Multidecadal Tendencies in ENSO and Global Temperatures Related to Multidecadal Oscillations

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MULTIDECADAL TENDENCIES IN ENSO AND GLOBAL TEMPERATURES RELATED TO MULTIDECADAL OSCILLATIONS

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Abstract: Perlwitz etal (2009) used computer model suites to contend that the 2008 North American cooling was naturally induced as a result of the continent's sensitivity to widespread cooling of the tropical (La Nina) and northeastern Pacific sea surface temperatures. But they concluded from their models that warming is likely to resume in coming years and that climate is unlikely to embark upon a prolonged period of cooling. We here show how their models fail to recognize the multidecadal behavior of sea surface temperatures in the Pacific Basin, *which determines the frequency of El Ninos and La Ninas and suggests that the cooling will likely continue for several decades. We show how this will be reinforced with multidecadal shift in the Atlantic.*

IPCC AND MULTIDECADAL SHIFTS

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In chapter 3 (Observations: Surface and Atmospheric Climate Change) of their 2007 report, the IPCC recognized circulation indices, including short term and decadal scale oscillations in the Pacific and Atlantic and attributed their origin as natural. They noted that the decadal variability in the Pacific (the Pacific Decadal Oscillation or PDO) is likely due to oceanic processes. "*Extratropical ocean influences are likely to play a role as changes in the ocean gyre evolve and heat anomalies are subducted and reemerge". (3.6.3)* The Atlantic Multidecadal Oscillation (AMO) is thought to be due to changes in the strength of thermohaline circulation. Ultimately, however, the IPCC fails to suggest a connection between these cyclical oceanic changes and observed global cyclical temperature changes. They only go as far as making a possible connection to regional variances. "*Understanding the nature of teleconnections and changes in their behavior is central to understanding regional climate variability and change. (3.6.1)*

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 known as the Great Pacific Climate Shift (Figure 1). Later, this shift was shown to be part of a cyclical regime change showing decadal like ENSO variability (Zhang, 1996; 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.

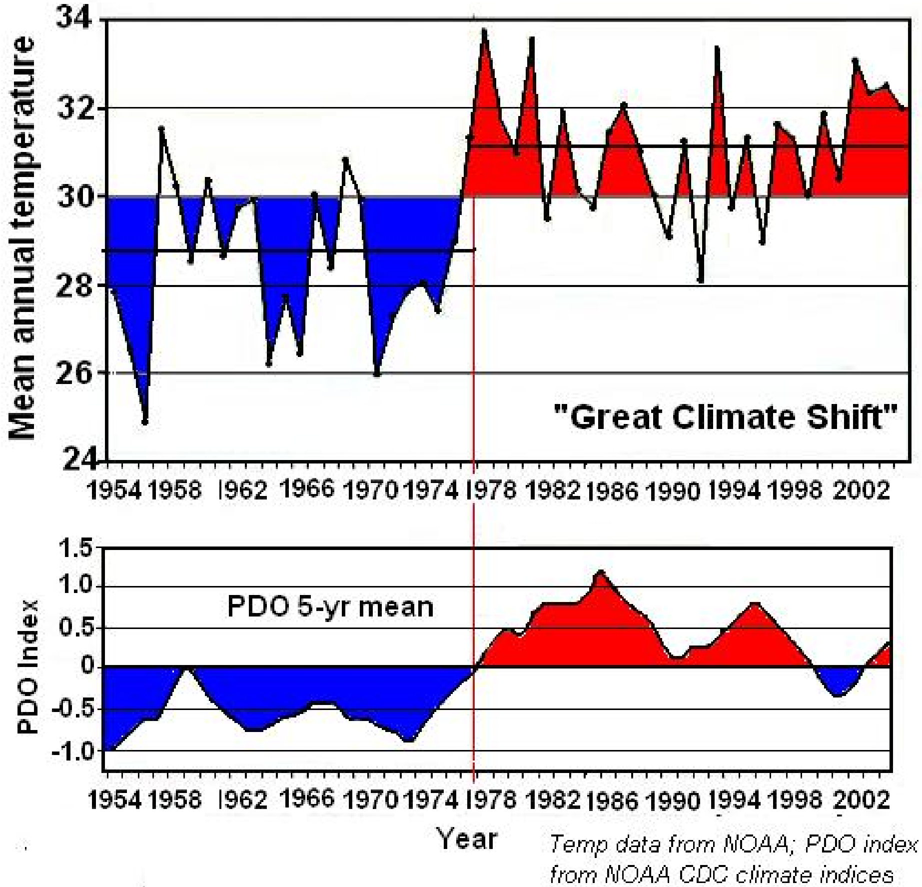


Figure 1: Correlation of The Great Pacific Climate Shift and the Pacific Decadal Oscillation

Note in figure 2 how the CO2 showed no change during this PDO shift, suggesting it was unlikely to have played a role.

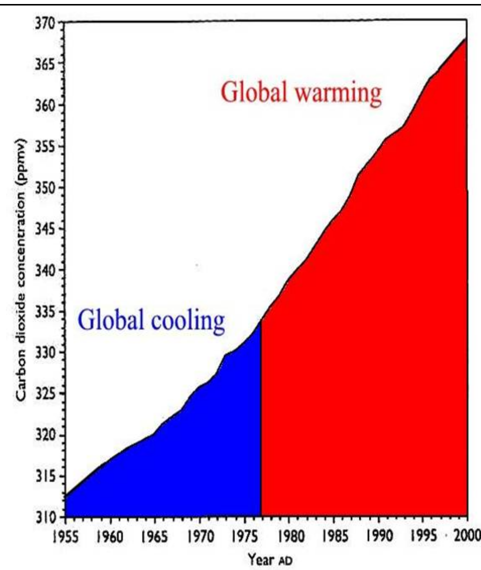


Figure 2: Atmospheric CO2 showed no change across the Great Pacific Shift so could not have been the cause of it

Mantua et al**.** (1997) found that the "Pacific Decadal Oscillation" (PDO) is a long-lived**,** El Niño-like pattern of Pacific climate variability. While the two climate oscillations have similar spatial climate fingerprints, they have very different timing. Two main characteristics distinguish PDO from El Niño/Southern Oscillation (ENSO): 20th century PDO "events" persisted for 20-to-30 years, while typical ENSO events persisted for 6 to 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.

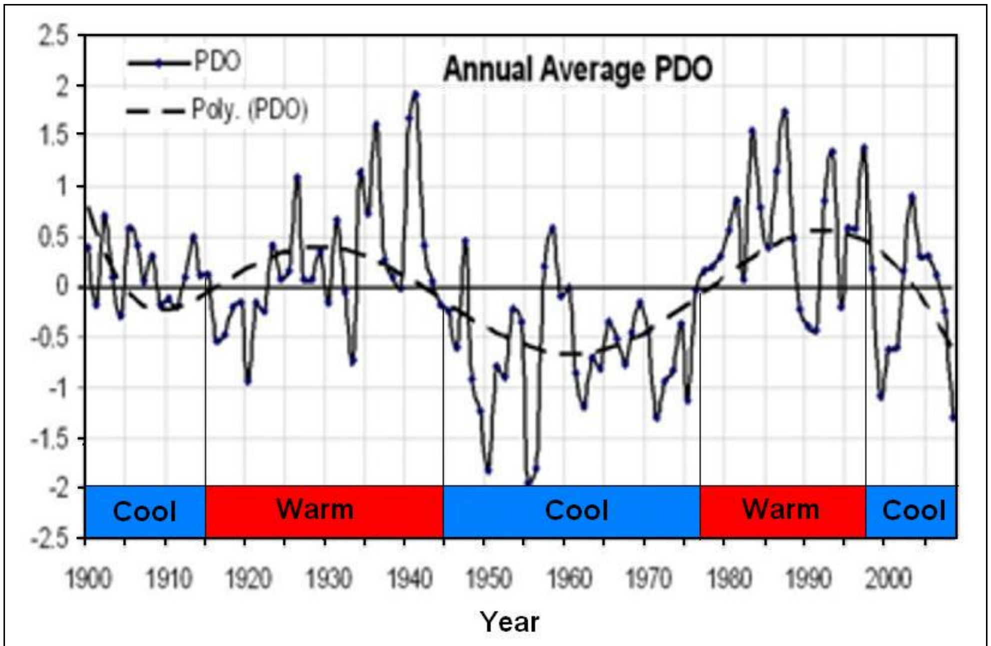


Figure 3. Annual average PDO 1900-2009. Note the multidecadal nature of the cycle with a period of approximately 60 years.

MULTIVARIATE ENSO INDEX (MEI)

Wolter in 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 1950-93 reference period. Negative values of the MEI represent the cold ENSO phase, (La Niña), while positive MEI values represent the warm ENSO phase (El Niño).

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 ENSO measure, Wolter's MEI correlates with the PDO. Mclean etal (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 seven months earlier. The SOI is a rough indicator of general atmospheric circulation and thus global climate change.

