

# **GEOLOGIC EVIDENCE OF THE CAUSE OF GLOBAL WARMING AND COOLING—ARE WE HEADING FOR GLOBAL CATASTROPHY?**

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## **ABSTRACT**

As shown in the Greenland GISP2 ice cores, late Pleistocene abrupt temperature fluctuations occurred in only 20–100 years, clearly not caused by atmospheric CO<sub>2</sub> because they occurred thousands of years before atmospheric CO<sub>2</sub> levels began to rise. Global temperature curves show a cool reversal from ~1950 to ~1977), inferring that global temperatures then were not driven by atmospheric CO<sub>2</sub>. Solar irradiance curves almost exactly match the global temperature curve and satellite data suggest that the earth has received increased solar radiation over the past 25 years, coinciding with the present 25–year warm cycle. If the cycles continue as in the past, the current warm cycle should end soon, and global warming should abate, rather than increase, in the next 25-30 years. Using these data as a basis, the coming century should experience a cooler climate from ~2006 to ~2035, a warmer period (probably warmer than the 1977–2005 warm period) from ~2035 to ~2065, followed by another cooler period from ~2065 to about the end of the century. The coming decades will test this prediction.

## **INTRODUCTION**

The present global warming and discovery of abrupt climate changes in the geologic record have pushed climate changes into the forefront of scientific inquiry with a great deal at stake for human population. However, we don't yet have an unequivocal, "smoking gun," cause-and-effect answer to the question of the fundamental cause of global climate change and thus must rely on empirical data to formulate possible causal mechanisms. Despite the media blitz over the latest IPCC report, the report provides no tangible evidence that CO<sub>2</sub> is *causing* global warming. It *assumes* CO<sub>2</sub> is the cause and computer model simulations are all based on that assumption.

Global warming over the past century, the latter part of which was coincident with rise in atmospheric carbon dioxide levels, has led to dire predictions for the coming century and controversy among scientists about the cause of the warming. The purpose of this paper is not to present a comprehensive review of all of these issues (that would require a book!), but to point out some interesting relationships between present global warming and isotopic fingerprints from ice cores and recurrent glacial advance and retreat cycles recently and in the geologic past.

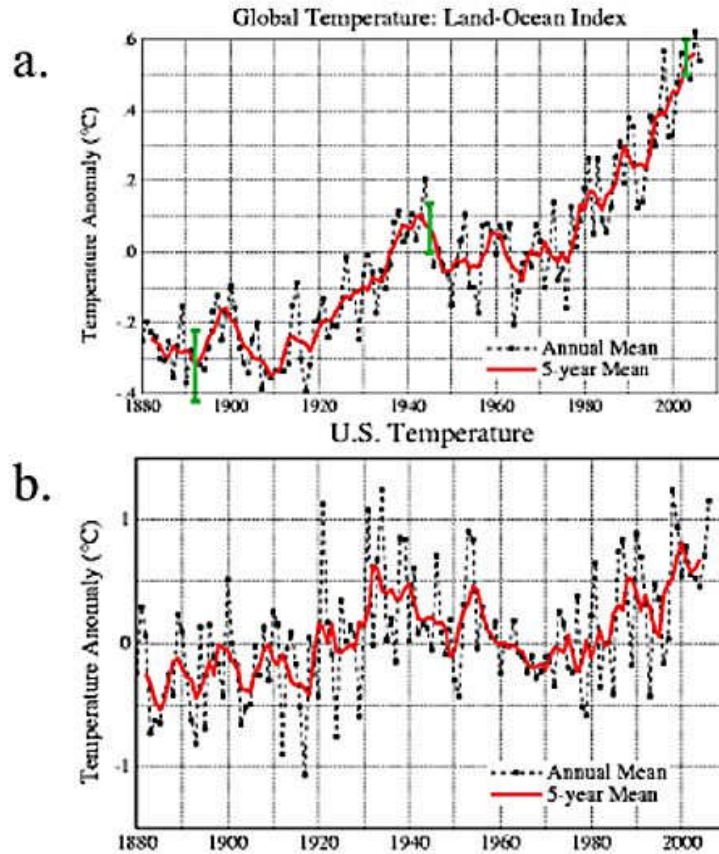
## **IS GLOBAL WARMING REAL?**

Little doubt remains that global temperatures have risen during the past several centuries. How much global warming has taken place and how much is expected the rest of this century? As shown on Figure 1, average, global, surface temperatures rose approximately 0.8 °C (~1.4° F) during the past century), but the rise hasn't been linear. For the past several hundred years, global temperatures have warmed and cooled in 25-35 year cycles, well before atmospheric CO<sub>2</sub> began to rise. Warming and cooling in the Northern Hemisphere mirrors the global curve and warming and cooling in the Southern Hemisphere follows a similar pattern.

As shown on Figure 1, the 1890 marked the low point of a cool period that extended into the early part of the century. From 1910 to about 1940, global temperatures rose 0.5. °C (0.9° F). However, during this time, industrial CO<sub>2</sub> input into the atmosphere remained low and didn't begin to rise sharply

until about 1945 (Fig. 2). This rise in global temperature cannot have been caused by anthropogenic input of CO<sub>2</sub> into the atmosphere because it preceded the increase in CO<sub>2</sub>.

