on data related to parameters other than temperature, such as precipitation. These studies are helpful to define the *timeframe* of the MWP; but they are not employed to infer anything about either its quantitative or qualitative thermal strength. 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.

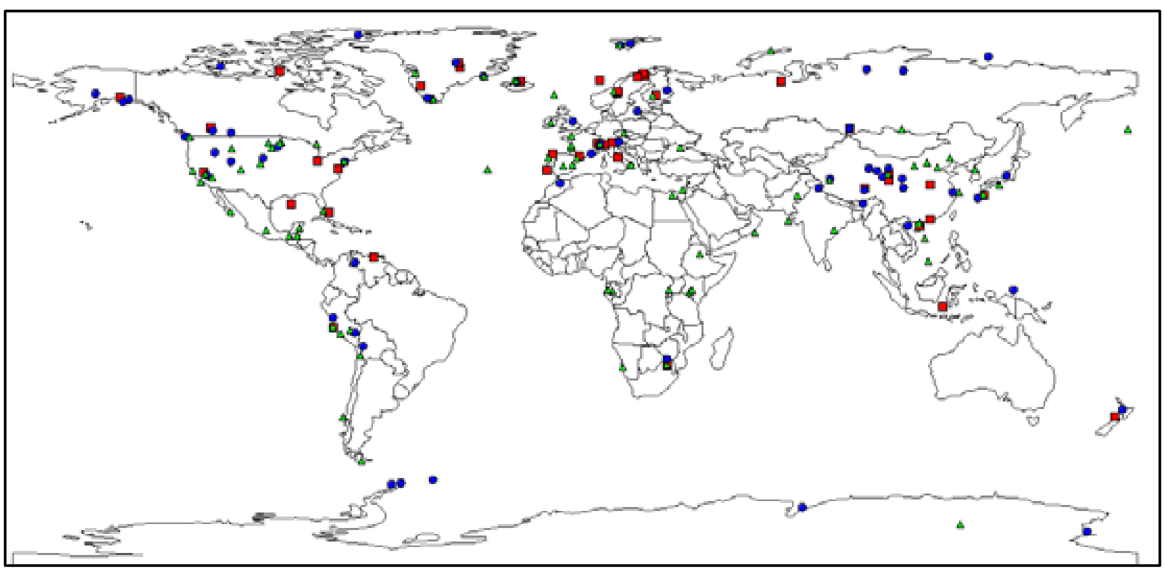


Figure 1. *Plot of the locations of proxy climate studies for which (a)* quantitative *determinations of the temperature difference between the MWP and CWP can be made (red squares), (b)* qualitative *determinations of the temperature difference between the MWP and CWP can be made (blue circles), and (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 (green triangles).*

<u>*4.8.1.2. When Did the MWP Occur and Was it Warmer Than the CWP?*</u>

A second question often posed with respect to the MWP is: *when did it occur?* A basic histogram of the *timeframe* (start year to end year) associated with the MWP of all studies plotted in Figure 1 is shown in Figure 2. As indicated in the figure, the peak timeframe of all studies occurs around 1050 AD, within a more generalized 800 to 1300 AD warm era.

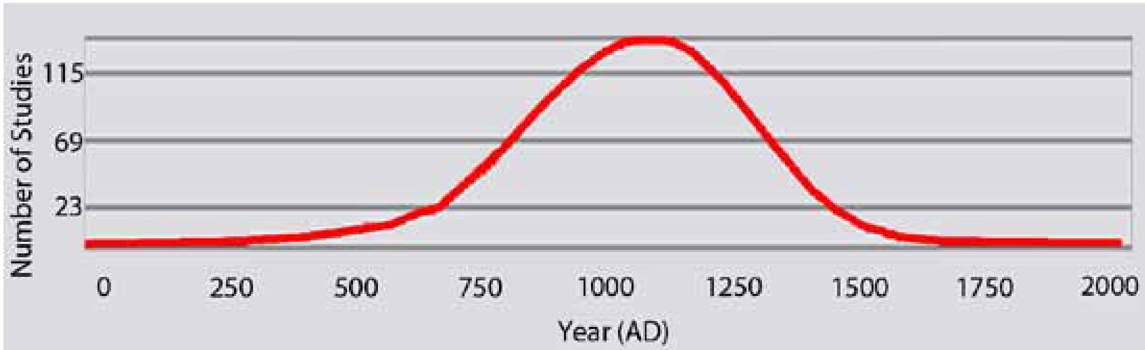


Figure 2. *Histogram showing the timeframe associated with all MWP studies plotted in Figure 1.*

