EVIDENCE OF THE CAUSE OF GLOBAL WARMING AND COOLING: RECURRING GLOBAL, DECADAL, CLIMATE CYCLES RECORDED BY GLACIAL FLUCTUATIONS, ICE CORES, OCEAN TEMPERATURES, HISTORIC MEASUREMENTS AND SOLAR VARIATIONS

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ABSTRACT

Abundant physical evidence of recurring global climate cycles over the past centuries is recorded by glacial fluctuations, ice cores, sea surface temperatures, historic measurements, and solar fluctuations. The pattern of naturally occurring, cyclic, climate changes is persistent over the past 500 years and provides a basis for projection of future climate changes. During the past century, glacial fluctuations record global climate changes that correlate with sea surface temperature changes. Four distinct periods of climate, two warming and two cooling, occurred: a cool period from 1880 to about 1915; a warm period from about 1915 to about 1945; a cool period from about 1945 to 1977; and a warm period from 1977 to 1998. Global cooling has occurred since 1999. These warm/cool periods correspond almost exactly to sea surface temperature changes (the Pacific Decadal Oscillation) and glacier advance and retreat. Twenty three earlier, cyclic, warm/cool periods of 25–30 years duration are recorded by glacier fluctuations, historic records, and changes in the $^{18}\text{O}/^{16}\text{O}$ isotope ratios in the Greenland ice cores since 1500 AD.

96% of global warming periods in the past 500 years could not have been the result of increase atmospheric CO$_2$ because significant rising of CO$_2$ emissions did not occur until after 1945.

The pattern of these cyclic warm/cool periods allows projection into the future and indicates that the global warming from 1977 to 1998 should be followed by three decades of global cooling. That is in fact now happening. The global temperature of 1998 has not been exceeded and deepening cooling has appeared.

The pattern of Pacific Decadal Oscillations (PDO) during the past century matches each of the four global climate periods—each time the PDO has been warm, the global climate has been warm and each time the PDO has been cool, the global climate has been cool. The warm PDO of 1977–1998 turned cool in 1999 and satellite thermal imagery shows that it has become entrenched, assuring at least three decades of global cooling. Time will test this prediction.

INTRODUCTION

Mild late 20$^{th}$ century global warming and the discovery of abrupt climate changes in the geologic record have pushed climate change into the forefront of scientific inquiry because of inferred high stakes for human populations. There is, however, no unequivocal, “smoking gun” evidence that CO$_2$ was the cause of global warming from 1977 to 1998. The 2007 IPCC report provides no tangible physical evidence that CO$_2$ is the cause of global warming. Rather, IPCC assumes that CO$_2$ was the cause, and computer model simulations are all based on that assumption.

Global warming over the latter part of the 20$^{th}$ century coincided with a rise in atmospheric carbon dioxide levels, leading to dire predictions for the coming century and controversy among scientists about the cause of the warming. This paper analyzes available data regarding the cause of global warming and cooling and compares it with the scope and magnitude of known variations in climate from geologic records.

GLOBAL WARMING AND CO$_2$ DURING THE PAST CENTURY

Little doubt exists that global temperatures have risen during the past several centuries. Temperatures have risen approximately 1$^{°}$ C (1.8$^{°}$ F) per century since the coldest part of the Little Ice Age ~400 years ago, but the rise has not been linear. Global temperatures have warmed and cooled in numerous 25-35 year cycles, well before atmospheric CO$_2$ began to rise significantly.

Two episodes of global warming and two episodes of global cooling occurred during the twentieth century (Figs 1,2). The warming and cooling was somewhat more pronounced in the Northern Hemisphere than the global average, probably because of the greater land mass area in the Northern Hemisphere. Overall, temperatures rose
about 0.8 °C (1.4° F) during the century, which is about the same rate of warming as has occurred since the Little Ice Age.

Figure 1. NASA GISS global temperatures 1895 to 2007.

Figure 2. Record high temperatures in the U.S. during the 20th century. Note that the greatest number of high temperatures were recorded in the 1930s.

1880 to 1915 cool period. Atmospheric temperature measurements, glacier fluctuations, and oxygen isotope data from Greenland ice cores all record a cool period from about 1880 to about 1915, reaching a low about 1890. Many cold temperature records in North America were set during this period. Glaciers advanced, some nearly to terminal positions reached during the Little Ice Age about 400 years ago. 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 about 1915. The 1880 –1915 cool period shows up well in the oxygen isotope curve of the Greenland Ice Sheet (Fig. 3)

Figure 3. GISP2 oxygen isotope record of the 1880-1915 cool period.

1915 to 1945 warm period could not be caused by atmospheric CO2. Global temperatures rose steadily in the 1920s, 1930s, and early 1940s. By the mid 1940s, global temperatures were about 0.5 °C (0.9 °F) warmer than they had been at the turn of the century (Figure 1). More high temperature records for the century were recorded in the 1930s than in any other decade of the 20th century (Fig. 2).

Glaciers during this period retreated and, in general, followed the warming climate pattern. All of this occurred before CO₂ emissions began to soar after 1945 (Fig. 3), so at least half of the warming of the past century cannot have been caused by manmade CO₂.
Temperatures in the 1930s in the Arctic and Greenland were warmer than at present and rates of warming were higher, warming 4°C (7°F) in two decades. Greenland temperatures generally followed the global temperature pattern, warming in the 1920s, 1930s, and early 1940s, cooling until about 1977, and then rising again until the turn of the century. The average rate of warming from 1920 to 1930 was considerably higher than from 1980–2005, despite the fact that the 1920-1930 warming occurred before CO$_2$ could have been the cause. Temperatures in Greenland during the Medieval Warm Period (900-1300 AD) were generally warmer than today.

**1945 to 1977 cool period with soaring CO2 emissions.** Global temperatures began to cool in the mid–1940’s at the point when CO$_2$ emissions began to soar (Fig. 4). Global temperatures in the Northern Hemisphere dropped about 0.5°C (0.9°F) from the mid-1940s until 1977 and temperatures globally cooled about 0.2°C (0.4°F) (Fig. 1). Many of the world’s glaciers advanced during this time and recovered a good deal of the ice lost during the 1915–1945 warm period. However, cooling during this period was not as deep as in the preceding cool period (1880 to 1915). 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 (1915 or 1977) and ending with the minimum extent of the recent 20 year warm period (1998). 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 4 shows CO$_2$ that even though emissions from 1945 to 1977 soared, global temperature dropped during that 30–year period. If CO$_2$ causes global warming, temperature should have risen, rather than declined, strongly suggesting that rising CO$_2$ did not cause significant global warming.

