Chapter 5

Relationship of Multidecadal Global Temperatures to Multidecadal Oceanic Oscillations

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Chapter Outline

1. INTRODUCTION

The sun and ocean undergo regular changes on regular and predictable time frames. Temperatures likewise have exhibited changes that are cyclical. Sir Gilbert Walker was generally recognized as the first to find large-scale

Evidence-Based Climate Science. DOI: 10.1016/B978-0-12-385956-3.10005-1

oscillations in atmospheric variables. As early as 1908, while on a mission to explain why the Indian monsoon sometimes failed, he assembled global surface data and did a thorough correlation analysis.

On careful interpretation of statistical data, Walker and Bliss (1932) were able to identify three pressure oscillations:

1. A flip flop on a big scale between the Pacific Ocean and the Indian Ocean which he called the Southern Oscillation (SO).
2. A second oscillation, on a much smaller scale, between the Azores and Iceland, which he named the North Atlantic Oscillation.
3. A third oscillation between areas of high and low pressure in the North Pacific, which Walker called the North Pacific Oscillation.

Walker further asserted that the SO is the predominant oscillation, which had a tendency to persist for at least 1—2 seasons. He went so far in 1924 as to suggest the SOI had global weather impacts and might be useful in predicting the world's weather. He was ridiculed by the scientific community at the time for these statements. Not until four decades later was the Southern Oscillation recognized as a coupled atmosphere pressure and ocean temperature phenomena (Bjerknes, 1969) and more than two decades further before it was shown to have statistically significant global impacts and could be used to predict global weather/climate, at times many seasons in advance. Walker was clearly a man ahead of his time.

Global temperatures, ocean-based teleconnections, and solar variances interrelate with each other. A team of mathematicians (Tsonis et al., 2003, 2007), led by Dr. Anastasios Tsonis, developed a model suggesting that known cycles of the Earth's oceans—the Pacific Decadal Oscillation, the North Atlantic Oscillation, El Nino (Southern Oscillation), and the North Pacific Oscillation—all tend to synchronize with each other. The theory is based on a branch of mathematics known as Synchronized Chaos. The model predicts the degree of coupling to increase over time, causing the solution to "bifurcate", or split. Then, the synchronization vanishes. The result is a climate shift. Eventually the cycles begin to synchronize again, causing a repeating pattern of warming and cooling, along with sudden changes in the frequency and strength of El Nino events. They show how this has explained the major shifts that have occurred including 1913, 1942, and 1978. These may be in the process of synchronizing once again with its likely impact on climate very different from what has been observed over the last several decades.

2. THE SOUTHERN OSCILLATION INDEX (SOI)

The Southern Oscillation Index (SOI) is the oldest measure of large-scale fluctuations in air pressure occurring between the western and eastern tropical Pacific (i.e., the state of the Southern Oscillation) during El Nino and La Nina episodes (Walker et al., 1932). Traditionally, this index has been calculated based on the differences in air pressure anomaly between Tahiti and Darwin, Australia. In general, smoothed time series of the SOI correspond very well with changes in ocean temperatures across the eastern tropical Pacific. The negative phase of the SOI represents below-normal air pressure at Tahiti and above-normal air pressure at Darwin. Prolonged periods of negative SOI values coincide with abnormally warm ocean waters across the eastern tropical Pacific typical of El Nino episodes. Prolonged periods of positive SOI values coincide with abnormally cold ocean waters across the eastern tropical Pacific typical of La Nina episodes.

As an atmospheric observation-based measure, SOI is subjected not only to underlying ocean temperature anomalies in the Pacific but also intra-seasonal oscillations, like the Madden−Julian Oscillation (MJO). The SOI often shows month-to-month-swings, even if the ocean temperatures remain steady due to these atmospheric waves. This is especially true in weaker El Nino or La Nina events, as well as La Nadas (neutral ENSO) conditions. Indeed, even week-to-week changes can be significant. For that reason, other measures are often preferred.

2.1. Nino 3.4 Anomalies

On February 23, 2005, NOAA announced that the NOAA National Weather Service, the Meteorological Service of Canada and the National Meteorological Service of Mexico reached a consensus on an index and definitions for El Nino and La Nina events (also referred to as the El Nino Southern Oscillation or ENSO). Canada, Mexico, and the United States all experience impacts from El Nino and La Nina.

The index was called the ONI and is defined as a 3-month average of sea surface temperature departures from normal for a critical region of the equatorial Pacific (Niño 3.4 region; 120W−170W, 5N−5S). This region of the tropical Pacific contains what scientists call the “equatorial cold tongue”, a band of cool water that extends along the equator from the coast of South America to the central Pacific Ocean. North America’s operational definitions for El Nino and La Nina, based on the index, are:

> **El Nino:** A phenomenon in the equatorial Pacific Ocean characterized by a positive sea surface temperature departure from normal (for the 1971−2000 base period) in the Niño 3.4 region greater than or equal in magnitude to 0.5 °C (0.9 °F), averaged over three consecutive months.
>
> **La Nina**: A phenomenon in the equatorial Pacific Ocean characterized by a negative sea surface temperature departure from normal (for the 1971−2000 base period) in the Niño 3.4 region greater than or equal in magnitude to 0.5 °C (0.9 °F), averaged over three consecutive months.

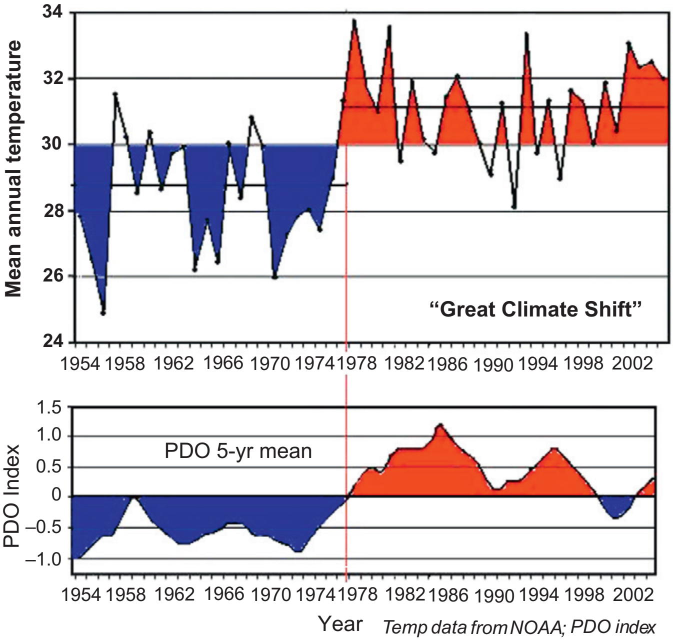
3. MULTIVARIATE ENSO INDEX (MEI)

Wolter (1987) attempted to combine oceanic and atmospheric variables to track and compare ENSO events. He developed the Multivariate ENSO Index (MEI) using the six main observed variables over the tropical Pacific. These six variables are: sea-level pressure (P), zonal (U), and meridional (V) components of the surface wind, sea surface temperature (S), surface air temperature (A), and total cloudiness fraction of the sky (C).

The MEI is calculated as the first unrotated Principal Component (PC) of all six observed fields combined. This is accomplished by normalizing the total variance of each field first, and then performing the extraction of the first PC on the co-variance matrix of the combined fields (Wolter and Timlin, 1993).

In order to keep the MEI comparable, all seasonal values are standardized with respect to each season and to the 1950–1993 reference period. Negative values of the MEI represent the cold ENSO phase (La Nina) while positive MEI values represent the warm ENSO phase (El Nino). Figure 2 is a plot of the three indices since 2000 (Wolter and Timlin, 1993).

NINO 34 is well correlated with the MEI. The SOI is much more variable month-to-month than the MEI and NINO 34. The MEI and NINO are more reliable determinants of the true state of ENSO, especially in weaker ENSO events.