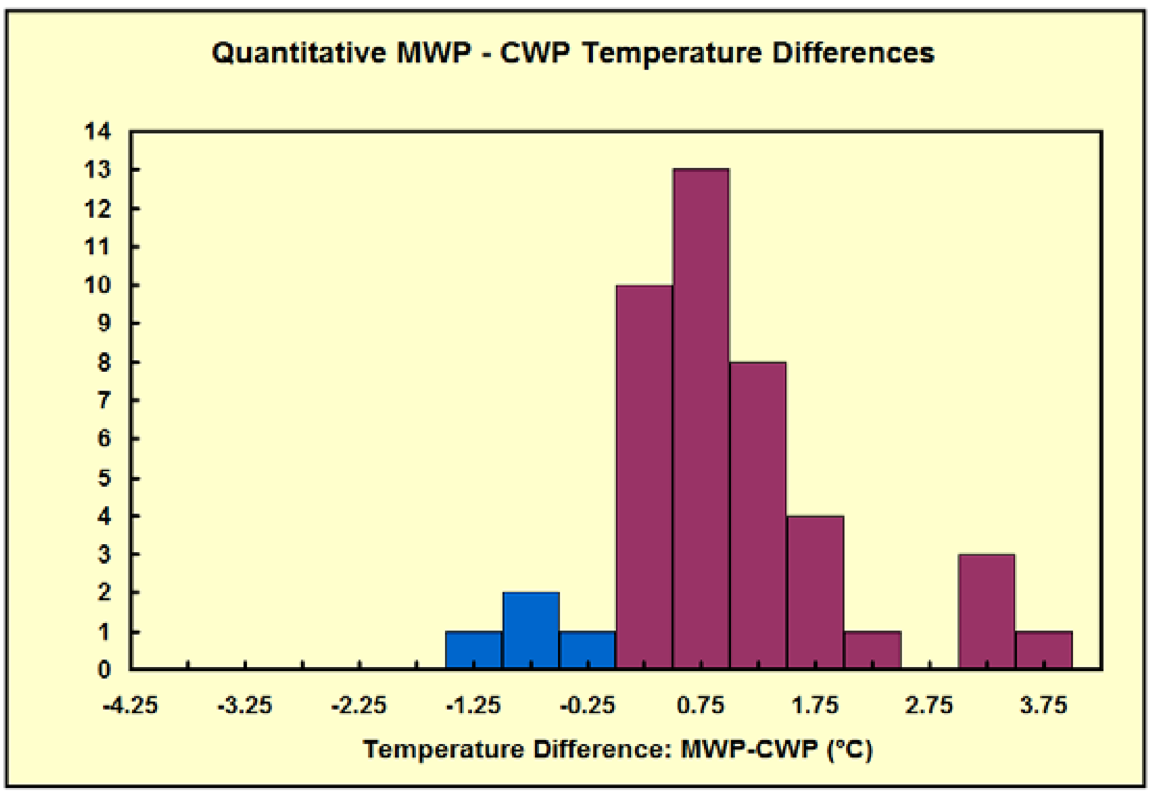


Figure 3. *The distribution, in 0.5°C increments, of studies that allow one to identify the degree by which peak Medieval Warm Period temperatures either exceeded (positive values, red) or fell short of (negative values, blue) peak Current Warm Period temperatures.*

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 (red squares) shown in Figure 1 to create Figure 3. As this figure reveals, there are a few studies in which the MWP was determined to have been cooler than the CWP (blue columns); but the vast majority of the temperature differentials are positive (red columns), indicating the MWP was warmer than the CWP. The average of all such differentials is 1.06°C, while the median is 0.95°C.

We can further generalize the superior warmth of the MWP by analyzing the *qualitative* studies in Figure 1, which we have done in Figure 4. Here we have plotted the number of studies in Figure 1 in which the MWP was warmer than, cooler than, or about the same as, the CWP, based upon actual data presented by the authors of the original works. As with Figure 3, there are a couple of studies in which the MWP was determined to have been cooler than the CWP, plus a few that found them of approximately the same warmth; but the vast majority of studies indicates an MWP that was *warmer* than the CWP.