**Figure 4.** CO$_2$ emissions from 1850 to 2000. Note that CO$_2$ emissions were low during the global warming from 1850 to 1880 and rose slowly during the deep global cooling from 1880 to about 1915. Emissions were fairly constant during the strong global warming from 1915 to 1945. While emissions were soaring from 1945 to 1977, the global climate cooled, rather than warmed as it should have if CO$_2$ was the cause of global warming.

**1977 to 1998 global warming** The global cooling that prevailed from ~1945 to 1977 ended abruptly in 1977 when the Pacific Ocean shifted from its cool mode to its warm mode in a single year and global temperatures began to rise, initiating two decades of global warming (Fig. 1). This sudden reversal of climate in 1977 has been called the “Great Pacific Climate Shift” (Fig. 5) because it happened so abruptly. During this warm period, alpine glaciers retreated, Arctic sea ice diminished, melting of the Greenland Ice Sheet accelerated, and other changes occurred.
Mean annual temperatures for Anchorage, Fairbanks, and Nome (upper graph) and Pacific Decadal Oscillation Index (PDO) (lower graph) reflecting Pacific sea surface temperatures. The sudden switch from cool to warm PDO caused the “Great Climate Shift” in 1977 that initiated the latest global warming period. Figure 5B. Atmospheric CO$_2$ from 1955 to 2000. Note that CO$_2$ rose smoothly across the ‘Great Pacific Climate shift’ from cool to warm in 1977 without any sign of unusual increase.

The abruptness of the shift in Pacific sea surface temperatures and corresponding change from global cooling to global warming in 1977 is highly significant and strongly suggests a cause-and-effect relationship. The rise of atmospheric CO$_2$, which accelerated after 1945 shows no sudden change that could account for the “Great Pacific Climate Shift” (Fig. 5B).

During the 1977–1998, atmospheric CO$_2$ continued to rise, the only period in the past four centuries when global warming and atmospheric CO$_2$ have risen together. However, this doesn’t prove a cause-and-effect relationship—just because two things happen together doesn’t prove that one is the cause of the other.

The global warming from 1977 to 1998 has received much attention in the news media and represents the period now popularly called “global warming”. Previously, warming during the entire 20th century was referred to as the time of “global warming” but when it became apparent that increasing atmospheric CO$_2$ could not explain warming and cooling prior to 1977, advocates of CO$_2$ as the cause of the warming restricted what is now labeled as “global warming” to the post-1977 warming.

Global cooling from 1999 to 2009. No global warming has occurred above the 1998 level. In 1998, the PDO was in its warm mode. In 1999, the PDO flipped from its warm mode into its cool mode and satellite imagery confirms that the cool mode has become firmly entrenched since then and global cooling has deepened significantly in the past few years.

MELTING GLACIERS

Ice sheets

Greenland Ice Sheet

During the 1977-1998 warm period, the Greenland ice sheet experienced some melting and the news media has recently featured many stories that melting of the ice sheet is occurring at an unprecedented, extreme rate that threatens to raise sea level rapidly. However, past climatic records in show that Greenland is following a normal pattern of warming and cooling.

Melting of Greenland ice has waxed and waned repeatedly in the past, following both global temperatures and the warming/cooling patterns in the oceans. Until the 1977 “Great Pacific Climate Shift” that initiated global warming from 1977 to 1998, Greenland had been cooling for the previous three decades (1945 to 1977) (Fig. 6) and the ice sheet was growing. From 1915 to 1945, Greenland warmed faster than from 1977 to 1998 and was actually warmer in the 1930’s than at present (Fig. 6), so the 1977–1998 warming is not at all unusual, much less ‘extreme.’ Since the climate turned cool in 1999, we are unlikely to reach the warming levels of the 1930s.

Reconstruction the surface temperature history of the Greenland Ice Sheet over the past 50,000 years from ice cores show that late Pleistocene temperatures were 23 ± 2°C colder than at present (Dahl-Jensen et al., 1998).
Temperatures during the Holocene, 4,000 to 7,000 years ago rose to a maximum of 2.5°C warmer than at present and the Medieval Warm Period was 1°C warmer than present. In the 20th century, temperatures reached a maximum in the 1930s.

Temperature records over the past century in southern and central Greenland show that maximum temperatures in coastal Greenland occurred between 1930 and 1940, and current coastal temperatures are about 1°C below their 1940 values (Chylek et al., 2004). Between 1920 and 1930, the average annual temperature rose between 2 and 4°C and by as much as 6°C in the winter in less than ten years at five coastal locations. Since no significant increase in CO₂ occurred during that time, the warming cannot have been caused by CO₂.

Chylek et al. (2006) found that "two periods of intense warming (1995-2005 and 1920-1930) are clearly visible in the Godthab Nuuk and Ammassalik temperature records," but "the average rate of warming was considerably higher within the 1920-1930 decade than within the 1995-2005 decade." The 1920–1930 warming rate was 50% greater than the 1995-2005 decade.

Figure 6. Temperature changes in Greenland over the past century (Chylek et al., 2004, 2006). (Graphs modified from World Climate Report, 2004; based on data from Jones et al., 1986)

Antarctic ice sheet

Ocean water around the west Antarctic Peninsula that warmed during the 1977-1998 warm cycle has caused some breaking off of shelf ice, but the volume is insignificant and is not unusual during a warm cycle. The main Antarctic ice sheet (eastern Antarctica) is not shrinking. Fifty year records at the South Pole and at the Vostock station on the central ice sheet show no significant temperature change (Fig. 7). In fact, some historic human–built structures have been buried by thickening ice.
Figure 7. Temperature records from the South Pole station and Vostock station. Neither shows any indication of warming.

Arctic and Antarctic sea ice

Is polar sea ice disappearing? Assertions that Arctic sea ice is vanishing at an accelerating rate and that the Arctic Ocean will soon be ice free appear almost daily in the news media. Breaking off of large pieces of shelf ice in Antarctica is cited as showing accelerating warming in Antarctica. But what does the data show?

According to data from the University of Illinois, Antarctic sea ice area has increased recently and the anomaly has reached one million km$^2$, an area equal to Texas and California (or 250 Rhode Islands). The net global sea ice anomaly is also positive, an increase of 850,000 km$^2$ and arctic ice is at the highest level since 2002.

Figure 8A shows the increase of arctic sea ice since 2004 and Figure 8B shows the cooling arctic temperature since 2005. The alleged ‘accelerating decline’ of sea ice isn’t happening. It underwent normal melting during the 1977-1998 warm cycle, aided in large part by warm ocean water entering the Arctic through Bering Strait as a result of the 1977-1998 PDO warm cycle, but it is now increasing again during the present cool cycle.