Temp data from NOAA; PDO index from NOAA CDC climate indices

FIGURE 1 Correlation of the Great Pacific Climate Shift and the Pacific Decadal Oscillation.

4. THE PACIFIC DECADAL OSCILLATION (PDO)

The first hint of a Pacific basin-wide cycle was the recognition of a major regime change in the Pacific in 1977 that became to known as the Great Pacific Climate Shift (Fig. 1). Later, this shift was shown to be part of a cyclical regime change with decadal-like ENSO variability (Zhang et al., 1996, 1997; Mantua et al., 1997) and given the name Pacific Decadal Oscillation (PDO) by fisheries scientist Steven Hare (1996) while researching connections between Alaska salmon production cycles and Pacific climate.

Mantua et al. (1997) found the "Pacific Decadal Oscillation" (PDO) is a long-lived El Nino-like pattern of Pacific climate variability. While the two climate oscillations have similar spatial climate fingerprints, they have very different behavior in time. Two main characteristics distinguish PDO from El Nino/Southern Oscillation (ENSO): (1) 20th century PDO "events" persisted for 20-to-30 years, while typical ENSO events persisted for 6—18 months; (2) the climatic fingerprints of the PDO are most visible in the North Pacific/North American sector, while secondary signatures exist in the tropics — the opposite is true for ENSO. Note in Figures 1 and 2 how CO_2 showed no change during this PDO shift, suggesting it was unlikely to have played a role. Figures 3 and 4 show average annual PDO values.

A study by Gershunov and Barnett (1998) showed that the PDO has a modulating effect on the climate patterns resulting from ENSO. The climate signal of El Nino is likely to be stronger when the PDO is highly positive;

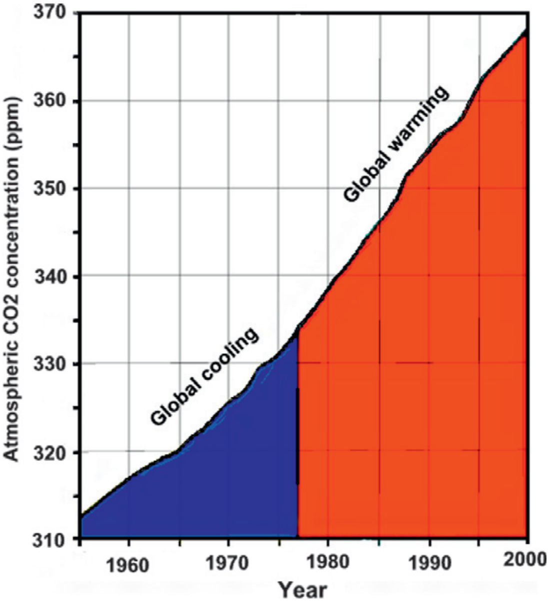


FIGURE 2 Atmospheric CO_2 showed no change across the Great Pacific Shift so could not have been the cause of it.

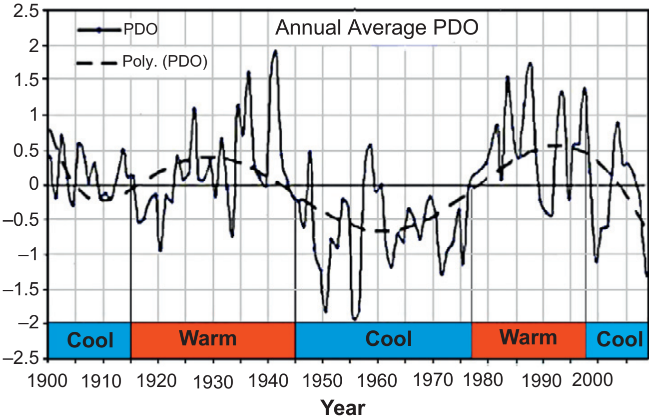


FIGURE 3 Annual average PDO 1900–2009. Note the multidecadal nature of the cycle with a period of approximately 60 years.

conversely the climate signal of La Nina will be stronger when the PDO is highly negative. This does not mean that the PDO physically controls ENSO, but rather that the resulting climate patterns interact with each other. The annual PDO and ENSO (Multivariate ENSO Index) track well since 1950.

5. FREQUENCY AND STRENGTH OF ENSO AND THE PDO

Warm PDOs are characterized by more frequent and stronger El Ninos than La Ninas. Cold PDOs have the opposite tendency. Figure 4 shows how well one

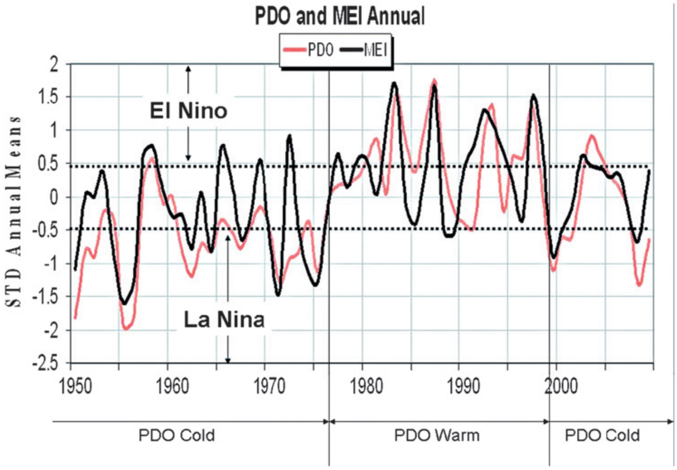


FIGURE 4 Annual average PDO and MEI (Multivariate ENSO Index) from 1950 to 2007 clearly correlate well. Note how the ENSO events amplify or diminish the favored PDO state.

ENSO measure, Wolter's MEI, correlates with the PDO. Mclean et al. (2009) showed that the mean monthly global temperature (GTTA) using the University of Alabama Huntsville MSU temperatures corresponds in general terms with the another ENSO measure, the Southern Oscillation Index (SOI) of 7 months earlier. The SOI is a rough indicator of general atmospheric circulation and thus global climate change.

Temperatures also follow suit (Fig. 5). El Ninos and the warm mode PDOs have similar land-based temperature patterns, as do cold-mode PDOs and La Ninas.

Strong similarity exists between PDO and ENSO ocean basin patterns. Land temperatures also are very similar between the PDO warm modes and El Ninos and the PDO cold modes and La Ninas. Not surprisingly, El Ninos occur more frequently during the PDO warm phase and La Ninas during the PDO cold phase. It maybe that ocean circulation shifts drive it for decades favoring El Ninos which leads to a PDO warm phase or La Ninas and a PDO cold phase (the proverbial chicken and egg), but the 60-year cyclical nature of this cycle is well established (Fig. 6).

About 1947, 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 CO_2 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 (Fig. 7).

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 1977, 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 (Miller et al., 1994). This rapid switch from cool to warm has become to known as "The Great Pacific Climatic Shift" (Fig. 1). Atmospheric

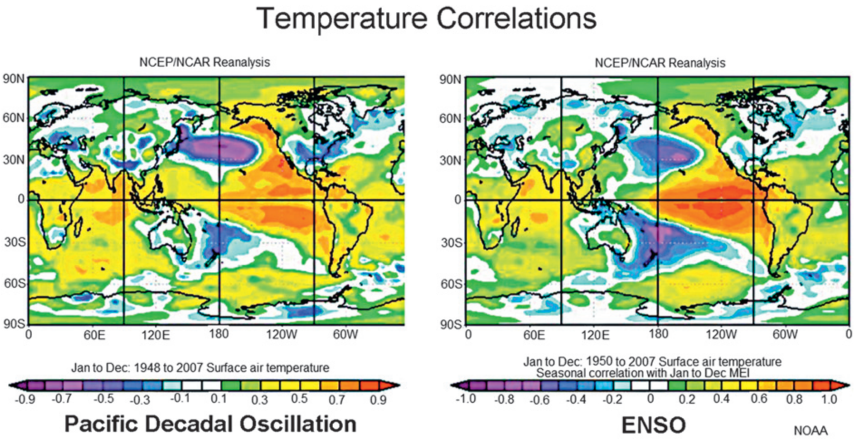
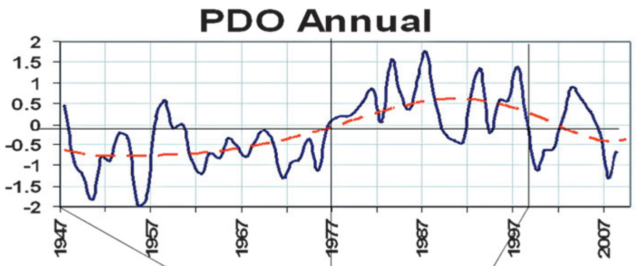


FIGURE 5 PDO and ENSO compared.



