

Geologic Evidence of Recurring Climate Cycles and Their Implications for the Cause of Global Climate Changes—The Past is the Key to the Future

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1. INTRODUCTION

Recent global warming (1978–1998) has pushed climate changes into the forefront of scientific inquiry with a great deal at stake for human populations. With no unequivocal, “smoking gun”, cause-and-effect evidence that increasing CO₂ caused the 1978–1998 global warming, and despite the media blitz over the 2007 IPCC report, no tangible physical evidence exists that CO₂ is *causing* global warming. Computer climate models *assume* that CO₂ is the cause and computer model simulations are all based on that assumption.

The IPCC report has been hotly contested by many scientists (e.g., Idso and Singer, 2009; Spencer, 2010a,b; Horner, 2008). Abundant physical evidence from the geologic past provides a record of former periods of recurrent global warming and cooling that were far more intense than recent warming and cooling. These geologic records provide a clear evidence of global warming and cooling that could not have been caused by increased CO₂. Thus, we can use these records to project global climate in the future—the past is the key to the future.

2. IS GLOBAL WARMING REAL?

Little doubt remains that global temperatures have risen since the Little Ice Age several centuries ago. Although surface historic temperature records have been shown to be questionable due to poor siting practices and tampering of data by various governmental agencies, historical accounts, fluctuations of glaciers, and ice core records affirm that warming and cooling have indeed occurred. Temperatures have risen approximately a degree or so per century since the coldest part of the Little Ice Age ~500 years ago, but the rise has not been linear. Global temperatures have warmed and cooled many times in 25–35-year cycles, well before the atmospheric CO₂ began to rise significantly.

Two episodes of global warming and two episodes of global cooling occurred during the 20th century (Fig. 1). Overall, temperatures during the century rose about the same as the rate of warming per century since the Little Ice Age 500 years ago.

1880–1915 cool period: Atmospheric temperature measurements, glacier fluctuations, and oxygen isotope data from Greenland ice cores record a cool period from about 1880 to about 1915 (Fig. 2). Glaciers advanced, some nearly to the terminal positions reached during the Little Ice Age. Many cold temperature records in North America were set during this period. Temperatures reached a low point about 1890, rose slightly about 1910, and by about 1915 began to warm.

1915–1945 warm period: Global temperatures rose steadily in the 1920s, 1930s, and early 1940s (Fig. 3). 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. More high temperature records for the century were recorded in the 1930s than in any other decade of the 20th century (Fig. 1).

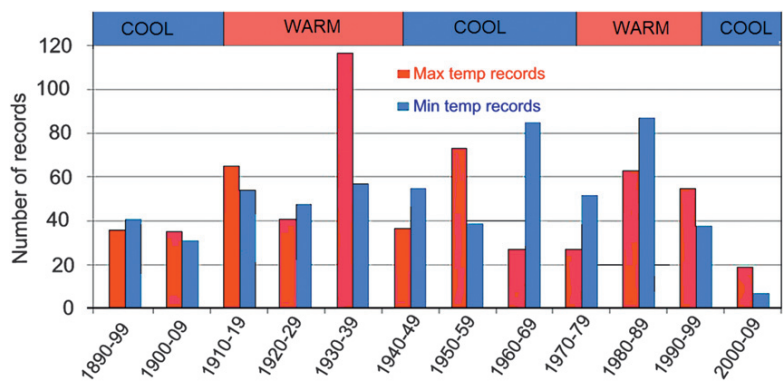


FIGURE 1 Warm and cool temperature records.

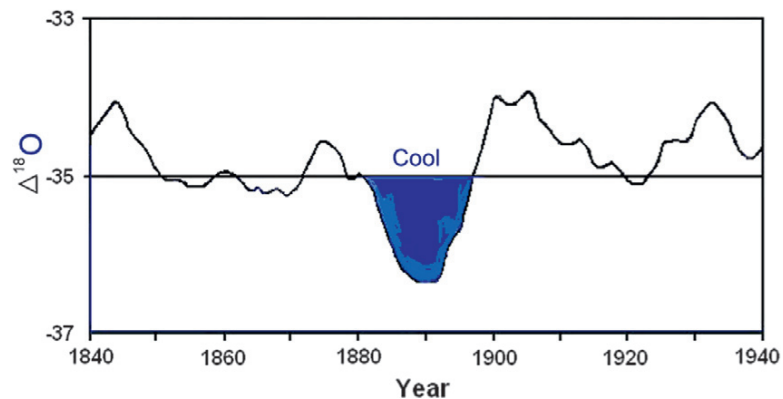


FIGURE 2 Cool period in the late 1800s and early 1900s from Greenland ice core oxygen isotope ratios.

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 to 2005 despite the fact that the 1920–1930 warming occurred before CO₂ could be a factor. Temperatures in Greenland during the Medieval Warm Period (900–1300 A.D.) were generally warmer than today.

1945–1977 cool period: Global temperatures began to cool in the mid-1940s at the point when CO₂ emissions began to soar. Global temperatures in the Northern Hemisphere dropped about 0.5 °C (0.9 °F) from the mid-1940s

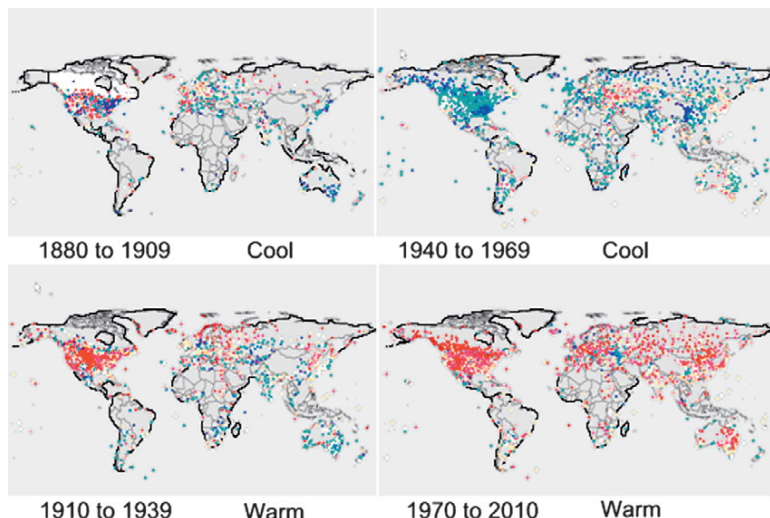


FIGURE 3 Temperatures during two periods of global warming and two periods of cooling in this century. Blue dots are stations recording cooling, red dots are stations recording warming. (GISS raw data).

until 1977 and temperatures globally cooled about 0.2°C (0.4°F). 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 (1880–1915).

1977–1998 warm period: The global cooling that prevailed from 1945 to 1977 (Fig. 3) ended abruptly in 1977 when the Pacific Ocean shifted from its cool mode to its warm mode (Fig. 4) and global temperatures began to rise, initiating two decades of global warming. 1977 has been called the year of the “Great Climate Shift”. During this warm period, alpine glaciers retreated, Arctic sea ice diminished, and renewed melting of the Greenland Ice Sheet occurred.

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 Climate Shift”.

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.

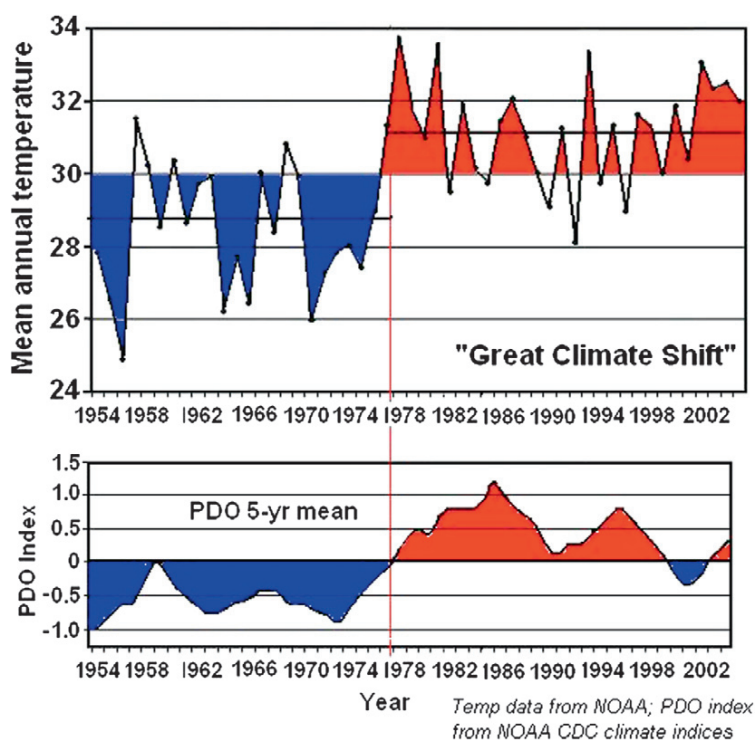


FIGURE 4 Mean annual temperatures for Anchorage, Fairbanks, and Nome (upper graph) and Pacific Decadal Oscillation (PDO) Index (lower graph) reflecting Pacific sea surface temperatures. The sudden switch from cool to warm PDO caused the “Great Climate Shift” in 1977 that initiated the latest global warming period.

2.1. Does Global Warming Prove that it was Caused by Increasing CO₂?

The news media has bombarded the public with countless pictures of melting glaciers as proof that CO₂ is causing global warming. No one disputes that glaciers have retreated from their maximums around 1910–1915, but does that prove it was caused by increased CO₂? Just because two things happened during the same time period does not prove that one is the cause of the other. During the 1880–1915 cool period, alpine glaciers advanced almost to their Little Ice Age (1300–1915) maximums, then retreated strongly during the 1915–1945 warm period with no significant change in atmospheric CO₂. Glaciers readvanced again from 1945 to 1977 in a cool period during which CO₂ emissions soared dramatically—just the opposite of what should have happened if CO₂ causes global warming. The lame excuse that sulfur emissions during the cool period caused the cooling is not credible because the cool



FIGURE 5 Greenland ice sheet (Photo by Austin Post).

period came to an abrupt halt in 1977 with no change in atmospheric sulfur or CO_2 . The cause had to be something other than either CO_2 or sulfur.

3. MELTING GLACIERS

3.1. Ice Sheets

3.1.1. *Greenland Ice Sheet*

During the 1977–1998 warm period, the Greenland Ice Sheet (Fig. 5) experienced some melting and the news media has featured many stories that melting of the ice sheet was occurring at an unprecedented, extreme rate that threatened to raise sea level rapidly. However, past climatic records show that Greenland is following a perfectly predictable, 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 (Chylek et al., 2004, 2006).

Temperatures in Greenland were cooler during the 1880–1915 global cool period (Figs. 6, 7). From 1915 to 1945, Greenland warmed faster than it did from 1977 to 1998 and was actually *warmer* in the 1930s than at present (Figs. 6, 7),

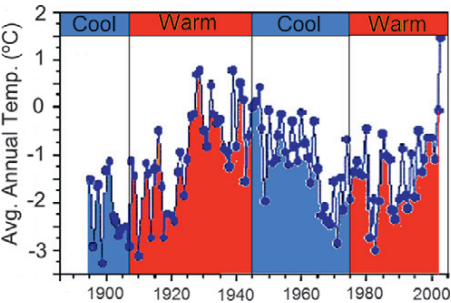


FIGURE 6 Temperature changes in Angmagssalik, Greenland over the past century (modified from Chylek et al., 2004, 2006).

so the 1977–1998 warming is not at all unusual, much less ‘extreme’. Until ‘The Great Climate Shift’ in 1977 that initiated global warming from 1977 to 1998, Greenland had been cooling for the previous three decades (1945–1977) (Figs. 6, 7) and the ice sheet grew.

3.1.2. Antarctic Ice Sheet

The Antarctic continent is 1.4 times bigger than the USA and has 90% of the Earth’s ice and 70–80% of its fresh water. The Antarctic ice sheet (Fig. 8) reaches thicknesses of 15,670 feet with a mean thickness of 7,300 feet. The lowest point is 8,188 feet below sea level. The average winter temperature at the South Pole is -60°C (-76°F) and the average summer temperature is

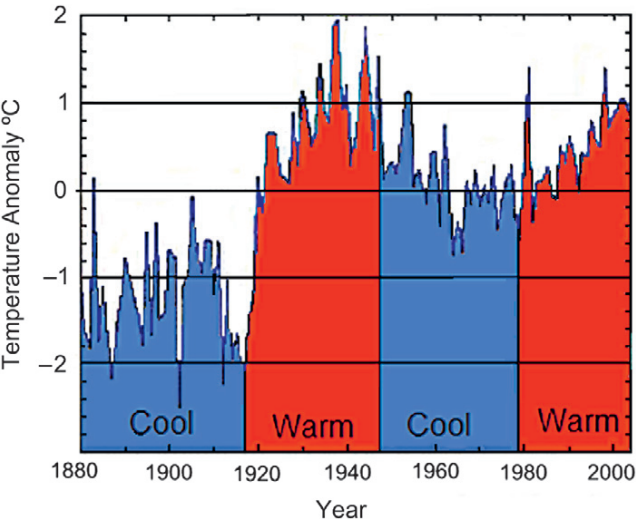


FIGURE 7 Temperature changes in the Arctic over the past century, 70–90° N latitude, –180 to 180 longitude (modified from Chylek et al., 2004, 2006).



FIGURE 8 Antarctica (NASA).