Figure 8. A. Growth of arctic sea ice since 2004. B. Cooling of arctic temperatures since 2005.

Breaking up of the Wilkins shelf ice received much attention in the news media, with allegations that normal iceberg spalling was in fact proof of accelerating warming of Antarctica. Breaking up of ice shelves is a local event that has been repeated many times over the past 15 years and before and does not amount to even a blip on the Southern Hemisphere ice extent.

The 2009 extent of Antarctic shelf ice compared to the 1979–2000 median extent (Fig. 9A) shows several areas of enhanced ice coverage and a few areas of decreased coverage, but overall, the Antarctic shelf ice has increased (Fig. 9B).
Alpine glaciers

Because their ice volume is not large and they are close to equilibrium with local climate, alpine glaciers record climatic changes by retreating during warm periods and advancing during cool periods. The news media has made much of the glacier recession resulting from the 1977 to 1998 warm period as proof of warming allegedly caused by rising atmospheric CO$_2$, but ignore the glacial advances that occurred during the 1945 to 1977 cool period when CO$_2$ rose dramatically. During the past century, alpine glaciers expanded during the 1880 to ~1915 cool period, retreated during the ~1915 to ~1945 warm period, expanded again during the ~1945 to 1977 cool period, and finally retreated again during the 1977 to 1998 warm period. Thus, three of the four most recent glacial oscillations occurred before significant rise of CO$_2$ (or advanced during rising CO$_2$) and cannot have been caused by changes in CO$_2$.

Alpine glaciers advanced far downvalley during the Little Ice Age (~1300 to late 1800s) and have generally retreated upvalley during the following warming from the cooler climates of the Little Ice Age. Thus, they are well upvalley from their Little Ice Age maximums, even during the later cool periods.

ATMOSPHERIC CARBON DIOXIDE

Atmospheric CO$_2$ is a non-toxic, colorless, odorless trace gas that constitutes a tiny, tiny portion of the Earth’s atmosphere, making up only ~0.038% of the Earth’s atmosphere (Fig. 10). In every 100,000 molecules of air, 78,000 are nitrogen, 21,000 are oxygen, 2,000 to 4,000 are water vapor, and only 30 are carbon dioxide.

Figure 10. Composition of the atmosphere. CO$_2$ makes up only 0.038% of the atmosphere.

CO$_2$ is soluble in water in amounts that vary with the temperature of the water. Cold water can hold more CO$_2$ than warm water and sea water contains about 75 times as much CO$_2$ as fresh water. As water temperature increases, the solubility of CO$_2$ decreases and CO$_2$ gas is given off into the atmosphere until a new equilibrium is established between the air and water. At 25°C, sea water contains about 50 times as much CO$_2$ as air. The high solubility and chemical reactivity of CO$_2$ permits ready exchange of CO$_2$ between the atmosphere and oceans. When global temperatures rise, as during interglacial periods, atmospheric CO$_2$ content increases, and when temperatures decline, as during Ice Ages, atmospheric CO$_2$ declines. Measurements of CO$_2$ from air trapped in polar ice cores over tens of thousands of years shows that atmospheric CO$_2$ concentrations typically vary from about 260 to 285 ppm, averaging about 280 ppm. Claims that higher CO$_2$ during interglacial periods indicates that CO$_2$ is the cause of the warmer interglacials are scientifically indefensible because the CO$_2$ increase lagged Antarctic deglacial warming by 600 to 800 ± 200 years (Fischer et al., 1999; Caillon et al., 2003).
CO2 as a greenhouse gas

Water vapor accounts for about 95% of the greenhouse gas, with CO2, methane, and a few other gases making up the remaining 5%. The greenhouse effect from CO2 is only about 3.6% (Fig. 11). The greenhouse effect of CO2 decreases exponentially, so the rise in atmospheric CO2 from about 0.030% in 1950 to .038% in 2008 could have caused warming of only about 0.1° C. The total increase in CO2 of the atmosphere since about 1945 has been 0.008%, which amounts to less than 1 molecule of CO2 per 10,000 molecules of air.

Figure 11. Percentage of total greenhouse effect of atmospheric gases.

Is Global Warming Caused by Rising CO2?

No tangible, physical evidence exists for a cause–and–effect relationship between changing atmospheric CO2 and global temperature changes over the last 150 years. The fact that CO2 is a greenhouse gas and that CO2 has increased doesn’t prove that CO2 has caused the warming phases observed from 1915 to 1945 and 1977 to 1998. As shown by isotope measurements from ice cores in Greenland and Antarctica and by measurements of atmospheric CO2 during El Nino warming, oceans emit more CO2 into the atmosphere during climatic warming. The ice core records indicate that after the last Ice Age, temperatures rose for about 600–800 years before atmospheric CO2 rose, showing that climatic warming caused CO2 to rise, not vice versa. The present high level of atmospheric CO2 may be the result of human input, but the contribution that it makes to global warming is very small.

Global warming of ~0.4° C occurred from about 1910 to 1940 without any significant increase in atmospheric CO2. Global cooling occurred from the mid 1940s to 1977 despite soaring CO2 in the atmosphere (Fig. 12A,B). Global temperatures and CO2 both increased from 1977 to 1998 but that doesn’t prove that the warming was caused by increased CO2. Although CO2 has risen from 1998 to 2008 no global warming has occurred. In fact, the climate has cooled. Thus, global warming bears almost no correlation with rising atmospheric CO2.
LESSONS FROM PAST GLOBAL CLIMATE CHANGES

Proponents of CO₂ as the cause of global warming have stated that never before in the Earth’s history has climate changed as rapidly as in the past century and that this proves that global warming is being caused by anthropogenic CO₂. Statements such as these are easily refutable by the geologic record. Figure 13 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 (Fig. 13). In addition, small temperature changes of up to a degree or so, similar to those observed in the 20th century record, occur persistently throughout the ancient climate record.

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 (~12° C; ~21° 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 (~400 ft) lower than present rose quickly and submerged large areas than had been dry land during the Ice Age. This warming occurred abruptly in only a few years (Steffensen et al., 2008).

2. A few centuries later, temperatures again plummeted (~11°; ~20° F) and glaciers advanced.

3. About 14,000 years ago, global temperatures rose rapidly (~4.5°C; ~8° F) once again and glaciers receded.

4. About 13,400 years ago, global temperatures plunged again (~8°C; ~14° F) and glaciers advanced.

5. About 13,200 years ago, global temperatures increased rapidly (~5°C; ~9° F) and glaciers receded.

6. 12,700 yrs ago global temperatures plunged sharply (~8°C; ~14° F) and a 1000 year period of glacial readvance, the Younger Dryas, began.