## Global and U.S. Mean Surface Temperatures



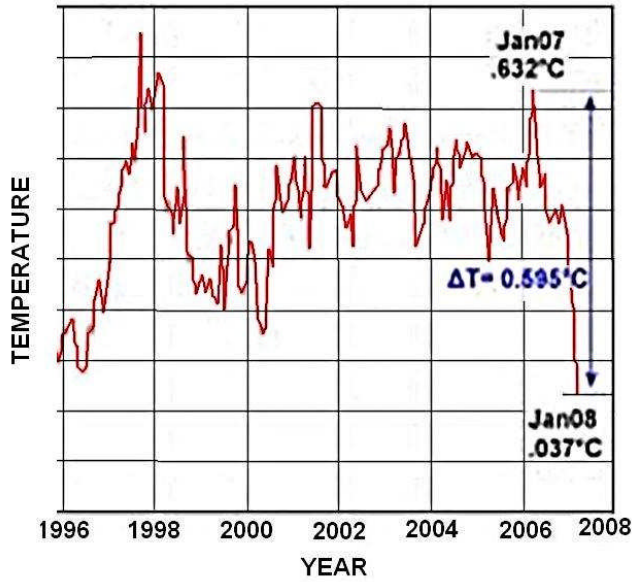
**Figure 1. a. Global temperature change from 1880 to 2007. (NASA-GISS). Note the warming period from ~1910 to ~1945, the cool period from ~1945 to 1977, and the warm period from 1977 to 1998.**

### **b. U.S. temperature change from 1880 to 2007.**

A ~30 year global cooling period occurred from the mid 1940s to 1977, during which time temperatures cooled 0.5° C (0.9° F) in the Northern Hemisphere and 0.2° C (0.4° F) globally (Fig. 3), despite rapid rise in atmospheric CO<sub>2</sub>. (Fig. 2). Many glaciers advanced significantly during this cool period. If CO<sub>2</sub> is the cause of global warming, the sharply rising atmospheric CO<sub>2</sub> during this time should have resulted in global warming, not ~30 years of global cooling.

In 1977, an abrupt climatic shift occurred and temperatures rose about 0.5°C (0.9° F) over the next 25 years as the earth entered the current warm period (Fig. 1a). During this time, atmospheric CO<sub>2</sub> continued to rise, but of the past four, 25–30–year global temperature fluctuations, only the last one (1977–present) could possibly be attributed to CO<sub>2</sub>.

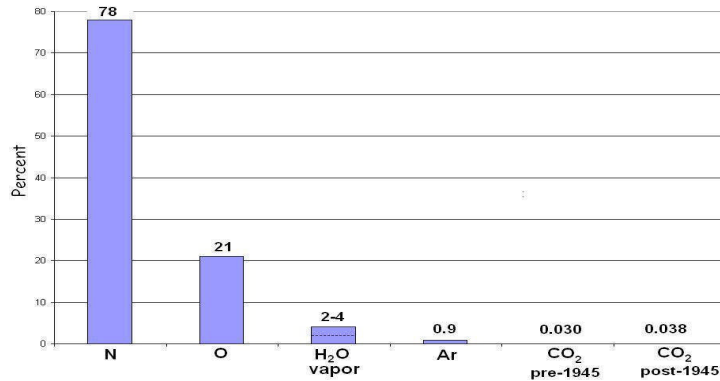
Global temperatures rose from 1977 to 1998, during which glacial melting accelerated and sea surface temperatures increased. However, the thermal high of 1998 has not been exceeded and temperatures during the past 10 years declined slightly to 2007, then plunged dramatically in 2007-2008 (Fig. 2)



**Figure 2. Global temperature 1996-2008**

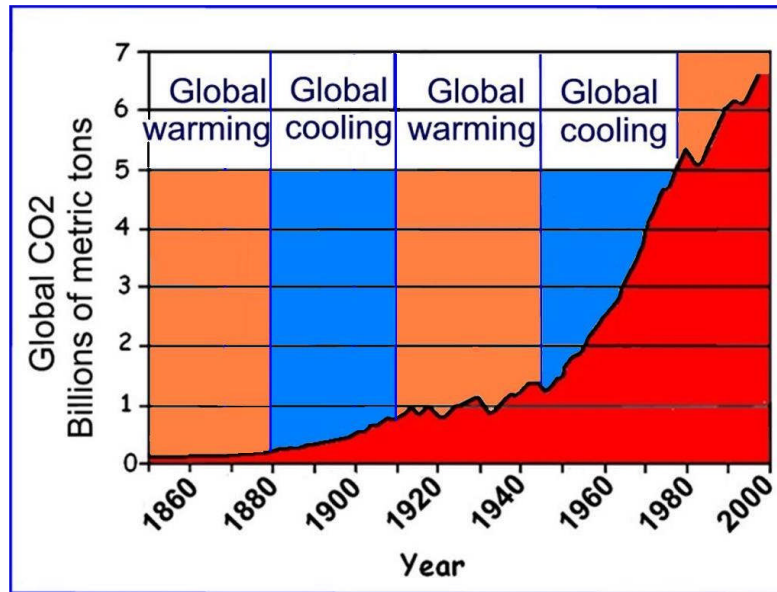
### RISE OF ATMOSPHERIC CARBON DIOXIDE

Although CO<sub>2</sub> has long been recognized as a greenhouse gas, it makes up only ~0.03% of the atmosphere (Figure 3), far less than water vapor (2-4%). Atmospheric CO<sub>2</sub> levels have risen since 1945 to 0.038%, but the question is whether or not an increase of only 0.008% can overshadow the effects of solar changes. The answer to this question may be found in the geologic record of global climate changes and changes in atmospheric CO<sub>2</sub>.