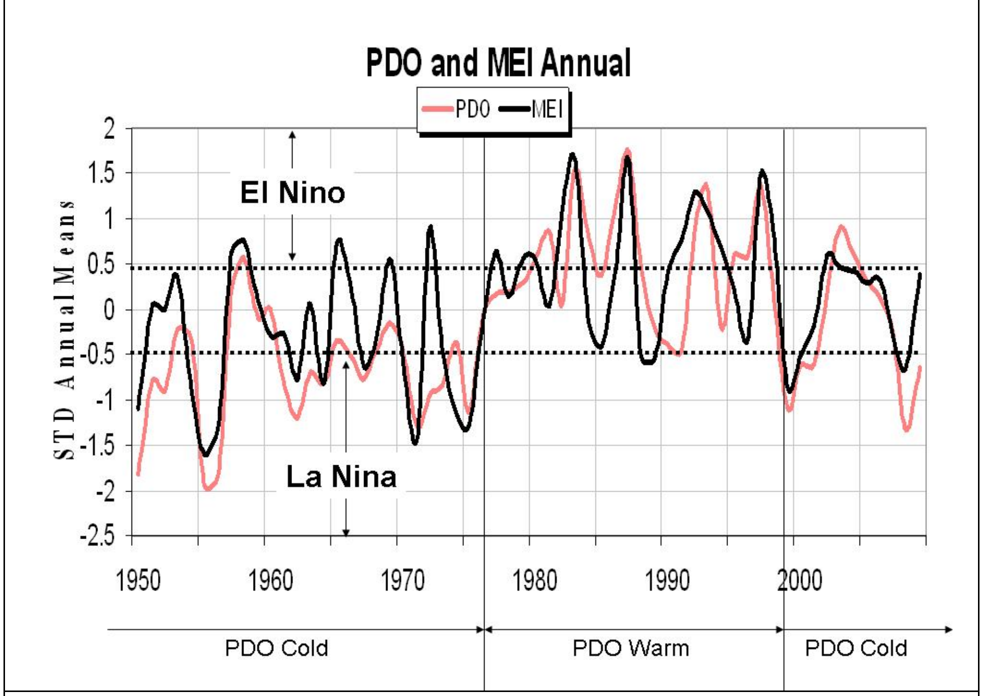


Figure 4. Annual average PDO and MEI (Multivariate ENSO Index) from 1950 to 2007 clearly correlate well. Note how the ENSO events amplify or diminish the favored PDO state.

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

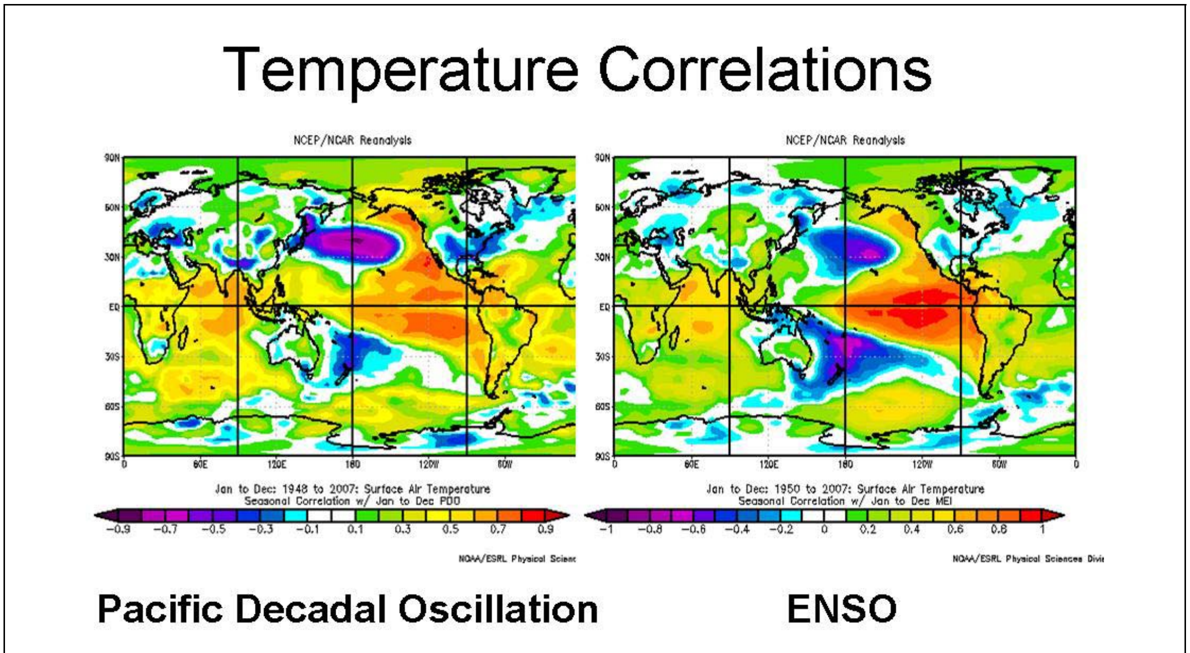
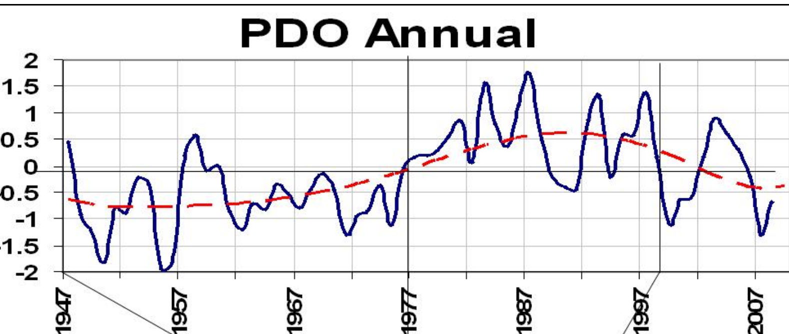


Figure 5. PDO and ENSO compared. Strong similarity between PDO and ENSO ocean basin patterns. Land temperatures also are very similar between the PDO warm modes and El Ninos and the PDO cold modes and La Ninas

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 (figure 6).



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 to 7 in the 1947 to 1977 cold phase) and 5 to 3 in the current, while in the warm phase from 1977 to 1998,

the El Ninos had a decided frequency advantage of 10 to 3.

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 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).

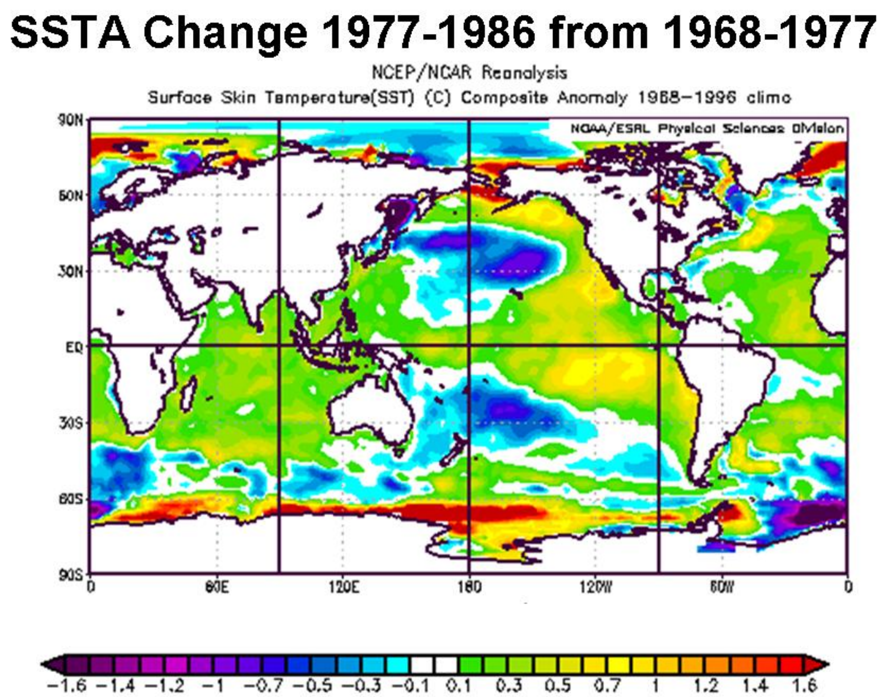


Figure 7. Difference in average sea surface temperatures between the decade prior to the GPCS and the decade after the GPCS. Yellow and green colors indicate warming of the NE Pacific off the coast of North America relative to what it had been from 1968-1977. Note the cooling in the west central North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