-27.5°C (-17.5°F). The lowest temperature ever recorded on Earth was -89.2°C (-128.6°F) at Vostok on the ice sheet. The average daily temperature is -55.1°C (-67.2°F) at Vostok and -49.4°C (-57°F) at the south pole. In order to get any significant amount of Antarctic ice to melt, temperatures would have to rise above the melting point, i.e., more than 100°F . Thus, claims of large scale melting of the Antarctic ice sheet are highly exaggerated.

The west Antarctic Peninsula extends northwestward from the main continent (Fig. 8) and contains a small proportion of the total ice in Antarctica. Warm ocean water around the west Antarctic Peninsula has caused some melting of ice and breaking off of shelf ice, but the volume is a small percentage of the main Antarctic ice sheet. The main Antarctic ice sheet is cooling (Fig. 9) and ice there is increasing, not melting. The paucity of weather stations in Antarctica makes interpretation of temperature distributions difficult. Steig et al. (2009) attempted to project temperatures from the West Antarctica Peninsula, where more data are available, to the main Antarctic ice sheet and contended that all of Antarctic was warming. This conclusion was hotly disputed by O'Donnell et al. (2010) who showed that warming over the period of 1957–2006 was concentrated in the West Antarctic Peninsula and the main Antarctic ice sheet varied from cooling to only slightly warmer. Both studies used statistical projection of far distant weather stations for their reconstructions. Temperature records from 1957 to 2007 at the South Pole and at Vostok (Fig. 10) on the main ice sheet show no warming in 50 years of record.

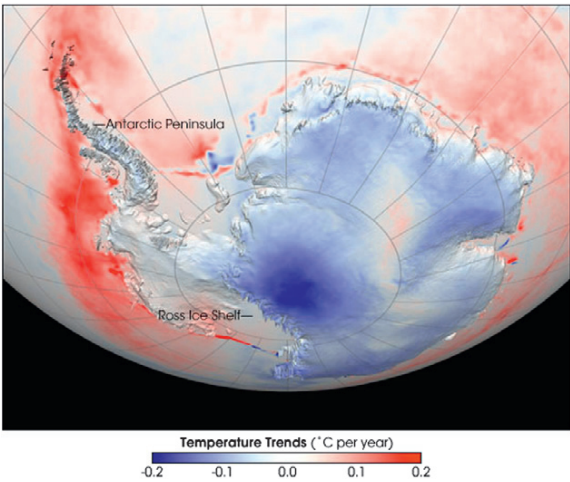


FIGURE 9 Temperature trends in Antarctica. Blue areas are getting colder, red areas warmer (NOAA, 2004).

3.1.3. Arctic and Antarctic Sea Ice

Is polar sea ice disappearing? Assertions that Arctic sea ice (Fig. 11) is vanishing at an accelerating rate and that the Arctic Ocean will soon be ice free appear almost daily in the news media. The news media frequently carries stories of breaking off of large pieces of shelf ice, which is claim of to be proof accelerating warming in the polar regions. But what does the data show?

Measurements of Arctic and Antarctic sea ice from satellite images began in 1979, just after the Great Climate Shift of 1977–1978 so the entire record covers only the most recent period of global warming (1978–1998). No satellite images are available from the 1945–1977 period of global cooling.

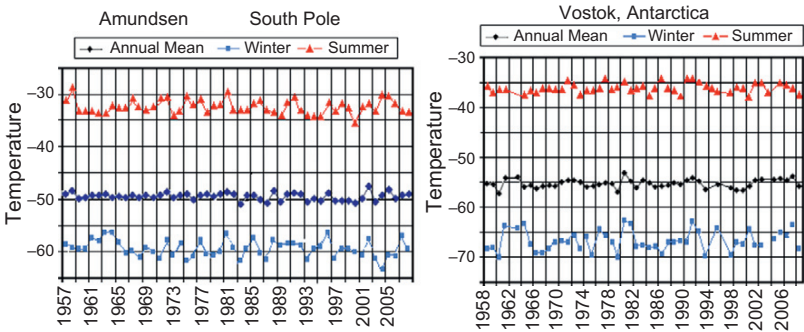


FIGURE 10 Temperature records from the South Pole and Vostock stations. Neither shows any indication of warming since 1957.

FIGURE 11 Arctic sea ice. There is no ice cap at the north pole so melting of thin, floating sea ice there has no effect whatsoever on sea level (NOAA photo).



Time-lapse images show substantial expansion and contraction of Arctic sea ice with the seasons (Fig. 12), so no single image is representative of annual changes. In general, Arctic sea ice diminished between 1979 and 2010, reaching a low in 2007, then rebounding in 2008, 2009, and 2010 (Figs. 12, 13). It underwent normal melting during the 1977–1998 warm cycle and was aided in large part by warm ocean water entering the Arctic thru Bering Strait as a result of the 1977–1998 warm cycle.

According to data from the University of Illinois, Antarctic sea ice area (Fig. 14) is nearly 30% above normal and the anomaly has reached 1 million km^2 , an area of excess sea ice equal to Texas and California (or 250 Rhode

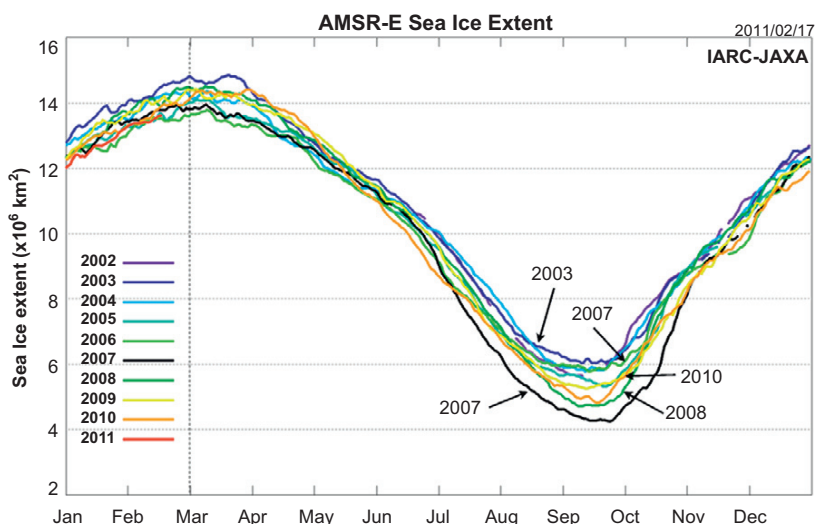


FIGURE 12 Arctic sea ice extent from 2002 to 2011. Arctic sea ice reached a low in 2007 but has rebounded in 2008, 2009, and 2010 (IARC-JAXA Information System).

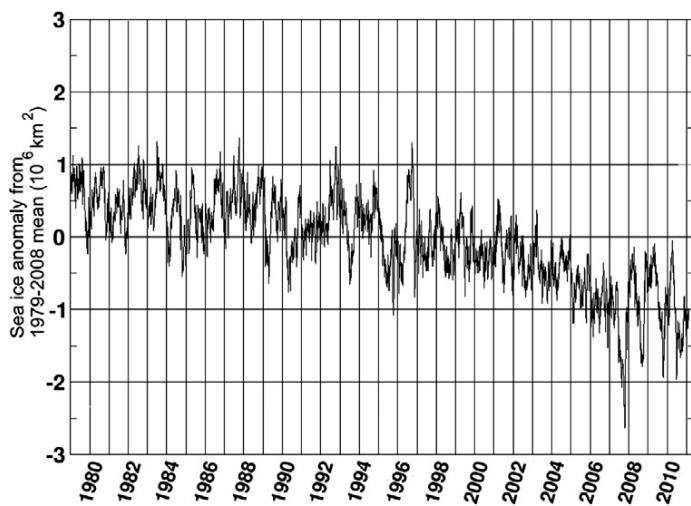


FIGURE 13 Arctic sea ice has declined since 1979 (Arctic Climate Research, University of Illinois; NOAA data).

Islands). The net global sea ice anomaly is also positive, 850,000 km² above the normal and arctic ice is the highest level since 2002. Figure 15 shows a comparison of Arctic and Antarctic sea ice from 1979 to 2009. Although Arctic sea ice has declined, Antarctic sea ice has increased (Fig. 16). The overall total of sea ice globally has increased since 1979.

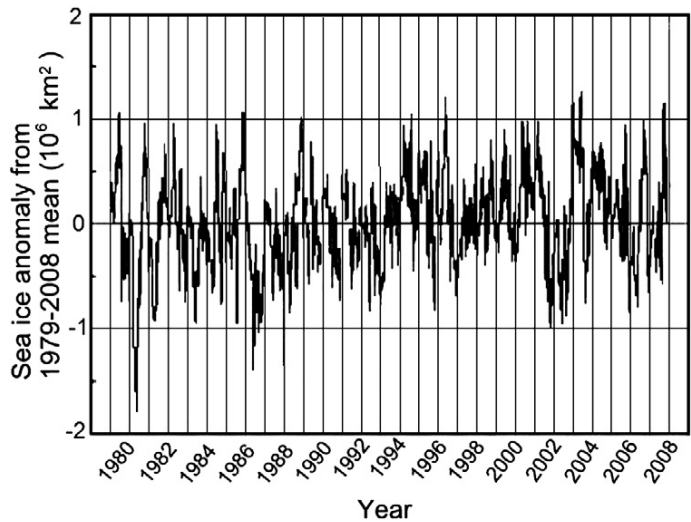


FIGURE 14 Antarctic sea ice has not declined since 1979 (Arctic Climate Research, University of Illinois; NOAA data).

Arctic and Antarctic Standardized Anomalies and Trends
Jan 1979 - Jul 2009

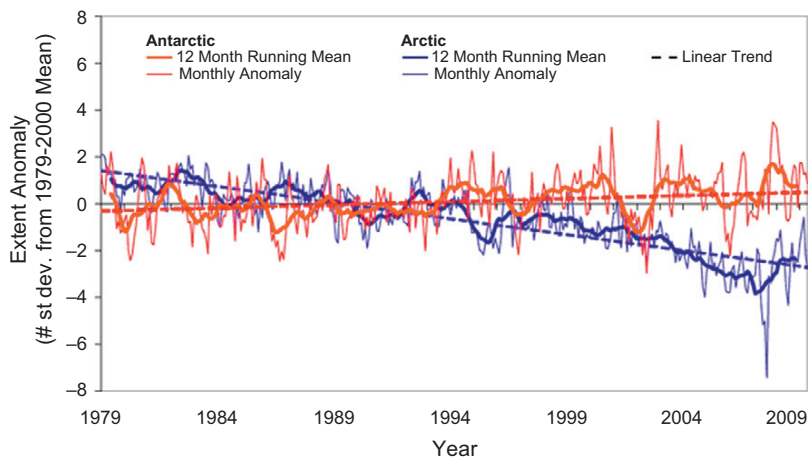


FIGURE 15 Comparison of sea ice extent in the Arctic and Antarctic from 1979 to 2009. Arctic sea ice extent declined, whereas Antarctic sea ice increased (National Snow and Ice Data Center, University of Colorado).

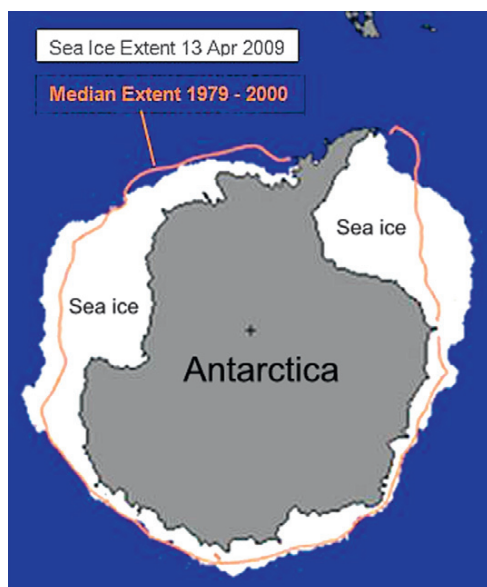


FIGURE 16 Extent of Antarctic sea ice in 2009 compared to the median extent from 1979 to 2000 (National Snow and Ice Data Center, University of Colorado).

3.2. Alpine Glaciers

Because their ice volume is not large and they are in equilibrium with local climate, Alpine glaciers record climatic changes by retreating during warm periods and receding 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 1945–1977 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 retreated during the 1977–1998 warm period. Thus, three of the four 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 warming following the cooler climates of the Little Ice Age. Thus, they are well upvalley from their Little Ice Age maximums.