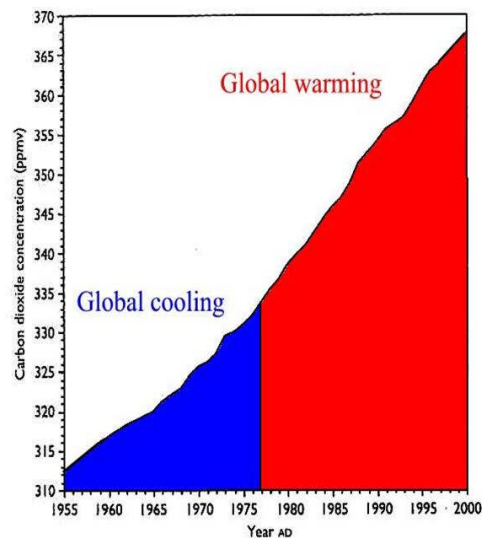


**Figure 2. Composition of the atmosphere.**

Measurements of CO<sub>2</sub> from air trapped in polar ice cores over tens of thousands of years shows that atmospheric CO<sub>2</sub> concentrations typically vary from about 270–285 ppm, averaging about 280 ppm. Atmospheric CO<sub>2</sub> concentrations have been stable at ~280 ± 10 ppm during the past millennium until the industrial revolution when it rose gradually. In 1945, CO<sub>2</sub> began to increase rapidly. Atmospheric CO<sub>2</sub> levels rose CO<sub>2</sub> to ~370 in 2000. However, from 1945 to 1977, while CO<sub>2</sub> levels rose from approximately 300 ppm to 330 ppm, the global temperature rise reversed and cooled about 0.2 degrees during the same period (Fig. 3).



**Figure 3A.** CO<sub>2</sub> emissions to the atmosphere since 1850. Note that emissions rose sharply beginning in ~1945, but 30 years of global cooling followed. Global warming in the early part of the century (~1910-1945) occurred without substantial increase in CO<sub>2</sub>.



**Figure 3B.** Atmospheric CO<sub>2</sub> since 1955. Note that no sudden change in CO<sub>2</sub> occurred in 1977 at the time of abrupt climate change from cool to warm.

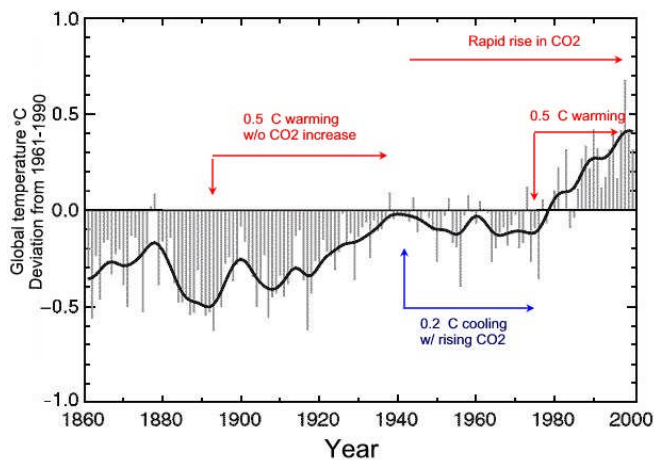
The high solubility and chemical reactivity of CO<sub>2</sub> permits ready exchange of CO<sub>2</sub> between the atmosphere and oceans. The amount of CO<sub>2</sub> in the oceans is about 50 times greater than in the atmosphere. CO<sub>2</sub> solubility depends on temperature, so changes in sea surface temperature affects CO<sub>2</sub> exchange with the atmosphere. Warming of sea surface water drives CO<sub>2</sub> into the atmosphere, as is seen in spikes in atmospheric CO<sub>2</sub> during strong El Niño years.

## GLOBAL WARMING AND CO<sub>2</sub> DURING THE PAST CENTURY

### Global warming from 1890 to 1945 not caused by atmospheric CO<sub>2</sub>

Atmospheric temperature measurements, glacier fluctuations, and oxygen isotope data from Greenland ice cores all record a cool period from about 1880 to about 1910, reaching a low about 1890. During this

period, global temperatures were about 0.9 °C (1.6 °F) cooler than at present. From 1880 to 1890, temperatures dropped 0.35 °C (0.6° F) in only 10 years. From 1890 to 1900, temperatures rose 0.25 °C (0.45 °F) in 10 years, after which temperatures dipped slightly (0.15 °C (0.3 °F) until 1910. From 1910 to 1945, global temperatures rose 0.4 °C (0.7 °F), half of the total temperature rise for the past century. As expected, glaciers during this period retreated and, in general, followed the warming climate pattern. All of this occurred before CO<sub>2</sub> emissions began to soar (after 1945) (Fig. 3A), so at least half of the warming of the past century cannot have been caused by manmade CO<sub>2</sub>.