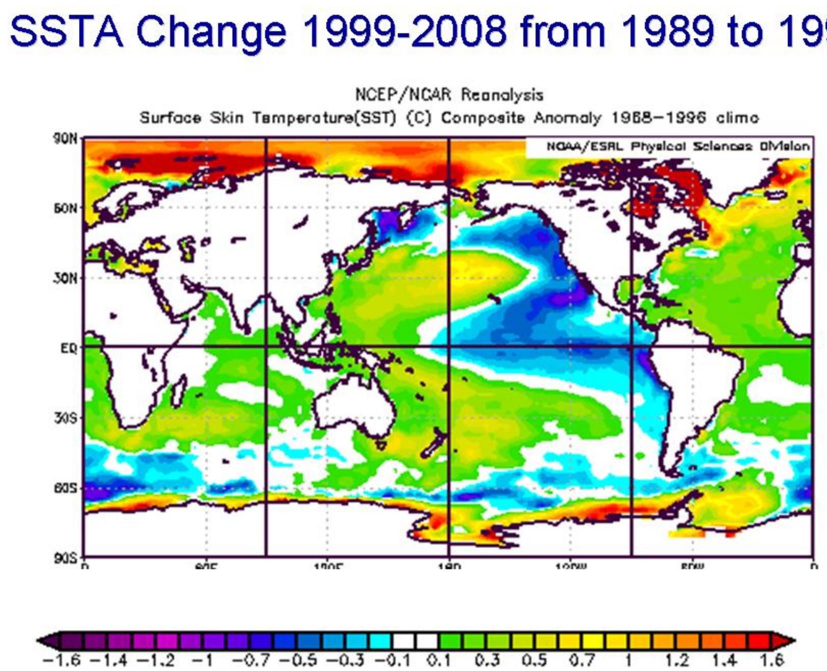


Figure 8. The PDO flipped back to the cold mode in 1999. The change can be seen with this sea surface temperature difference image of the decade after the GPCS minus the decade before the GPCS. Note here the strong cooling in the eastern Pacific and the warming of the west central North Pacific.

During the past century, global climates have consisted of two cool periods (1880-1915 and 1945 to 1977) and two warm periods (1915 to 1945 and 1977 to 1998). In 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. This rapid switch from cool to warm has become known as "The Great Pacific Climatic Shift" (Figure 1). Atmospheric 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 (Figure 3) have periods of about 25-30 years. Reconstruction of ancient PDO cycles shows PDO warm and cool phases dating back to 1662 A.D. (Moore et al., 2002; Verdon and Franks, 2006).

Verdon and Franks (2006) reconstruct 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 (Figure 9).

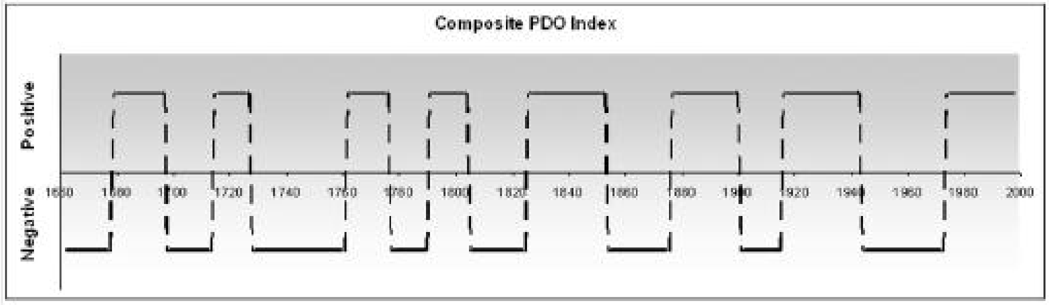


Figure 9. Verdon and Franks (2006) reconstructed PDO back to 1662 showing cyclical behavior over the whole period.

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

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 ^{16}O but a small amount consists of ^{18}O, an isotope of oxygen that is somewhat heavier. When water vapor (H_2O) condenses from the atmosphere as snow, it contains a ratio of $^{16}O/^{18}O$ ($\Delta^{18}O$) that reflects the temperature at the time. When the snow falls on a glacier and is converted to ice, it retains an isotopic 'fingerprint' of the temperature conditions at the time of condensation. Measurement of the $^{16}O/^{18}O$ ratios in glacial ice hundreds or thousands of years old allows reconstruction of past temperature conditions (Stuiver and Grootes, 2000; Stuiver, and 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. 1). Figure 1 shows a number of well–known climatic events. For example, the isotope record shows the Maunder Minimum, the Dalton Minimum, the 1880–1915 cool period, the 1915– ~1945 warm period, and the ~1945–1977 cool period, as well as many other cool and warm periods. Temperatures fluctuated between warm and cool at least 22 times between 1480 AD and 1950 (Figure 10). None of the warming periods could have possibly been caused by increased CO_2 because they all preceded rising CO_2.

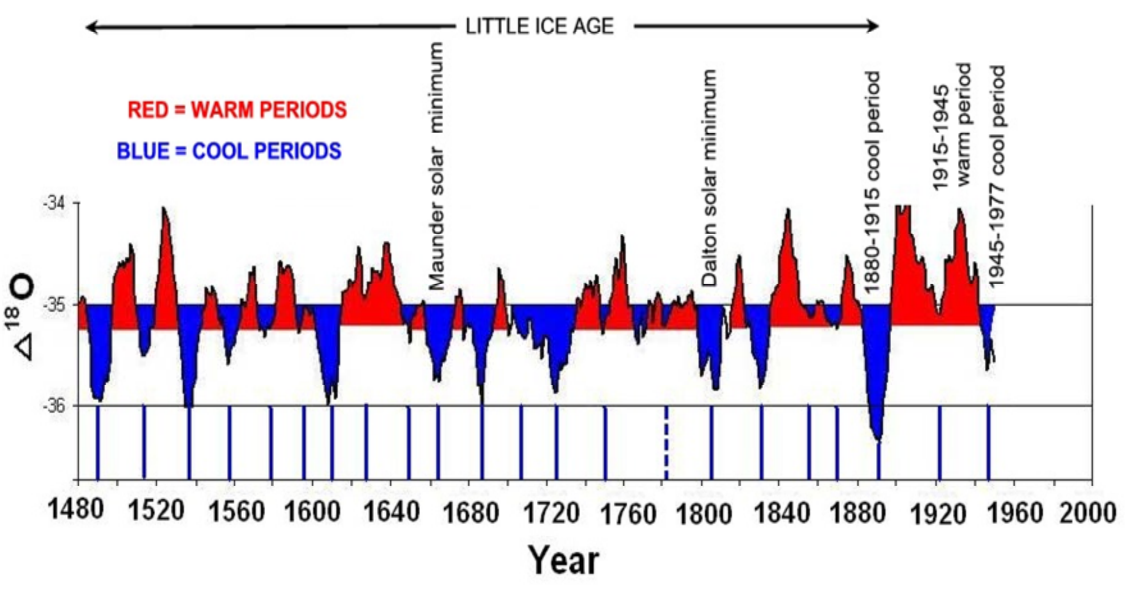


Figure 10. Cyclic warming and cooling trends in the past 500 years (plotted from GISP2 data, Stuiver and Grootes, 2000).

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.

CORRELATON OF THE PDO AND GLACIAL FLUCTUATIONS IN THE PACIFIC NW

For example, the ages of moraines downvalley from the present Deming glacier on Mt. Baker match the ages of the cool periods in the Greenland ice core. Because historic glacier fluctuations coincide with global temperature changes and PDO, these earlier glacier fluctuations could also well be due to oscillations of the PDO (figure 11).

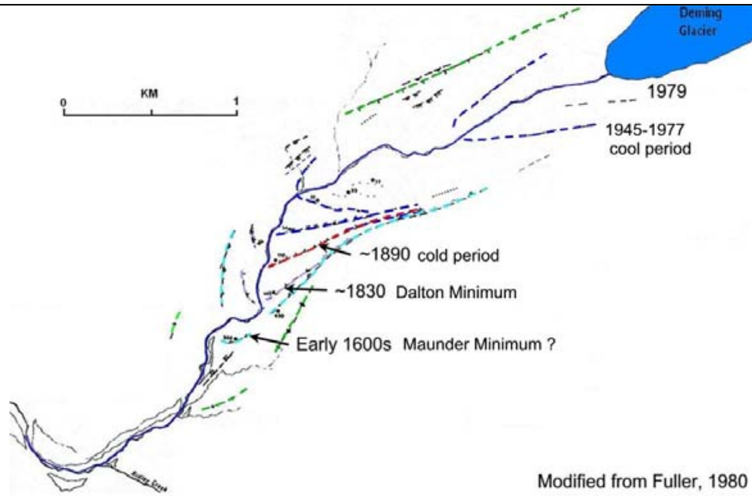


Figure 11. Ice marginal deposits (moraines) showing fluctuations of the Deming glacier, Mt. Baker, WA corresponding to climatic warming and cooling in Greenland ice cores.

Glaciers on Mt. Baker, WA show a regular pattern of advance and retreat (Figure 12) 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.

