GLACIERS, SEA ICE AND ICECAPS

By Joseph D'Aleo CCM and George Taylor CCM

Glaciers

Glaciers worldwide are in general retreat as they have been since the end of the little ice age in the 1800s. There is quite a bit of variability in this picture worldwide with some glaciers advancing.

Most archives from the Northern Hemisphere and the tropics show small or absent glaciers between 9,000 and 6,000 years ago. Glaciers began growing thereafter, up to the 1800s. This tendency is primarily related to changes in the Earth's orbit, however shorter, decadal-scale, regionally diverse glacier responses must have been driven by other factors which are complex and poorly understood

General retreat of glacier termini started after 1800, with considerable mean retreat rates in all regions after 1850 lasting throughout the 20th century. A slowdown of retreats between about 1970 and 1990 is evident in the raw data. Retreats were again generally rapid in the 1990s. In the Northern Hemisphere, the rate of glacier mass loss was twice as rapid in the1990s compared to the period from the 1960s to1990 though advances of glaciers have been observed in western Scandinavia and New Zealand.

There are few records of directly measured glacier mass balances, and they stretch back only to the mid 20th century. When a real weighting and spatial interpolation are used to estimate large-scale patterns from the available data, the 1990s trend towards glacier retreat appears to have leveled off or reversed after 1998.

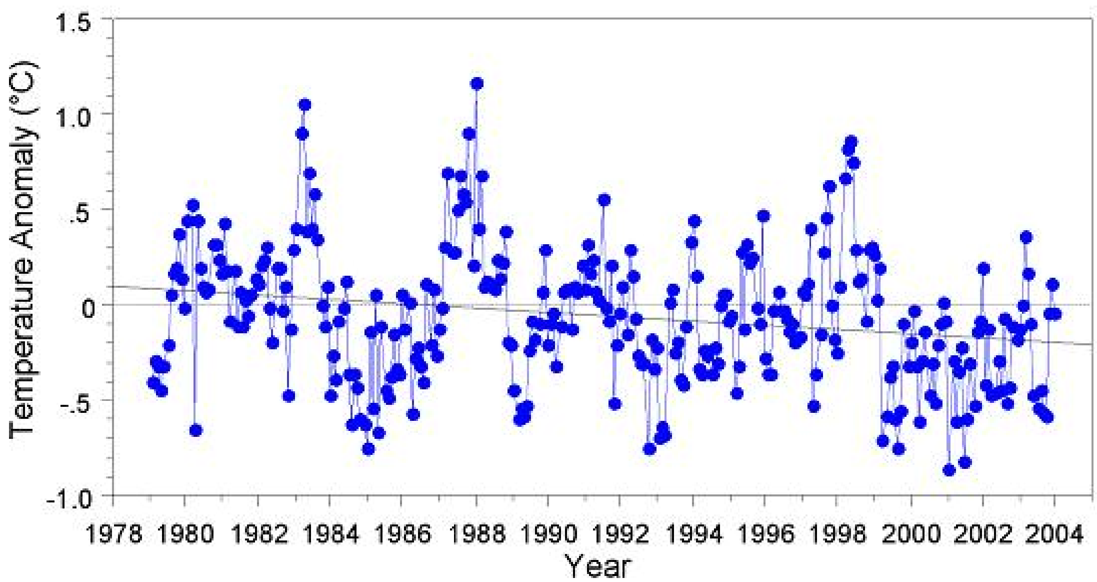
On a regional basis the pattern of glacier regimes remains complex. Precipitation and solar changes appear to be important factors, especially in the tropics, including Kilimanjaro. Although reports on individual glaciers or limited glacier areas support the global picture of ongoing strong ice shrinkage in almost all regions, some exceptional results indicate the complexity of both regional to local scale climate and respective glacier regimes._ Whereas Himalayan glaciers have generally shrunk at varying rates, several high glaciers in the central *Karakoram* are reported to have advanced and/or thickened at their tongues, probably due to enhanced transport of moisture to high altitudes.