4. ATMOSPHERIC CARBON DIOXIDE

Atmospheric CO_2 is a non-toxic, colorless, odorless gas that constitutes a tiny portion of the Earth's atmosphere, making up only ~0.038% of the atmosphere (Fig. 17). In every 100,000 molecules of air, 78,000 are nitrogen,

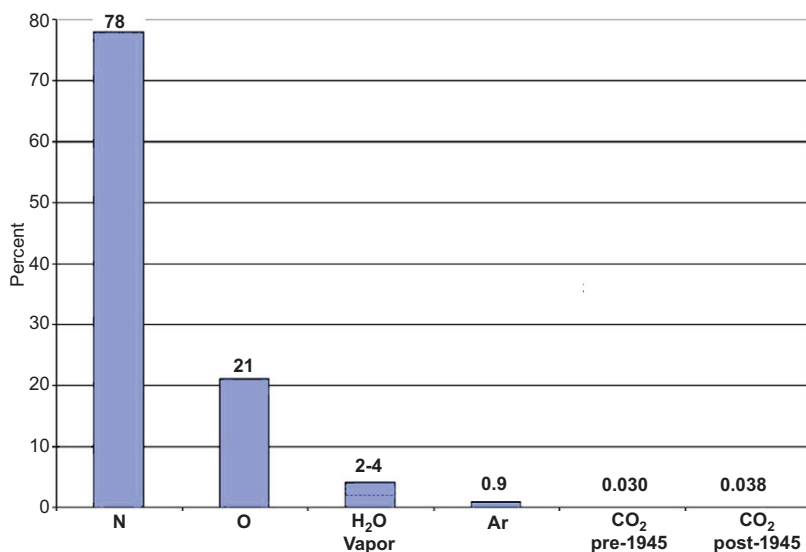


FIGURE 17 Composition of the atmosphere. CO_2 makes up only 0.03% of the atmosphere.

21,000 are oxygen, 2,000–4,000 are water vapor, and only 30 are carbon dioxide.

CO₂ is soluble in water and varies with the temperature of the water. Cold water can hold more CO₂ than warm water and seawater contains about 75 times as much CO₂ as fresh water. As water temperature increases, the solubility of CO₂ decreases and is given off into the atmosphere to establish a new equilibrium between the air and water. At 25 °C, water contains about 50 times as much CO₂ as air. The high solubility and chemical reactivity of CO₂ permit ready exchange of CO₂ between the atmosphere and oceans. CO₂ solubility depends on temperature, so changes in sea surface temperature affect CO₂ exchange with the atmosphere.

When global temperatures rise, as during interglacial periods, atmospheric CO₂ rises and when temperatures decline, as during Ice Ages, atmospheric CO₂ declines. Measurements of CO₂ from air trapped in polar ice cores over tens of thousands of years show that atmospheric CO₂ concentrations typically vary from about 260 to 285 ppm, averaging about 280 ppm. Higher CO₂ levels during the past interglacial periods do not indicate that CO₂ is the *cause* of the warmer interglacials because the CO₂ increase *lagged* Antarctic warming by 600 to 800 ± 200 years (Fischer et al., 1999; Caillon et al., 2003).

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%. Most of the greenhouse warming effect takes place within the first 20 ppm of CO₂. After that, the effect decreases exponentially (Fig. 18) so the rise in atmospheric CO₂ from 0.030% to 0.038%

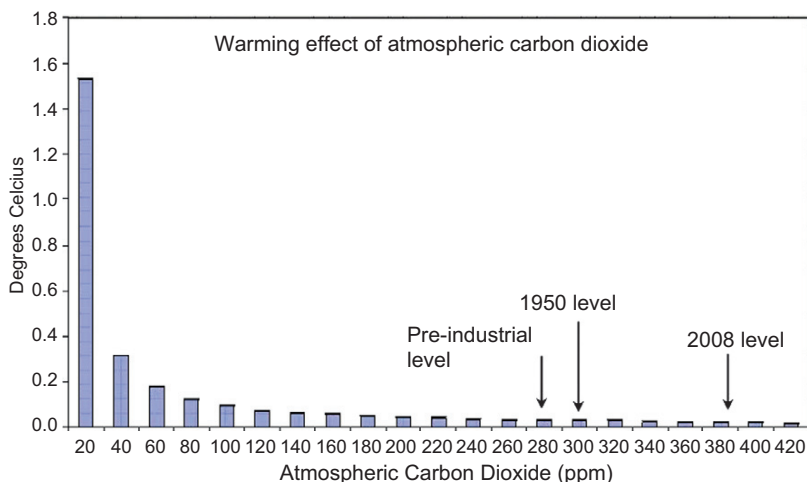


FIGURE 18 Warming effect of CO₂ (from D. Archibald).

from 1950 to 2008 could have caused warming of only about 0.01°C . The total change in CO_2 of the atmosphere amounted to an addition of only 1 molecule of CO_2 per 10,000 molecules of air.

Atmospheric CO_2 rose slowly from the mid-1700s to 1945. Emissions began to soar abruptly in 1945 after World War II (Fig. 19). CO_2 has risen at a fairly constant rate since then, going from about 300 ppm in 1955 to about 385 ppm in 2007.

At the abrupt 1977 ‘Great Climate Shift’ when the global climate shifted from cooling to warming, no significant change occurred in the rate of increase of CO_2 (Fig. 20), suggesting that CO_2 had nothing to do with the shifting of the climate.

CO_2 which makes up only 0.038% of the atmosphere and constitutes only 3.6% of the greenhouse effect has increased only 0.008% since emissions began to soar after 1945. How can such a tiny, tiny increment of CO_2 cause the 10°F increase in temperature predicted by CO_2 advocates? The obvious answer is that it can’t. Computer climate modelers build into their models a high water vapor component, which they claim is due to increase atmospheric water vapor caused by very small warming from CO_2 , and since water vapor makes up 95% of the greenhouse effect, they claim the result will be warming. The problem is that there is no evidence whatsoever of any increase in atmospheric water vapor content. Until the modelers can prove that water vapor has increased, their models are not credible.

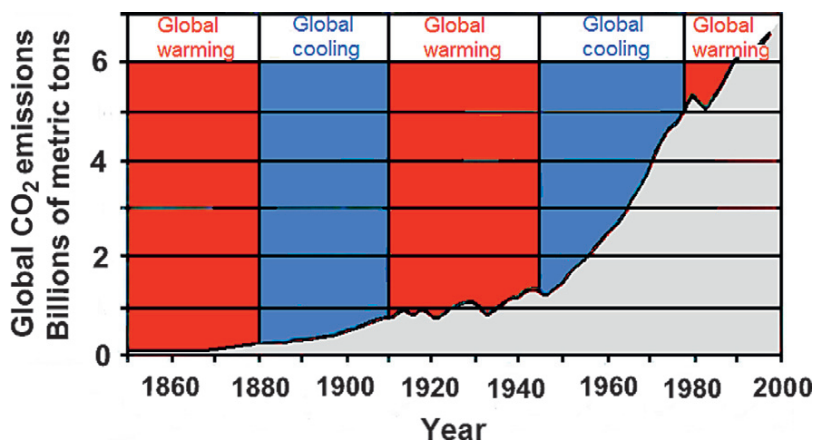
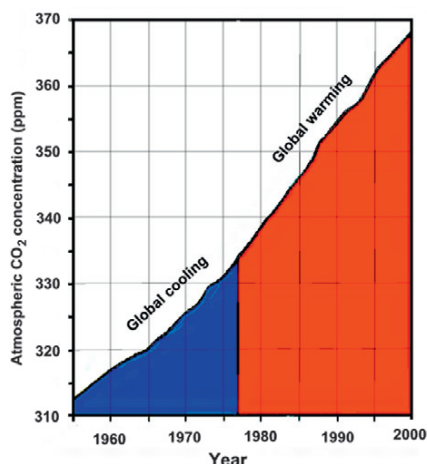


FIGURE 19 CO_2 emissions from 1850 to 2000. Note that CO_2 emissions were low during the global warming from 1850 to 1880 and rose slowly during the deep global cooling from 1880 to about 1915. Emissions were fairly constant during the strong global warming from 1915 to 1945. While emissions were soaring from 1945 to 1977, the global climate cooled, rather than warmed as it should have if CO_2 was the cause of global warming.

FIGURE 20 Atmospheric CO₂ from 1955 to 2000. Note that CO₂ rose smoothly without any sign of unusual increase across the ‘Great climate shift’ from cool to warm in 1977.



4.1. Global Warming and CO₂ During the Past Century

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. 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.

4.1.1. Global Warming from 1915 to 1945 could not be Caused by Atmospheric CO₂

From 1915 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 CO₂ emissions began to soar (after 1945) (Figs. 19), so at least half of the warming of the past century cannot have been caused by manmade CO₂.

4.1.2. Global Cooling Occurred from 1945 to 1977 While CO₂ Emissions Soared

Global temperatures began to cool in the 1940s at the point when CO₂ emissions began to soar (Fig. 19). For 30 years thereafter temperatures declined 0.2 °C (0.4 °F) globally and 0.5 °C (0.9 °F) in the Northern Hemisphere. During this 30-year period (1945–1977), glaciers ceased the recession of the preceding ~30 years and advanced. By 1977, many advancing glaciers had recovered much of the length lost in the previous ~30 years 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 (1915 or 1977) and ending with the minimum extent of the present 30-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.

Even though CO₂ emissions rose sharply from 1945 to 1977, global temperature dropped during that 30-year period. If CO₂ causes global warming, temperature should have risen, rather than declined, strongly suggesting that rising CO₂ does not cause significant global warming. Clearly the climate was driven by natural causes.

4.1.3. Global Warming from 1977 to 1998

In 1977, global temperatures, which had been declining since the late 1940s, abruptly reversed and began to rise. This sudden reversal of climate has been termed as “The Great Climate Shift” because it happened so abruptly (Miller et al., 1994). Global temperatures rose ~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. The warmest year was 1998, after which global temperatures declined slightly until 2007 when sharp cooling began.

During this time, atmospheric CO₂ has continued to rise, the only period in the past century when global warming and atmospheric CO₂ have risen together. However, this doesn’t prove a cause-and-effect relationship—just because two things happened together doesn’t prove that one is the cause of the other.

4.2. Is Global Warming Caused by Rising CO₂?

No tangible, physical evidence exists that proves a cause-and-effect relationship between global climate changes and atmospheric CO₂. The fact that CO₂ is a greenhouse gas and that CO₂ has increased doesn’t prove that CO₂ has caused global warming. Ninety five percent of greenhouse gas warming is due to water vapor and there is no evidence that atmospheric water vapor has increased. Only 3.6% of the greenhouse effect is due to CO₂.

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.

5. LESSONS FROM PAST GLOBAL CLIMATE CHANGES

Those who advocate CO₂ 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 CO₂. Statements such as these are easily refutable by the geologic record. Figure 21 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 the profound climate reversals over the past 15,000 years.

The GISP2 Greenland ice core isotope data have proven to be a great source of climatic data from the geologic past. Paleo-temperatures for thousands of years have been determined by Minze Stuiver and Peter Grootes from nuclear accelerator measurements of thousands of oxygen isotope ratios (¹⁶O/¹⁸O), and these data have become a world standard (Grootes and Stuiver, 1997). Oxygen isotope ratios are a measure of paleo-temperatures at the time snow fell that was later converted to glacial ice. The age of such temperatures can be accurately measured from annual layers of accumulation of rock debris marking each summer's melting of ice and concentration of rock debris on the glacier. The top of the core is 1987.

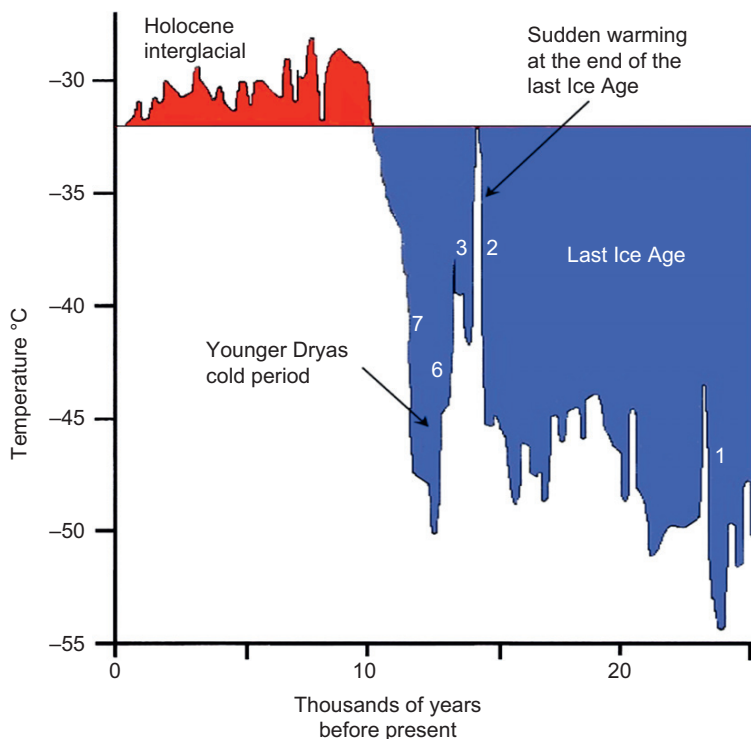


FIGURE 21 Greenland temperatures over the past 25,000 years recorded in the GISP2 ice core. Strong, abrupt warming is shown by nearly vertical rise of temperatures, strong cooling by nearly vertical drop of temperatures (modified from Cuffey and Clow, 1997).

The ratio of ^{18}O to ^{16}O depends on the temperature at the time snow crystals formed, which were later transformed into glacial ice. Ocean volume may also play a role in $\delta^{18}\text{O}$ values, but $\delta^{18}\text{O}$ serves as a good proxy for temperature. The oxygen isotopic composition of a sample is expressed as a departure of the $^{18}\text{O}/^{16}\text{O}$ ratio from an arbitrary standard

$$\delta^{18}\text{O} = \frac{(^{18}\text{O}/^{16}\text{O})_{\text{sample}} - (^{18}\text{O}/^{16}\text{O})_{\text{standard}} \times 10^3}{(^{18}\text{O}/^{16}\text{O})_{\text{standard}}}$$

where $\delta^{18}\text{O}$ is the of ratio $^{18}\text{O}/^{16}\text{O}$ expressed in per mil (0/00) units.