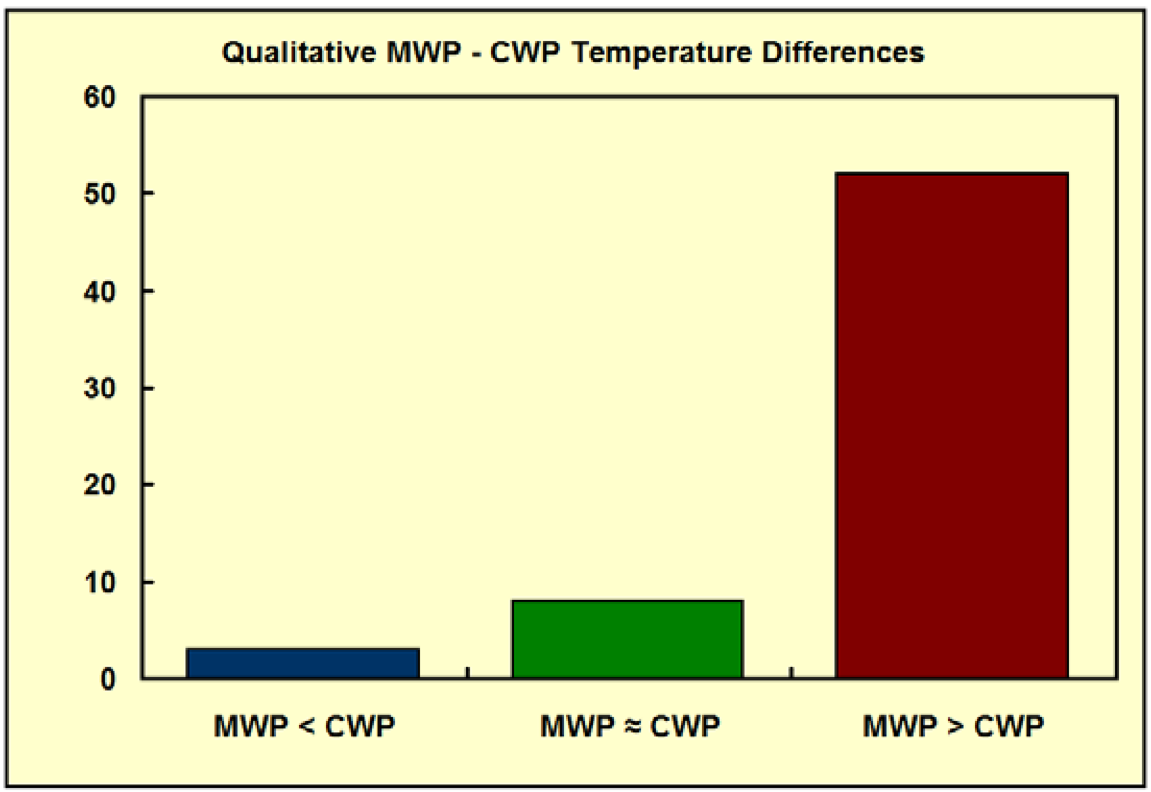


Figure 4. *The distribution of studies that allow one to determine whether peak Medieval Warm Period temperatures were warmer than (red), equivalent to (green), or cooler than (blue), peak Current Warm Period temperatures.*

The huge – and still growing! – Medieval Warm Period Project of *CO_2 Science* hosts a readily-accessible collection of totally independent databases that demonstrate a globally-synchronous

MWP between approximately 800 and 1300 AD, when temperatures were significantly warmer than those of the present. The strength of this thesis is enhanced by the fact that the work cited above derives from over 200 peer-reviewed journal articles produced by over 630 individual scientists working in 370 separate institutions from 39 different countries – and counting, as *CO_2 Science* has many additional articles "waiting in the wings" to be reviewed. If there were ever an example of true scientific consensus on an issue, this should be it. Nevertheless, climate alarmists continue to ignore -- and even deny -- the reality and implications of this important natural warm period of earth's climatic history

As indicated in the beginning of this section, it is often *claimed* that temperatures over the latter part of the 20th 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. Thus, the corollary claim that anthropogenic CO_2 emissions from the burning of fossil fuels have caused the planet's current "unprecedented" warmth cannot be substantiated; for late 20^{th}-century temperatures are *not* unprecedented, falling well within the range of natural millennial-scale variability. Consequently, there is no compelling reason to believe the historical rise in the atmosphere's CO_2 concentration had any significant impact on 20^{th} century temperatures, since it was warmer than it is now fully 1000 years ago, when there was 25% less CO_2 in the air than there is today.

In the rest of this section, we further demonstrate the truth of this thesis by highlighting the results of several studies from regions across the globe that show the existence of a Medieval Warm Period.

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4.8.2. 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 5-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% 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. In fact, 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 3000-year temperature record for South Africa that revealed several multi-century warm and cold periods. Of particular interest with respect to the Medieval Warm Period was their finding of 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 via 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 1100-year low and woody taxa were significantly underrepresented in the pollen assemblage. We also note, with respect to this finding, that when two independent data sets tell essentially the same story -- in this particular case, a tale of a two-century-long depression of precipitation and elevated temperature (which leads to lower lake levels) -- one can have increased confidence that the story they tell is true.

Expanding on the earlier work of Holmgren *et al*. (2001), 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. Hence, it attests to the global extent of these significant intervals of relative warmth and coolness; and it suggests that *after the coldest such period of the entire Holocene*, it was only to be expected that there would be a significant increase in mean global air temperature when the next scheduled warming occurred.

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 1300-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.

Skiping forward two more years, Ngomanda *et al*. (2007) derived high-resolution (<40 years) paleoenvironmental reconstructions for the last 1500 years based on pollen and carbon isotope data obtained from sediment cores retrieved from Lakes Kamalete and Nguene in the lowland rainforest of Gabon. As for what they found, 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." Hence, it would appear 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* [our italics] 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* [our italics] climatic variability (Vincens *et al*., 1999; Elenga *et al*., 2004)," all of which observations suggest there is nothing unusual, unnatural or unprecedented about the African continent's Current Warm Period status.

Last of all, we come to the paper of Esper *et al*. (2007), who 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." This work revealed, as they describe it, that "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 20th 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 20th century.

In light of these several research findings, which have been published in the standard peer-reviewed scientific literature, it would appear that (1) the Medieval Warm Period did indeed leave its mark over wide reaches of Africa, and that (2) the Medieval Warm Period was probably much more extreme in this part of the world 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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4.8.3. Antarctica

We begin with the study of Hemer and Harris (2003), who 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 5700 ^{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 number of properties of 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," demonstrating that the same millennial-scale climatic oscillation that reverberates throughout the region of the North Atlantic is also manifest in the Southern Ocean.