Norwegian coastal glaciers advanced in the 1990s and started to shrink around 2000 as a result of almost simultaneous reduced winter accumulation and greater summer melting. Norwegian glacier termini farther inland have retreated continuously at a more moderate rate. Glaciers in the New Zealand Alps advanced during the 1990s, possibly due to increased precipitation, but since 2000 most have started to shrink. There are two notable exceptions, the tourist attraction Franz Josef and the Fox glaciers continued advancing down their valleys in the past year and may soon be close to positions reached 40 years ago.

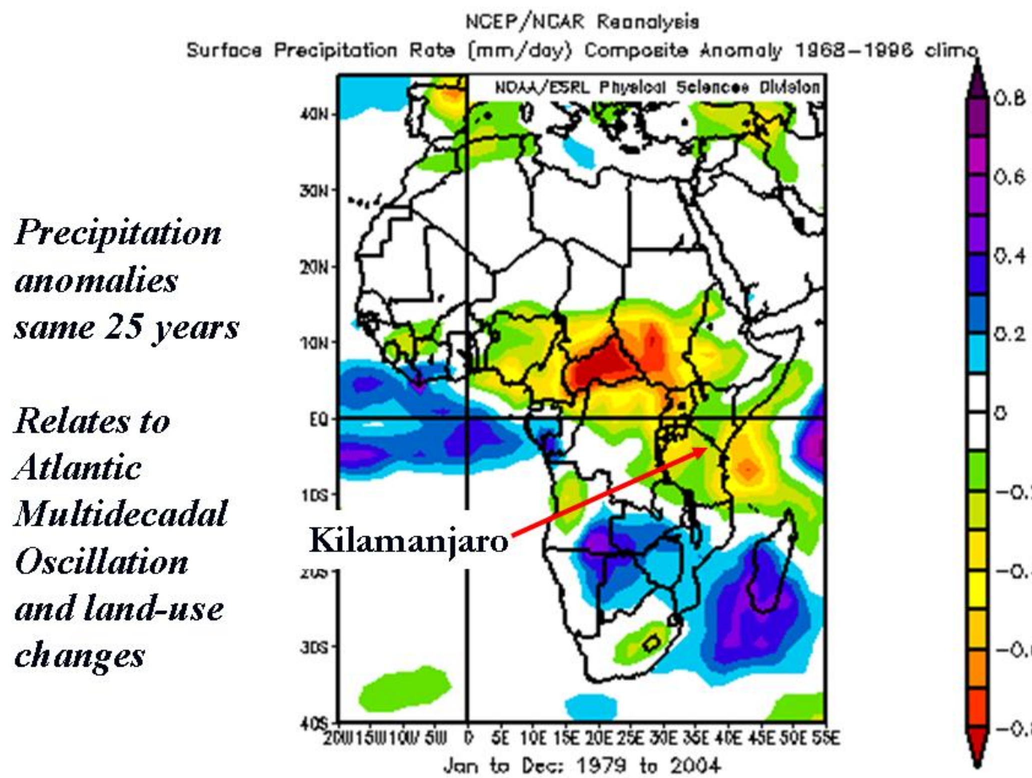
Tropical glaciers, being in principle very sensitive to changes in both temperature and atmospheric moisture, have shrunk mostly in response to regional changes in atmospheric moisture content and related energy and mass balance variables such as solar radiation, precipitation, albedo, and sublimation during the 20th century. Inter-annual variation in the seasonal pattern of moisture strongly dominates the behavior of tropical glaciers.

Glaciers on Kilimanjaro behave exceptionally. Even though the thickness of the tabular ice on the summit plateau has not changed dramatically over the 20th century, the ice has shown an incessant retreat of the vertical ice walls at its margins, for which solar radiation is identified as the main driver. The mass balance on the horizontal top ice surfaces is governed by precipitation amount and frequency and associated albedo, and has sporadically reached positive annual values even in recent years. In contrast to the plateau ice, the shrinkage of the glaciers on Kilimanjaro's slopes is constantly decelerating.

Temperatures at Kilimanjaro have been cooling for the past 25 years and the retreat is believed connected to reduced cloudiness and precipitation, which may be shifts in precipitation patterns due to the result of the Atlantic Multidecadal Oscillation and land use changes (deforestation).