PDO	Cold	Warm	Cold
	1947-1977	1978-1998	1999-2009
El Nino	7	10	3
La Nina	14	3	5

FIGURE 6 Note how during the PDO cold phases, La Nina dominate (14—7 in the 1947—1977 cold phase) and 5—3 in the current, while in the warm phase from 1977 to 1998, the El Ninos had a decided frequency advantage of 10—3.

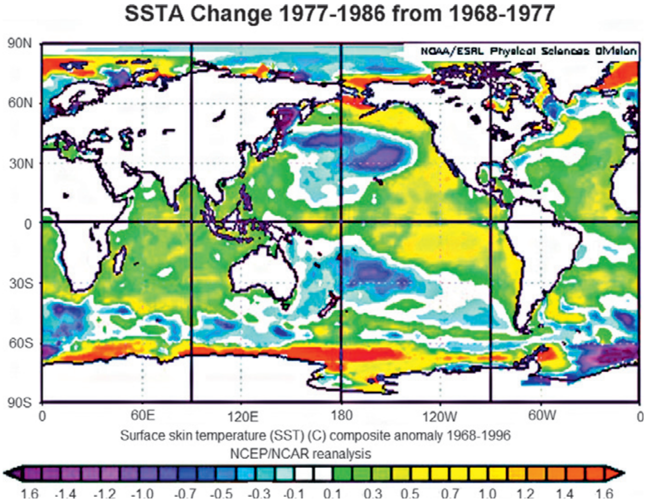


FIGURE 7 Difference in average sea surface temperatures between the decade prior to the GPCS and the decade after the GPCS. Yellow and green colors indicate warming of the NE Pacific off the coast of North America relative to what it had been from 1968 to 1977. Note the cooling in the west central North Pacific.

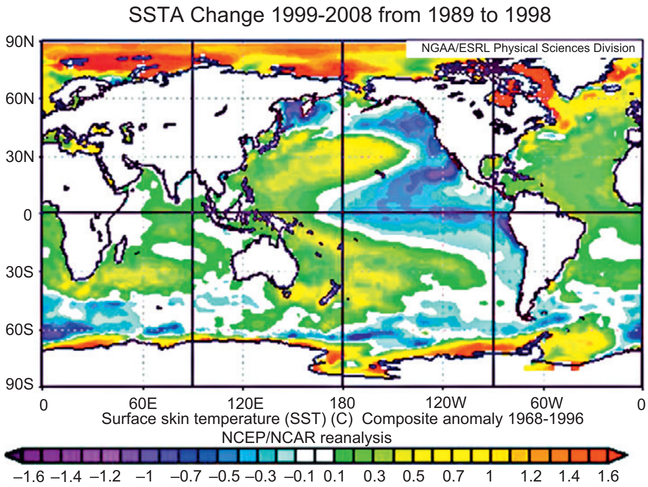


FIGURE 8 Sea surface temperature difference image of the decade after the GPCS minus the decade before the GPCS. Note the strong cooling in the eastern Pacific and the warming of the west central North Pacific.

CO_2 showed no unusual changes across this sudden climate shift and was clearly not responsible for it. Similarly, the global warming from ~1915 to ~1945 could not have been caused by increased atmospheric CO_2 because that time preceded the rapid rise of CO_2, and when CO_2 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. 3) have periods of about 25−30 years.

The PDO flipped back to the cold mode in 1999. The change can be seen with this sea surface temperature difference image of the decade after the GPCS minus the decade before the GPCS (Fig. 8).

Verdon and Franks (2006) reconstructed the positive and negative phases of PDO back to A.D. 1662 based on tree ring chronologies from Alaska, the Pacific Northwest, and subtropical North America as well as coral fossil from Rarotonga located in the South Pacific. They found evidence for this cyclical behavior over the whole period (Fig. 9).

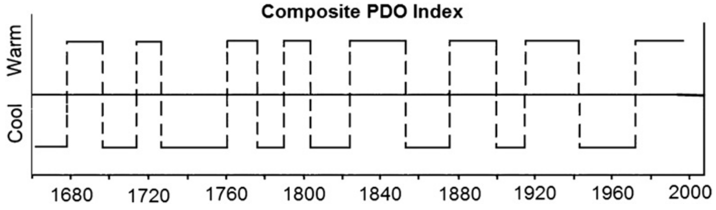
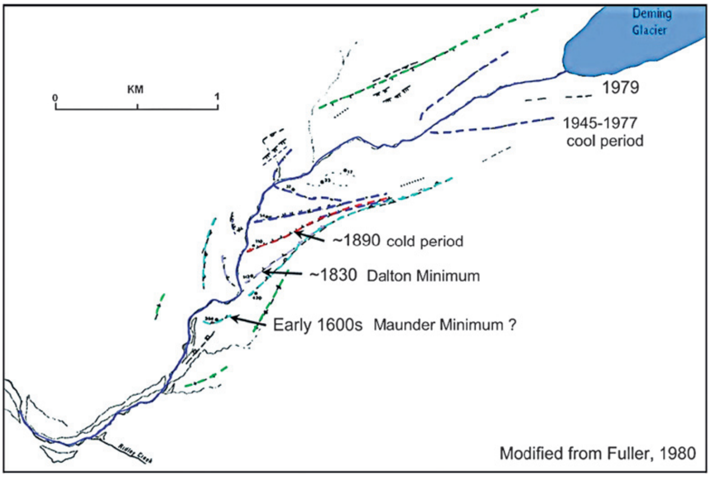


FIGURE 9 Verdon and Franks (2006) reconstructed the PDO back to 1662 showing cyclical behavior over the whole period.



Modified from Fuller, 1980

FIGURE 10 Ice marginal deposits (moraines) showing fluctuations of the Deming glacier, Mt. Baker, WA corresponding to climatic warming and cooling in Greenland ice cores.

6. CORRELATION OF THE PDO AND GLACIAL FLUCTUATIONS IN THE PACIFIC NORTHWEST

The ages of moraines downvalley from the present Deming glacier on Mt. Baker (Fuller, 1980; Fuller et al., 1983) match the ages of the cool periods in the Greenland ice core. Because historic glacier fluctuations (Harper, 1993) coincide with global temperature changes and PDO, these earlier glacier fluctuations could also well be due to oscillations of the PDO (Fig. 10).

Glaciers on Mt. Baker, WA show a regular pattern of advance and retreat (Fig. 11) which matches the Pacific Decadal Oscillation (PDO) in the NE Pacific Ocean. 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.