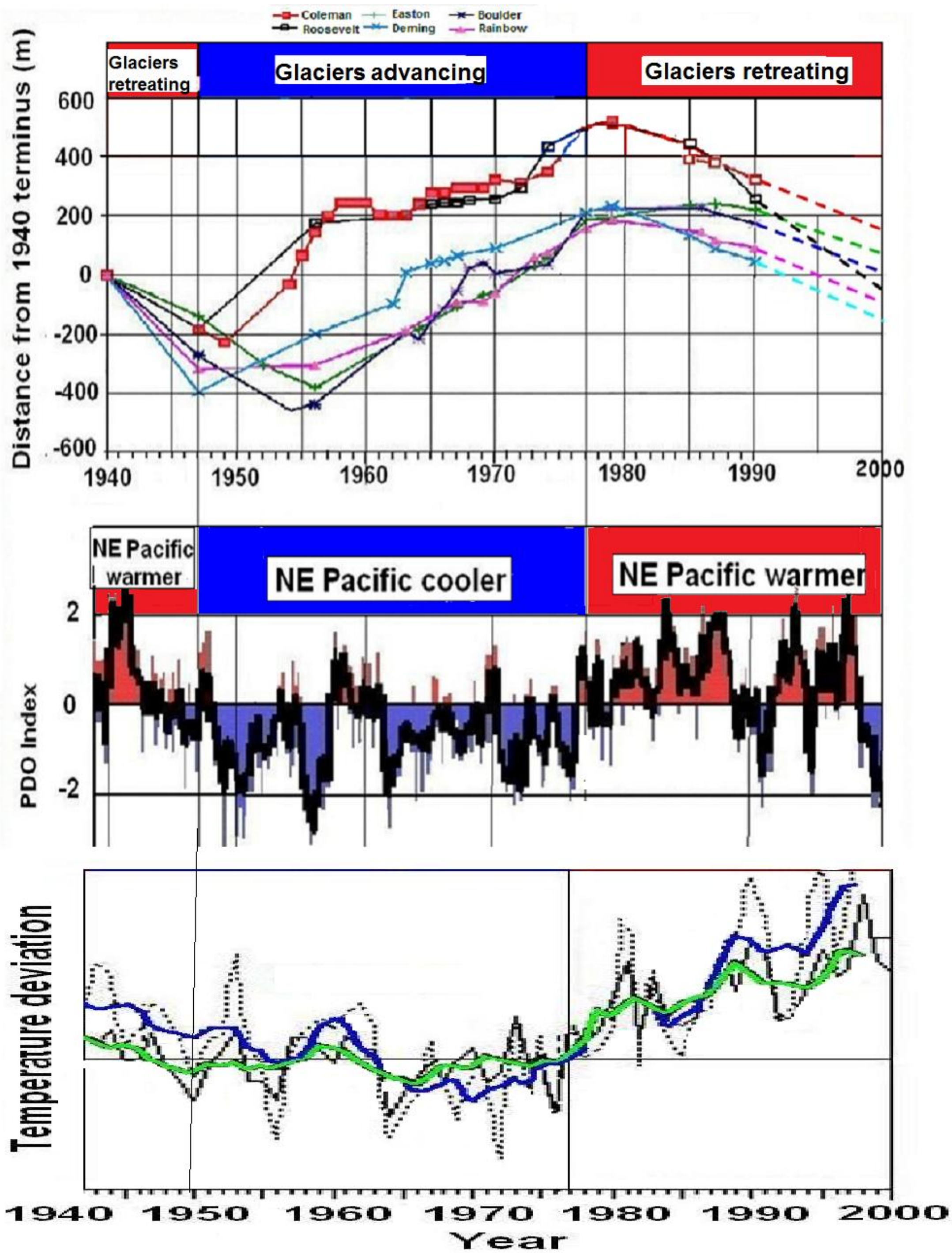


Figure 12. Correlation of glacial fluctuations, global temperature changes, and the Pacific Decadal Oscillation.

THE ATLANTIC MULTIDECADAL OSCILLATION (AMO)

Like the Pacific, the Atlantic exhibits multidecadal tendencies and a characteristic tripole structure. 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.

NORTH ATLANTIC OSCILLATION AND ARCTIC OSCILLATION AND THE AMO

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. 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 as key climate pacemakers for large scale climate variations over the centuries.

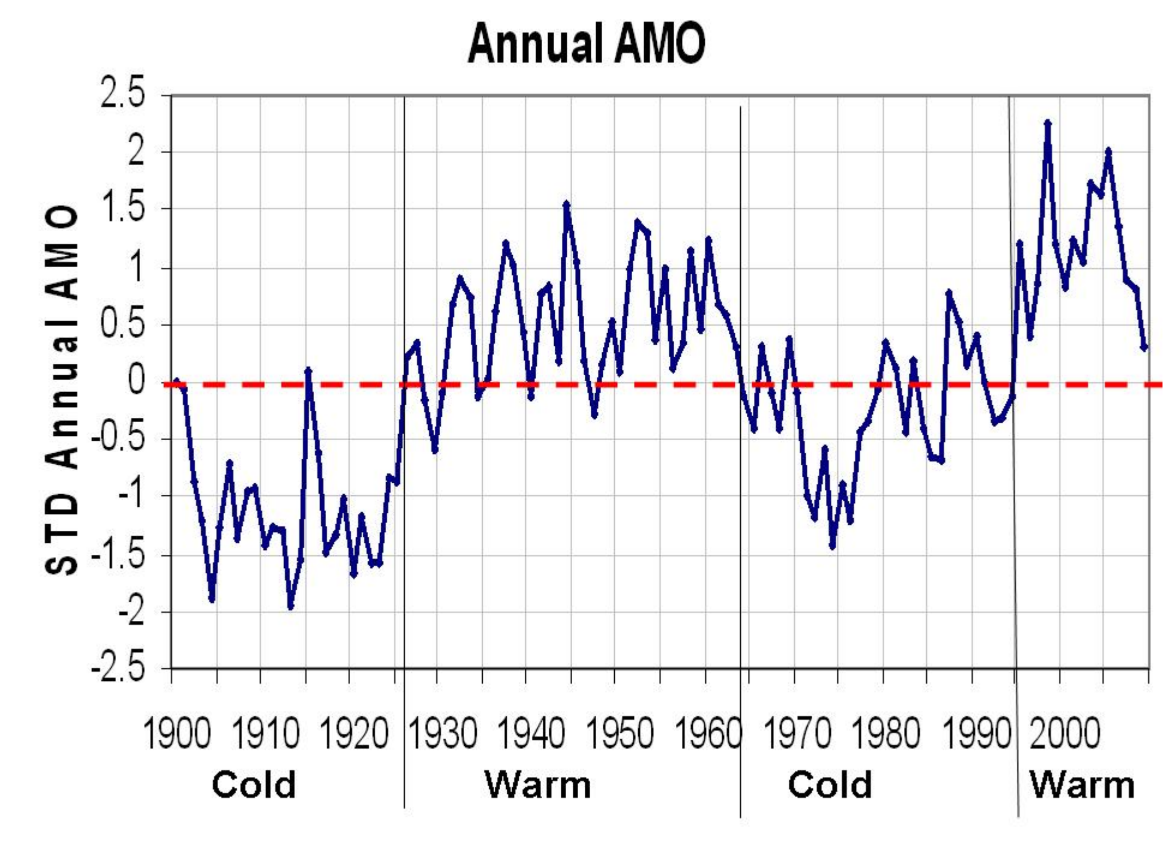


Figure 13: AMO annual mean (STD) showing a similar 60-70 year cycle as the PDO but

with a lag of about 15 years to the PDO

Arctic Oscillation (also known as the Northern Annular Mode (NAM) Index) is defined as the amplitude of the pattern defined by the leading empirical orthogonal function of winter monthly mean NH MSLP anomalies poleward of 20ºN (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 tripole 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, as can be seen below. A lag of a few years occurs after the flip of the AMO and the tendencies appear to be 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 to 15 years.

As noted in the AR4 (3.6.6.1), 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). Boberg and Lundstedt (2002) showed the solar wind can play a role in fluctuations of the NAO.