Temperature trend for the past 25 years at Kilimanjaro.



Precipitation Anomalies during the same 25 year period. Note the strip of dryness across central Africa related to Atlantic Multidecadal Oscillation changes and local land use changes (deforestation).

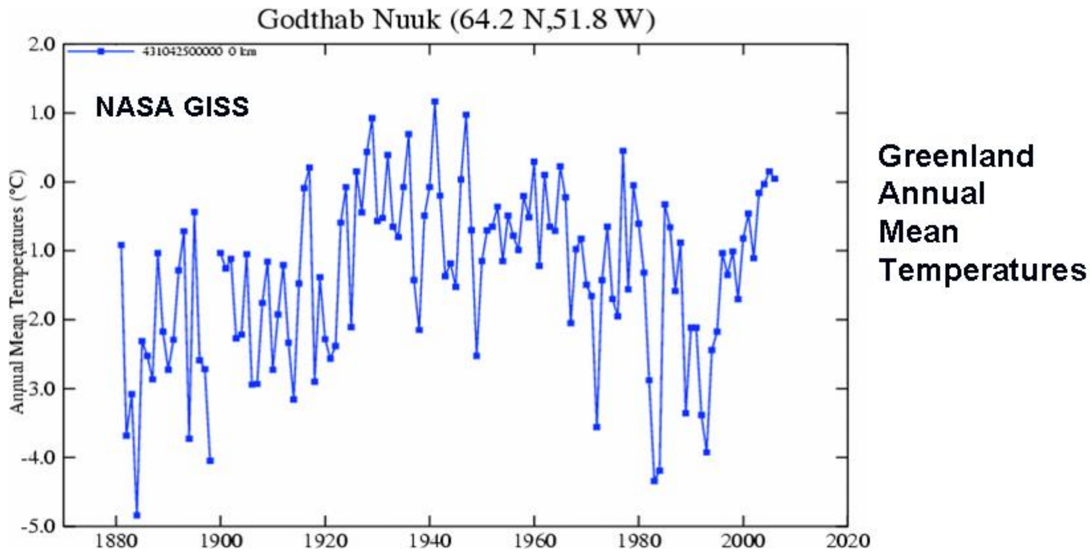
GREENLAND

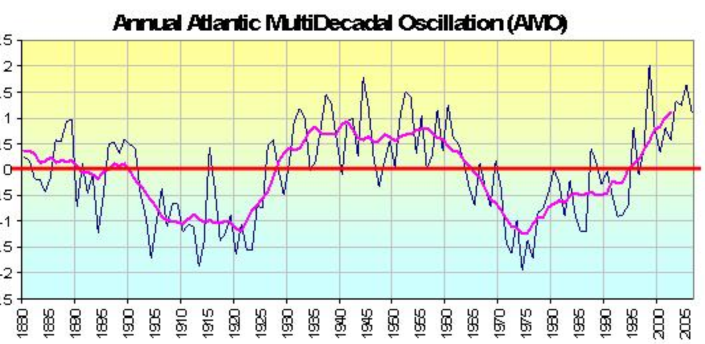
Many recent studies have addressed Greenland mass balance. They yield a broad picture of slight inland thickening and strong near-coastal thinning, primarily in the south along fast-moving outlet glaciers. Assessment of the data and techniques suggests overall mass balance of the Greenland Ice Sheet ranging between growth by 25 Gigatonnes per year (Gt/year) and shrinkage by 60 Gt/year for 1961.2003. This range changes to shrinkage by 50 to 100 Gt/year for 1993.2003 and by even higher rates between 2003and 2005. However, interannual variability is very large, driven mainly by variability in summer melting and sudden glacier accelerations. Consequently, the short time interval covered by instrumental data is of concern in separating fluctuations from trends.

But in a paper published in Science in February 2007, Dr Ian Howat of the University of Washington paper published online this afternoon by Science reports that two of the largest glaciers have suddenly slowed, bringing the rate of melting last year down to near the previous rate. At one glacier, Kangerdlugssuaq, "average thinning over the glacier during the summer of 2006 declined to near zero, with some apparent thickening in areas on the main trunk."