7. ENSO VS. TEMPERATURES

Douglass and Christy (2008) compared the NINO 34 region anomalies to the tropical UAH lower troposphere and showed a good agreement, with some departures during periods of strong volcanism. During these volcanic events, high levels of stratospheric sulfate aerosols block incoming solar radiation and produce multi-year cooling of the atmosphere and oceans. A similar comparison of UAH global lower tropospheric data with the MEI Index also shows good agreement, with some departure during periods of major

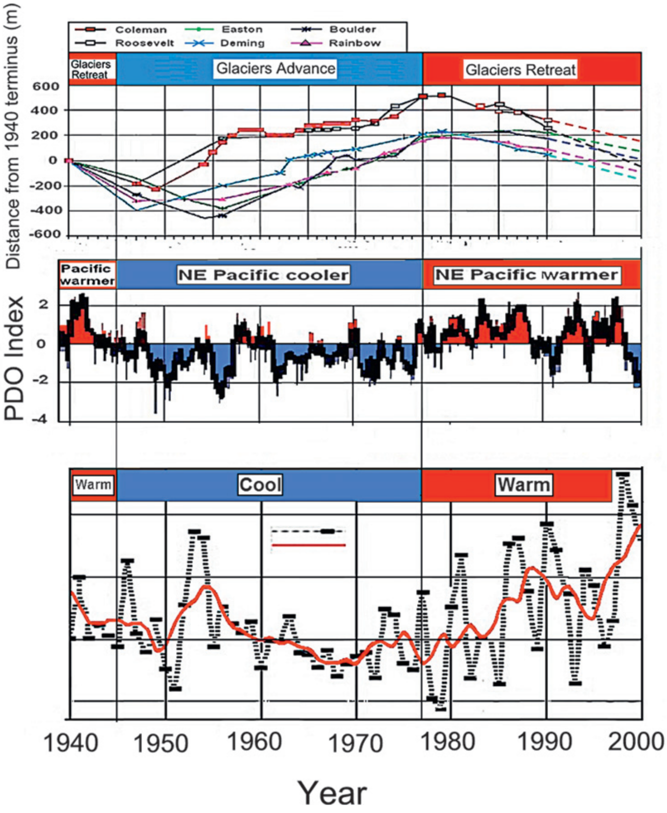


FIGURE 11 Correlation of glacial fluctuations, global temperature changes, and the Pacific Decadal Oscillation.

volcanism in the early 1980s and 1990s. Alaskan temperatures clearly show discontinuities associated with changes in the PDO.

8. THE ATLANTIC MULTIDECADAL OSCILLATION (AMO)

Like the Pacific, the Atlantic exhibits multidecadal tendencies and a characteristic tripole structure (Figs. 12, 13). For a period that averages about 30 years, the Atlantic tends to be in what is called the warm phase with warm temperatures in the tropical North Atlantic and far North Atlantic and relatively cool temperatures in the central (west central). Then the ocean flips into the opposite (cold) phase with cold temperatures in the tropics and far North Atlantic and a warm central ocean. The AMO (Atlantic sea surface temperatures standardized) is the average anomaly standardized from 0 to 70N. The AMO has a period of 60 years maximum to maximum and minimum to minimum.

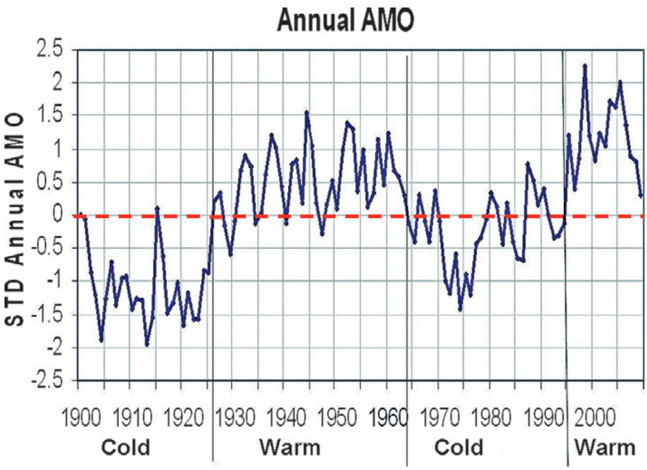


FIGURE 12 AMO annual mean (STD) showing a similar 60–70-year cycle as the PDO but with a lag of about 15 years to the PDO.

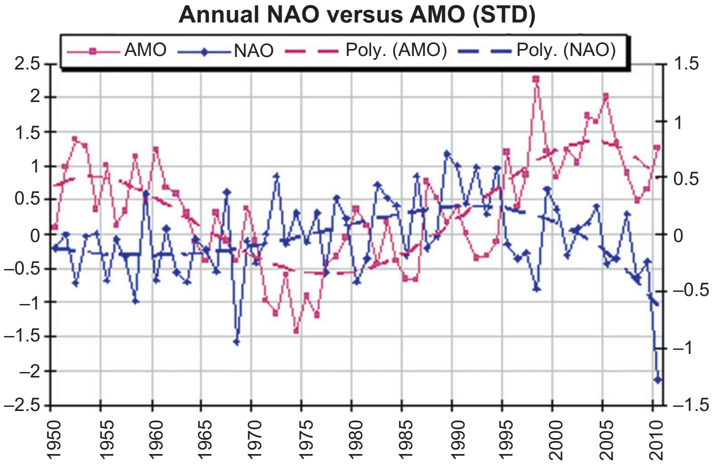


FIGURE 13 Annual Average AMO and NAO compared. Note the inverse relationship with a slight lag of the NAO to the AMO.

9. NORTH ATLANTIC OSCILLATION, THE ARCTIC OSCILLATION, AND THE AMO

The North Atlantic Oscillation (NAO), first found by Walker in the 1920s, is the north–south flip flop of pressures in the eastern and central North Atlantic (Walker and Bliss, 1932). The difference of normalized MSLP anomalies between Lisbon, Portugal, and Stykkisholmur, Iceland has become the widest used NAO index and extends back in time to 1864 (Hurrell, 1995), and to 1821 if Reykjavik is used instead of Stykkisholmur and Gibraltar instead of Lisbon (Jones et al., 1997). Hanna et al. (2003) and Hanna et al. (2006) showed how these cycles in the Atlantic sector play a key role in temperature variations in Greenland and Iceland. Kerr (2000) identified the NAO and AMO (Fig. 13) as key climate pacemakers for large-scale climate variations over the centuries.

The Arctic Oscillation (also known as the Northern Annular Mode Index (NAM)) is defined as the amplitude of the pattern defined by the leading empirical orthogonal function of winter monthly mean NH MSLP anomalies poleward of 20°N (Thompson and Wallace, 1998, 2000). The NAM/Arctic Oscillation (AO) is closely related to the NAO.

Like the PDO, the NAO and AO tend to be predominantly in one mode or the other for decades at a time, although since, like the SOI, it is a measure of atmospheric pressure and subject to transient features, it tends to vary much more from week-to-week and month-to-month. All we can state is that an inverse relationship exists between the AMO and NAO/AO decadal tendencies. When the Atlantic is cold (AMO negative), the AO and NAO tend more often to the positive state, when the Atlantic is warm, on the other hand, the NAO/AO tend to be more often negative. The AMO tri-pole of warmth in the 1960s below was associated with a predominantly negative NAO and AO while the cold phase was associated with a distinctly positive NAO and AO in the 1980s and early 1990s (Figs. 14, 15). A lag of a few years occurs after the flip of the AMO and the tendencies appear to be

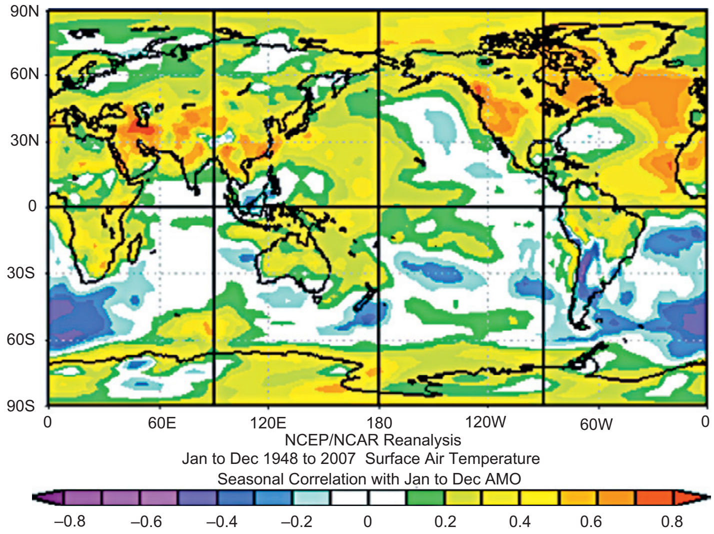


FIGURE 14 Correlation of the AMO with annual surface temperatures.