At about the same time, 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); and 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* [our italics]," 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 7000-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 2000 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 20th-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." We agree, noting 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." Hence, the ten researchers conclude their report 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 fourteen 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.

Most 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 that "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." In fact, they go so far as to state 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% 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. And this conclusion, along with the findings of the other studies we have reviewed, suggests there is nothing that is *unusual*, *unnatural* or *unprecedented* about the current level of earth's warmth, which further suggests that the historical increase in the atmosphere's CO_2 concentration may not have had anything to do with concomitant 20th-century 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/a/antarcticmwp.php.

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4.8.4. Arctic

We begin our review of the Medieval Warm Period in the Arctic with the study of Dahl-Jensen *et al*. (1998), who 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 it is there now.

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, which, 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 1100 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 6000 to 3000 years BP was marked by warmth and stability, but that the climate cooled thereafter until its culmination in the Little Ice Age. From 1300-900 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 4600-year history of mean summer sea surface temperature at that location. Starting from a maximum value of about 8.1°C at 4400 years BP, the climate was found to have cooled fitfully for about 1700 years and then more consistently over the final 2700 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. Hence, these data also clearly indicate that the Medieval Warm Period in this part of the Arctic was significantly warmer than it is there now.

Moving on, Moore *et al*. (2001) analyzed sediment cores from Donard Lake, Baffin Island, Canada, producing a 1240-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 13th 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 13th 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.
The following year, 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 7400-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. And in a telling commentary on current climate-alarmist claims, they report that "the relatively warm conditions of the late twentieth century do not exceed those reconstructed for several earlier time intervals." In fact, the warmth of *many* of the earlier warm intervals significantly *exceeded* the warmth of the late 20th century.

Seppa and Birks (2002) 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. 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." 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 20th 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 *hockeystick* 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 20th century's final decade.

Advancing two years closer to the present, Knudsen *et al*. (2004) documented climatic changes over the last 1200 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 that "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.

Fast-forwarding another two years, 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.

Moving ahead a final two years, 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 eleven 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."

So what did they find? As the six scientists describe it, the story told by both the varve thickness and sediment accumulation rate histories of Lower Murray Lake is that "the twelfth and thirteenth centuries were relatively warm," and in this regard we note their data indicate 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 20th century*, which has also been shown to be the case for Donard Lake (66.25°N, 62°W) by Moore *et al*. (2001).

In thus concluding this subsection, it is clear that the suite of measurements described in the studies reviewed above continues to indicate that the Arctic -- which climate models suggest should be super-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, which further suggests that the planet's more modest current warmth need not be the result of historical increases in these two trace gases of the atmosphere.

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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4.8.5. Asia

4.8.5.1. 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 δ^{18}O data obtained from the Guliya ice cap of the Qinghai-Tibet Plateau. Similarly, Hong *et al*. (2000) developed a 6000-year δ^{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 δ^{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 δ^{18}O variations in cores retrieved from peat deposits at the northeastern edge of the Qinghai-Tibet Plateau that from AD 1100-1300 "the δ^{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 1400 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 1000 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 δ^{13}C and δ^{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 last 1270 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 3000 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 1000 and 1300 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 2000-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."

Last of all, 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 twenty prior studies to derive a 2000-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; while 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, if not *most*, parts of China exhibited warmer conditions than those of modern times. And since those earlier high temperatures were obviously caused by something other than high atmospheric CO_2 concentrations, whatever was responsible for them could well 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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4.8.5.2. 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 1500 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 2200-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 20th 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."

In concluding this brief review of Russian work, we highlight the study of Krenke and Chernavskaya (2002), who 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. And what is known is that in many places it was warmer during the MWP than it was during the latter part of the 20th century. For example, they report that "the northern margin of boreal forests in Canada was shifted [north] by 55 km during the MWP, and the tree line in the Rocky Mountains in the southern United States and in the Krkonose Mountains was higher by 100-200 m than that observed at the present time."

In reference to the "hockeystick" temperature reconstruction of Mann *et al*. (1998, 1999), the two members of the Russian Academy of Sciences say "the temperature averaged over the 20th century was found to be the highest among all centennial means, although it remained within the errors of reconstructions for the early millennium." They pointedly remind us, however, that "one should keep in mind that the reconstructions of the early period were based nearly entirely on tree-ring data, which, because of the features of their interpretation, tend to underestimate low-frequency variations, so the temperatures of the Medieval Warm Period were possibly underestimated," after which they go on to provide yet additional evidence for that conclusion, reporting that "the limits of cultivated land or receding glaciers have not yet exceeded the level characteristic of the early millennium."