Dr. Howat went on to add "Greenland was about as warm or warmer in the 1930's and 40's, and many of the glaciers were smaller than they are now. This was a period of rapid glacier shrinkage world-wide, followed by at least partial re-expansion during a colder period from the 1950's to the 1980's. Of course, we don't know very much about how the glacier dynamics changed then because we didn't have satellites to observe it. However, it does suggest that large variations in ice sheet dynamics can occur from natural climate variability. The problem arises in the possibility that, due to anthropogenic warming, warm phases will become longer and more severe, so that each time the glaciers go through a period of retreat like this, they won't fully grow back and they will retreat farther the next time."

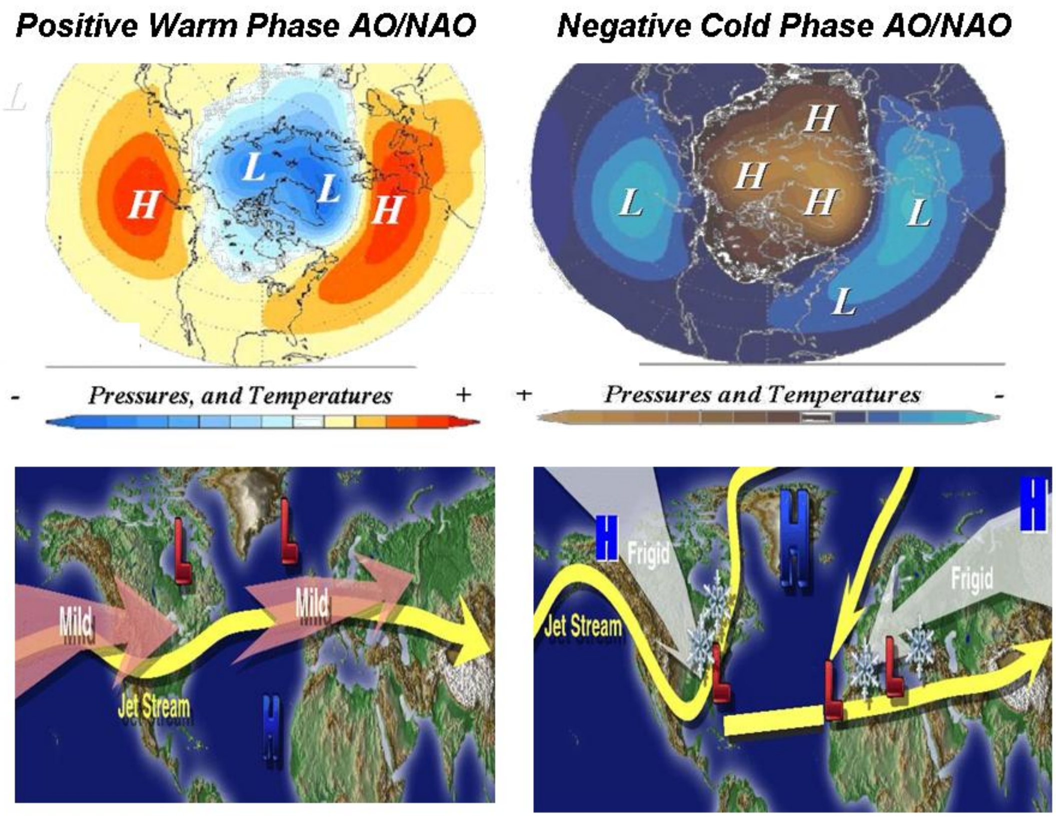
Temperatures indeed were warmer in the 1930s and 1940s in Greenland. They cooled back to the levels of the 1880s by the 1980s and 1990s before resuming a rise in the middle 1990s. The recent warming is not yet at the same level as that of the 1930s and 1940s. The cyclical behavior of temperatures and of icecap advance and retreat relate to the same Atlantic Multidecadal Oscillation shown below the temperature plot for Godthab Nuuk in southwest Greenland. Note how closely the temperatures track with the AMO (which is a measure of the Atlantic temperatures 0 to 70N). It should be noted that Greenland was cooling and its icecap growing the entire period from the late 1950s to the middle 1990s even as Greenhouse gases rose steadily.