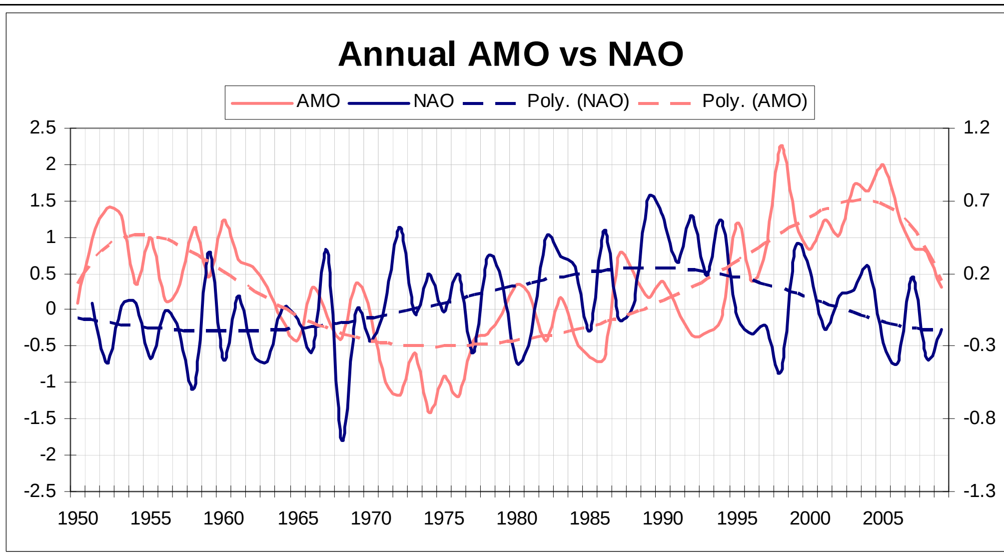


Figure 14. Annual Average AMO and NAO compared. Note the inverse relationship with a slight lag of the NAO to the AMO.

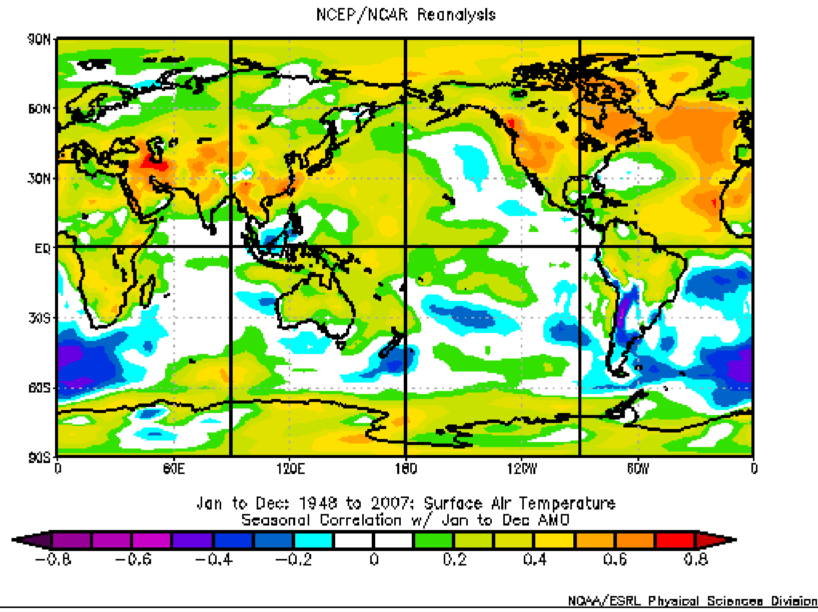


Figure 15: Correlation of the AMO with annual surface temperatures

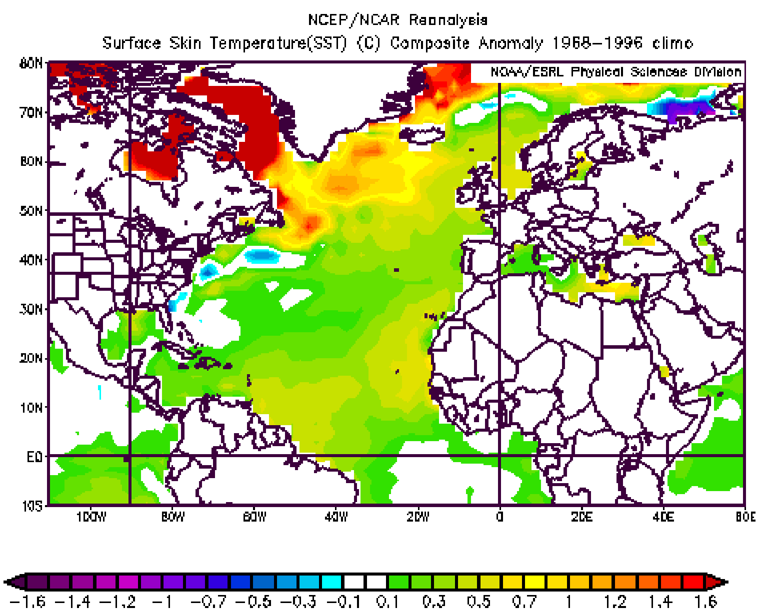


Figure 16. Difference in sea surface temperatures 1996-2004 from 1986 to 1995. It shows the evolution to the warm Atlantic Multidecadal Oscillation.

SYNCHRONIZED DANCE OF THE TELECONNECTIONS

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 (see Science Daily review here).

> *'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, 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 to 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.' Tsonis said that 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'. It interviewed a 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, Tsonis said, 56 per cent of the surface of the United States was covered by snow. *'That hasn't happened for several decades,'* he 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.'*

Tsonis said: '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.' 'This isn't just a blip. We can expect colder winters for quite a while'.

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 though with regional variations and the cold modes with general broad climatic cooling. I normalized the two indices to make them more comparable and added the two. 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 Figure 17.

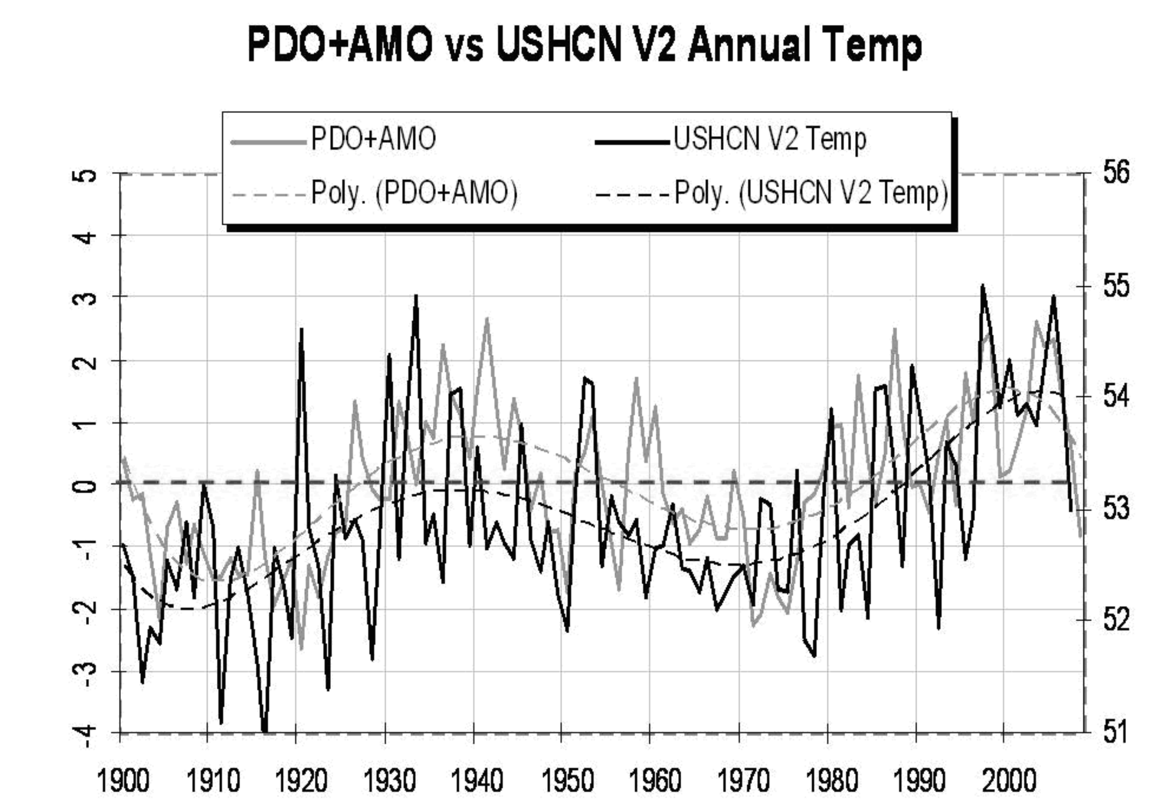


Figure 17: NASA GISS version of NCDC USHCN Version2 versus PDO+AMO. The mutlidecadal cycles with periods of 60 years match the USHCN warming and cooling cycles. Annual temperatures end at 2007.

With an 11 year smoothing of the temperatures and PDO+AMO to remove any effect of the 11 year solar cycles, we get an even better correlation with an r-squared of 0.85.