The $\delta^{18}\text{O}$ data clearly show remarkable swings in climate over the past 100,000 years. In just the past 500 years, Greenland warming/cooling temperatures fluctuated back and forth about 40 times, with changes in every 25–30 years (27 years on the average). None of these changes could have been caused by changes in atmospheric CO_2 because they predate the large CO_2 emissions that began about 1945. Nor can the warming of 1915–1945 be related to CO_2 , because it pre-dates the soaring emissions after 1945. Thirty years of global cooling (1945–1977) occurred during the big post-1945 increase in CO_2 .

5.1. Magnitude and Rate of Abrupt Climate Changes

But what about the *magnitude* and *rates of climates change*? How do past temperature oscillations compare with recent global warming (1977–1998) or with warming periods over the past millennia. The answer to the question of magnitude and rates of climate change can be found in the $\delta^{18}\text{O}$ and ice core temperature data.

Temperature changes in the GISP2 core over the past 25,000 years are shown in Fig. 21 (from Cuffey and Clow, 1997). The temperature curve in Fig. 21 is a portion of their original curve. Color has been added to make it easier to read. The horizontal axis is time and the vertical axis is temperature based on the ice core $\delta^{18}\text{O}$ and borehole temperature data. Details are discussed in their paper. Places where the curve becomes nearly vertical signify times of very rapid temperature change. Keep in mind that these are temperatures in Greenland, not global temperatures. However, correlation of the ice core temperatures with worldwide glacial fluctuations and correlation of modern Greenland temperatures with global temperatures confirms that the ice core record does indeed follow global temperature trends and is an excellent proxy for global changes. For example, the portions of the curve from about 25,000 to 15,000 represent the last Ice Age (the Pleistocene) when huge ice sheets, thousands of feet thick, covered North America, northern Europe, and northern Russia and alpine glaciers readvanced far downvalley.

How do the magnitude and rates of change of modern global warming/cooling compare to warming/cooling events over the past 25,000 years? We can compare the warming and cooling in the past century to approximate 100-year periods in

the past 25,000 years. The scale of the curve doesn't allow enough accuracy to pick out exactly 100-year episodes directly from the curve, but that can be done from the annual dust layers in ice core data. Thus, not all of the periods noted here are exactly 100 years. Some are slightly more, some are slightly less, but they are close enough to allow comparison of magnitude and rates with the past century.

Temperature changes recorded in the GISP2 ice core from the Greenland Ice Sheet (Fig. 1) (Cuffey and Clow, 1997) show that the global warming experienced during the past century pales into insignificance when compared to the magnitude of profound climate reversals over the past 25,000 years. 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.

Some of the more remarkable sudden climatic warming periods are listed below. Numbers correspond to the temperature curves in Fig. 21.

1. About 24,000 years ago, while the world was still in the grip of the last Ice Age and huge continental glaciers covered large areas, a sudden warming of about 10 °C (20 °F) occurred.
2. About 14,000 years ago, a sudden, intense, climatic warming (~13 °C; ~22 °F) caused dramatic melting of large Pleistocene ice sheets that covered Canada and the northern U.S., all of Scandinavia, and much of northern Europe and Russia.
3. Shortly thereafter, temperatures dropped abruptly about 10 °C (20 °F) and temperatures then remained cold for several thousand years but oscillated between about 4 °C (8 °F) warmer and cooler.
4. About 13,000 years ago, global temperatures plunged sharply (~12 °C; ~21 °F) and a 1,300-year cold period, the Younger Dryas, began.
5. 11,500 years ago, global temperatures rose sharply (~12 °C; ~21 °F), marking the end of the Younger Dryas cold period and the end of the Pleistocene vIce Age. The end of the Younger Dryas cold period warmed by 5 °C (9 °F) over 30–40 years and as much as 8 °C (14 °F) over 40 years.

Figure 22 shows comparisons of the largest magnitudes of warming/cooling events per century over the past 25,000 years. At least three warming events were 20–24 times the magnitude of warming over the past century and four were 6–9 times the magnitude of warming over the past century. The magnitude of the only modern warming which might possibly have been caused by CO₂ (1978–1998) is insignificant compared to the earlier periods of warming.

5.1.1. Holocene Climate Changes (10,000 Years Ago to Present)

Most of the past 10,000 have been warmer than the present. Figure 23 shows temperatures from the GISP2 Greenland ice core. With the exception of a brief cool period about 8,200 years ago, almost all of the entire period from 1,500 to 10,500 years ago was significantly warmer than the present.

Another graph of temperatures from the Greenland ice core for the past 10,000 years is shown in Fig. 24. It shows essentially the same temperatures as

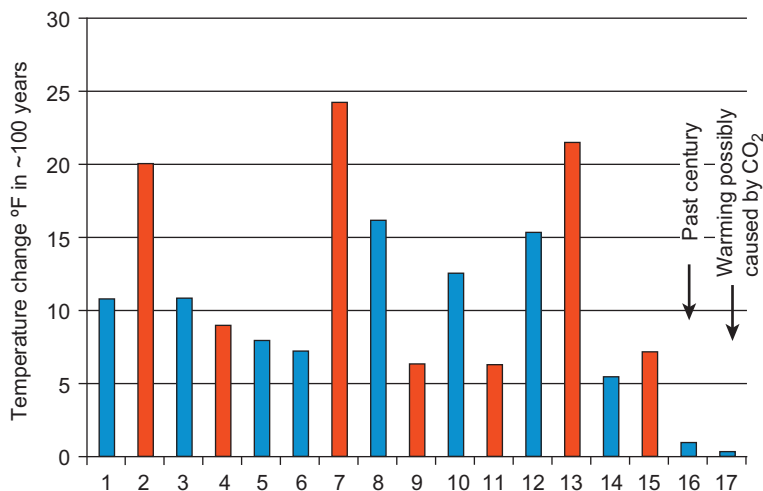


FIGURE 22 Magnitudes of the largest warming/cooling events over the past 25,000 years. Temperatures on the vertical axis are rise or fall of temperatures in about a century. Each column represents the rise or fall of temperature shown in Fig. 21. Event number 1 is about 24,000 years ago and event number 15 is about 11,000 years old. The sudden warming about 14,000 years ago caused massive melting of these ice sheets at an unprecedented rate (Steffensen et al., 2008).

Cuffey and Clow (1997) but with somewhat greater detail. What both of these temperature curves show is that virtually all of the past 10,000 years have been warmer than the present.

5.1.1.1. Early Holocene Climate Changes

8,200 years ago, the post-Ice Age interglacial warm period was interrupted by a sudden global cooling that lasted for a few centuries (Fig. 25). During this time, alpine glaciers advanced and built moraines. The warming that followed

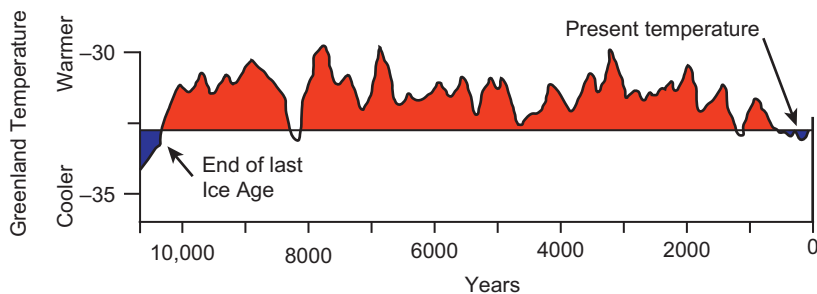


FIGURE 23 Temperatures over the past 10,500 years recorded in the GISP2 Greenland ice core. Red corresponds to temperatures warmer than the present (modified from Cuffey and Clow, 1997).

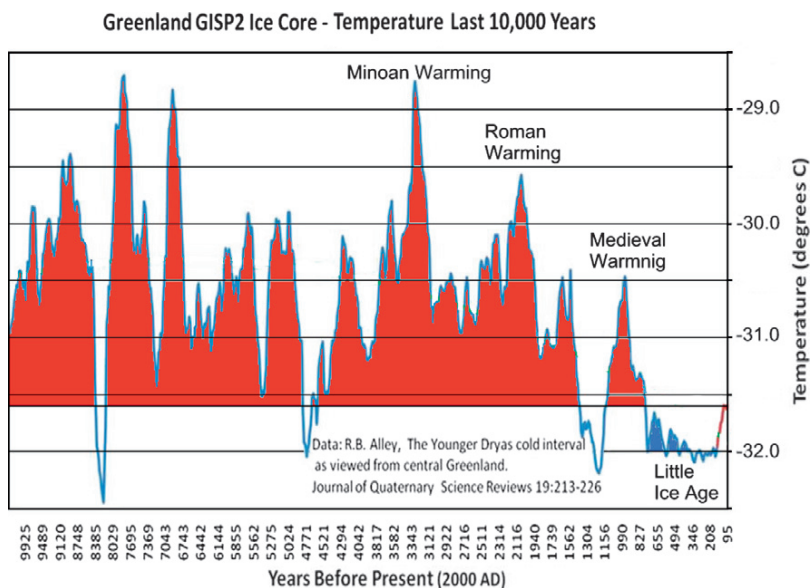


FIGURE 24 Temperatures over the past 10,000 years recorded in the GISP2 Greenland ice core (modified from Alley, 2000).

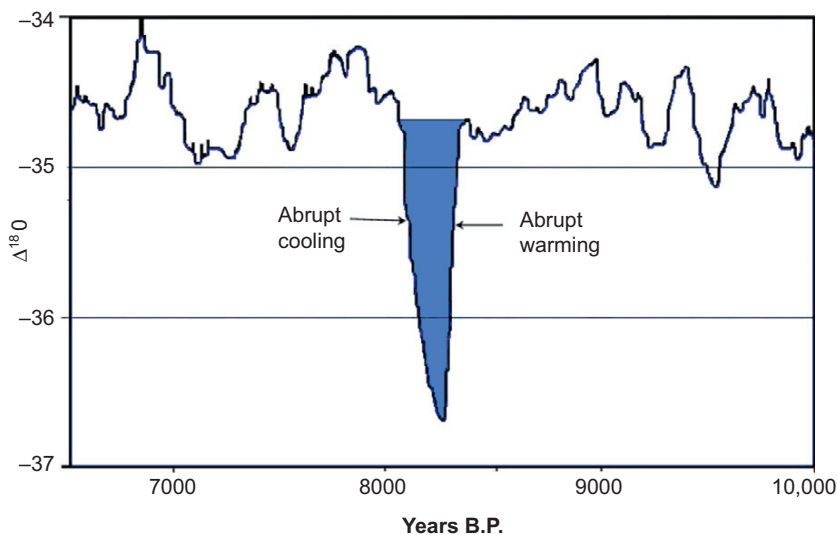


FIGURE 25 The 8,200-year B.P. sudden climate change, recorded in oxygen isotope ratios in the GISP2 ice core, lasted about 200 years.

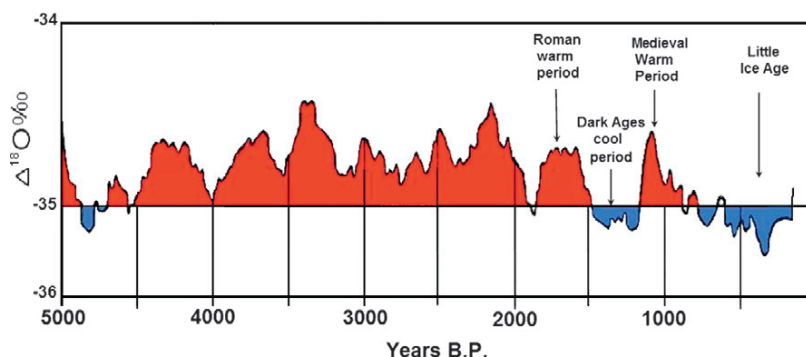


FIGURE 26 Oxygen isotope ratios for the past 5,000 years. Red areas are warm periods and blue areas are cool periods. Except for the Dark Ages Cool Period, almost all of the last 5,000 years was warmer than present until about 700 years ago.

the cool period was also abrupt. Neither the abrupt climatic cooling nor the warming that followed was preceded by atmospheric CO_2 changes.

The Greenland ice core isotope curve shows that almost all of the past 5,000 years, except for the Dark Ages Cool Period, were warmer than present until about 700 years ago (Fig. 26).

5.1.1.2. 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 B.C. to 450 B.C. and the Romans wrote that the Tiber River froze and snow remained on the ground for long periods (Singer and Avery, 2007).

5.1.1.3. 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 and Avery, 2007).

5.1.1.4. 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).