**Figure 4. Global cooling during soaring atmospheric CO<sub>2</sub> emissions 1945 to 1977.**

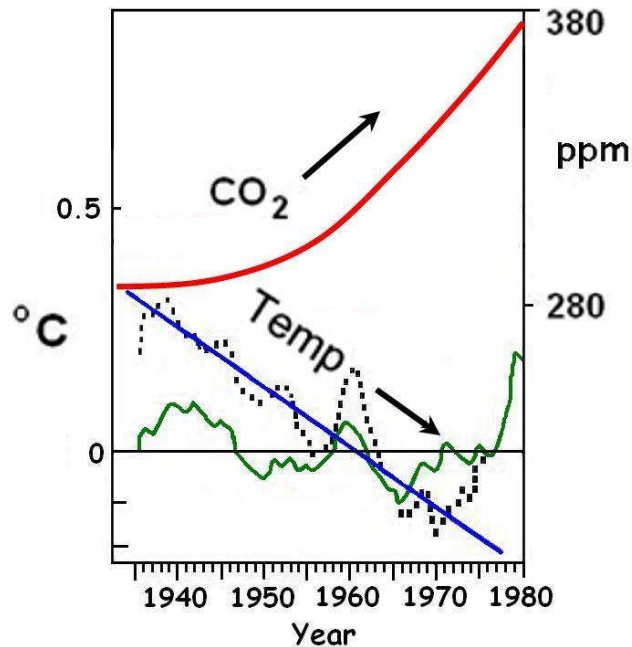
Global temperatures began to cool in the late 1940's at the point when CO<sub>2</sub> emissions began to soar (Fig. 3A). For 30 years thereafter temperatures declined 0.2 °C (0.4 °F) globally and 0.5 °C (0.9 °F) in the Northern Hemisphere (Fig. 5).

During this 30 year period (1945–1977), glaciers ceased the recession of the preceding ~30 years and began to advance. By 1980, many advancing glaciers had recovered much of the length lost in the previous ~30 year of warming. Many examples of glacial recession during the past century cited in the news media show contrasting terminal positions beginning with the maximum extent at the end of a ~30 year cool period and ending with the minimum extent of the present 30 year warm period. A much better gauge of the effect of climate on glaciers would be to compare glacier terminal positions between the ends of successive cool periods or the ends of successive warm periods.

Figure 5 shows global temperature and atmospheric CO<sub>2</sub> from 1940 to 1980. Note that even though CO<sub>2</sub> rises sharply, global temperature drops during that period. If CO<sub>2</sub> causes global warming, temperature should have risen, rather than declined.

#### **Global warming during rising atmospheric CO<sub>2</sub> from 1977 to 2007**

In 1977, global temperatures, which had been declining since the late 1940's, abruptly reversed and began to rise. Since then, global temperatures have risen ~0.5 °C (0.9 °F), alpine glaciers have retreated, Arctic sea ice has diminished, melting of the Greenland Ice Sheet has accelerated, and other changes have occurred. During this time, atmospheric CO<sub>2</sub> has continued to rise, the only period in the past century when global warming and atmospheric CO<sub>2</sub> have risen together.



**Figure 5.** Global cooling during rapid increase in atmospheric CO<sub>2</sub> from 1940 to 1977.

### Is Global Warming Caused by Rising CO<sub>2</sub>?

No tangible, physical evidence exists that proves a cause-and-effect relationship between global climate changes and atmospheric CO<sub>2</sub>. The fact that CO<sub>2</sub> is a greenhouse gas and that CO<sub>2</sub> has increased doesn't prove that CO<sub>2</sub> has caused global warming. As shown by isotope measurements from ice cores in Greenland and Antarctica and by measurements of atmospheric CO<sub>2</sub> during El Nino warming oceans emit more CO<sub>2</sub> into the atmosphere during climatic warming. The ice core records indicate that after the last Ice Age, temperatures rose for about 800 years *before* atmospheric CO<sub>2</sub> rose, showing that climatic warming causes CO<sub>2</sub> to rise, not vice versa. No doubt exists that the present high levels of atmospheric CO<sub>2</sub> are the result of human input, but the contribution that it makes to global warming remains to be proven.

#### Assertions by the ICPP and other CO<sub>2</sub> proponents

As seen in the previous discussion, no correlation exists between atmospheric CO<sub>2</sub> and the many global climate changes that have occurred over the past several centuries and the past 15,000 years. In a Newsweek article (August 13, 2007), author Sharon Begley states "*Current warming is 10 times greater than ever before seen in the geologic record. The chance that warming is natural is less than 10 percent.*" Every competent geologist knows that this statement is totally false and contrary to vast amounts of well-established data. Global climates have warmed about 4-7° F in a series of ~30 year cycles since the Little Ice Age 400 years ago, all with no correlation with atmospheric CO<sub>2</sub>, yet the author claims that "*the pattern of warming has a human fingerprint.*" What is needed to bring clarity to the issue is not rhetoric like this, but a hard look at the huge amount of geologic data that shows we've had climate changes 20 times greater than the past century in a fourth of the time.