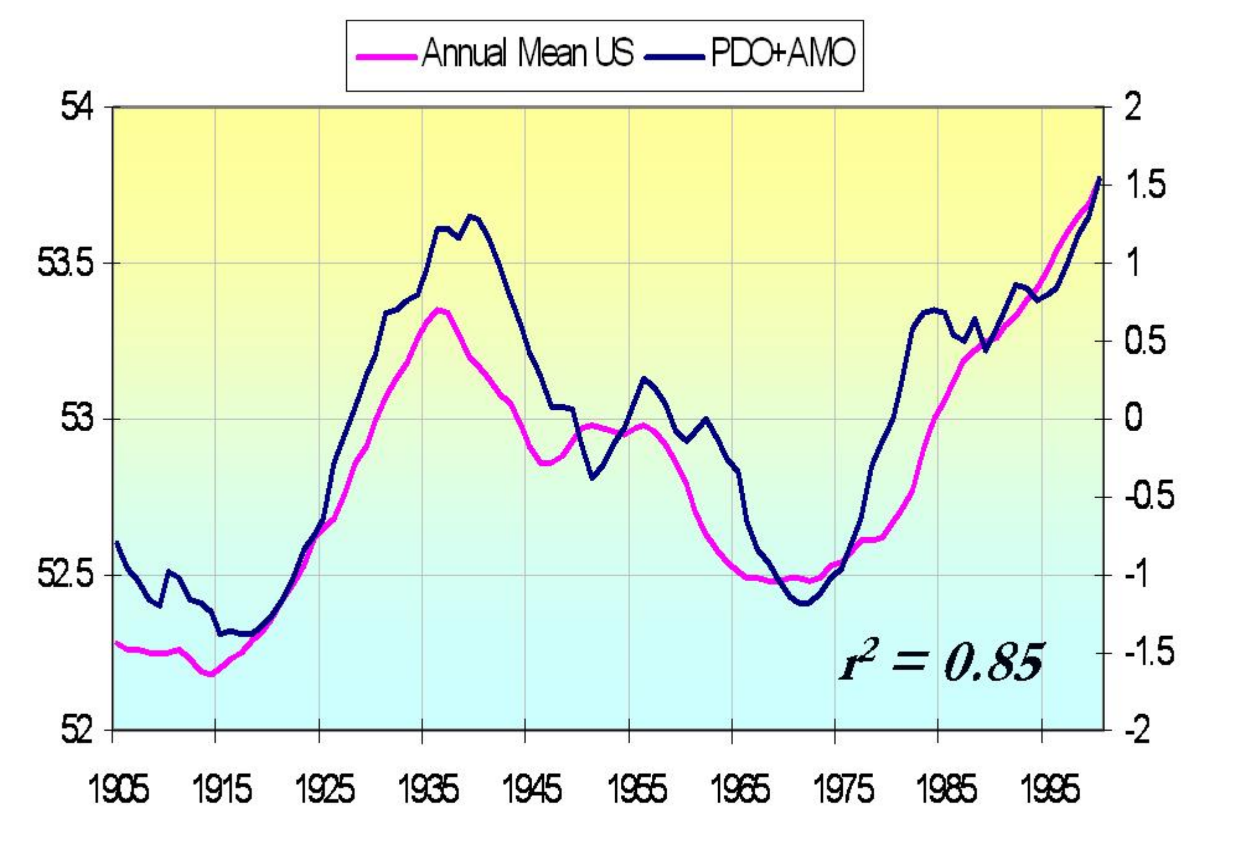


Figure 18: With 22 point smoothing, the correlation of US temperatures and the ocean multidecadal oscillations is clear with an r-squared of 0.85

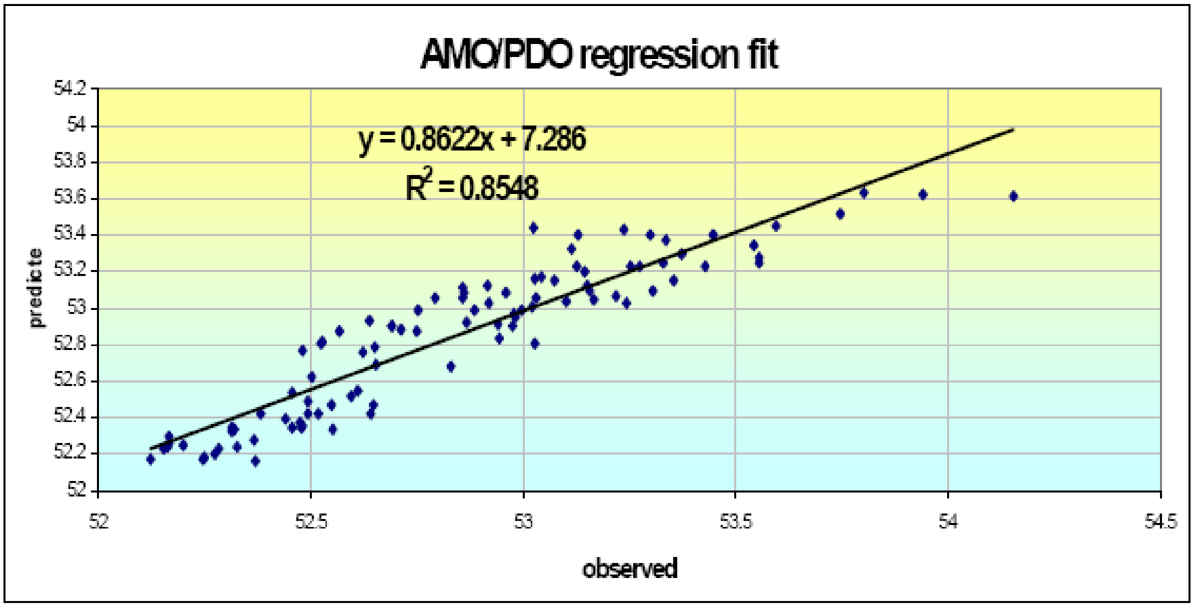


Figure 19: The AMO/PDO regression fit to USHCN version 2

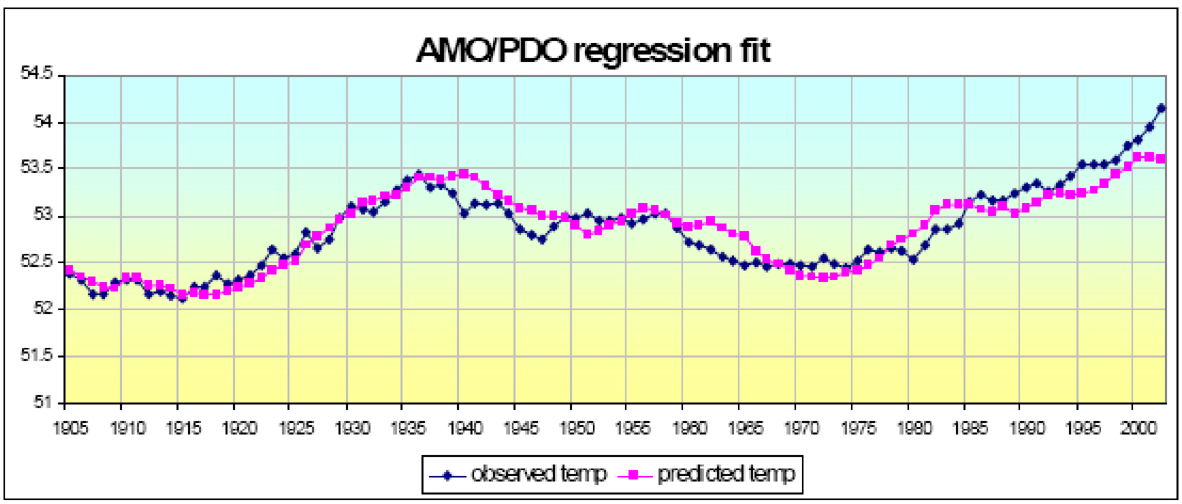


Figure 20: using the PDO/AMO to predict temperatures works well here with some departure after around 2000.

Note this data plot started in 1905 because the PDO was only available from 1900. The divergence 2000 and after was either (1) greenhouse warming finally kicking in or (2) an issue with the new USHCN version 2 data.