7. 11,500 yrs ago, global temperatures rose sharply (~12° C; ~21° 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 (~4° C; ~7° F) that lasted for a few centuries (Fig. 14). 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$_2$ changes.

![Figure 14. The 8200 year B.P. 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 Period (MWP) was a time of warm climate from about 900–1300 AD when global temperatures were apparently somewhat warmer than at present. Its effects were particularly 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, 2007).

The Vikings colonized southern Greenland in 985 AD during the Medieval Warm Period (Lassen et al., 2004) when milder climates allowed favorable open-ocean conditions for navigation and fishing. This was "close to the maximum Medieval warming recorded in the GISP2 ice core at 975 AD (Stuiver et al., 1995).

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 2nd 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 3rd report (Climate Change 2001) reassessed the MWP on the basis of statistical manipulation 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. 15) became known as “the hockey stick” of climate change and was used in the 2001 IPCC report to assert that climate had not changed throughout the entire history of human civilization and there has never been an environmental shift remotely similar to this until the rise of

![Figure 15. Mann et al. (1998) “hockey stick” graph of temperature change over the past 1000 years (IPCC)](image)

The Mann “hockey stick” was at odds with hundreds of historical and isotope sources, including (1) the Greenland GRIP ice core isotope data, (2) sea surface temperatures from the Sargasso Sea sediments (Fig. 16A) (Keigwin, 1996), paleotemperature data other than tree rings (Fig. 16B) (Loehle, 2007), and (4) reconstructed summer sea surface temperatures near Iceland (Fig. 17) (Sicre et al., 2008).

McIntyre and McKitrick (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 has been comprehensively invalidated, to the great embarrassment of the IPCC.

![Figure 16A. Surface temperatures of the Sargasso Sea reconstructed from isotope ratios in marine organisms (Keigwin, 1996). B. Reconstructed paleo-temperatures without tree ring data (Loehle, 2007)](image)
The Little Ice Age (1300 A.D. to the 20th century)

At the end of the Medieval Warm Period, ~1230 AD, temperatures dropped ~4°C (~7° F) in ~20 years and the cold period that followed is known as the Little Ice Age. The colder climate that ensued for several centuries was devastating (see e.g., Grove, 1988, 2004; Singer and Avery, 2007; Fagan, 2000). Temperatures of the cold winters and cool, rainy summers were too low for growing of cereal crops, resulting in widespread famine and disease. When temperatures declined during the 30–year cool period from the late 1940’s to 1977, some climatologists and meteorologists predicted a return to a new Little Ice Age.

Glaciers expanded worldwide (see e.g., Grove, 1988, 2004; Singer and Avery, 2007). Glaciers in Greenland began advancing and pack ice extended southward in the North Atlantic in the 13th century. 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 (Fagan, 2000; Singer and Avery, 2007).

Winters during the Little Ice Age were bitterly cold in many parts of the world. 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. 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.

In 1609, Galileo perfected the telescope, allowing observation of sun spots. From 1645 to 1715, solar activity was extremely low, with 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 and Dalton sunspot minima also occurred during significant cold periods within the Little Ice Age. Low solar activity during the Little Ice Age is also shown by changes in the production rates of radiocarbon and $^{10}\text{Be}$ in the upper atmosphere.

Fluctuations since the Little Ice Age—short-term climate cycles

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-long warm/cool cycles appear in the record of glacial fluctuations and isotope records in Greenland ice cores. Each warming period has been slightly warmer than the preceding one and each cool period has not been quite as cool as the previous one. During each warm cycle, glaciers retreated and during each cool cycle, glaciers advanced. Glacier termini have receded progressively upvalley from their Little Ice Age maximums.

North America

Comparison of historic retreats and advances of Jackson and Agassiz glaciers in Glacier National Park, Montana, with tree-ring reconstructions of North Pacific surface temperature anomalies shows that the maximum Little Ice Age glacial advance coincides with a period of cooling that began in the late 1700s and persisted until about 1830 with only one brief interruption (Pederson et al., 2004). The mid–19th century recession of the Jackson

Figure 17. Summer sea surface temperatures near Iceland. (Sicre et al., 2008)
and Agassiz glaciers correlates with strong climatic warming, and both glaciers retreated ~3-14 m/yr (Carrara and McGimsey, 1981). Strong warming from ~1915 to ~1945 caused the glaciers to retreat at rates >100 m/yr. The North Pacific switched from its warm phase to its cool phase in the mid–1940s and modest glacier advances occurred until the 1970s. The Pacific Ocean switched back into its warm mode in 1977 and moderate retreat of the Jackson and Agassiz glaciers took place through the 1990s. These glacier oscillations coincide almost exactly with global climate changes and all but the last 20 years of the more than 230 year record took place well before CO₂ could possibly have been a factor.

**Mt. Baker**

These relationships are well shown on glaciers on Mt. Baker, Washington, where large, distinct, Little Ice Age moraines mark the former glacier termini well below present ice termini. Successively higher moraines mark progressive advances and stillstands resulting from warm/cool cycles. The later moraines match observed global climate changes.

The oldest Little Ice Age moraines have trees growing on them dating back to the 1500’s. A buried forest on the Coleman glacier moraine (Fig. 18), dated at 680 ± 80 and 740 ± 80 ¹⁴C yrs B.P., grew during the Medieval Warm Period atop an older moraine. The forest was buried by a Little Ice Age moraine. Annual rings from trees growing on successively younger moraines upvalley show moraine–building episodes in the 1600’s, ~1750, ~1790, ~1850, and ~1890.

![Figure 18. Little Ice Age moraine burying forest that grew during the Medieval Warm Period, Coleman glacier, Mt. Baker, WA.](image)

Ice margins of Mt. Baker glaciers are shown on air photos dating back to 1943 and on some earlier ground and air photos (Figs. 19, 20, 21) (Harper, 1993). Glaciers that had been retreating since at least the 1920’s advanced during the 1947–1977 cool period to positions downvalley from their 1943 termini. They began to retreat once again at the start of the 1977–2007 warm cycle and present termini of the Easton and Boulder glaciers are about 1500 ft. upvalley from their 1979 positions.
Figure 19A  Ice retreat from Little Ice Age margins. The upper forested area on the right side of the photo marks the extent of Little Ice Age glaciers below modern glacier margins. (Photo by J. Scurlock)

These glacier fluctuations closely follow the global cooling record and indicate that the ~30 yr. warming and cooling cycles seen in the glacial record mimic global climate changes. Thus, pre-historic glacial fluctuations also appear to record global climate changes.