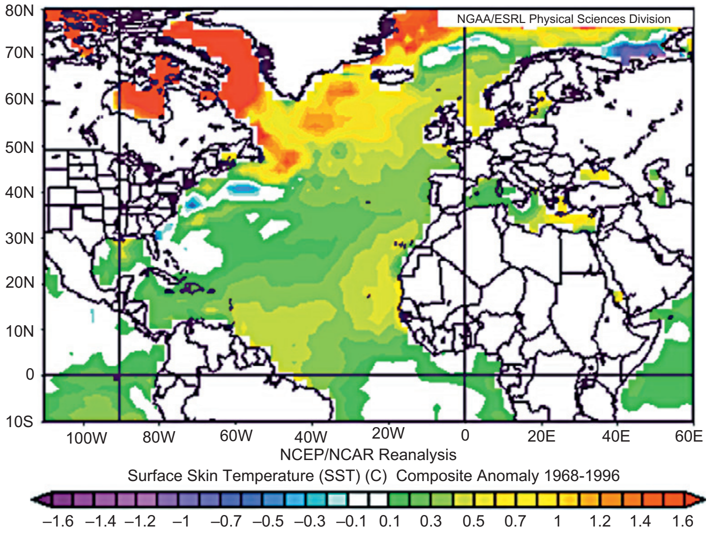


FIGURE 15 Difference in sea surface temperatures 1996–2004 from 1986 to 1995. It shows the evolution to the warm Atlantic Multidecadal Oscillation.

greatest at the end of the cycle. This may relate to timing of the maximum warming or cooling in the North Atlantic part of the AMO or even the PDO/ ENSO interactions. The PDO typically leads the AMO by 10–15 years. The relationship is a little more robust for the cold (negative AMO) phase than for the warm (positive) AMO. There tends to be considerable intra-seasonal variability of these indices that relate to other factors (stratospheric warming and cooling events that are correlated with the Quasi-Biennial Oscillation or QBO for example).

10. SYNCHRONIZED DANCE OF THE TELECONNECTIONS

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, 2006a,b, 2007, 2008a,b,c) and the establishment of cool Pacific sea surface temperatures confirms that the present cool phase will persist for several decades.

Latif and his colleagues at Leibniz Institute at Germany's Kiel University predicted the new cooling trend in a paper published in 2009 and warned of it again at an IPCC conference in Geneva in September 2009.

'A significant share of the warming we saw from 1980 to 2000 and at earlier periods in the 20th Century was due to these cycles — perhaps as much as 50 per cent. They have now gone into reverse, so winters like this one will become much more likely. Summers will also probably be cooler, and all this may well last two decades or longer. The extreme retreats that we have seen in glaciers and sea ice will come to a halt. For the time being, global warming has paused, and there may well be some cooling.'

According to Latif and his colleagues (Latif and Barnett, 1994; Latif et al., 2009) this in turn relates to much longer-term shifts — what are known as the Pacific and Atlantic 'multi-decadal oscillations' (MDOs). For Europe, the crucial factor here is the temperature of the water in the middle of the North Atlantic, now several degrees below its average when the world was still warming.

Prof. Anastasios Tsonis, head of the University of Wisconsin Atmospheric Sciences Group, has shown (2007) that these MDOs move together in a synchronized way across the globe, abruptly flipping the world's climate from a 'warm mode' to a 'cold mode' and back again in 20—30-year cycles.

'They amount to massive rearrangements in the dominant patterns of the weather,' he said yesterday, 'and their shifts explain all the major changes in world temperatures during the 20th and 21st Centuries. We have such a change now and can therefore expect 20 or 30 years of cooler temperatures.'

The period from 1915 to 1940 saw a strong warm mode, reflected in rising temperatures, but from 1940 until the late 1970s, the last MDO cold-mode era, the world cooled, despite the fact that carbon dioxide levels in the atmosphere continued to rise. Many of the consequences of the recent warm mode were also observed 90 years ago. For example, in 1922, the Washington Post reported that Greenland's glaciers were fast disappearing, while Arctic seals were 'finding the water too hot'. The Post interviewed Captain Martin Ingebrigsten, who had been sailing the eastern Arctic for 54 years: 'He says that he first noted warmer conditions in 1918, and since that time it has gotten steadily warmer. Where formerly great masses of ice were found, there are now moraines, accumulations of earth and stones. At many points where glaciers formerly extended into the sea they have entirely disappeared. As a result, the shoals of fish that used to live in these waters had vanished, while the sea ice beyond the north coast of Spitsbergen in the Arctic Ocean had melted. Warm Gulf Stream water was still detectable within a few hundred miles of the Pole.'

In contrast, 56% of the surface of the United States was covered by snow. 'That hasn't happened for several decades,' Tsonis pointed out. 'It just isn't true to say this is a blip. We can expect colder winters for quite a while.' He recalled that towards the end of the last cold mode, the world's media were preoccupied by fears of freezing. For example, in 1974, a Time magazine cover story predicted 'Another Ice Age', saying: 'Man may be somewhat responsible — as a result of farming and fuel burning [which is] blocking more and more sunlight from reaching and heating the Earth.'

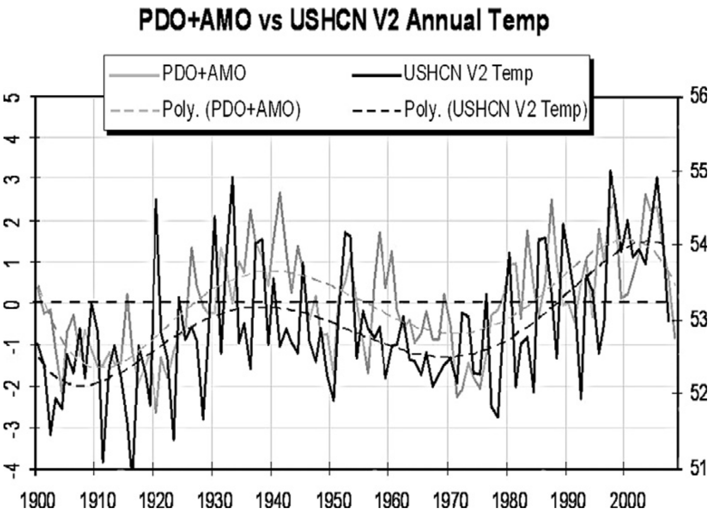


FIGURE 16 NASA GISS version of NCDC USHCN version 2 vs. PDO + AMO. The mutlidecadal cycles with periods of 60 years match the USHCN warming and cooling cycles. Annual temperatures end at 2007. With an 11-year smoothing of the temperatures and PDO + AMO to remove any effect of the 11-year solar cycles, gives an even better correlation with an r^2 of 0.85.

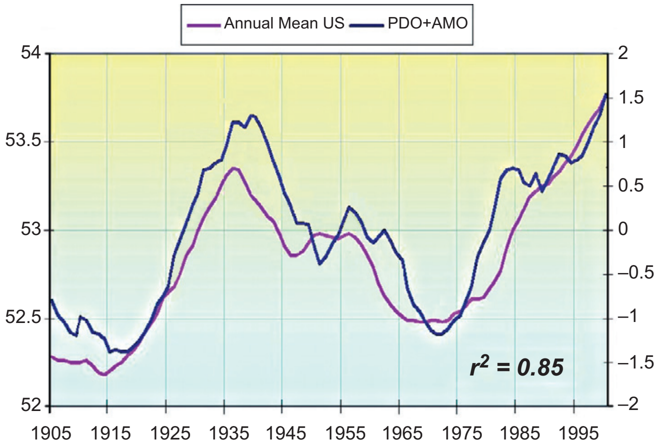


FIGURE 17 With 22 point smoothing, the correlation of U.S. temperatures and the ocean multidecadal oscillations is clear with an r^2 of 0.85. Figure 18 shows the AMO/PDO regression fit to USHCN version 2. The PDO/AMO works well in predicting temperatures (Fig. 19). Figure 20 shows the difference in U.S. annual mean temperatures for USHCN version 2 minus USHCN version 1.