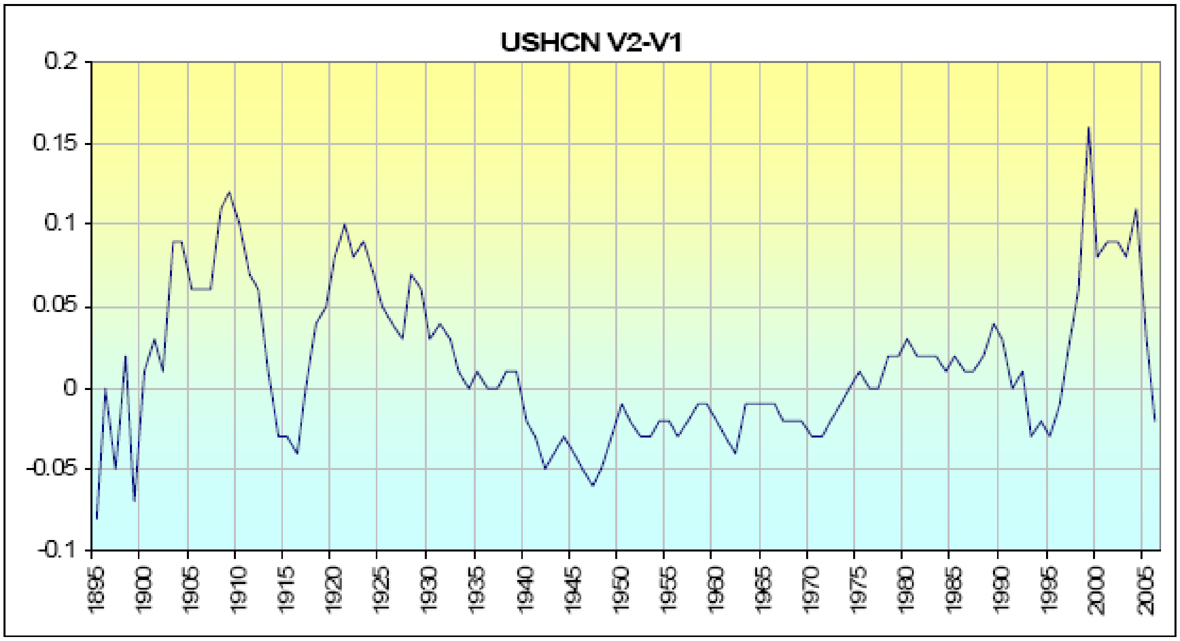


Figure 21: The difference in US annual Mean temperatures for USHCN version 2 minus USHCN version 1. The elimination of the urbanization adjustment led to a hard to explain spike in the 1997-2005 time period.

The plot 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 the adjustment up of the 1998-2005 temperatures by as much as 0.15F (unexplained).

THE COOL PHASE OF PDO IS NOW ENTRENCHED

We have shown how these two ocean oscillations drive climate shifts. The PDO leads the way and its effect is later amplified by the AMO. 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 global cooling for the past 10 years, but also assure that cool temperatures will continue for several more decades.

The cool phase of the PDO is now entrenched and ‘global warming’ (the term used for warming from 1977 to 1998) is over.

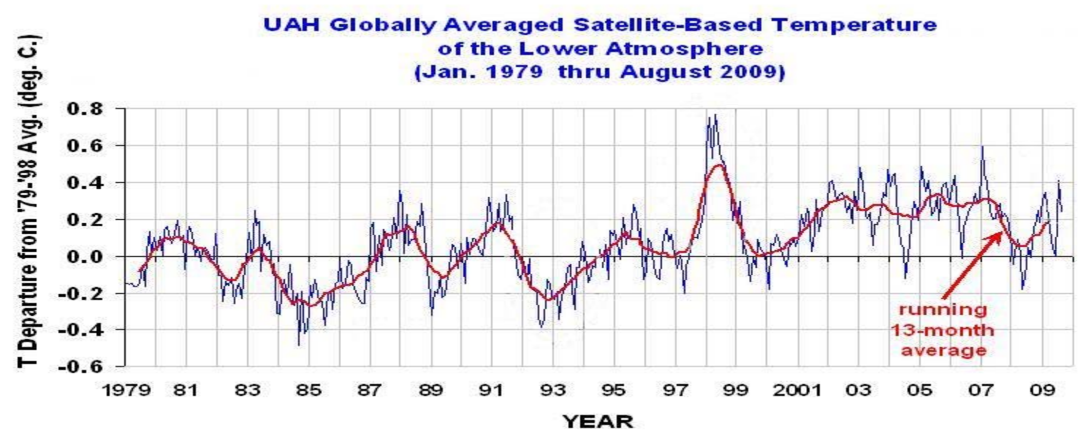


Figure 22: UAH globally averaged lower atmospheric temperatures

No statistically significant global warming has taken place since 1995 and a cooling has occurred during the past several years. One possible 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. (ADDED)

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 assure that cooler temperatures will continue for several more decades.

WHERE ARE WE HEADED DURING THE COMING CENTURY?

The record of natural climate change and the measured temperature record during the last 150 years, gives no reason for alarm about dangerous warming caused by human CO_2 emissions. Predictions based on past warming and cooling cycles over the past 500 years accurately predicted the present cooling phase (Easterbrook, 2001, 2005, 2006a,b, 2007, 2008a,b,c; Easterbrook and Kovanen, 2000) and the establishment of cool Pacific sea surface temperatures confirms that the present cool phase will persist for several decades.

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, 2006 a,b, 2007, 2008 a,b,c; Easterbrook and Kovanen, 2000) to accurately predict the cooling phase that is now happening. Establishment of cool Pacific sea surface temperatures since 1999 indicates that the cool phase will persist for the next several decades.

We can look to past natural climatic cycles as a basis for predicting future climate changes. The climatic fluctuations over the past few hundred years suggest ~30 year climatic cycles of global warming and cooling, on a general warming trend from the Little Ice Age cool period. If the trend continues as it has for the past several centuries, global temperatures for the coming century might look like those in Figure 23. Global cooling began in 1999 and should last for several decades because in 1999 the Pacific Ocean switched from its warm mode to its cool and every time that has happened in the past century the climate follows (Fig. 23). The switch to the PDO cool mode to its cool mode virtually assures cooling global climate for several decades.

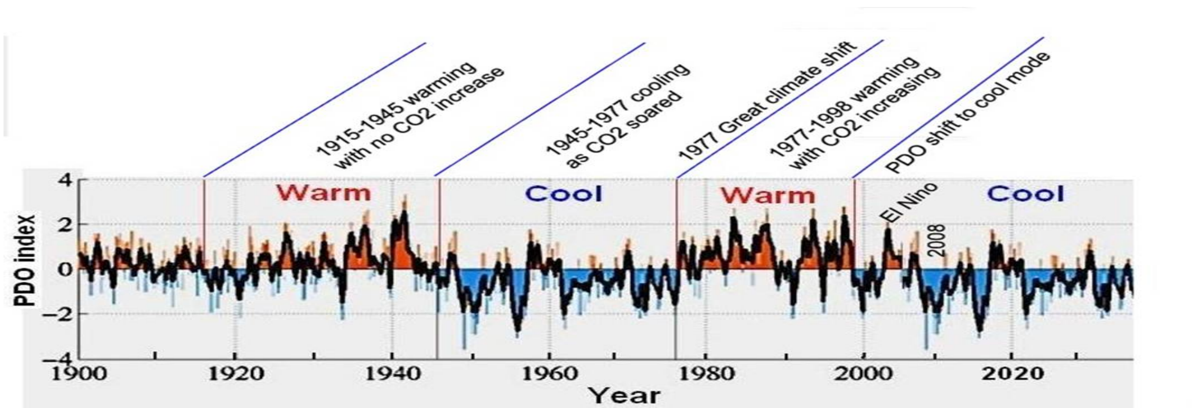


Figure 23: using past behavior of the PDO to predict future

The left side of Figure 24 is the warming/cooling history of the past century. The right side of the graph shows that we have entered a global cooling phase that fits the historic pattern very well. Three possible projections are shown: (1) moderate cooling (similar to the 1945 to 1977 cooling); (2) deeper cooling (similar to the 1945 to 1977 cooling); or (3) severe cooling (similar to the 1790 to 1830 cooling). Only time will tell which of these will be the case, but at the moment, the sun is behaving very similar to the Dalton Minimum (sunspot cycle 4/5), which was a very cold time. This is based on the similarity of sun spot cycle 23 to cycle 4 (which immediately preceded the Dalton Minimum).