5.1.1.5. Climate Changes Over the Past 500 Years

The oxygen isotope curve of the Greenland GISP ice core shows a remarkable oscillation of warm/cool periods since 1480 A.D. (Fig. 27). At least 40 periods

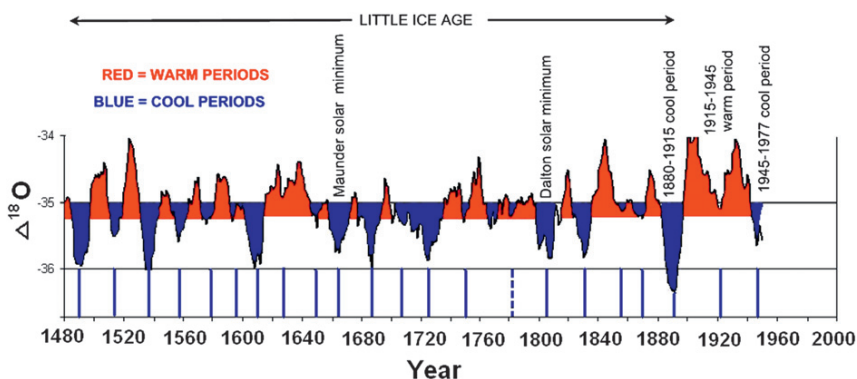


FIGURE 27 Greenland ice core isotope curve showing warming and cooling periods since 1480 A.D. The vertical lines at the bottom show peak cool periods which occurred with an average of every 27 years.

of warming and cooling have occurred since 1480 A.D., all well before CO₂ emissions could have been a factor. Historic warm and cool periods are well shown on the curve. The warm/cool cycles vary from about 25 to 30 years with an average of 27 years, almost identical to the typical Pacific Decadal Oscillation period (discussed later).

5.1.1.6. 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 A.D. to 1300 A.D. 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 m, but from about 1100 A.D. to 1300 A.D., vineyards extended up to 780 m, implying temperatures warmer by about 1.0–1.4 °C (Oliver, 1973). Wheat and oats were grown around Trondheim, Norway, suggesting climates about 1 °C warmer than present (Fagan, 2000).

Elsewhere in the world, prolonged droughts affected the southwestern United States and Alaska warmed. Sediments 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 A.D. to 1270 A.D. 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

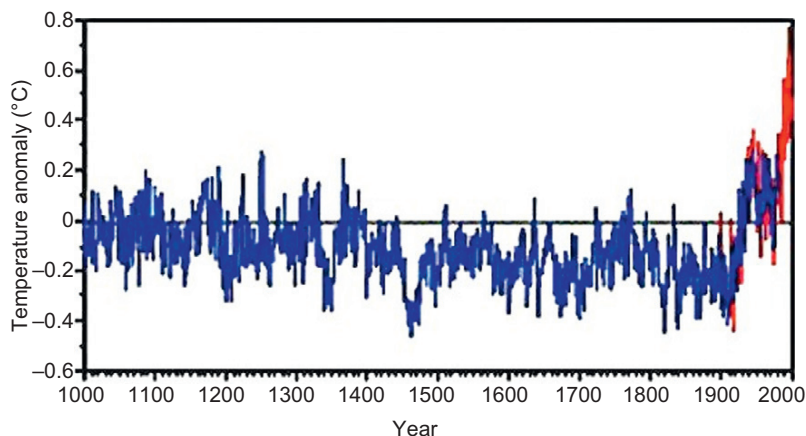


FIGURE 28 Mann et al. (1998) “hockey stick” graph of temperature change over the past 1,000 years based on tree rings.

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 is summarized in Fagan (2007) and Singer and Avery (2007). Evidence that the Medieval Warm Period was a global event is so widespread that one wonders why Mann et al. (1998) ignored it.

The Hockey Stick Trick Over a period of many decades, several thousand papers were published establishing the Medieval Warm Period (MWP) from about 900 A.D. to 1300 A.D. and the Little Ice Age (LIA) from about 1300 A.D. to 1915 A.D. as global climate changes. Thus, it came as quite a surprise when Mann et al. (1998) (Fig. 28) concluded that neither the MWP nor the Little Ice Age actually happened on the basis of a tree-ring study and that became the official position of the 2001 Intergovernmental Panel on Climate Change (IPCC). The IPCC 3rd report (Climate Change 2001) then totally ignored the several thousand publications detailing the global climate changes during the MWP and the LIA and used the Mann et al. tree-ring study as the basis for the now 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.*” (Gore, 2007). This claim was used as the main evidence that increasing atmospheric CO₂ was causing global warming so, as revealed in the ‘Climategate’ scandal, advocates of the CO₂ theory were very concerned about the strength of data that showed the Medieval Warm Period (MWP) was warmer than the 20th century and that global warming had occurred naturally, long before atmospheric CO₂ began to increase. The contrived elimination of

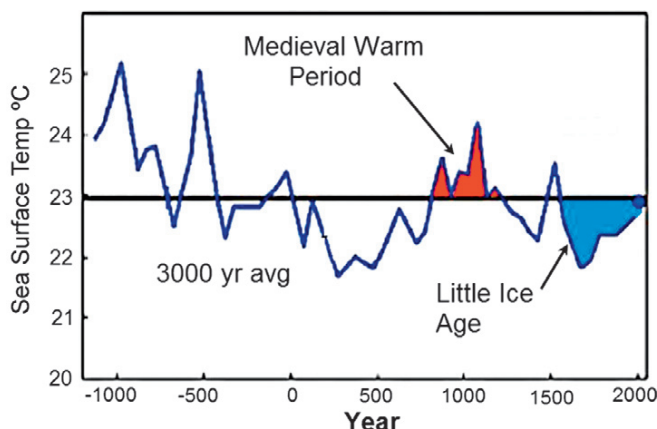
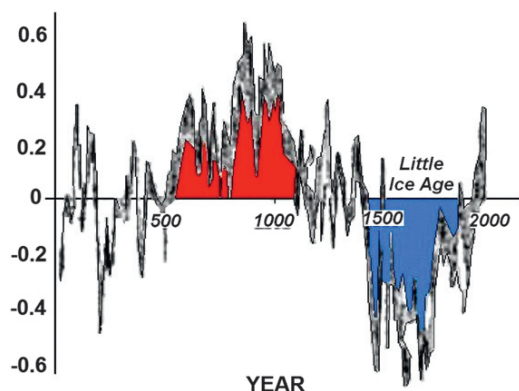


FIGURE 29 Surface temperatures of the Sargasso Sea reconstructed from isotope ratios in marine organisms (Keigwin, 1996).

the MWP and Little Ice Age by Mann et al. became known as “the hockey stick” of climate change where the handle of the hockey stick was supposed to represent constant climate until increasing CO_2 levels caused global warming, the sharp bend in the lower hockey stick.

The Mann et al. “hockey stick” temperature curve was at so at odds with thousands of published papers, including the Greenland GRIP ice core isotope data, sea surface temperatures in the Sargasso Sea sediments (Fig. 29) (Keigwin, 1996), paleo-temperature data other than tree rings (Fig. 30) (Loehle, 2007), and sea surface temperatures near Iceland (Fig. 31) (Sicre et al., 2008) one can only wonder how a single tree-ring study could purport to prevail over such a huge amount of data. At best, if the tree-ring study did not accord with so much other data, it should simply mean that the tree rings were

FIGURE 30 Reconstructed paleo-temperatures without tree ring data (Loehle, 2007).



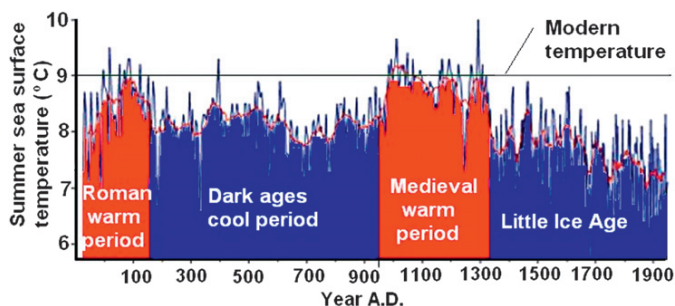


FIGURE 31 Summer sea surface temperatures near Iceland (Sicre et al., 2008).

not sensitive to climate change, not that all the other data were wrong. McIntyre and McKittrick (2003, 2005) 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 totally invalid and an embarrassment to the IPCC.

Why, then, did Mann’s hockey stick persuade so many non-scientists and gain such widespread circulation? The answer is apparent in revelations from e-mails disclosed in the Climategate scandal (Mosher and Fuller, 2010; Montford, 2010). These e-mails describe how they tried to “hide the decline” in temperatures, using various “tricks” in order to perpetuate a dogmatic view of anthropogenic global warming.

5.1.1.7. The Little Ice Age (1300 A.D. to the 20th Century)

At the end of the Medieval Warm Period, ~1230 A.D., 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. Temperatures of the cold winters and cool, rainy summers were too low for growing of cereal crops, resulting in widespread famine and disease (Fagan, 2000; Grove, 2004). When temperatures declined during the 30-year cool period from the late 1940s to 1977, climatologists and meteorologists predicted a return to a new Little Ice Age.

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. 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 sunspots. From 1645 to 1715, the number of sunspots observed 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 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}Be in the upper atmosphere.

Global temperatures have risen about 1°F per century since the cooling of the Little Ice Age, but the warming has not been continuous. Numerous ~30-year warming periods have been interspersed with ~30-year cooling periods (Fig. 27). However, each warming period has been slightly warmer than the preceding one and 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. However, because each warm cycle was slightly warmer than the previous one and each cool cycle not quite as cool as the previous one, glacier termini have progressively receded upvalley from their Little Ice Age maximums. These relationships are well shown on glaciers on Mt. Baker, Washington where large distinct Little Ice Age moraines mark the glacier termini well below present ice termini (Figs. 32, 33). The oldest Little Ice Age moraines have trees growing on them dating back to the 1500s. Successively higher moraines upvalley mark progressive advances and stillstands resulting from warm/cool cycles. The later moraines match the historic global climate changes.

A buried forest on the Coleman glacier moraine (Fig. 34), dated at 680 ± 80 and 740 ± 80 ^{14}C years B.P., grew during the Medieval Warm Period atop an older moraine (Easterbrook, 2010). The forest was later buried by a Little Ice Age moraine about 1300 A.D. Annual rings from trees growing on successively younger moraines upvalley show moraine-building episodes in the 1600s, ~1750, ~1790, ~1850, and ~1890, matching historic periods of global warming and cooling.

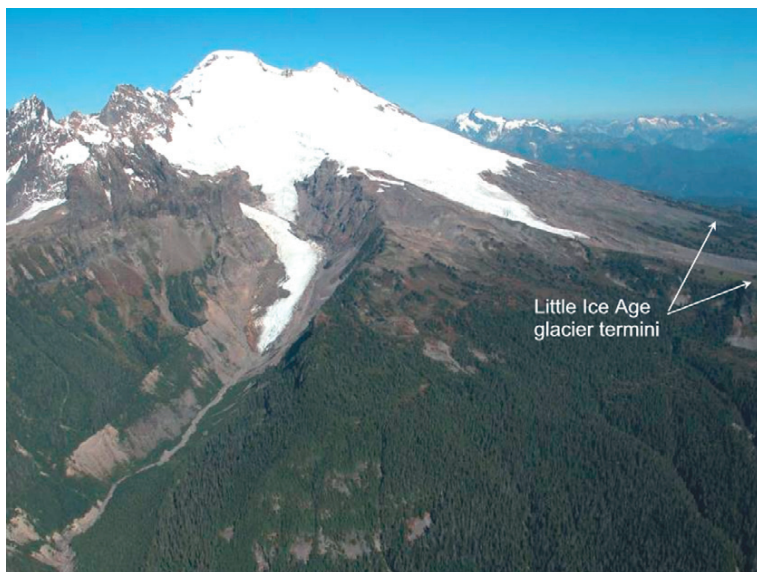


FIGURE 32 Ice retreat from Little Ice Age margins, Deming and Easton glaciers, Mt. Baker, Washington.

Ice margins of Mt. Baker glaciers are shown on air and ground photos dating back to 1943 (Figs. 35–40) (Easterbrook, 2010; Harper, 1993). Glaciers that had been retreating since at least the 1920s 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 feet upvalley from their 1979 positions.

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

Glaciers on Mt. Baker show a regular pattern of advance and retreat which matches sea surface temperatures in the NE Pacific Ocean (the Pacific Decadal Oscillation) (Fig. 41). The glacier fluctuations are clearly driven by changes in the sea surface temperatures. An important aspect of this is that the sea surface temperature records extend to about 1900, but the glacial record goes back many centuries and can be used as a proxy for climate changes.

Climate changes are also recorded in the Greenland Ice Sheet isotope data. Regular warm/cool cycles of approximately the same duration as the glacial moraine record extend back 500 years (Fig. 27).

The importance of the various types of evidence of climate fluctuations is that they show long-standing evidence of cool/warm cycles over many

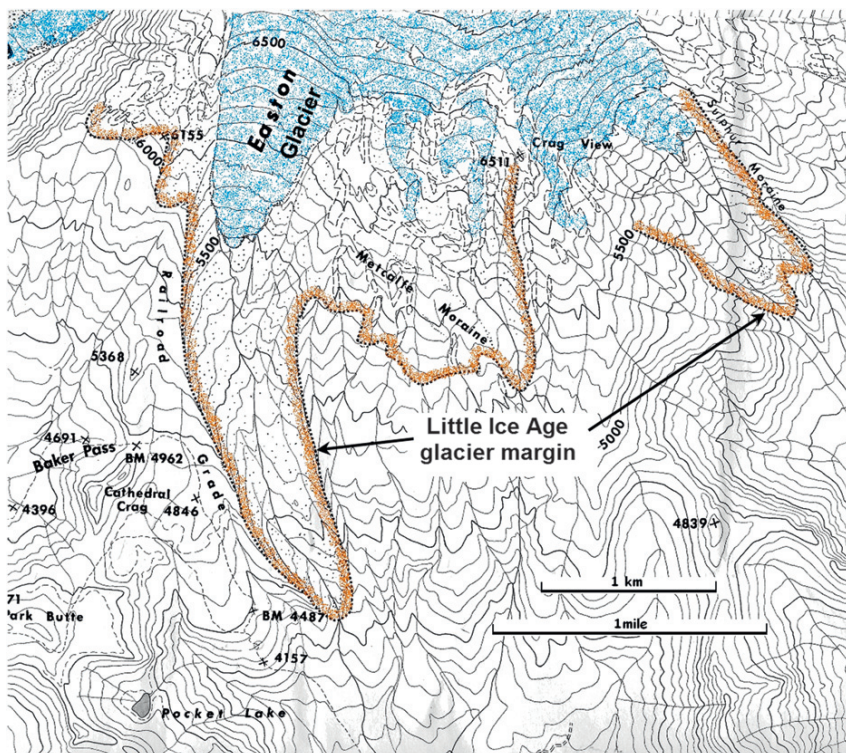


FIGURE 33 Little Ice Age glacier margins, Mt. Baker, WA.

centuries. Adding more recent, observed climatic fluctuations to the earlier records show that we are now right where we ought to be in this pattern, i.e., just past the end of the recent 20-year warm period. Extending this ongoing record into the future provides an opportunity to predict coming climate changes.