Figure 20A  Easton glacier, Mt. Baker, WA (Photo by J. Scurlock)

Figure 20B. Retreat and advance of the Easton glacier. (Modified from Harper, 1993)

Figure 20C. Retreat of the Easton glacier since 1979, the beginning of the recent 20 yr. warm cycle. (Photo by J. Scurlock)
Glaciers on Mt. Baker (Fig. 19) show a regular pattern of advance and retreat which matches the Pacific Decadal Oscillation (PDO) in the NE Pacific Ocean (Fig. 23). The glacier fluctuations are clearly correlated with, and probably driven by, changes in the PDO. An important aspect of this is that the PDO record extends to the about 1900 but the glacial record goes back many years and can be used as a proxy for older climate changes.

Figure 22. Comparison of advance and retreat of glaciers. Comparison of advance and retreat on Mt. Baker with the Pacific Decadal Oscillation. (Glacial data modified from Harper, 1993; PDO from PDO data)


**Polar glacial changes**

On the Kenai Peninsula and at Yakutat Bay along the Gulf of Alaska coast, glaciers retreated during the Medieval Warm Period for at least a few centuries prior to 1200 AD, then advanced to their Holocene maximums during the early fifteenth century, the middle seventeenth century, and the last half of the nineteenth century when glacier equilibrium-line altitudes were depressed 150–200 m below present values (Calkin et al., 2001).

A significant post–Little Ice Age glacial retreat in the first and second decades of the twentieth century occurred on Novaya Zemlya, a Russian island between the Barents and Kara Seas in the Arctic Ocean. By 1952, the region’s glaciers had experienced between 75 percent to 100 percent of their net twentieth century retreat; and during the next 50 years, recession of more than half of the glaciers stopped, and many tidewater glaciers began to advance (Zeeberg and Forman, 2001).

The Solheimajokull outlet glacier of the Vatnajokull ice cap in Iceland advanced 0.4 km from 1705 to 1740, then retreated 2 km by 1783. During the Dalton sunspot minimum (1790–1820), it readvanced 1.6 km by 1794 and reached 2.0 km by 1820. Recession of the Lambatungnjokull outlet glacier of the Vatnajokull ice cap was greatest during the 1930s and 1940s, averaging ~20 m per year, then slowed during the ~1945–1977 global cool period. Little overall retreat has occurred since the 1980s (Bradwell et al., 2006). The Skafafellsjokull, Fjallsjokull, Skalafellsjokull, and Flaajokull outlet glaciers show similar glacier fluctuations over the past 200 years.

A strong warming ~1920 changed the mean annual air temperature at Spitsbergen from -9.5°C to -4.0°C in only 5 years, the sharpest documented instrumental drop (Humlum et al., 2005). Temperature then dropped about 4°C from 1957 to 1968. The mass balance of the Storglaciaren in northern Sweden has become positive over the last decade (Braithwaite and Zhang, 2000).

During the Medieval Warm Period, the Wilson piedmont glacier in Antarctica was less extensive than it is now and appears to have advanced during Little Ice Age, followed by retreat in the twentieth-century (Hall and Denton, 2002). Glacial activity in Antarctica seems to have followed a similar pattern of glacial fluctuation as the rest of the world.

**South America**

The two major ice fields of Patagonia, the Hielo Patagonico Norte and the Hielo Patagonico Sur, retreated during higher temperatures of the Roman Warm Period (200 BC to 600 AD, advanced during the Dark Ages Cold Period (440 AD to 900 AD), retreated during the Medieval Warm Period (900 AD to 1300 AD), and readvanced again during the Little Ice Age (Glasser et al., 2004). The Little Ice Age advance of the ice caps between 1600 AD and 1700 was the most extensive of the Holocene (Koch and Kilian, 2005; Mercer, 1970; Rothlisberger, 1986; Aniya, 1996). Other glaciers formed prominent moraines ~1870 and 1880 (Warren and Sugden, 1993; Winchester et al., 2001; Luckman and Villalba, 2001)."

The importance of the various types of evidence of climate fluctuations is that they show long–standing evidence of cool/warm cycles over many centuries. Adding more recent, observed climatic fluctuations to the earlier records shows that we are now right where we ought to be in this pattern, i.e., ending the 1977–1998 warm period and beginning a new period of global cooling. Extending the historic and ongoing record into the future provides an opportunity to predict coming climate changes.

**Magnitude and significance of previous global climate changes**

The global climate changes during the late Pleistocene were far more intense (12 to 20 times as intense, in some cases, than the global warming of the past century, and they took place in as little as 20–100 years. As shown on Figure 13, the global warming of the past century (0.8° C) is virtually insignificant when compared to the magnitude of the earlier natural climate change.

None of these sudden global climate changes could possibly have been caused by human CO$\text{\textsubscript{2}}$ input to the atmosphere because they all took place long before human CO$\text{\textsubscript{2}}$ contributions to the atmosphere began. However, the cause of the ten ‘natural’ climate changes that occurred earlier could easily have been the same as the cause of present global warming.

If CO$\text{\textsubscript{2}}$ is indeed the cause of global warming, then global temperatures should mirror the rise in CO$\text{\textsubscript{2}}$. For the past 1000 years, atmospheric CO$\text{\textsubscript{2}}$ levels have remained fairly constant at about 280 ppm (parts per million). Atmospheric CO$\text{\textsubscript{2}}$ concentrations began to rise during the industrial resolution early in the 20th century. In 1945, atmospheric CO$\text{\textsubscript{2}}$ rose sharply. By 1980 it had risen to just under 340 ppm. During this time, however, global temperatures fell about 0.5° C (0.9° F) in the Northern Hemisphere and about 0.2° C (0.4° F) globally (Fig. 3). In
1977, global atmospheric temperatures again reversed suddenly, rising about 0.5°C (0.9°F) above the 1945-1977 cool cycle in 20 years. We ended the 1977–1998 warm cycle in 1998 and began the new cool cycle in 1999. If CO\(_2\) is the cause of global warming, why did temperatures fall for 30 years while CO\(_2\) was sharply accelerating? Logic dictates that this anomalous cooling cycle during accelerating CO\(_2\) levels must mean either (1) rising CO\(_2\) is not the cause of global warming or (2) some process other than rising CO\(_2\) is capable of overriding its effect on global atmospheric warming. If we look at temperature patterns since the Little Ice Age (~1600 to 1860 A.D.), a very similar pattern emerges—25–30 year–long periods of alternating warm and cool temperatures during overall warming from the Little Ice Age low of about 4°C (~7°F). These temperature fluctuations took place well before any effect of anthropogenic atmospheric CO\(_2\) and were far greater. About 80% of the CO\(_2\) from human activities was added to the air after 1940, so the early 20th Century and earlier warming trends had to be natural and the recent trend in surface warming cannot be primarily attributable to human–made greenhouse gases. Thus, CO\(_2\) cannot possibly have been the cause of these climatic changes, so why should we suppose that the last one must be?