Concentrating on data wholly from within Russia, Krenke and Chernavskaya 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 Russian Academicians 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, as their efforts have exposed the bankruptcy of the climate-alarmist claim that 20th-century warming is outside the realm of natural variability and must therefore be due to anthropogenic CO_2 emissions. Last of all, and in contradiction of another of Mann *et al*.'s contentions, Krenke and Chernavskaya unequivocally state, based on the results of their comprehensive study of the relevant scientific literature, 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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4.8.5.3. 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 around 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 2000 and 1700 years ago, their data reveal the existence of a relatively cool climate. Then, from 1700 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 7th century; and between AD 900 and 1000, tree growth was exceptionally rapid, at rates that 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 far more conducive to good tree growth than the Modern 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 notorious hockeystick 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 and Company 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 15th 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 goodly portion of that trend may well 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 what they appear to be in Esper *et al*.'s LTM and RCS reconstructions.

In conclusion, as ever more data continue to accumulate, and as more correct procedures are employed to analyze them, the world's true temperature history is becoming ever more clear; and what's beginning to take shape will ultimately spell the end of the IPCC's ill-conceived rush to judgment on identifying both the nature and the cause of the post-Little Ice Age climatic amelioration.

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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4.8.6. 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 1500-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 8300 years and one spanning a period of 4400 years. The longer of the two cores indicated a warm interval from about 8000 to 3000 years before present, followed by cooling pulses coincident with lowered salinity and extended ice cover in the vicinity of 5000, 3500 and 2500 years ago. The shorter core additionally revealed cooling pulses at tentative dates of 1400, 300 and 100 years before present. For the bulk of the past 4400 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 4500-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."

Over in Ireland, in a cave in the southwestern part of the country, McDermott *et al*. (2001) derived a $ð^{18}O$ 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 $ð^{18}O$ 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.

Continuing our mini-review of the Medieval Warm Period in Europe, 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.

Last of all, 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."

In light of this varied array of empirical evidence, 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, contrary to the claims of climate alarmists who say the warmth of that time was nothing special. In addition, there is reason to believe that the planet may be on a natural climate trajectory that is taking it back to a state reminiscent of the Medieval Warm Period, which we could call the Modern Warm Period. And there is nothing we can do about it *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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4.8.7. North America

What do studies of non-Arctic North America reveal about the nature of the Medieval Warm Period over this vast region?

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 20th 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 4000 years. Periods of both increasing and decreasing grain size (related to moisture availability) were noted throughout the 4000-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).

Working our way southward, 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 1650 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 1600 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 2300 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 $ð^{18}O$ 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)."

In summing up these several findings, 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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4.8.8. South America

Was there a Medieval Warm Period anywhere in addition to the area surrounding the North Atlantic Ocean, where its occurrence is uncontested? This question is of utmost importance to the ongoing global warming debate, since if there was, and if the locations where it occurred were as warm then as they are currently, there is no need to consider the temperature increase of the past century as anything other than the natural progression of the persistent millennial-scale oscillation of climate that regularly brings the earth several-hundred-year periods of modestly higher and lower temperatures that are totally independent of variations in atmospheric CO_2 concentration. Hence, we here consider this question as it applies to South America, a region far removed from the lands where the existence of the Medieval Warm Period was first recognized.

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 1400 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 4000-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 long and dreary 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 1000 years ago, the former 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 preceding 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 5670 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 Modern 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 eleven other references in support of this statement.

Consequently, because heavy winter rainfalls along and off coastal Peru only occur 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, for example, 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) hockeystick 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 total 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," which suggests that these *droughts within dry periods* were likely the proverbial straws that broke the camel's back.

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 must have also led to hard times for the people of Mesoamerica and northern tropical South America; for according to the data of Haug *et al*., the Little Ice Age produced *by far* 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 only exhibited a significant in-phase variation with global temperature change over the Little Ice Age to Modern Warm Period transition. This being the case, it should be clear that the climatic amelioration of the past century or more has had 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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4.9. Atmospheric Methane

In Chapter 2 of this document, we reported on several real-world phenomena that can act to reduce or extract methane (CH_4) from the atmosphere, most of which feedbacks are enhanced as the air's CO_2 concentration rises. That those feedbacks may already be operating and having a significant impact on global methane concentrations is illustrated in a discussion of observed atmospheric methane trends.

Up until recently, the Intergovernmental Panel on Climate Change (IPCC) has long predicted that earth's tropospheric methane concentration would rise dramatically throughout the 21st century; see, for example, Ehhalt and Prather (2001). Today, most models still project methane concentrations will rise above the current 1.77 ppm value by 2100, perhaps doubling, albeit some models project it will stabilize or fall slightly. Why is the atmospheric methane concentration so important? Because methane's contribution to anthropogenic radiative forcing, including direct and indirect effects, is about 0.7 W m^{-2}, which amounts to about half that of CO_2. Thus, getting the *right* methane concentration at any point in the future is crucial for all model-based predictions of global temperature. In the present section we review observed trends in this important greenhouse gas over the past quarter-century.

We begin with the graph of real-world data from Simpson *et al*. (2002), reproduced on the next page as Figure 4.9.1, which clearly shows a linear-trend decline in CH_4 growth rates since the mid-1980s, which at the time of their publication, they vehemently contended was "premature to believe," even though their own data bore witness against them in demonstrating that such was in fact occurring.