FIGURE 34 Little Ice Age moraine burying a forest that grew during the Medieval Warm Period, Coleman glacier, Mt. Baker, WA.

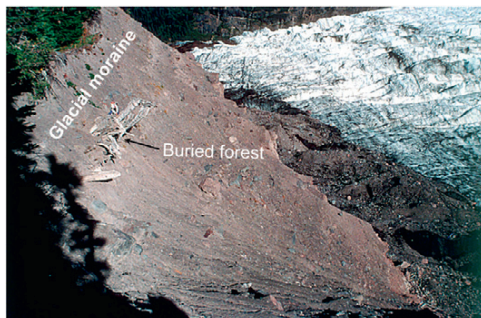




FIGURE 35 Easton glacier and Little Ice Age moraine, Mt. Baker, WA.

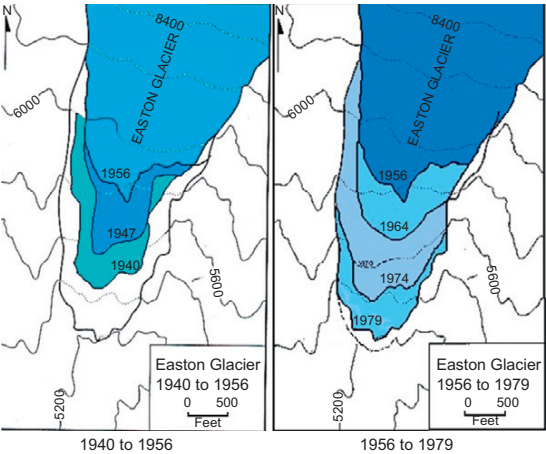


FIGURE 36 Retreat and advance of the Easton glacier (modified from Harper, 1993).



FIGURE 37 Retreat of the Easton glacier since 1979.

FIGURE 38 Boulder glacier, Mt. Baker, WA.



FIGURE 39 Retreat and advance of the Boulder glacier.

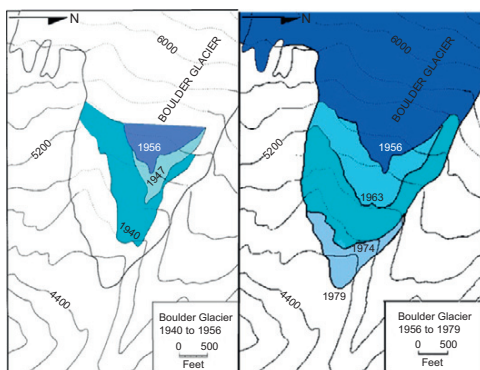
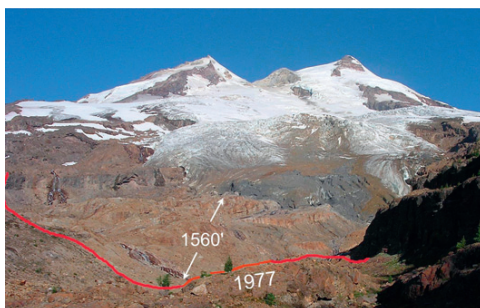


FIGURE 40 Retreat of the Boulder glacier since 1979, the beginning of the present 30-year warm cycle.



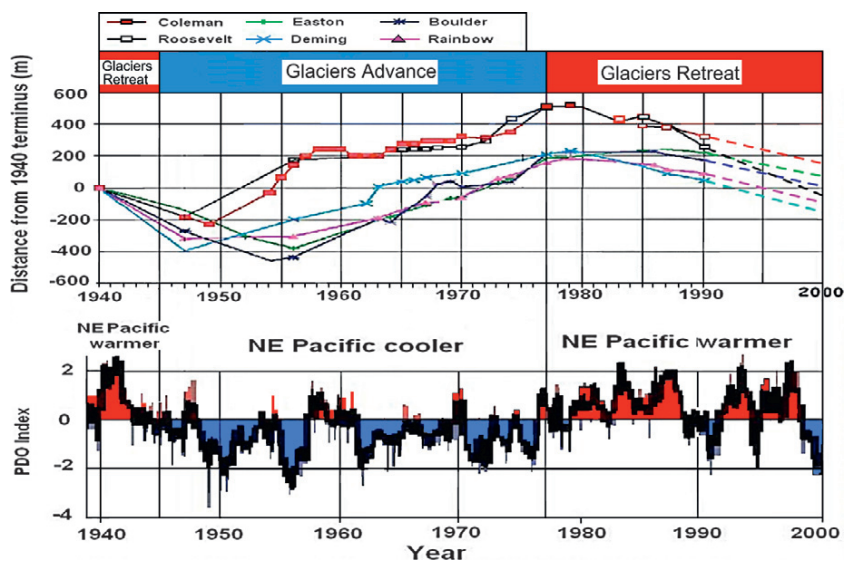


FIGURE 41 Comparison of advance and retreat of glaciers on Mt. Baker, WA with the Pacific Decadal Oscillation.

5.2. Significance of Previous Global Climate Changes

If CO_2 is indeed the cause of global warming, then global temperatures should mirror the rise in CO_2 . For the past 1,000 years, atmospheric CO_2 levels have remained fairly constant at about 280 parts per million (ppm). Atmospheric CO_2 concentrations began to rise during the industrial revolution early in the 20th century. In 1945, atmospheric CO_2 began to rise sharply and by 1980 it had risen to about 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. In 1977, global atmospheric temperatures again reversed suddenly, rising about 0.5°C (0.9°F) above the 1945–1977 cool cycle in 25 years. 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 and CO_2 is thus not significant. Temperature patterns since the Little Ice Age (~1600 A.D. to 1860 A.D.) show a very similar pattern—25–30 periods of alternating warm and cool temperatures. These temperature fluctuations took place well before any effect of anthropogenic atmospheric CO_2 and many were far greater. Most of the CO_2 from human activities was added to the air after 1945, 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, CO₂ cannot have been the cause of these climatic changes, so why should we suppose that the last one must be?

6. THE PACIFIC DECADAL OSCILLATION (PDO)

The Pacific Decadal Oscillation (PDO) refers to cyclical variations in sea surface temperatures in the Pacific Ocean. A summary of the PDO is given in D'Aleo (this volume). It was discovered in the mid-1990s by fisheries scientists studying the relationship between Alaska salmon runs, Pacific Ocean temperatures, and climate. Hare (1996), Zhang et al. (1997), 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 25–30 years then switched to the cool phase and vice versa. The PDO differs from El Niño/La Niña warm/cool oscillations, which persist for only 6–18 months in an east-west belt near the equator.

Figure 42 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 Fig. 42, 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 Niño in 2005–2006).

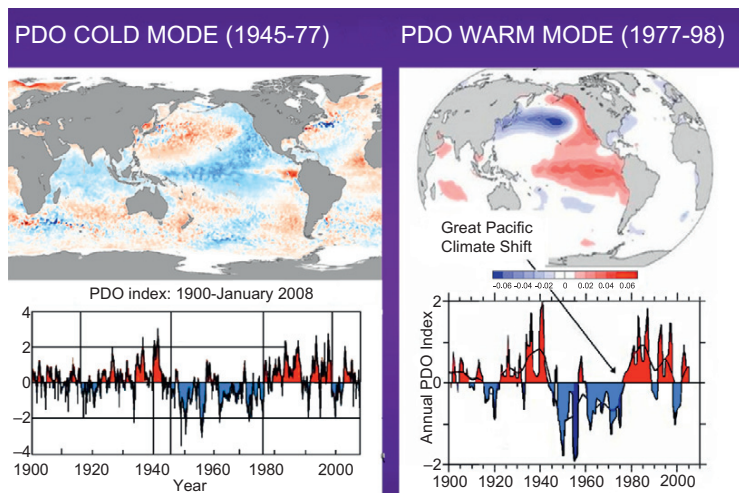


FIGURE 42 In 1945, the PDO (Pacific Decadal Oscillation) switched from its warm mode to its cool mode and global climate cooled from then until 1977, despite the sudden soaring of CO₂ emissions. In 1977, the PDO switched back from its cool mode to its warm mode, initiating what is regarded as ‘global warming’ (from 1977 to 1998).

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 CO₂ (Easterbrook, 2005, 2008a,b).

During the past century, global climates have consisted of two cool periods (1880–1915 and 1945–1977) and two warm periods (1915–1945 and 1977–1998). 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” (Fig. 4). Atmospheric CO₂ showed no unusual changes across this sudden climate shift (Fig. 20) and was clearly not responsible for it. Similarly, the global warming of 1915–1945 could not have been caused by increased atmospheric CO₂ because that time preceded the rapid rise of CO₂ after 1945 (Fig. 19) 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 have periods of about 25–30 years. Reconstruction of ancient PDO cycles by Verdon and Franks (2006) shows PDO warm and cool phases dating back to 1662 A.D.

6.1. The Cool Phase of the 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 1998 temperatures has occurred (Fig. 43) and the winters of

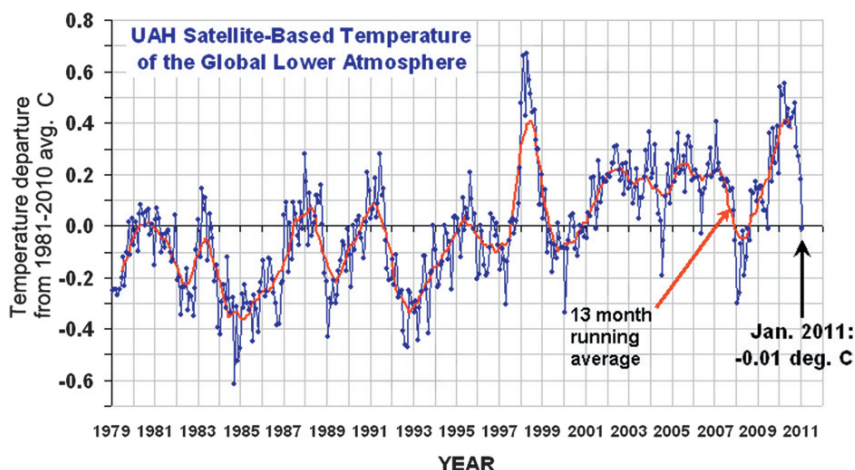


FIGURE 43 Satellite-based temperature of the global lower atmosphere from 1979 to 2011 (UAH, Spencer).

2006–2007, 2008–2009, 2010–2011 have set many records for snow and cold temperatures.

Figure 42 shows examples of the two temperature modes of the Pacific Ocean, its cool mode, which prevailed from about 1945 to 1977(left side) and its warm mode, which prevailed from 1977 to 1998. In each case, the global climate exactly followed the ocean temperature. The Pacific switches back and forth from warm to cool modes about every 30 years, a phenomenon known as the Pacific Decadal Oscillation (PDO).

Switching of the PDO back and forth from warm to cool modes has been documented by NASA satellite imagery. The satellite image from 1997 (Fig. 44) is typical of the warm PDO mode (1945–1977) with most of the eastern Pacific adjacent to North America showing shades of yellow to red, indicating warm water.

The satellite image from 1999 (Fig. 45) 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 1977–1998 warm cycle). The images below (Figs. 45–48) show the switch of the PDO from its warm cycle to the present cool cycle.

Each time this has occurred in the past century, global temperatures have remained cool for about 30 years. Thus, the current sea surface temperatures not only explain why we have had no global warming for the past 10 years, but also assure that cool temperatures will continue for several more decades (Easterbrook, 2001, 2006a,b, 2007, 2008c).