**THE PACIFIC DECADAL OSCILLATION (PDO)**

The Pacific Decadal Oscillation (PDO) refers to cyclical variations in sea surface temperatures in the Pacific Ocean. A detailed summary of the PDO is given in D’Aleo (this volume) and additional data may be found in Minobe (1997, 1999; Trenberth and Hurrell, 1994; Tsonis et al, 2007),. It was discovered in the mid 1990s by fisheries scientists studying the relationship between Alaska salmon runs, Pacific Ocean temperatures, and climate and named by Hare in 1996. Zhang et al. (1996), and Mantua et al. (1997) found that cyclical variations in salmon and other fisheries correlated with warm/cool changes in Pacific Ocean temperatures that followed a regular pattern. Each warm PDO phase lasted about 25 to 30 years then switched to the cool phase and vice versa. The PDO differs from El Nino/La Nina warm/cool oscillations, which persist for only 6-18 months in an east-west belt near the Equator.

Figure 23 shows the cold and warm modes of the PDO. During a typical PDO cold mode, cool sea surface temperatures extend from the equator northward along the coast of North America into the Gulf of Alaska. During a typical PDO warm mode, warm sea surface temperatures extend from the equator northward along the coast of North America into the Gulf of Alaska. As seen in the lower part of Figure 22, the PDO was warm from about 1915 to about 1945, cool from about 1945 to 1977, warm from 1977 to 1998, and cool beginning in 1999 (interrupted by El Nino in 2005-2006).

Global temperatures are tied directly to sea surface temperatures. When sea surface temperatures are cool (cool phase PDO), as from 1945 to 1977), global climate cools. When sea surface temperatures are warm (warm phase PDO), as from 1977 to 1998, the global climate warms, regardless of any changes in atmospheric CO\(_2\).
PDO COLD MODE (1945-77)        PDO WARM MODE (1977-98)

Figure 23. In 1945, the PDO (Pacific Decadal Oscillation) switched from its warm mode to its cool mode and global climate cooled from then until 1977, despite the sudden soaring of CO2 emissions. In 1977, the PDO switched back from its cool mode to its warm mode, initiating what is regarded as ‘global warming’ from 1977 to 1998. (from NASA imagery and PDO data)

During the past century, global climates have consisted of two cool periods (1880-1915 and 1945 to 1977) and two warm periods (1915 to 1945 and 1977 to 1998). In 1997, the PDO switched abruptly from its cool mode, where it had been since about 1945, into its warm mode and global climate shifted from cool to warm. This rapid switch from cool to warm has become known as “The Great Pacific Climatic Shift” (Figure 23) (Miller et al., 1994). Atmospheric CO2 showed no unusual changes across this sudden climate shift (Fig. 5B) and was clearly not responsible for it. Similarly, the global warming of 1915 to 1945 could not have been caused by increased atmospheric CO2 because that time preceded the rapid rise of CO2 and when CO2 began to increase rapidly after 1945, 30 years of global cooling occurred (1945-1977).

The two warm and two cool PDO cycles during the past century (Fig. 23) have periods of about 25-30 years. Reconstruction of ancient PDO cycles shows PDO warm and cool phases dating back to 1662 A.D. (Moore et al., 2002; Verdon and Franks, 2006).

The cool phase of PDO is now entrenched and ‘global warming’ (1977-1998) is over

‘Global warming’ (the term used for warming from 1977 to 1998) is over. No warming above the level temperatures in 1998 has occurred and global cooling has deepened since 2005 (Fig. 24).

Figure 24. No global warming has taken place since 1998 and deepening cooling has occurred during the past several years. The reason for global cooling over the past decade is the switch of the Pacific Ocean from its warm mode (where it has been from 1977 to 1998) to its cool mode in 1999.
Switching of the PDO back and forth from warm to cool modes has been documented by NASA’s satellite imagery (Figs. 25, 26). The satellite image from 1989 is typical of the warm mode (1945-1977) with most of the eastern Pacific adjacent to North America showing shades of yellow to red, indicating warm water.

![Satellite image of ocean temperature, 1989](image)

**Figure 25** Satellite image of ocean temperature, 1989. Yellow colors indicate warm water, blue colors indicate cool water. The eastern Pacific off the coast of North America was characterized by warm water from 1977 to 1998 and the global climate warmed. (NASA image)

The satellite image from 1999 (Fig. 27) shows a strong contrast to the 1997 image, with deep cooling of the eastern Pacific and a shift from the PDO warm to the PDO cool mode. This effectively marked the end of ‘global warming’ (i.e., the 1977 to 1998 warm cycle). Figures 27–30 show that the switch of the PDO from its warm cycle to the present cool cycle has become firmly established.

![Satellite image of ocean temperature, 1997](image)

**Figure 26.** Satellite image of ocean temperature, 1997, showing strong warm PDO in the eastern Pacific. The deep red band at the equator is a strong El Nino that made 1997-98 particularly warm. (NASA image)
Figure 27. Satellite image of ocean temperature, 1999, showing the development of a strong cool PDO in the eastern Pacific that marked the end of ‘global warming’ and the beginning of the present cool cycle. (NASA image)

Figure 28. Satellite image of ocean temperature, 2001, showing entrenchment of the PDO cool cycle in the eastern Pacific off the coast of North America. (NASA image)

Figure 29. Satellite image of ocean temperature, 2006, showing continued entrenchment of the PDO cool cycle in the eastern Pacific off the coast of North America. (NASA image)
Figure 30. Satellite image of ocean temperature, March 2009, showing the continued entrenchment of the PDO cool cycle in the eastern Pacific off the coast of North America. (NASA image)

Each time this has occurred in the past century, global temperatures have remained cool for about 30 years (Fig. 31). Thus, the current sea surface temperatures not only explain why we have had global cooling for the past 10 years, but also assure that cool temperatures will continue for several more decades.

Figure 31. Annual average PDO to 1900. Each warm/cool cycle lasts about 25-30 years and matches global climate changes. (Modified from D’Aleo, this volume)

THE ATLANTIC MULTIDECADAL OSCILLATION (AMO)

The Atlantic Ocean also has multidecadal warm and cool modes with periods of about 30 years (Fig. 32), much like the PDO. During warm phases, the Atlantic is warm in the tropical North Atlantic and far North Atlantic and relatively cool in the central area. During cool phases, the tropical area and far North Atlantic are cool and the central ocean is warm. The AMO is the average anomaly from 0 to 70N. For a more detailed discussion, see D’Aleo (this volume).