With respect to these data, and especially the data from the 1990s, Simpson *et al*. cautioned "against viewing each year of high CH_4 growth as an anomaly against a trend of declining CH_4 growth." Yet that is *precisely* what the data suggest, to us at least, i.e., a declining baseline upon which are superimposed periodic anomalous growth-rate spikes.

In this interpretation, however, we are not alone. The first of the 1990s' large CH_4 spikes is widely recognized as having been caused by the eruption of Mt. Pinatubo in June of 1991 (Bekki *et al*., 1994; Dlugokencky *et a*l., 1996; Lowe *et al*., 1997); while the last and most dramatic of the spikes has been linked to the remarkably strong El Niño of 1997-98 (Dlugokencky *et al*., 2001). Furthermore, as noted earlier, Dlugokencky *et al*. (1998), Francey *et al*. (1999) and Lassey *et al*. (2000) have all felt confident in interpreting the data in such a way as to suggest that the annual rate-of-rise of the atmosphere's CH_4 concentration is indeed declining and leading to a cessation of growth in the atmospheric burden of methane.

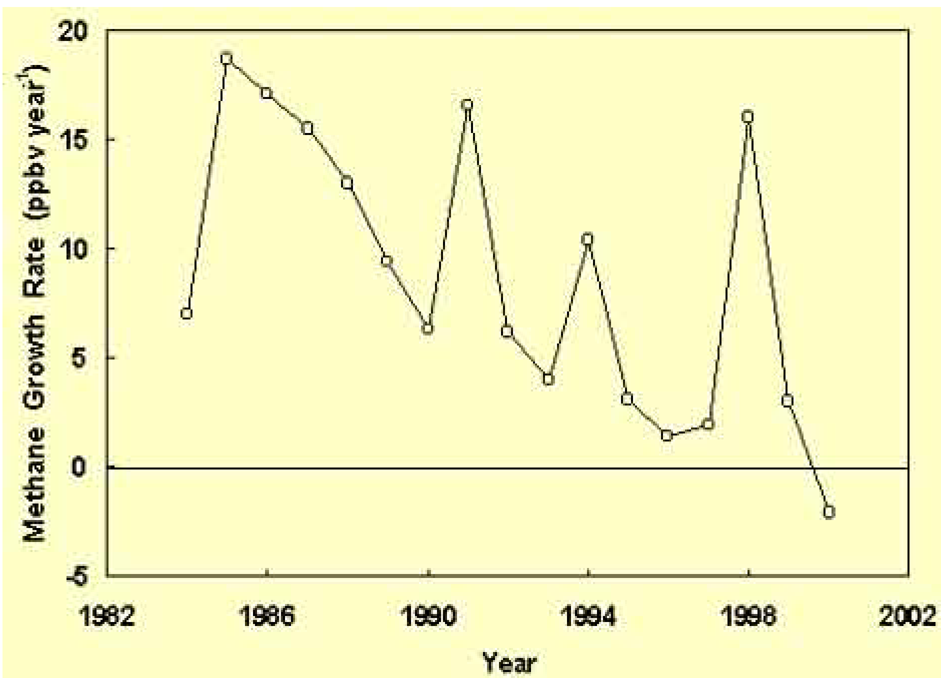

Figure 4.9.1. *Global tropospheric methane (CH_4) growth rate vs. time. Adapted from Simpson* et al*. (2002).*

Projecting ahead, therefore, if anomalous events such as those recorded in the 1990s continue to occur at similar intervals, the global atmospheric CH_4 concentration should continue to rise - but only very slowly - for just a few more years, after which the declining background CH_4 growth rate, which may have already turned negative, will have dropped low enough to have the capacity to totally overwhelm any short-term positive impacts of periodic anomalous CH_4

spikes. Then we should be able to see an actual decline in the atmosphere's global CH_4 concentration, which should gradually accelerate in the negative direction, as subsequent anomalous CH_4 spikes fail to penetrate into positive territory. This projection, in our opinion, is not only plausible, but is the one most likely to ultimately be found to be correct, based on what we feel is the most rational interpretation of the data portrayed in the preceding figure.

Subsequent to the publication of Simpson *et al*.'s study, Dlugokencky *et al*. (2003) revisited the subject with an additional two years' of data. Based on measurements from 43 globally-distributed remote boundary-layer sites that were obtained by means of the methods of Dlugokencky *et al*. (1994), they defined an evenly-spaced matrix of surface CH_4 mole fractions as a function of time and latitude, from which they calculated global CH_4 concentration averages for the years 1984-2002. We have extracted their results from their graphical presentation and re-plotted them as shown in Figure 4.9.2. below, where it can be seen that they fall into three natural groupings: initial and latter stages, to which we have fit linear regressions, and an intervening middle stage, to which we have fit a second-order polynomial.