In February 2007, The International Panel on Climate Change (IPCC) released a summary report for policymakers by 33 authors. The panel conducted no research of its own but relied on previously published material. Neither the summary report nor the earlier full report contains any tangible, physical, cause-and-effect evidence that global warming is *caused* by anthropogenic CO<sub>2</sub> emissions. The IPCC conclusions are based on the empirical observation that global temperatures have risen during the past century and CO<sub>2</sub> has also risen and on computer model simulations that assume global temperatures will rise with increasing atmospheric CO<sub>2</sub>. Because the coincidence of increase in global temperature and



atmospheric CO<sub>2</sub> is an empirical relationship, that does not in itself prove that rising CO<sub>2</sub> is causing global warming. Nonetheless, the IPCC summary report for policymakers concludes that “*Most of the observed increases in globally averaged temperatures since the mid-20<sup>th</sup> century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations.*” They also concluded that “*The widespread warming of the atmosphere and ocean, together with ice mass loss, support the conclusion that it is extremely unlikely that global climate change of the past fifty years can be explained without external forcing, and very likely that it is not due to known natural causes alone.*” Curiously, they later state the “*It is very unlikely that climate changes of a least the seven centuries prior to 1950 were due to variability generated within the climate system alone. A significant fraction of the reconstructed Northern Hemisphere interdecadal temperature variability over those centuries is very likely attributed to volcanic eruptions and changes in solar irradiance, and it is likely that anthropogenic forcing contributed to the early 20<sup>th</sup> century warming evident in these records.*” The report does not elaborate on why, if solar irradiance or volcanic eruptions were responsible for earlier climate changes, they could not also be the cause of changes since 1950, nor how anthropogenic emissions could be responsible for early 20<sup>th</sup> century warming before CO<sub>2</sub> emissions began to soar after 1945.

In his book “The Inconvenient truth Gore (2006) attributes global warming of the past century to anthropogenic CO<sub>2</sub> emissions, alleging that “*Our civilization has never experienced any environmental shift remotely similar to this. Today’s climate pattern has existed throughout the entire history of human civilization*” and that “*Every place—every city, every farm is located or has been developed on the basis of the same climate patterns we have always known.*”

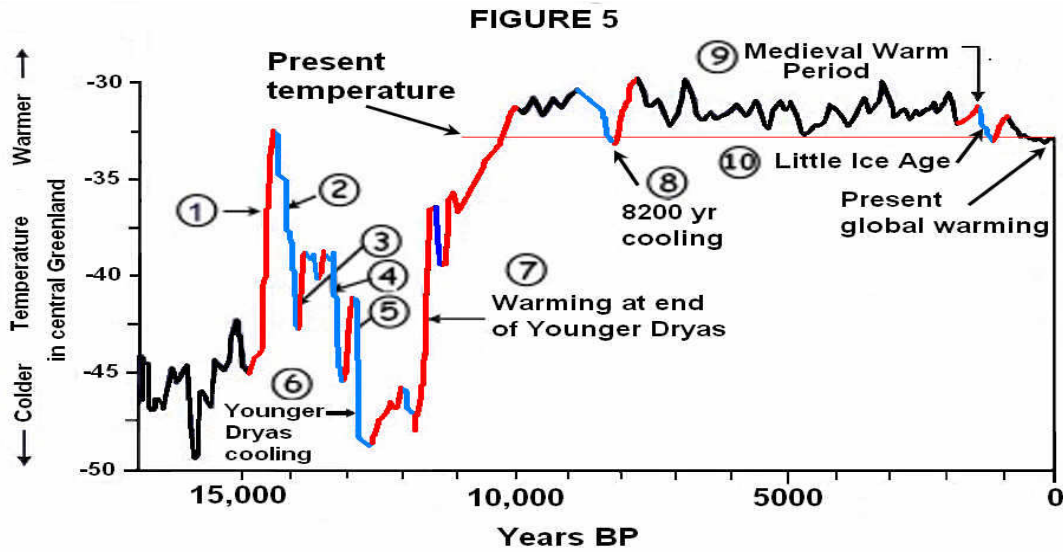
Gore (2006) contends that the possibility of global warming being caused by natural climate cycles is a misconception. “*Climate does naturally change. By studying tree rings, lake sediments, ice cores, and other natural features that provide a record of past climates, scientist know that changes in climate, including abrupt changes, have occurred throughout history. But these changes all took place with natural variations in carbon dioxide levels that were small than the ones we are now causing. Cores taken from deep in the ice of Antarctica show that carbon dioxide levels are higher now than they have been at any time in the last 650,000 years, which means we are outside the realm of natural climate variation. More CO<sub>2</sub> in the atmosphere means warming temperatures.*” This is one example among many of circular reasoning and bad logic—it correctly admits that natural climatic cycles have been responsible for abrupt climate changes in the past when CO<sub>2</sub> levels were low and could not be the cause of the climate changes, then arrives at the peculiar conclusion that climatic warming must be caused by increasing CO<sub>2</sub>.

Gore (2006) and other proponents of the CO<sub>2</sub> as the cause of global warming allege that “*there is virtually no serious disagreement remaining on any of these central points that make up the consensus view of the world scientific community.*” The basis for this claim apparently is based, at least in part, on the IPCC report and the claim that virtually all of the world’s scientists endorse it. However, the summary 2007 report for policymakers was compiled by only 33 authors and the full report, to be released in June 2007, was assembled by 143 authors and reviewed by 27 editors, hardly representative of the entire scientific community. Lindzen (2006) points out, “there is no consensus” -- no one has polled the world’s several hundred thousand scientists. Gore (2006) claimed that of 928 articles dealing with climate change in the past 10 years, none expressed any doubt about the cause of global warming. Lindzen (2006), however, found that of those 928 publications, only 13 favored CO<sub>2</sub> as the cause of global warming. Clearly, what needs to be done is to get away from the rhetoric and politicizing of global warming and carefully analyze the facts as they exist.