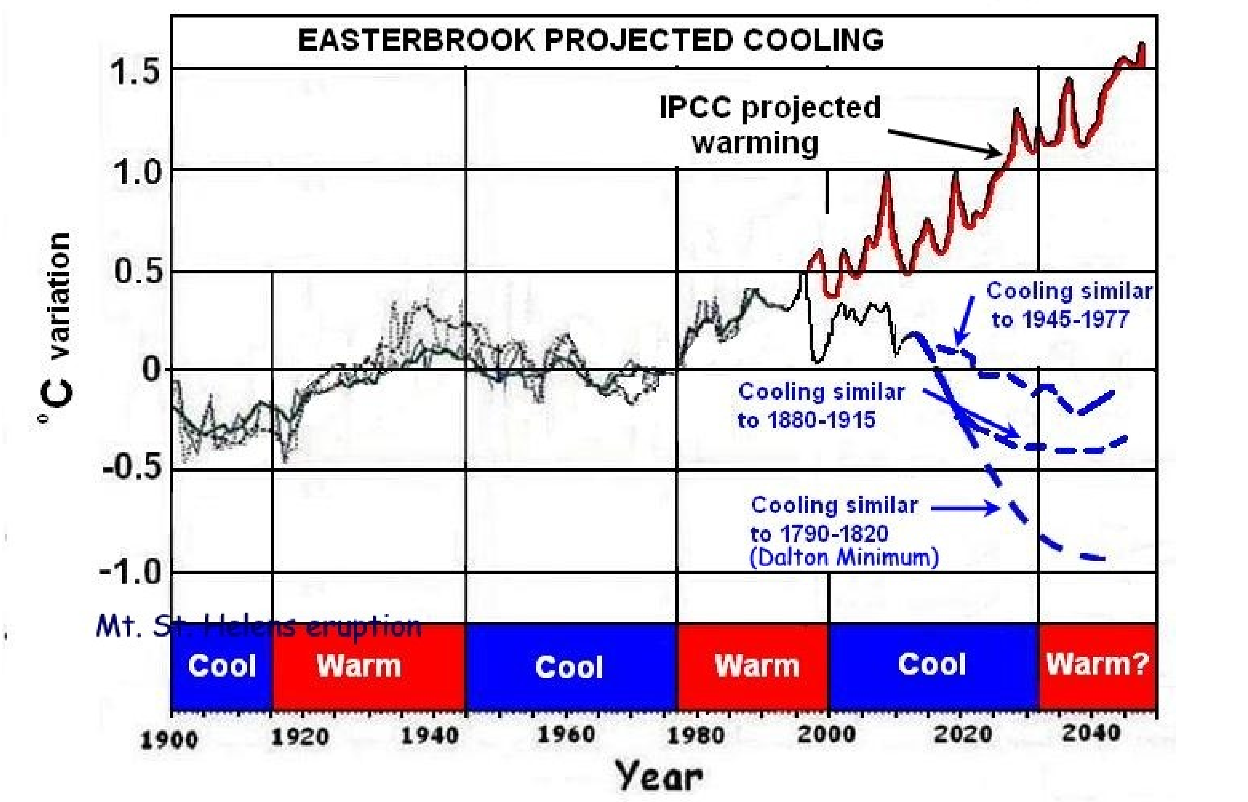


Figure 24: projected climate for the century based on climatic patterns over the past 500 years and the switch of the PDO to its cool phase.

We live in a most interesting time. As the global climate and solar variation reveals themselves in a way not seen in the past 200 years, we will surely attain a much better understanding of what causes global warming and cooling. Time will tell. If the climate continues its 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 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:

Bjerknes, J. (1969): Atmospheric Teleconnections from the equatorial Pacific, Monthly Weather Review, 97, 153-172

D'Aleo, J., Grube, P. (2002): The Oryx Resource Guide to El Nino and La Nina, Greenwood Publishing

D'Aleo, J., 2009, Atmospheric and solar oscillations with linkage to the earth's mean temperature trend: an assessment in the context of the global warming debate: Geological Society of America Special Paper, in press.

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, v. 33, p. 253.

Easterbrook, D.J., 2005, Causes and effects of abrupt, global, climate changes and global warming: Geological Society of America, Abstracts with Program, vol. 37, p. 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, vol. 38, p. 77.

Easterbrook, D.J., 2006b, The cause of global warming and predictions for the coming century: Geological Society of America, Abstracts with Program, vol. 38, p.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, vol. 39, No. 6, p. 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, vol. 40, p.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. and 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, vol. 32, p. 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., and Burke, R.M., 1983, Holocene glacial activity in five valleys on the flanks of Mt. Baker, Washington: Geological Society of America, Abstracts with Program, vol. 15, p. 43.

Gershunov, A. and T.P. Barnett. Interdecadal modulation of ENSO teleconnections. Bulletin of the American Meteorological Society*, 79(12): 2715-2725.*

Grootes, P.M., and 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, vol. 102, p. 26455-26470.

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

Hanna, E. and Cappelen, J. (2003). Recent cooling in coastal southern Greenland and relation with the North Atlantic Oscillation. Geophysical Research Letters 30(3): doi: 10.1029/2002GL015797. issn: 0094-8276.

Hanna, E., Jonsson, T., Olafsson, J. and 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.*

Hansen, J., R. Ruedy, J. Glascoe, and Mki. Sato, 1999: GISS analysis of surface temperature change. J. Geophys. Res.*,* ***104****, 30997-31022, doi:10.1029/1999JD900835.*

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

Harper, J. T., 1993, Glacier fluctuations on Mount Baker, Washington, U.S.A., 19401990, and climatic variations: Arctic and Alpine Research, vol. 4, p. 332-339.

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

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

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 Oscilation using early instrumental pressure observations from Gibralter and southwest Iceland, In J. Climatology, 17, 1433-1450

Kerr, R. A., A North Atlantic climate pacemaker for the centuries, Science, 288 (5473), 984-1986, 2000.

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

M. Latif,M., Park,W., Ding,H. and ***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, vol. 78, p. 1069-1079.

McLean, J. D., C. R. de Freitas, and R. M. Carter (2009), Influence of the Southern Oscillation on tropospheric temperature, Journal of Geophysical Research, 114, D14104, doi:10.1029/2008JD011637.

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

Minobe, S., 1997, A 50-70 year climatic oscillation over the North Pacific and North America: Geophysical Research Letters, vol. 24, p 683-686.

Minobe, S., 1999, Resonance in bidecadal and pentadecadal climate oscillations over the North Pacific: Role in climatic regime shifts: Geophysical Research Letters, vol. 26, p. 855-858.

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

Perlwitz, J., M. Hoerling, J. Eischeid, T. Xu, and A. Kumar (2009), A strong bout of natural cooling in 2008, Geophys. Res. Lett., 36, L23706, doi:10.1029/2009GL041188.

Sicre, M.,; Jacob, J., Ezat, U., Rousse, S., Kissel, C., Yiou, P., Eiriksson, J., Knudsen, K.L., Jansen, E., Turon, J., 2008, Decadal variability of sea surface temperatures off North Iceland over the last 2000 years: Earth and Planetary Science Letters, vol. 268, p.137-142.

Soon, W., 2005, Variable solar irradiance as a plausible agent for multidecadal variations in the Arctic-wide surface air temperature record of the past 130 years: Geophysical Research Letters, vol. 32, L16712.

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, vol. 321, p.680-684.

Stuiver, M., 1961, Variations in radio carbon concentration and sunspot activity: Geophysical Research, vol. 66, p. 273-276.

Stuiver, M., 1994, Atmospheric ^{14}C as a proxy of solar and climatic change: In Nesme-Ribes, ed., The solar engine and its influence on terrestrial atmosphere and climate: Springer-Verlag, Berlin, p. 203-220.

Stuiver, M., and Brasiunas, T.F., 1991, Isotopic and solar records: in Bradley, R.S., ed., Global changes of the past, Boulder University, Corporation for Atmospheric Research, p. 225-244.

Stuiver, M., and Brasiunas, T.F., 1992, Evidence of solar variations: in Bradley, R.S., and Jones, P.D., eds., Climate since A.D. 1500, Routledge, London, p. 593-605.

Stuiver, M. and Grootes, P.M.,.2000, GISP2 Oxygen Isotope Ratios: Quaternary Research, 54/3.

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

Stuiver, M., Braziunas, T.F., Becker, B., and Kromer, B., 1991, Climatic, solar, oceanic, and geomagnetic influences on late-glacial and Holocene atmospheric $^{14}C/^{12}C$ change: Quaternary Research, ol. 35, p. 1-24.

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

Thompson, D.W.J., Wallace, J.M.;(1998), The Arctic Oscillation signature in the wintertime geopotential height and temperature fields. Geophys. Res. Lett. 25, 1297-1300

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

Trenberth, K.E. and Hurrell, J.W., 1994, Decadal atmosphere–ocean variations in the Pacific: Climate Dynamics, vol. 9, p. 303-319.

Tsonis, A.A., Hunt, G., and Elsner, G.B. On the relation between ENSO and global climate change, Meteorol Atmos Phys 000, 1–14 (2003),DOI 10.1007/s00703-002-0597-z

Tsonis, A.A., Swanson,K.L., and Kravtsov,S., 2007: A new dynamical mechanism for major climate shifts. Geophys. Res. Lett., 34, L13705, doi:10.1029/ 2007GL030288

Usoskin, I. G.,Mursula, K., Solanki, S. K., Schu¨ssler,M. & Alanko, K. Reconstruction of solar activity for the last millenium using 10Be data. Astron. Astrophys. 413, 745–751 (2004).
Verdon, D. C., and S. W. Franks, 2006. Long-term behaviour of ENSO: Interactions with the PDO over the past 400 years inferred from paleoclimate records. Geophysical Research Letters, 33, L06712, doi:10.1029/2005GL025052

Walker, G., Bliss:1932 "World Weather V, Memoirs Royal Met Soc 4 53-84)

Wolter, K., and M.S. Timlin, 1993: Monitoring ENSO in COADS with a seasonally adjusted principal component index. Proc. of the 17th Climate Diagnostics Workshop, Norman, OK, NOAA/N MC/CAC, NSSL, Oklahoma Clim. Survey, CIMMS and the School of Meteor., Univ. of Oklahoma, 52-57

Zhang, Y., J. M. Wallace, and D. Battisti, ENSO-like interdecadal variability: 1990-1993, J. Clim., 10, 1004-1020, 1997.

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

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