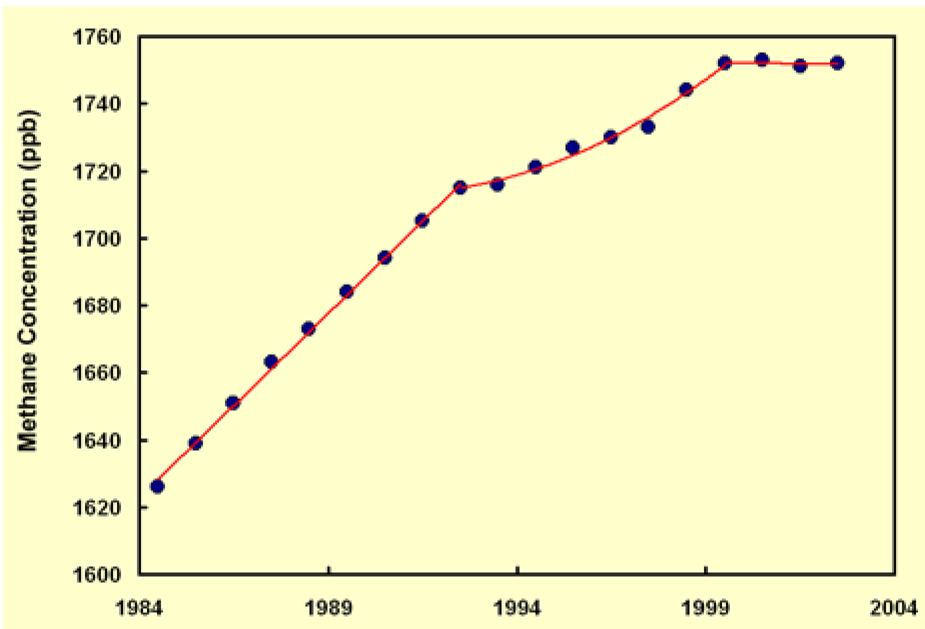

Figure 4.9.2. *Global tropospheric methane (CH_4) concentration vs. time. Adapted from Dlugokencky* et al*. (2003).*

With respect to these data, Dlugokencky *et al*. note that the globally-averaged atmospheric methane concentration "was constant at ~1751 ppb from 1999 through 2002," which suggests, in their words, that "during this 4-year period the global methane budget has been at steady state." They caution, however, that "our understanding is still not sufficient to tell if the prolonged pause in CH_4 increase is temporary or permanent." We agree. However, based on the fact that the data describe an initial stage of significant yearly CH_4 increase, a subsequent stage of much smaller yearly CH_4 increase, and a latter stage of no yearly CH_4 increase, we feel confident in suggesting that if the recent pause in CH_4 increase is indeed temporary, it will likely be followed by a decrease in CH_4 concentration, since that would be the next logical step in the observed progression from significant, to much smaller to no yearly CH_4 increase.

In the next finding on the subject, Khalil *et al*. (2007) essentially "put the nails in the coffin" of the idea that rising atmospheric CH_4 concentrations pose any further global warming threat at all. In their study, the three Oregon (USA) researchers combined two huge atmospheric methane data sets to produce the unified dataset depicted in Figure 4.9.3. below.

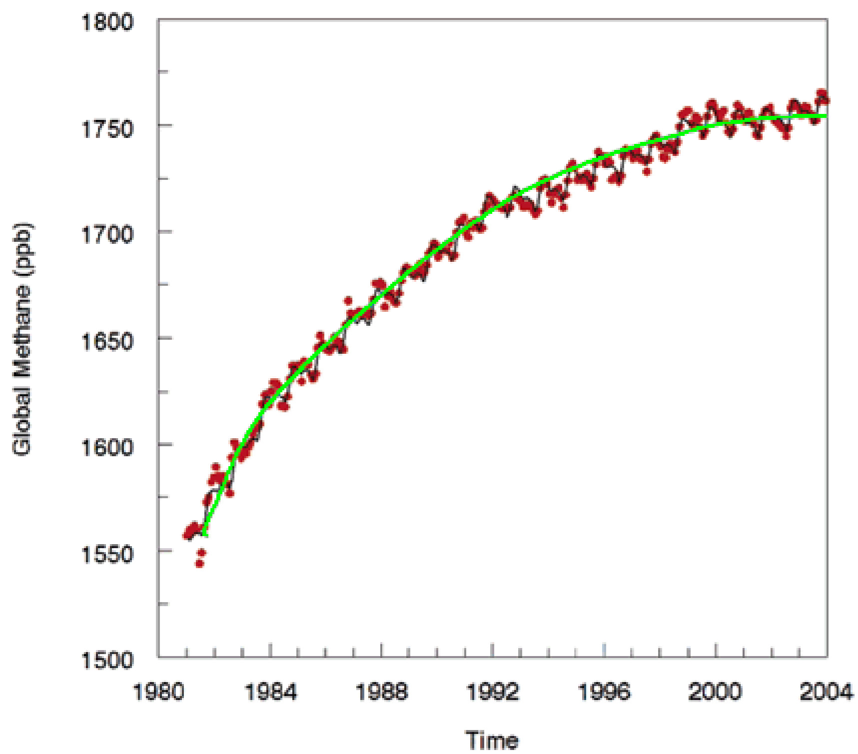

Figure 4.9.3. *Global methane (CH_4) concentration. Adapted from Khalil* et al. *(2007).*

In viewing this graph, to which we have added the smooth green line, it is again clear that the rate of methane increase in the atmosphere has dropped dramatically over time. As Khalil *et al*. describe it, "the trend has been decreasing for the last two decades until the present when it has reached near zero," and they go on to say that "it is questionable whether human activities can cause methane concentrations to increase greatly in the future."