Figure 32. A. AMO cycles and global warming and cooling. B. PDO + AMO and arctic mean temperature. (Modified from D’Aleo, this volume)
SHORT-TERM WARM/COOL CYCLES FROM THE GREENLAND ICE CORE

Variation of oxygen isotopes in ice from Greenland ice cores is a measure of temperature (Fig. 33). Most atmospheric oxygen consists of $^{16}$O but a small amount consists of $^{18}$O, an isotope of oxygen that is somewhat heavier. When water vapor (H$_2$O) condenses from the atmosphere as snow, it contains a ratio of $^{18}$O/$^{16}$O ($\Delta^{18}$O) that reflects the temperature at the time. When the snow falls on a glacier and is converted to ice, it retains an isotopic ‘fingerprint’ of the temperature conditions at the time of condensation. Measurement of the $^{16}$O/$^{18}$O ratios in glacial ice hundreds or thousands of years old allows reconstruction of past temperature conditions (Stuiver and Grootes, 2000; Stuiver, and Brasunas, 1991, 1992; Grootes and Stuiver, 1997; Stuiver et al., 1995; Grootes, et al., 1993). High resolution ice core data show that abrupt climate changes occurred in only a few years (Steffensen et al., 2008).

The GISP2 ice core data of Stuiver and Grootes (2000) can be used to reconstruct temperature fluctuations in Greenland over the past 500 years (Fig. 33). Figure 33 shows a number of well-known climatic events. For example, the isotope record shows the Maunder Minimum, the Dalton Minimum, the 1880–1915 cool period, the 1915–~1945 warm period, and the ~1945–1977 cool period, as well as many other cool and warm periods. Temperatures fluctuated between warm and cool at least 22 times between 1480 AD and 1950 (Fig. 33). None of the warming periods could have possibly been caused by increased CO$_2$ because they all proceeded rising CO$_2$.

![Figure 33](image)

**Figure 33.** Cyclic warming and cooling trends in the past 500 years (plotted from GISP2 data, Stuiver and Grootes, 2000).

The Greenland ice core isotope record matches climatic fluctuations recorded in alpine glacier advances and retreats (Fig. 34). For example, the ages of moraines downvalley from the present Deming glacier on Mt. Baker match the ages of the cool periods in the Greenland ice core. Because historic glacier fluctuations coincide with global temperature changes and PDO, these earlier glacier fluctuations could also well be due to oscillations of the PDO.
**Figure 34.** Glacial moraines of the Deming glacier, Mt. Baker, WA corresponding to cool periods in the Greenland ice core isotope record. (Modified from Fuller, 1980; Fuller et al., 1983).

Only one out of all of the global warming periods in the past 500 years occurred at the same time as rising CO₂ (1977–1998). About 96% of the warm periods in the past 500 years could not possibly have been caused by rise of CO₂. The inescapable conclusion of this is that CO₂ is not the cause of global warming.

**SOLAR VARIABILITY AND CLIMATE CHANGE**

The global climate changes described above have coincided with changes in sunspot activity, solar irradiance, and rates of production of \(^{14}\text{C}\) and \(^{10}\text{Be}\) (Stuiver, 1961, 1994; Stuiver and Quay, 1979; Stuiver et al., 1991; Beer et al., 1994, 1996; Neff et al., 2001; Bard et al., 1997; Usoskiin et al., 2004) in the atmosphere by radiation, suggesting that the climate changes are caused by fluctuations in solar activity. A good example of the relationship between solar activity and climate occurred during the Maunder Minimum (Maunder, 1894, 1922; Eddy, 1976, 1977; Hoyt and Shatten, 1997; Soon, 2005; Soon and Yaskell, 2004; Krivova et al., 2007; Lean, 2000; Grove, 1988, 2004; Fagan, 2000).

When Galileo perfected the telescope in 1609, scientists could see sunspots for the first time. They were of such interest that records were kept of the number of sunspots observed, and although perhaps not entirely accurate due to cloudy days, lost records, etc., the records show a remarkable pattern for nearly a century (Fig. 35). From 1600 to 1700 AD, very few sunspots were seen, despite the fact that many scientists with telescopes were looking for them, and reports of aurora borealis were minimal. Between 1650 and 1700 AD, global climates turned bitterly cold (the Little Ice Age), demonstrating a clear correspondence between sun spots and cool climate. After 1700 AD, the number of observed sunspots increased sharply from nearly zero to 50–100 (Fig. 35).

**Figure 35.** Sunspots during the Maunder Minimum. (Modified from Eddy, 1976)

The Maunder Minimum was preceded by the Sporer Minimum (~1410–1540 AD) and the Wolf Minimum (~1290–1320 AD) (Fig. 7). Each of these periods is characterized by low numbers of sunspots, significant changes in the rate of production of \(^{14}\text{C}\) in the atmosphere, and cooler global climates. During the Maunder Minimum, almost no sun spots occurred for 50 years. The Dalton sun spot minimum, which occurred between 1790 and 1830, was also a time of deep global cooling, as was the period from 1890 to 1915. A more modest global cooling from 1945 to 1977 was also a time of sun spot minima (Fig. 36).
Figure 36. Correspondence of cold periods and solar minima from 1500 to 2000. Each of the five named solar minima was a time of sharply reduced global temperatures (blue areas).

The correlation between sun spots and global climate is remarkable. Unlike CO₂, which shows only a 4% correlation with climate changes over the past 500 years, the correlation of sun spots with climate change is very close (Figs. 37, 38).

Figure 37. Solar irradiance and global warming and cooling from 1750 to 1990. During this 250 year period, the two curves follow a remarkably similar

Figure 38. Correlation of sun spot numbers and temperatures in Greenland and Antarctica. (Modified from Usoskin (2004)).

Global temperature change, sunspots, solar irradiance, \(^{10}\)Be and \(^{14}\)C production

Good correlations can now be made between global temperature change, sunspots (Eddy, 1976; Stuiver and Quay, 1980; Baldwin and Dunkerton, 2005), solar irradiance (Lean, 1989, 1991, 2000, 2001, Lean and Rind, 1998; Lean et al., 1995, 2002), and \(^{10}\)Be (Beer et al., 1994, 1996, 2000) and \(^{14}\)C production (Fig. 38) (Stuiver, 1961, 1994; Stuiver and Brasienas, 1991, 1992; Stuiver et al., 1991, 1995; Matter et al., 2001) in the atmosphere. \(^{10}\)Be is produced in the upper atmosphere by radiation bombardment. Increased radiation results in increased \(^{10}\)Be production. Plots of \(^{10}\)Be production and sunspots indicate a good correlation between the two. Thus, \(^{10}\)Be measurements can serve as a proxy for solar activity. Matter et al. (2001) found a close correlation between \(\Delta^{18}\)O temperature data and \(\Delta^{14}\)C from stalagmites in Oman (Fig. 38).