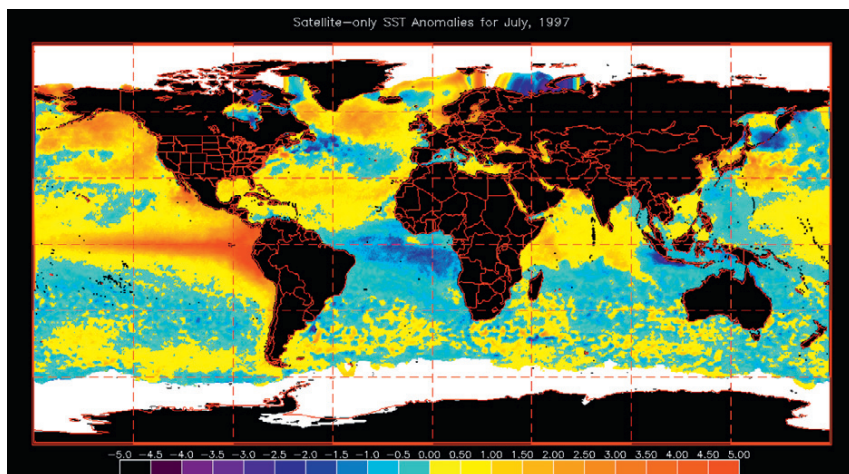


FIGURE 44 Satellite image of ocean temperature, 1997, showing strong warm PDO in the eastern Pacific. The deep red band at the equator is a strong El Niño that made 1997–1998 particularly warm.

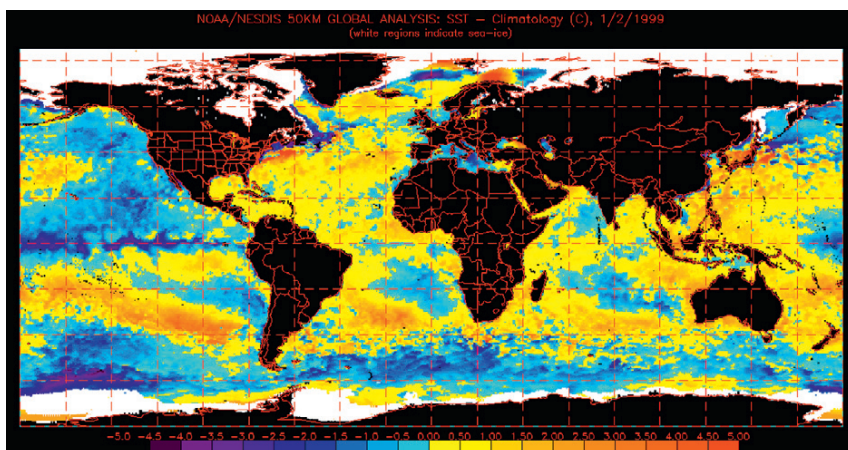


FIGURE 45 Satellite image of ocean temperature, 1999, showing the development of a strong cool PDO in the eastern Pacific that marked the end of 'global warming' and the beginning of the present cool cycle.

7. THE ATLANTIC MULTIDECADAL OSCILLATION (AMO)

The Atlantic Ocean also has multidecadal warm and cool modes with periods of about 30 years, 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. For a more detailed discussion, see D'Aleo (this volume).

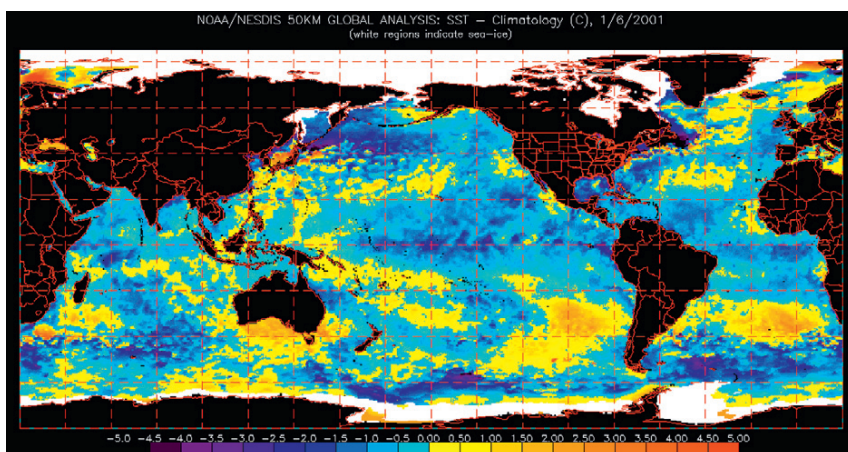


FIGURE 46 Satellite image of ocean temperature, 2001, showing entrenchment of the PDO cool cycle in the eastern Pacific off the coast of North America.

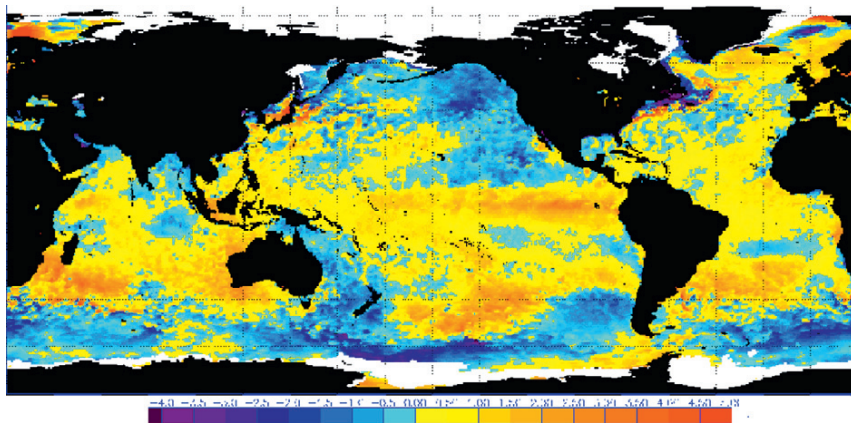


FIGURE 47 Satellite image of ocean temperature, 2006, showing continued entrenchment of the PDO cool cycle in the eastern Pacific off the coast of North America.

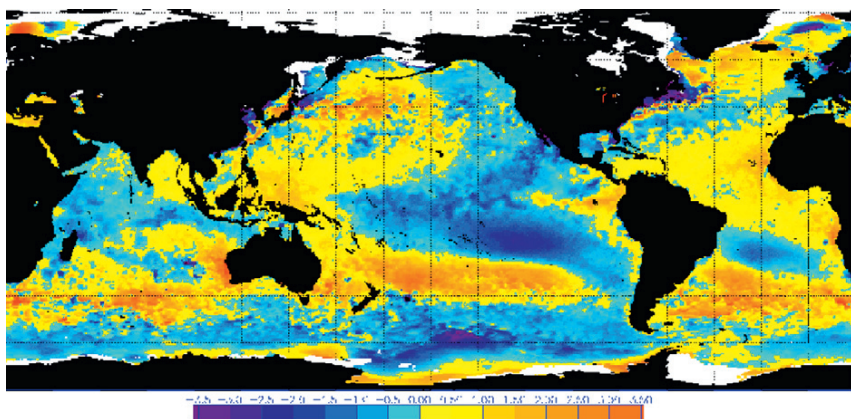


FIGURE 48 Satellite image of ocean temperature, February 22, 2011, showing the continued entrenchment of the PDO cool cycle in the eastern Pacific off the coast of North America.

Figures 49 and 50 show AMO and PDO cycles since 1900. Figure 51 shows the strong correlation between the PDO + AMO cycles and Arctic mean temperatures.

8. 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}C and ^{10}Be in the atmosphere by radiation, suggesting that the climate changes are caused by fluctuations in solar activity. A good example of the relationship between

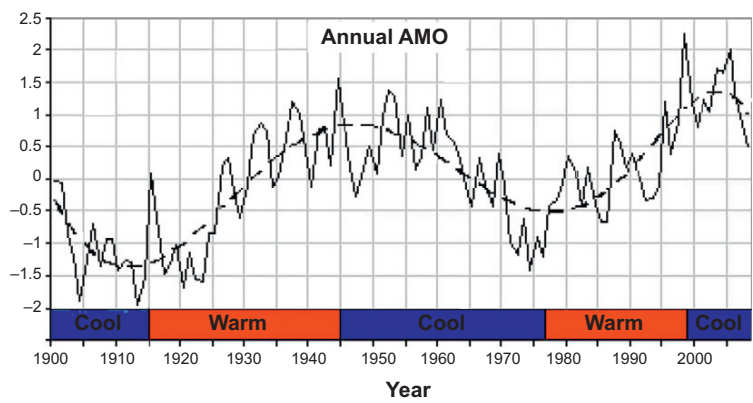


FIGURE 49 AMO cycles and global warming and cooling back to 1900 (modified from D’Aleo and Easterbrook, 2010).

solar activity and climate occurred during the Maunder Minimum. 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 more than a century (Fig. 52). From 1600 A.D. to 1700 A.D., very few sunspots were seen, despite the fact that many scientists with telescopes were looking for them, and reports of aurora borealis were minimal. This interval is known as

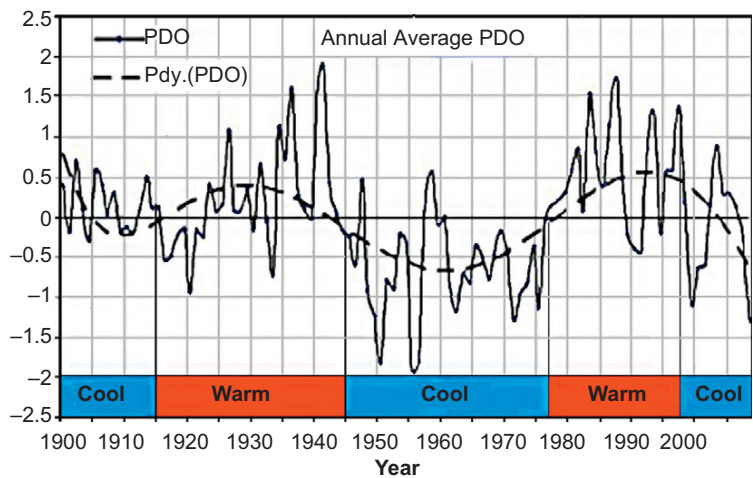
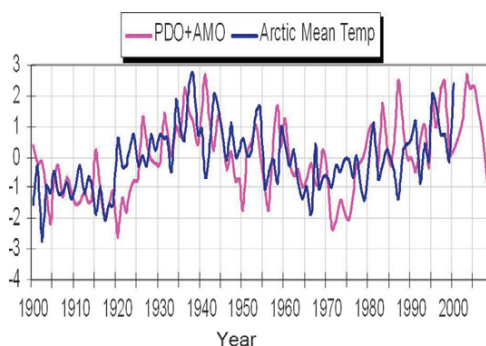


FIGURE 50 Annual average PDO back to 1900. Each warm/cool cycle lasts about 25–30 years and matches global climate changes (modified from D’Aleo and Easterbrook, 2010).

FIGURE 51 PDO + AMO oscillations since 1900 and arctic mean temperatures (modified from D'Aleo and Easterbrook, 2010).



the Maunder Minimum (Maunder, 1894; Maunder, 1922; Eddy, 1976; Soon, 2005). Between 1650 A.D. and 1700 A.D., global climates turned bitterly cold (the Little Ice Age), demonstrating a clear correspondence between sunspots and cool climate. After 1700 A.D., the number of observed sunspots increased sharply from nearly zero to 50–100 (Fig. 52) and the global climate warmed.

The Maunder Minimum was preceded by the Sporer Minimum (~1410–1540 A.D.) and the Wolf Minimum (~1290–1320 A.D.) (Fig. 53). Each of these periods is characterized by low numbers of sunspots, significant changes in the rate of production of ^{14}C in the atmosphere, and cooler global climates. During the Maunder Minimum, almost no sunspots occurred. The Dalton sunspot 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 sunspot minima (Fig. 53).

The correlation between sunspots and global climate is remarkable. Unlike CO_2 , which shows only a 4% correlation with climate changes over the past 500 years, the correlation of sunspots with climate change is close to 100% (Figs. 54, 55).

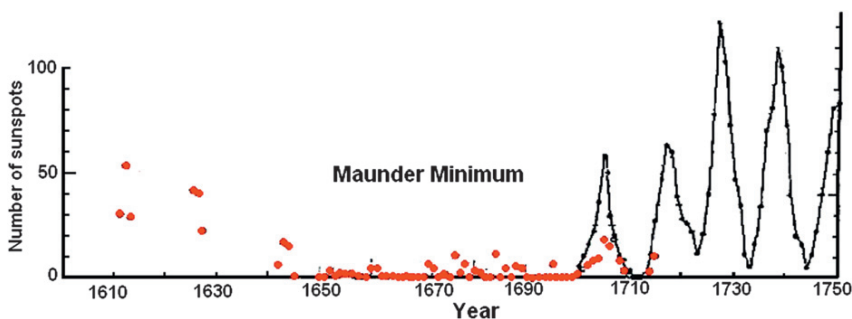


FIGURE 52 Sunspots during the Maunder Minimum (modified from Eddy, 1976).

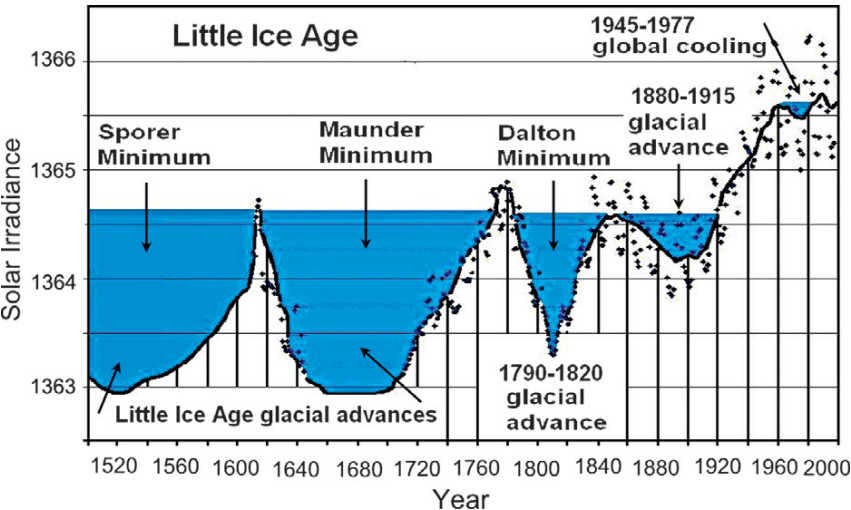


FIGURE 53 Correspondence of cold periods and solar minima from 1500 to 2000. Each of the five named solar minima was a time of sharply reduced global temperatures (blue areas).