## **LESSONS FROM PAST GLOBAL CLIMATE CHANGES**

Proponents of CO<sub>2</sub> as the cause of global warming have stated that never before in the Earth’s history of has climate changed as rapidly as in the past century and that proves global warming is being caused by anthropogenic CO<sub>2</sub>. Statements such as these are easily refutable by the geologic record. Figure 5 shows temperature changes recorded in the GISP2 ice core from the Greenland Ice Sheet. The global warming experienced during the past century pales into insignificance when compared to the magnitude

of at least ten sudden, profound climate reversals over the past 15,000 years (Figure 5).



**Figure 5.** Temperature changes over the past 15,000 years. Red lines represent times of sudden warming, blue lines represent times of rapid cooling. Numbers refer to the events listed below. (Modified from Cuffey and Clow, 1997 and Alley, 2004)

### Late Pleistocene abrupt climate changes

The magnitude and timing of past climatic changes are recorded in the isotope data from Greenland and Antarctic ice cores. These data clearly show that abrupt climate changes many times greater than those of the past century have occurred many times in the geologic past. Numbers correspond to the temperature curves on Figure 5.

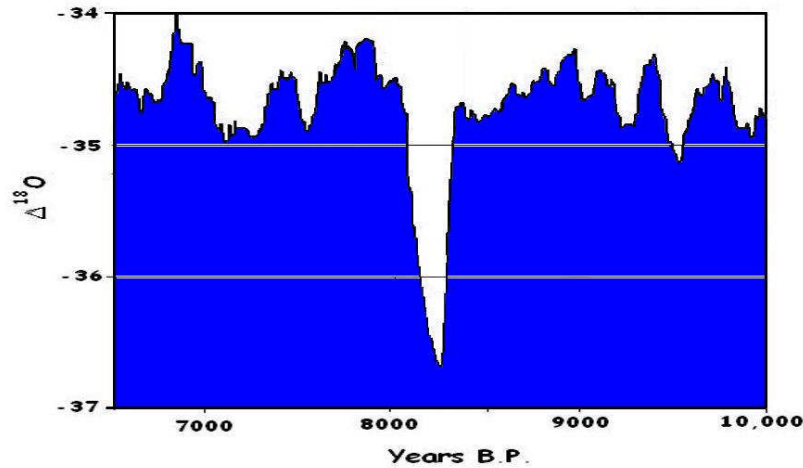
- 1. About 15,000 yrs ago, a sudden, intense, climatic warming ( $\sim 12^{\circ}\text{C}$ ;  $\sim 21^{\circ}\text{F}$ ) caused dramatic melting of large Ice Age ice sheets that covered Canada and the northern U.S., all of Scandinavia, and much of northern Europe and Russia. Sea level that had been 120 m ( $\sim 400$  ft) lower than present rose quickly and submerged large areas that had been dry land during the Ice Age.
- 2. A few centuries later, temperatures again plummeted ( $\sim 11^{\circ}$ ;  $\sim 20^{\circ}\text{F}$ ) and glaciers advanced.
- 3. About 14,000 years ago, global temperatures rose rapidly ( $\sim 4.5^{\circ}\text{C}$ ;  $\sim 8^{\circ}\text{F}$ ) once again and glaciers receded.
- 4. About 13,400 years ago, global temperatures plunged again ( $\sim 8^{\circ}\text{C}$ ;  $\sim 14^{\circ}\text{F}$ ) and glaciers advanced.
- 5. About 13,200 years ago, global temperatures increased rapidly ( $\sim 5^{\circ}\text{C}$ ;  $\sim 9^{\circ}\text{F}$ ) and glaciers receded.
- 6. 12,700 yrs ago global temperatures plunged sharply ( $\sim 8^{\circ}\text{C}$ ;  $\sim 14^{\circ}\text{F}$ ) and a 1000 year period of glacial readvance, the Younger Dryas, began.
- 7. 11,500 yrs ago, global temperatures rose sharply ( $\sim 12^{\circ}\text{C}$ ;  $\sim 21^{\circ}\text{F}$ ), marking the end of the Younger Dryas cold period and the end of the Pleistocene Ice Age.

### Early Holocene climate changes

8,200 years ago, the post-Ice Age interglacial period was interrupted by a sudden global cooling ( $\sim 4^{\circ}\text{C}$ ;  $\sim 7^{\circ}\text{F}$ ) that lasted for a few centuries (Figure 5, 6). During this time, alpine glaciers advanced



and built moraines. The warming that followed the abrupt cool period was also abrupt. Neither the abrupt climatic cooling nor the warming that followed was preceded by atmospheric CO<sub>2</sub> changes.



**Figure 6.** The 8200 sudden climate change, recorded in oxygen isotope ratios in the GISP2 ice core, lasted about 200 years.

### Late Holocene climate changes

#### 750 B.C. to 200 B.C. cool period

Prior to the founding of the Roman Empire, Egyptians records show a cool climatic period from about 750 to 450 B.C. and the Romans wrote that the Tiber River froze and snow remained on the ground for long periods (Singer, 2007).

#### The Roman warm period (200 B.C. to 600 A.D.)

After 100 B.C., Romans wrote of grapes and olives growing farther north in Italy that had been previously possible and of little snow or ice (Singer, 2007).