One year later, Schnell and Dlugokencky (2008) provided an update through 2007 of atmospheric methane concentrations as determined from weekly discrete samples collected on a regular basis since 1983 at the NOAA/ESRL Mauna Loa Observatory. Our adaptation of the graphical rendition of the data provided by the authors is presented in Figure 4.9.4. below.

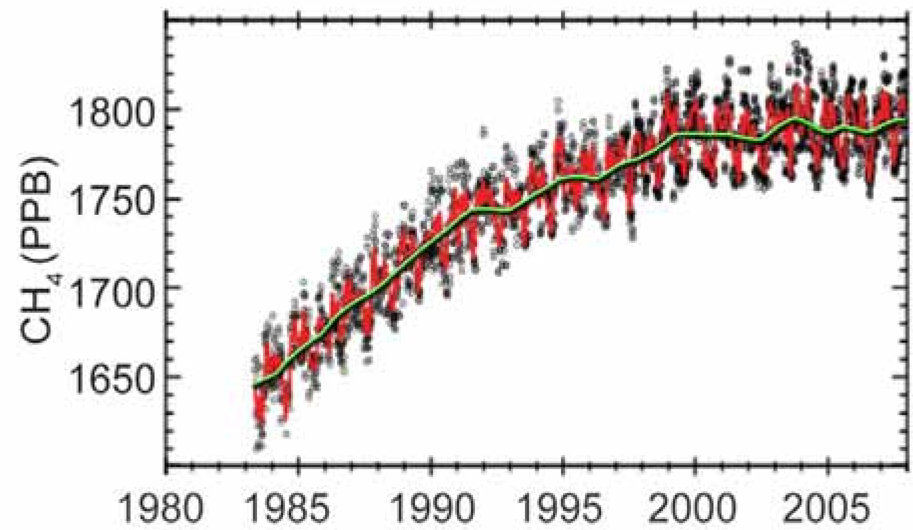

Figure 4.9.4. *Trace gas mole fractions of methane (CH_4) as measured at Mauna Loa, Hawaii. Adapted from Schnell and Dlugokencky (2008).*

In commenting on the data contained in the figure above, Schnell and Dlugokencky state that "atmospheric CH_4 has remained nearly constant since the late 1990s." This is a most important finding, because, as they also note, "methane's contribution to anthropogenic radiative forcing, including direct and indirect effects, is about 0.7 W m^{-2}, about half that of CO_2." In addition, they say that "the increase in methane since the preindustrial era is responsible for approximately one-half the estimated increase in background tropospheric O_3 during that time."

Lastly, Rigby *et al*. analyzed methane data obtained from the Advanced Global Atmospheric Gases Experiment (AGAGE) and the Australian Commonwealth Scientific and Industrial Research Organization (CSIRO) over the period January 1997 to April 2008. The results of their analysis indicated that methane concentrations "show renewed growth from the end of 2006 or beginning of 2007 until the most recent measurements," with the record-long range of methane growth rates mostly hovering about zero, but sometimes dropping five parts per billion (ppb) per year into the negative range, while rising near the end of the record to mean positive values of 8 and 12 ppb per year for the two measurement networks.

Although some people might be alarmed by these findings, as well as by the US, UK and Australian researchers' concluding statement that the methane growth rate during 2007 "was significantly elevated at all AGAGE and CSIRO sites simultaneously for the first time in almost a decade," there is also *reassurance* in the recent findings. We note, for example, that near the end of 1998 and the beginning of 1999, both networks measured even *larger* methane growth rate increases of approximately 13 ppb per year, before dropping back to zero at the beginning of the new millennium. And we note that the most current displayed data from the two networks indicate the beginning of what could well be another downward trend.

Additional reassurance in this regard comes from the work of Simpson *et al*. (2002), the findings of whom we reproduced previously in Figure 4.9.1. As can be seen there, even *greater* methane growth rates than those observed by Rigby *et al*. occurred in still earlier years. Hence, these periodic one-year-long upward spikes in methane growth rate must be the result of some *normal phenomenon*, the identity of which, however, has yet to be determined.

In light of these finding, it can be appreciated that over the past decade there have been essentially *no increases* in these two negative impacts of methane emissions to the atmosphere, and that the leveling out of the atmosphere's methane concentration -- the exact causes of which, in the words of Schnell and Dlugokencky, "are still unclear" -- has resulted in a full *one-third reduction* in the combined radiative forcing that would otherwise have been produced by a continuation of the prior rates-of-rise of the concentrations of the two atmospheric greenhouse gases.

The above observations are especially important given that most CH_4 emission scenarios considered by the IPCC result in increasing atmospheric CH_4 for at least the next 3 decades, and many of the scenarios projected large increases through the 21st century. Hence, if the future course of atmospheric CH_4 concentration will be to *decline*, or at least rise no higher, the IPCC is *way* off base, and there will be a significant natural amelioration of a large portion of the many deleterious consequences the IPCC projects.

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

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