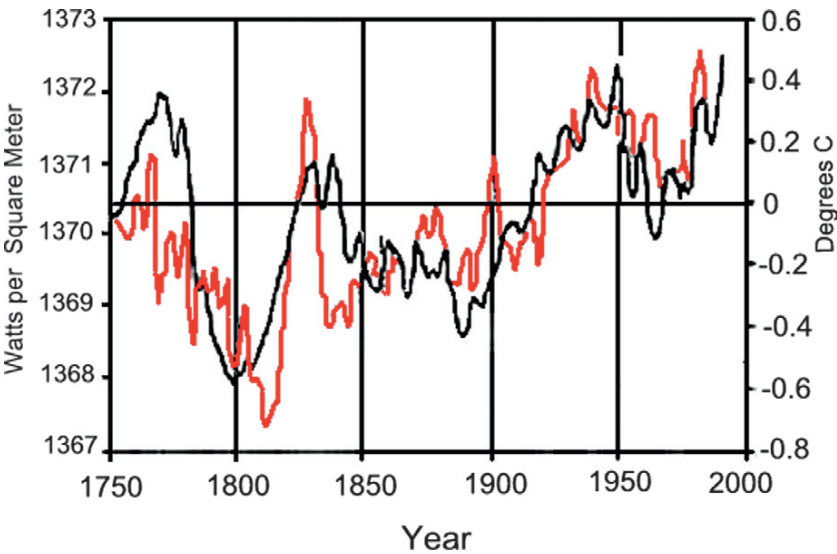


FIGURE 54 Solar irradiance and global temperature from 1750 to 1990. During this 250-year period, the two curves follow a remarkably similar pattern (modified from Hoyt and Schatten, 1997).

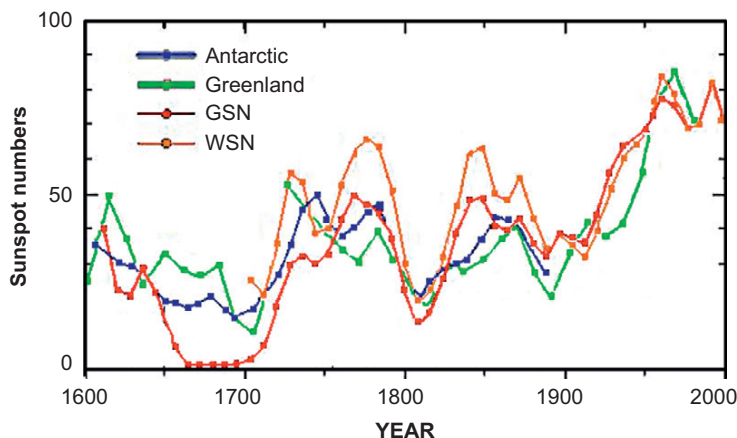


FIGURE 55 Correlation of sunspot numbers and temperatures in Greenland and Antarctica and cooling (modified from Usoskin et al., 2004).

8.1. 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, 1977; Stuiver and Quay, 1979), solar irradiance, and ^{10}Be (Beer et al., 1994, 1996, 2000; Beer et al., 2000) and ^{14}C production (Stuiver, 1961, 1994; Stuiver and Brasiunas, 1991, 1992; Stuiver et al., 1991, 1995) in the atmosphere. ^{10}Be is produced in the upper atmosphere by radiation bombardment of oxygen. 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.

Figure 56 shows a remarkable correlation between temperature, as measured from oxygen isotope variation, and variation in the rate of production of radiocarbon by radiation in the upper atmosphere, suggesting that temperature variations are caused by changes in radiation.

For many years, solar scientists considered variation in solar irradiance to be too small to cause significant climate changes. However, Svensmark has proposed a new concept of how the sun may impact Earth's climate (Svensmark and Calder, 2007; Svensmark and Friis-Christensen, 1997; Svensmark et al., 2007). Svensmark recognized the importance of cloud generation as a result of ionization in the atmosphere caused by cosmic rays. Clouds highly reflect incoming sunlight and tend to cool the Earth. The amount of cosmic radiation is greatly affected by the sun's magnetic field, so during times of weak solar magnetic field, more cosmic radiation reaches the Earth. Thus, perhaps variation in the intensity of the solar magnetic field may play an important role in climate change.

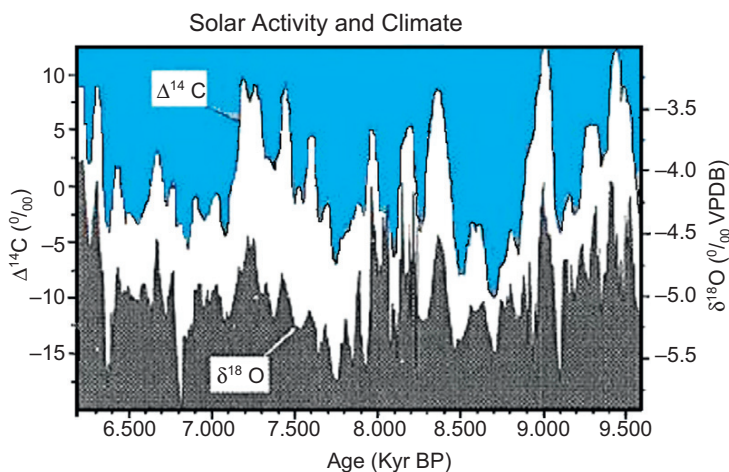


FIGURE 56 Correlation of temperature ($\delta^{18}\text{O}$) and radiocarbon production ($\delta^{14}\text{C}$) from a stalagmite in Oman (Matter et al., 2001).

9. WHERE ARE WE HEADED DURING THE COMING CENTURY?

9.1. IPCC Predictions

What does the century have in store for global climates? According to the Intergovernmental Panel on Climatic Change (IPCC), the Earth is in store for climatic catastrophe this century. Computer models predict global warming of as much as $5\text{--}6\text{ }^{\circ}\text{C}$ ($10\text{--}11\text{ }^{\circ}\text{F}$), predicated on the assumption that global warming is caused by increasing atmospheric CO_2 and that CO_2 will continue to rise.

The ramifications of such an increase in global warming are far reaching, even catastrophic in some areas. Such a rise of global surface temperatures would have devastating results. The Arctic Ocean would likely become free of its cover of sea ice, the Greenland Ice Sheet would diminish, and alpine glaciers would retreat rapidly, resulting in decreased water supply in areas that depend on snowmelt. Melting of Greenland and Antarctic ice would cause sea level to rise, flooding low coastal areas and submerging low coral islands in the oceans. Crops in critical agricultural areas would fail, resulting in widespread food shortages for people in agriculturally marginal areas. Wheat/grain belts, such as the mid-continent area of North America, would have to shift northward. Droughts would become increasingly severe in dry areas. Environmental impacts would be severe, resulting in extinction of some species and drastic population decreases in other.

IPCC computer models have predicted that global temperatures will rise $1\text{ }^{\circ}\text{F}$ per decade for the next 10 decades and be $10\text{ }^{\circ}\text{F}$ warmer by 2100 (Fig. 57).

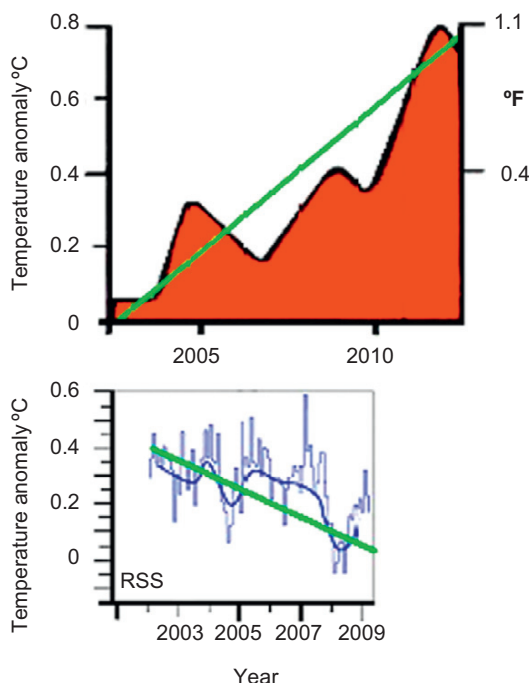


FIGURE 57 Comparison of IPCC global temperature prediction and actual temperature. Top: IPCC prediction in 2000 of 1 °F temperature increase per decade. Bottom: actual temperature for the decade.

According to their models, global temperature should have warmed 1 °F from 2000 to 2111, but global climates have actually cooled, not warmed, since 1998. Thus, the computer models have failed badly in predicting global climates and therefore must be considered unreliable.

9.2. Predictions Based on Past Climate Patterns

Predictions based on past warming and cooling cycles over the past 500 years accurately predicted the end of the 1977–1998 warm period and the establishment of cool Pacific sea surface temperatures. Past patterns strongly suggest that the next several decades will be cooler, not warmer.

Considering the positive correlations between solar activity and global climate change, what if the cause of global warming is solar, rather than atmospheric CO₂? Then all of the computer models are meaningless, and 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 rising trend from the Little Ice Age cool period. The PDO over the past century (Fig. 58)

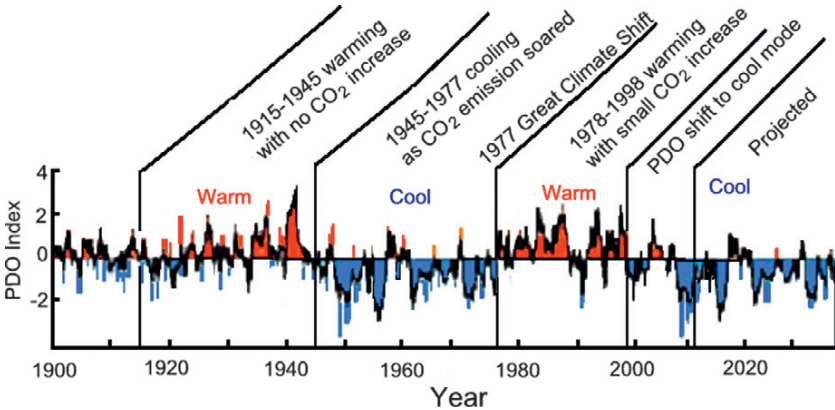


FIGURE 58 Pacific Decadal Oscillation pattern over the past century, extended into the next several decades.

has a consistent cyclic pattern that matches global climate changes. If the past climatic trend continues as it has for the past 500 years (Fig. 27) and if the PDO cyclic pattern continues as it has for the past century, global temperatures for the coming century might look like those shown in Fig. 59. When the Pacific Ocean switched from its warm mode to its cool in 1999 virtually assures global cooling for several decades, as it has with each mode switch in the past century.

The left side of Fig. 59 is the warming/cooling history of the past century. The right side of the graph shows the IPCC predicted temperature and several

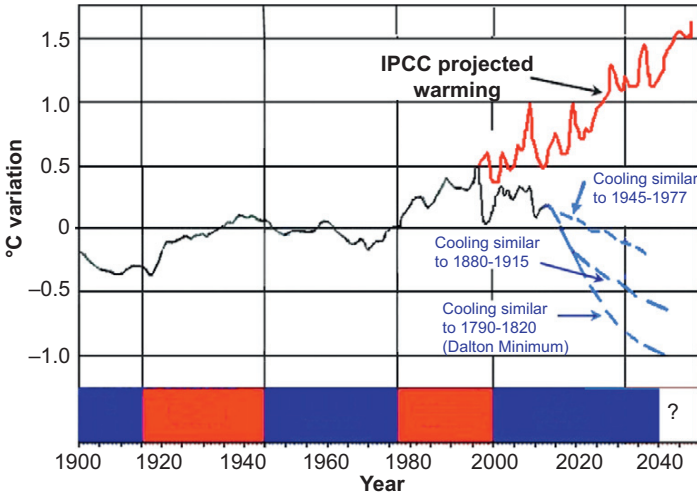


FIGURE 59 Projected climate for the century based on climatic patterns over the past 500 years and the switch of the PDO to its cool phase.

possible temperature patterns that we may well encounter if the cyclic climatic patterns of the past 400 years continue.

Three possible projections are shown: (1) moderate cooling (similar to the 1945–1977 cooling); (2) deeper cooling (similar to the 1880–1915 cooling); or (3) severe cooling (similar to the 1790–1830 cooling) during the Dalton Solar Minimum. A fourth possibility, very severe cooling similar to the Maunder Minimum, is also possible, but less likely. Time will tell which of these will be the case, but at the moment, the sun is behaving very similar to the Dalton Solar Minimum (Archibald, 2010), which was a very cold time. This is based on the similarity of sunspot cycle 23 to cycle 4 (which immediately preceded the Dalton Minimum).

We live in a most interesting time. As the global climate and solar variation reveal 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.

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