Figure 38. Correlation of temperature (\(\delta^{18}\)O) and solar activity (\(\delta^{14}\)C) from a stalagmite in Oman (Matter et al., 2001)

Correlations of solar variation and climate have recently been made by Soon (2005), Soon and Yaskell, (2004), Scafetta (2009), and Scafetta and West (2005, 2007, 2008) and a mechanism for explaining the relationship between solar fluctuations and climate has been proposed (Svensmark, 1998, 2006; Svensmark and Friis–Christensen, 1997; Marsh and Svensmark, 2000a,b; Svensmark et al., 2007; Svensmark and Calder, 2007).
Svensmark experimentally verified that galactic cosmic rays significantly accelerate the formation of cloud condensation nuclei and proposed that during periods of greater solar magnetic activity, greater shielding of the earth occurs so that fewer cosmic rays penetrate to the lower atmosphere to form cloud condensation nuclei. With less cloud formation, less solar radiation is reflected, resulting in warming of the atmosphere.

**Recent solar variation**

As we approach the predicted solar minima, the sun is behaving in a manner not seen since the Little Ice Age Dalton Minimum (1790 to ~1825) (Solanki et al., 2004). The change from sun spot cycle 23 to cycle 24 was expected in 2007 and the number of days with no sun spots has exceeded all but one record back to the Dalton Minimum. Cycle 23 now resembles cycle 4, which preceded the Dalton Minimum (Fig. 36). The transition from cycle 23 to cycle 24 now appears headed lower than the Dalton Minimum (Fig. 39B).

![Sun spot cycle 23 resembles cycle 4 which preceded the Dalton Minimum](image)

**Figure 39.** Sun spot cycles during the Dalton Minimum (1790–1825).

**Where are we headed during the coming century?**

The record of natural climate change and the measured temperature record during the last 150 years, gives no reason for alarm about dangerous warming caused by human CO$_2$ emissions. Predictions based on past warming and cooling cycles over the past 500 years accurately predicted the present cooling phase (Easterbrook, 2001, 2005, 2006 a,b, 2007, 2008 a,b,c; Easterbrook and Kovanen, 2000) and the establishment of cool Pacific sea surface temperatures confirms that the present cool phase will persist for several decades.

What does the century have in store for global climates? According to the IPCC and computer modelers who believe that CO$_2$ is the cause of global warming, the Earth is in store for climatic catastrophe later this century. Computer models predict global warming of as much as 5-6° C (10-11° F) predicated on the assumption that global warming is caused by increasing atmospheric CO$_2$ and that CO$_2$ will continue to rise rapidly.

The ramifications of such an increase in global warming is predicted to be far reaching, even catastrophic. The Arctic Ocean could become free of its cover of sea ice, the Greenland ice sheet could diminish rapidly, and alpine glaciers could disappear. Water supply in areas that depend on snowmelt could be severely impacted. Melting of Greenland and Antarctic ice could cause sea level to rise, flooding low coast areas and submerging low coral islands in the oceans. Crops in critical agricultural areas could fail, resulting in widespread starvation of millions of people in agriculturally marginal areas. Wheat/grain belts, such as the mid-continent area of North America, would have to shift northward. Droughts could become increasingly severe in dry areas. Environmental impacts would be severe, resulting in extinction of some species and drastic population decreases in other. All of this is based on computer models with no demonstrable physical cause–and–effect data. However, as seen in the data on preceding pages and the geologic record, global climate change is caused by natural forces and the catastrophic climate changes predicted by the IPCC are untenable.

IPCC computer models have predicted the global temperatures will rise 1° per decade (Fig. 40A) for the next 10 decades and be 10° warmer by 2100. According to their models, global temperature should have warmed 1° from 2000 to 2011, but global climates have actually cooled, not warmed, since 1998 (Fig. 40B). Thus, the computer models have failed badly in predicting global climates and therefore must be considered unreliable.
Predictions Based on Past Climate Patterns

Past warming and cooling cycles over the past 500 years were used by Easterbrook (2001, 2005, 2006 a,b, 2007, 2008 a,b,c; Easterbrook and Kovanen, 2000) to accurately predict the cooling phase that is now happening. Establishment of cool Pacific sea surface temperatures since 1999 indicates that the cool phase will persist for the next several decades.

We can look to past natural climatic cycles as a basis for predicting future climate changes. The climatic fluctuations over the past few hundred years suggest ~30 year climatic cycles of global warming and cooling, on a general warming trend from the Little Ice Age cool period. If the trend continues as it has for the past several centuries, global temperatures for the coming century might look like those in Figure 41. Global cooling began in 1999 and should last for several decades because in 1999 the Pacific Ocean switched from its warm mode to its cool and every time that has happened in the past century the climate follows (Fig. 41). The switch to the PDO cool mode to its cool mode virtually assures cooling global climate for several decades.

The left side of Figure 42 is the warming/cooling history of the past century. The right side of the graph shows that we have entered a global cooling phase that fits the historic pattern very well. Three possible projections are shown: (1) moderate cooling (similar to the 1945 to 1977 cooling); (2) deeper cooling (similar to the 1945 to 1977 cooling); or (3) severe cooling (similar to the 1790 to 1830 cooling). Only time will tell which of these will be the case, but at the moment, the sun is behaving very similar to the Dalton Minimum (sunspot cycle 4/5, which was a very cold time. This is based on the similarity of sun spot cycle 23 to cycle 4 (which immediately preceded the Dalton Minimum).
Figure 42. Projected climate for the century based on climatic patterns over the past 500 years and the switch of the PDO to its cool phase.

We live in a most interesting time. As the global climate and solar variation reveals themselves in a way not seen in the past 200 years, we will surely attain a much better understanding of what causes global warming and cooling. Time will tell. If the climate continues its deepening cooling and the sun behaves in a manner not witnessed since 1800, we can be sure that climate changes are dominated by the sun and that atmospheric CO2 has a very small role in climate changes. If the same climatic patterns, cyclic warming and cooling, that occurred over the past 500 years continue, we can expect several decades of global cooling, followed by continued decadal cycles of global warming and cooling.

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