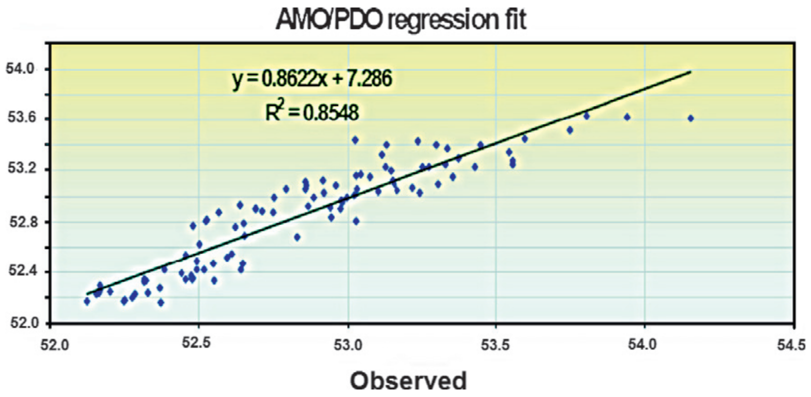


FIGURE 18 The AMO/PDO regression fit to USHCN version 2.

Tsonis observed 'Perhaps we will see talk of an ice age again by the early 2030s, just as the MDOs shift once more and temperatures begin to rise.' Although the two indices (PDO and AMO) are derived in different ways, they both represent a pattern of sea surface temperatures, a tripole with warm in the high latitudes and tropics and colder in between especially west or vice versa. In both cases, the warm modes were characterized by general global warmth and the cold modes with general broad climatic cooling though each with though with regional variations. I normalizing and adding the two indices makes them more comparable. A positive AMO + PDO should correspond to an above normal temperature and the negative below normal. Indeed that is the case for the US temperatures (NCDC USHCN v2) as shown in Fig. 16.

Correlation of U.S. temperatures and the ocean multidecadal oscillations gives an r^2 of 0.85 (Fig. 17). In Figures 18 and 19 the AMO/PDO was used to predict US temperatures using multiple regression approach. The results showed excellent results with some divergence near the end of the period.

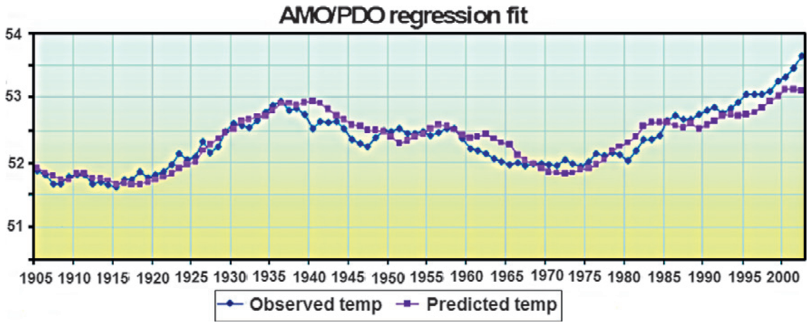


FIGURE 19 Using the PDO/AMO to predict temperatures works well here with some departure after around 2000.

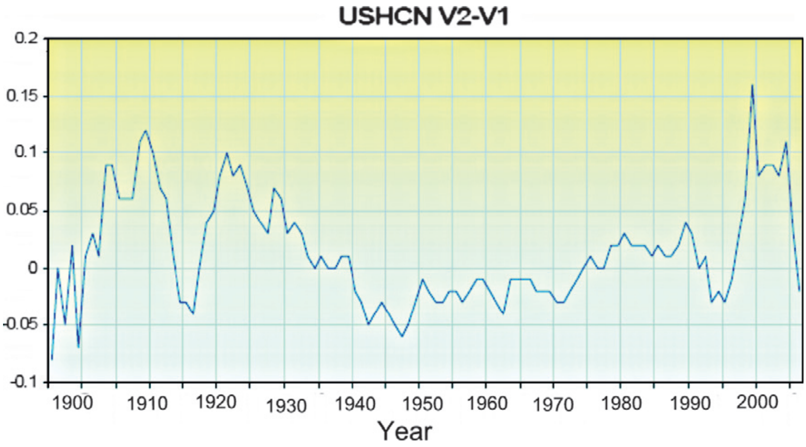


FIGURE 20 The difference in U.S. annual mean temperatures for USHCN version 2 minus USHCN version 1. The elimination of the urbanization adjustment led to a hard-to-explain spike in the 1997–2005 time period.

The plot (Fig. 20) of the difference between version 1 and version 2 suggests the latter as the likely cause. In version 2, the urban adjustment was removed. Note that the upward adjustment of the 1998–2005 temperatures by as much as 0.15 °F is unexplained.

11. 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. Most atmospheric oxygen consists of 16O but a small amount consists of 18O, an isotope of oxygen that is somewhat heavier. When water vapor (H_2O) condenses from the atmosphere as snow, it contains a ratio of $^{16}O/^{18}O$ that reflects the temperature at that time. When 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 Brasiunas, 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. 21). Figure 21 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 to ~1945 warm period, and the ~1945 to 1977 cool period, as well as many other cool and warm periods. Temperatures fluctuated between warm and cool at least 22 times

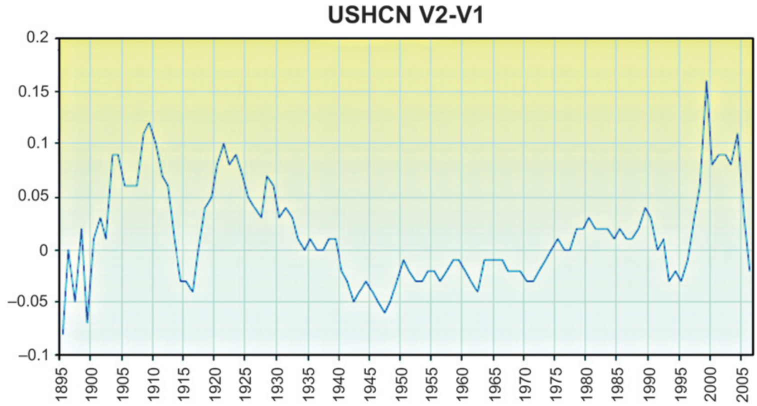


FIGURE 21 Cyclic warming and cooling trends in the past 500 years (plotted from GISP2 data, Stuiver and Grootes, 2000).

between 1480 A.D. and 1950 (Fig. 21). None of the warming periods could have possibly been caused by increased CO_2 because they all preceded rising CO_2.

Only one out of all of the global warming periods in the past 500 years occurred at the same time as rising CO_2 (1977−1998). About 96% of the warm periods in the past 500 years could not possibly have been caused by rise of CO_2. The inescapable conclusion of this is that CO_2 is not the cause of global warming. The Greenland ice core isotope record matches climatic fluctuations recorded in alpine glacier advances and retreats.

12. WHERE ARE WE HEADED DURING THE COMING CENTURY?

The cool phase of PDO is now entrenched. We have shown how the two ocean oscillations drive climate shifts. The PDO leads the way and its effect is later amplified by the AMO. Each of this has occurred in the past century, global temperatures have remained cool for about 30 years.

No statistically significant global warming has taken place since 1998 (Fig. 22), and cooling has occurred during the past several years (Hanna and Cappelen, 2003). A very likely 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. 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 stasis or global cooling for the past 10 years, but also should assure that cooler temperatures will continue for several more decades. There will be brief bounces upwards with periodic El Ninos, as we have seen in late 2009 and early 2010, but they will give way to cooling as the favored La Nina states returns. With a net La Nina tendency, the net result should be cooling.