#### The Dark Ages cool period (440 A.D. to 900 A.D.)

The Dark Ages were characterized by marked cooling. A particularly puzzling event apparently occurred in 540 A.D. when tree rings suggest greatly retarded growth, the sun appeared dimmed for more than a year, temperatures dropped in Ireland, Great Britain, Siberia, North and South America, fruit didn't ripen, and snow fell in the summer in southern Europe (Baillie in Singer, 2007). In 800 A.D., the Black Sea froze and in 829 A.D. the Nile River froze (Oliver, 1973).

#### The Medieval Warm Period (900 A.D. to 1300 A.D.)

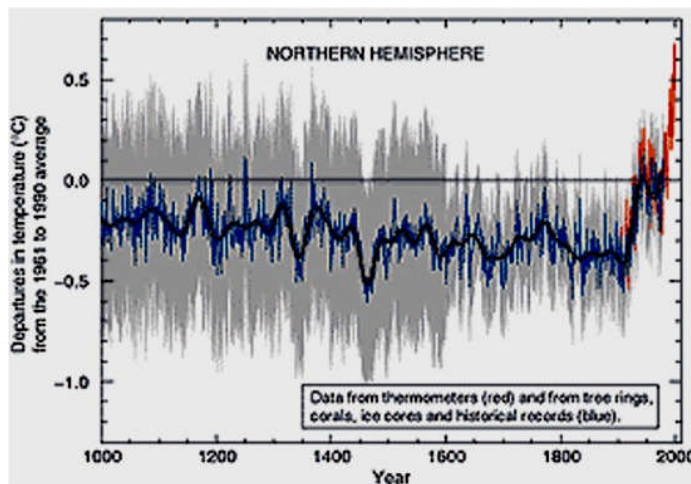
The Medieval Warm (MWP) Period was a time of warm climate from about 900–1300 AD when global temperatures were apparently somewhat warmer than at present. Its effects were evident in Europe where grain crops flourished, alpine tree lines rose, many new cities arose, and the population more than doubled. The Vikings took advantage of the climatic amelioration to colonize Greenland, and wine grapes were grown as far north as England where growing grapes is now not feasible and about 500 km north of present vineyards in France and Germany. Grapes are presently grown in Germany up to elevations of about 560 meters, but from about 1100 to 1300 A.D., vineyards extended up to 780 meters, implying temperatures warmer by about 1.0 to 1.4° C (Oliver, 1973, Tkachuck, 1983). Wheat and oats were grown around Trondheim, Norway, suggesting climates about warmer one degree C warmer than present (Fagan, 2000).

Elsewhere in the world, prolonged droughts affected the southwestern United States and Alaska warmed. Sediments in Lake Nakatsuna in central Japan record warmer temperatures. Sea surface

temperatures in the Sargasso Sea were approximately 1°C warmer than today and the climate in equatorial east Africa was drier from 1000–1270 AD. An ice core from the eastern Antarctic Peninsula shows warmer temperatures during this period.

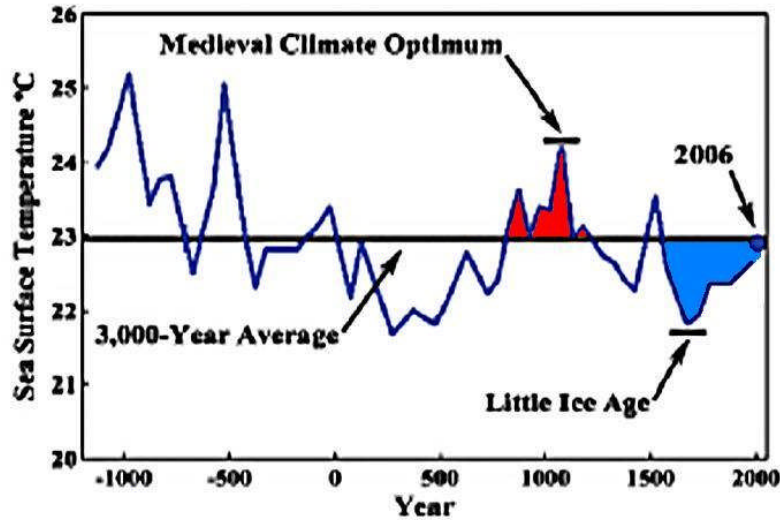
Oxygen isotope studies in Greenland, Ireland, Germany, Switzerland, Tibet, China, New Zealand, and elsewhere, plus tree-ring data from many sites around the world all confirm the presence of a global Medieval Warm Period. Soon and Baliunas (2003) found that 92% of 112 studies showed physical evidence of the MWP, only two showed no evidence, and 21 of 22 studies in the Southern Hemisphere showed evidence of Medieval warming. Evidence of the MWP at specific sites are summarized in Fagan (2007) and Singer (2007). Thus, evidence that the Medieval Warm Period was a global event is widespread. The IPCC 2<sup>nd</sup> report (Climate Change 1995) included a graph showing the MWP with warmer temperatures than today and the Little Ice Age with much cooler temperatures.