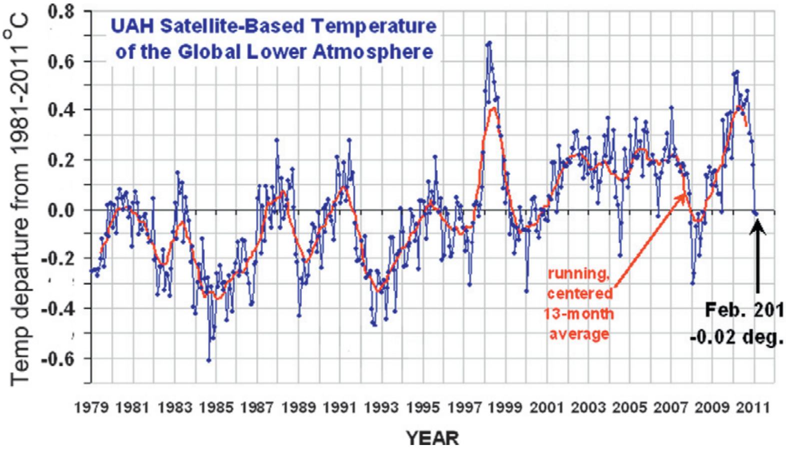


FIGURE 22 UAH globally averaged lower atmospheric temperatures.

12.1. Predictions Based on Past Climate Patterns

The past is the key to understanding the future. Past warming and cooling cycles over the past 500 years were used by Easterbrook (2001, 2005, 2006a,b, 2007, 2008a,b,c) 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 Fig. 23. The

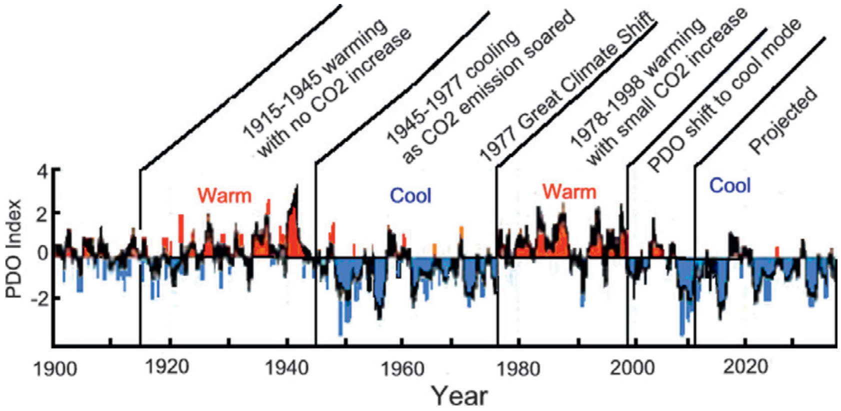


FIGURE 23 Using past behavior of the PDO to predict future.

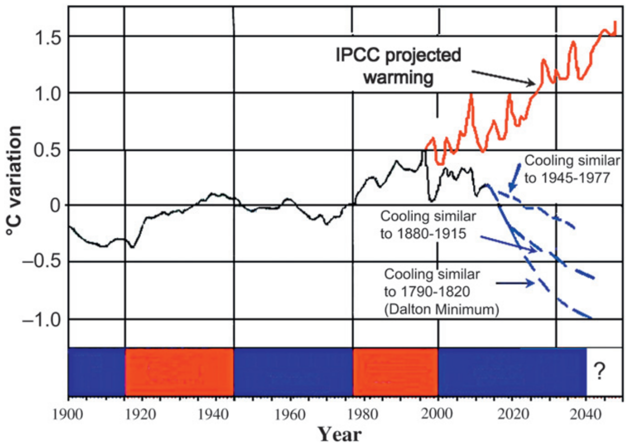


FIGURE 24 projected climate for the century based on climatic patterns over the past 500 years and the switch of the PDO to its cool phase.

left side of Fig. 23 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. The switch to the PDO cool mode to its cool mode virtually assures cooling global climate for several decades.

Three possible projections are shown in Fig. 24: (1) moderate cooling (similar to the 1945−1977 cooling); (2) deeper cooling (similar to the 1945−1977 cooling); or (3) severe cooling (similar to the 1790−1830 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 cycles 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).

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 ocean cycle 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 sea and that atmospheric CO_2 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 moderate to severe global cooling.

REFERENCES

Baldwin, M.P., Dunkerton, T.J., 2005. The solar cycle and stratospheric−tropospheric dynamical coupling. Journal of Atmospheric and Solar−Terrestrial Physics 67, 71−82.

Bjerknes, J., 1969. Atmospheric teleconnections from the equatorial Pacific. Monthly Weather Review 97, 153−172.

Boberg, F., Lundstedt, H., 2002. Solar wind variation related to fluctuations of the North Atlantic Oscillation. Geophysical Research Letters 29, 13.1−13.4.

Christy, J.R., Spencer, R.W., Braswell, W.D., 2000. MSU tropospheric temperatures: dataset construction and radiosonde comparisons. Journal of Atmospheric and Oceanic Technology 17, 1153−1170.

Clilverd, M.A., Clarke, E., Ulich, T., Rishbeth, H., Jarvis, M.J., 2006. Predicting Solar Cycle 24 and beyond. SpaceWeather 4.

Douglass, D.H., Christy, J.R., 2008. Limits on CO_2 climate forcing from recent temperature data of Earth. Energy and Environment.

Easterbrook, D.J., 2001. The next 25 years: global warming or global cooling? Geologic and oceanographic evidence for cyclical climatic oscillations. Geological Society of America, Abstracts with Program 33, 253.

Easterbrook, D.J., 2005. Causes and effects of abrupt, global, climate changes and global warming: Geological Society of America, Abstracts with Program 37, 41.

Easterbrook, D.J., 2006a. Causes of abrupt global climate changes and global warming predictions for the coming century: Geological Society of America, Abstracts with Program 38, 77.

Easterbrook, D.J., 2006b. The cause of global warming and predictions for the coming century: Geological Society of America, Abstracts with Program 38, 235−236.

Easterbrook, D.J., 2007. Geologic evidence of recurring climate cycles and their implications for the cause of global warming and climate changes in the coming century. Geological Society of America, Abstracts with Programs 39, 507.

Easterbrook, D.J., 2008a. Solar influence on recurring global, decadal, climate cycles recorded by glacial fluctuations, ice cores, sea surface temperatures, and historic measurements over the past millennium. Abstracts of American Geophysical Union Annual Meeting, San Francisco.

Easterbrook, D.J., 2008b. Implications of glacial fluctuations, PDO, NAO, and sun spot cycles for global climate in the coming decades: Geological Society of America, Abstracts with Programs 40, 428.

Easterbrook, D.J., 2008c. Correlation of climatic and solar variations over the past 500 years and predicting global climate changes from recurring climate cycles. Abstracts of 33rd International Geological Congress, Oslo, Norway.

Easterbrook, D.J., Kovanen, D.J., 2000. Cyclical oscillation of Mt. Baker glaciers in response to climatic changes and their correlation with periodic oceanographic changes in the northeast Pacific Ocean: Geological Society of America, Abstracts with Program 32, 17.

Fuller, S.R., 1980. Neoglaciation of Avalanche Gorge and the Middle Fork Nooksack River valley, Mt. Baker, Washington. M.S. thesis, Western Washington University, Bellingham, Washington.

Fuller, S.R., Easterbrook, D.J., Burke, R.M., 1983. Holocene glacial activity in five valleys on the flanks of Mt. Baker. Geological Society of America, Washington. Abstracts with Program 15, 43.

Gershunov, A., Barnett, T.P., 1998. Interdecadal modulation of ENSO teleconnections. Bulletin of the American Meteorological Society 79, 2715−2725.

Grootes, P.M., Stuiver, M., 1997. Oxygen 18/16 variability in Greenland snow and ice with 10^3 to 10^5-year time resolution. Journal of Geophysical Research 102, 26455−26470.

Grootes, P.M., Stuiver, M., White, J.W.C., Johnsen, S.J., Jouzel, J., 1993. Comparison of oxygen isotope records from the GISP2 and GRIP Greenland ice cores. Nature 366, 552−554.

Hanna, E., Cappelen, J., 2003. Recent cooling in coastal southern Greenland and relation with the North Atlantic Oscillation. Geophysical Research Letters 30.

Hanna, E., Jonsson, T., Olafsson, J., Valdimarsson, H., 2006. Icelandic coastal sea surface temperature records constructed: Putting the pulse on air−sea−climate interactions in the

Northern North Atlantic. Part I: Comparison with HadISST1 open-ocean surface temperatures and preliminary analysis of long-term patterns and anomalies of SSTs around Iceland. Journal of Climate 19, 5652−5666.

Hare, S.R., 1996. Low frequency climate variability and salmon production. PhD dissertation. School of Fisheries, University of Washington, Seattle, WA.

Harper, J.T., 1993. Glacier fluctuations on Mount Baker, Washington, U.S.A., 1940−1990, and climatic variations: Arctic and Alpine Research. Arctic and Alpine Research 4, 332−339.

Hathaway, D., 2006. Long range solar forecast, 2006 (Press release editor: Dr. Tony Phillips) http://science.nasa.gov/headlines/y2006/10may_longrange.htm.

Hurell, J.W., 1995. Decadal trends in the North Atlantic Oscillation, regional temperatures and precipitation. Science 269, 676−679.

Idso, C., Singer, S.F., 2009. Climate Change Reconsidered: 2009 Report of the Nongovernmental Panel on Climate Change (NIPCC). The Heartland Institute, Chicago, IL, p. 855.

IPCC-AR4, 2007. Climate Change: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

Jones, P.D., Johnson, T., Wheeler, D., 1997. Extension in the North Atlantic Oscillation using early instrumental pressure observations from Gibralter and southwest Iceland. Journal of Climatology 17, 1433−1450.

Kerr, R.A., 2000. A North Atlantic climate pacemaker for the centuries,. Science 288, 1984−1986.

Labitzke, K., 2001. The global signal of the 11-year sunspot cycle in the stratosphere. Differences between solar maxima and minima: Meteorologische Zeitschift 10, 83−90.

Latif, M., Barnett, T.P., 1994. Causes of decadal climate variability over the North Pacific and North America. Science 266, 634−637.

Latif, M., Park, W., Ding, H., Keenlyside, N., 2009. Internal and external North Atlantic sector variability in the Kiel climate model. Meteorologische Zeitschrift 18, 433−443.

Mantua, N.J., Hare, S.R., Zhang, Y., Wallace, J.M., Francis, R.C., 1997. A Pacific interdecadal climate oscillation with impacts on salmon production: Bulletin of the American Meteorological Society 78, 1069−1079.

Marsh, N.D., Svensmark, H., 2000. Low cloud properties influenced by cosmic rays. Physical Review Letters 85, 5004−5007.

McLean, J.D., de Freitas, C.R., Carter, R.M., 2009. Influence of the Southern Oscillation on tropospheric temperature. Journal of Geophysical Research 114.

Miller, A.J., Cayan, D.R., Barnett, T.P., Graham, N.E., Oberhuber, J.M., 1994. The 1976−77 climate shift of the Pacific Ocean: Oceanography 7, 21−26.

Moore, G.W.K., Holdsworth, G., Alverson, K., 2002. Climate change in the North Pacific region over the past three centuries. Nature 420, 401−403.

Perlwitz, J., Hoerling, M., Eischeid, J., Xu, T., Kumar, A., 2009. A strong bout of natural cooling in 2008. Geophysical Research Letters 36.

Scafetta, N., West, B.J., 2007. Phenomenological reconstructions of the solar signature in the Northern Hemisphere. Journal of Geophysical Research 112, 5004−5007.

Shaviv, N.J., 2005. On climate response to changes in the cosmic ray flux and radiative budget. Journal of Geophysical Research−Space Physics 110, p. A08105.

Steffensen, J.P., Andersen, K.K., Bigler, M., Clausen, H.B., Dahl-Jensen, D., Goto-Azuma, K., Hansson, M.J., Sigfus, J., Jouzel, J., Masson-Delmotte, V., Popp, T., Rasmussen, S.O., Roethlisberger, R., Ruth, U., Stauffer, B., Siggaard-Andersen, M., Sveinbjornsdottir, A.E., Svensson, A., White, J.W.C., 2008. High-resolution Greenland ice core data show abrupt climate change happens in few years. Science 321, 680−684.

Stuiver, M., Brasiunas, T.F., 1991. Isotopic and solar records. In: Bradley, R.S. (Ed.), Global Changes of the Past. Boulder University, Corporation for Atmospheric Research, pp. 225–244.

Stuiver, M., Brasiunas, T.F., 1992. Evidence of solar variations. In: Bradley, R.S., Jones, P.D. (Eds.), Climate Since A.D. 1500. Routledge, London, pp. 593–605.

Stuiver, M., Grootes, P.M., 2000. GISP2 oxygen isotope ratios. Quaternary Research 54/3.

Stuiver, M., Quay, P.D., 1979. Changes in atmospheric carbon-14 attributed to a variable sun. Science 207, 11–27.

Stuiver, M., Grootes, P.M., Brasiunas, T.F., 1995. The GISP2 ^{18}O record of the past 16,500 years and the role of the sun, ocean, and volcanoes: Quaternary Research 44, 341–354.

Svensmark, H., Friis-Christensen, E., 1997. Variation of cosmic ray flux and global cloud cover—a missing link in solar–climate relationships. Journal of Atmospheric and Solar–Terrestrial Physics 59, 1125–1132.

Thompson, D.W.J., Wallace, J.M., 1998. The Arctic Oscillation signature in the wintertime geopotential height and temperature fields. Geophysical Research Letters 25, 1297–1300.

Thompson, D.W.J., Wallace, J.M., 2000. Annular modes in the extratropical circulation. Part 1: Month-to-Month variability. Journal of Climate 13, 1000–1016.

Tsonis, A.A., Hunt, G., Elsner, G.B., 2003. On the relation between ENSO and global climate change. Meteorology and Atmospheric Physics, 1–14.

Tsonis, A.A., Swanson, K.L., Kravtsov, S., 2007. A new dynamical mechanism for major climate shifts. Geophysical Research Letters 34.

Verdon, D.C., Franks, S.W., 2006. Long-term behaviour of ENSO: interactions with the PDO over the past 400 years inferred from paleoclimate records. Geophysical Research Letters 33.

Walker, G., Bliss, 1932. World Weather V. Memoirs Royal Meteorological Society 4, 53–84.

Wang, Y.M., Lean, J.L., Sheeley, N.R., 2005. Modeling the sun's magnetic field and irradiance since 1713. Astrophysical Journal 625, 522–538.

Wolter, K., 1987. The Southern Oscillation in surface circulation and climate over the tropical Atlantic, Eastern Pacific, and Indian Oceans as captured by cluster analysis: Journal of Climate and Applied Meteorology 26, 540–558.

Wolter, K., Timlin, M.S., 1993. Monitoring ENSO in COADS with a seasonally adjusted principal component index: Proceedings of the 17th Climate Diagnostics Workshop, Norman, OK, Oklahoma Climatological Survey, CIMMS and the School of Meteorology. University of Oklahoma, pp. 52–57.

Zhang, Y., Wallace, J.M., Battisti, D., 1997. ENSO-like interdecadal variability: 1990–1993. Journal of Climatology 10, 1004–1020.

Zhang, Y., Wallace, J.M., Battisti, D., 1997. ENSO-like interdecadal variability: 1990–1993. Journal of Climatology 10, 1004–1020.

Zhang, Y., Wallace, J.M., Iwasaka, N., 1996. Is climate variability over the North Pacific a linear response to ENSO? Journal of Climatology 9, 1468–1478.