Despite all of this physical evidence of the global MWP, the IPCC 3<sup>rd</sup> report (Climate Change 2001) reassessed the MWP on the basis of tree ring studies by Mann et al. (1998) and concluded that neither the MWP nor the Little Ice Age were global climatic events. Mann’s graph (Fig. 7) became known as “the hockey stick” of climate change and was used in the 2001 IPCC report to assert that climate had not changed until led to Gore’s 2007 famous assertion that “*Our civilization has never experienced any environmental shift remotely similar to this. Today’s climate pattern has existed throughout the entire history of human civilization.*”

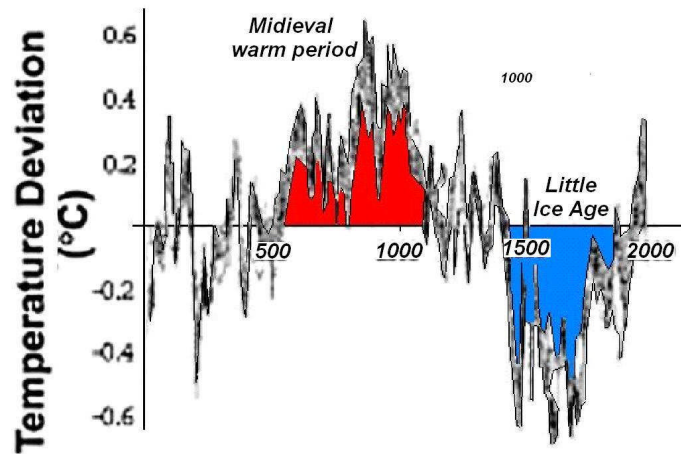


**Figure 7.** Mann (1998) “hockey stick” graph of temperature change over the past 1000 years

The Mann “hockey stick” was at odds with hundreds of historical and isotope sources, including the Greenland GRIP ice core isotope data, sea surface temperatures in the Sargasso Sea sediments (Fig. 8) (Keigwin, 1996), and paleo-temperature data other than tree rings (Fig. 9) (Loehle, 2007). McIntyre and McKittrick (2003) evaluated the data in the Mann paper and concluded that the Mann curve was invalid “*due to collation errors, unjustifiable truncation or extrapolation of source data, obsolete data, geographical location errors, incorrect calculation of principal components and other quality control defects.*” Thus, the “hockey stick” concept of global climate change is now widely considered invalid and an embarrassment to the IPCC.



**Figure 8.** Surface temperatures of the Sargasso Sea reconstructed from isotope ratios in marine organisms (Keigwin, 1996).



**Figure 9.** Reconstructed paleo-temperatures without tree ring data (Loehle, 2007)

**The Little Ice Age (1300 A.D. to the 20<sup>th</sup> century)**

At the end of the Medieval Warm Period, temperatures dropped dramatically in ~20 years and the cold period that followed is known as the Little Ice Age (LIA). The colder climate that ensued for several centuries was devastating. Temperatures of the cold winters and cool, rainy summers were too low for effective growing of cereal crops, resulting in widespread famine and disease.

Glaciers in Greenland began advancing and pack ice extended southward in the North Atlantic in the 13th century. Glaciers expanded worldwide. The population of Europe had become dependent on cereal grains as a food supply during the Medieval Warm Period and when the colder climate, early snows, violent storms, and recurrent flooding swept Europe, massive crop failures occurred. Three years of torrential rains that began in 1315 led to the Great Famine of 1315-1317. The Thames River in London froze over, the growing season was significantly shortened, crops failed repeatedly, and wine production dropped sharply.

Winters during the Little Ice Age were bitterly cold in many parts of the world (Fagan, 2000; Grove, 2004). Advance of glaciers in the Swiss Alps in the mid-17th century gradually encroached on farms and buried entire villages. The Thames River and canals and rivers of the Netherlands frequently froze over during the winter. New York Harbor froze in the winter of 1780 and people could walk from Manhattan to Staten Island. Sea ice surrounding Iceland extended for miles in every direction, closing many harbors. The population of Iceland decreased by half and the Viking colonies in Greenland died out in the 1400s because they could no longer grow enough food there and pack ice became an increasingly difficult problem. In parts of China, warm weather crops that had been grown for centuries were abandoned. In North America, early European settlers experienced exceptionally severe winters.

The cold and terrible famines of the early 1300s abated somewhat after a century or so, then turned even colder in the 16<sup>th</sup> and 17<sup>th</sup> centuries. The largest settlement in Greenland, about 225 farms, survived until about 1500 but with a shortened growing season and encroaching sea ice their situation became increasingly desperate (Fagan, 2000; Grove, 2004). In England, the Thames froze over and during the bitter cold winter of 1684, a three-mile wide strip of ice froze along the English channel. In 1695, ice blocked the coast of Ireland for much of the year and the entire cod fishery there failed (Fagan, 2000). Famines from 1690 to 1700 and in 1725 and 1816 resulted in several million deaths (Fagan, 2000).

Glaciers all over the world advanced to their most extended positions since the last Ice Age and build moraines well downvalley from their present termini. Villages in the European Alps were damaged or destroyed and alpine tree lines dropped several hundred meters.

In 1609, Galileo perfected the telescope, allowing observation of sun spots. From 1645 to 1715, solar activity was extremely low, with some years having no sunspots at all. This period of low sunspot activity, known as the Maunder Minimum, coincided with the thermal low of the Little Ice Age. The Spörer Sunspot Minimum also occurred during a significant cold period of the Little Ice Age. Low solar activity during the Little Ice Age is also shown by changes in the production rates of radiocarbon and <sup>10</sup>Be in the upper atmosphere.

Global temperatures have risen about 1° F per century since the Little Ice Age, but the warming has not been continuous. Numerous 25-35 year warm/cool cycles appear in the record of glacial fluctuations and isotope records in Greenland ice cores.