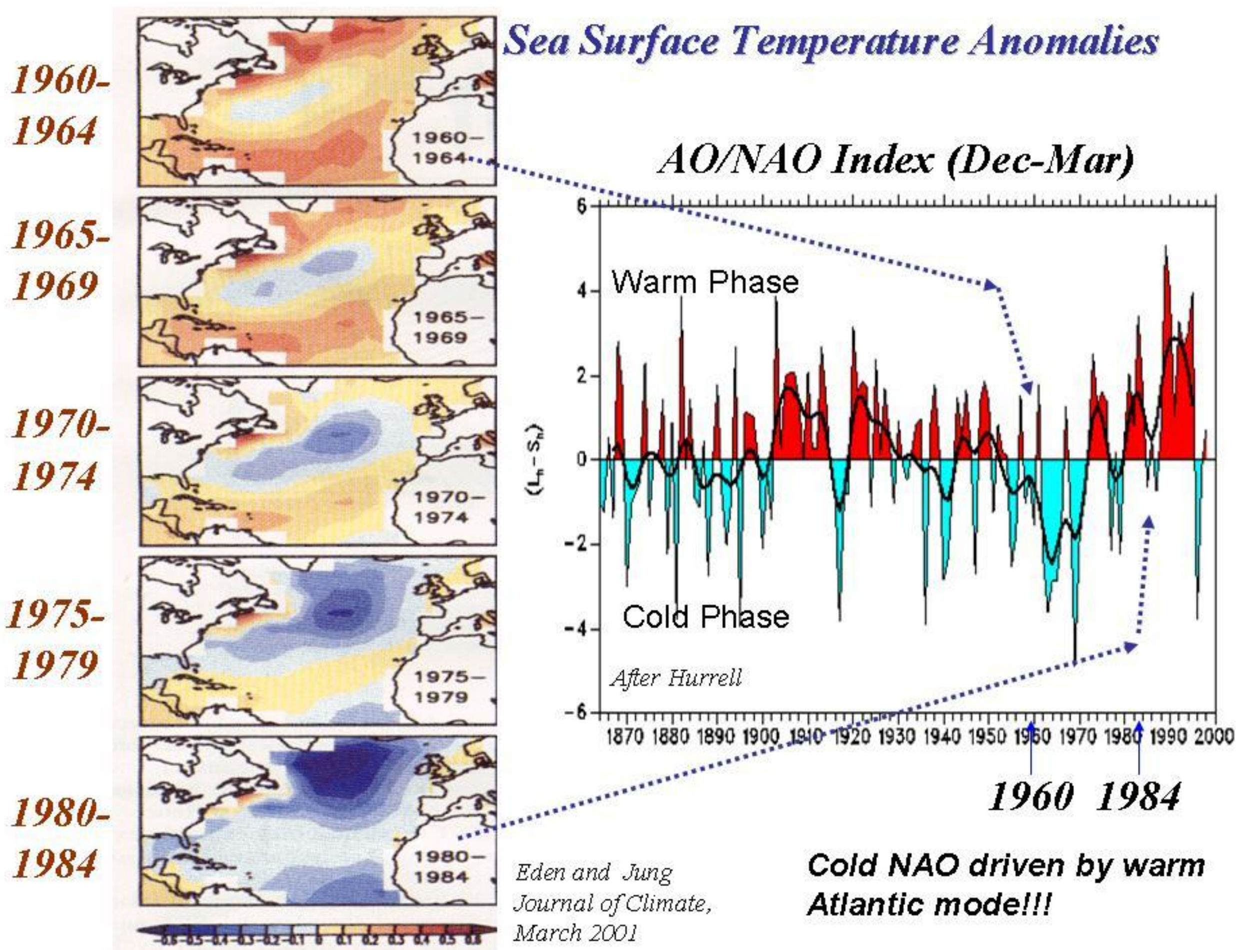


This Greenland AMO correlation is driven by the inverse AMO correlation with the Artic and North Atlantic Oscillations (also called the Northern Annular Mode or NAM).

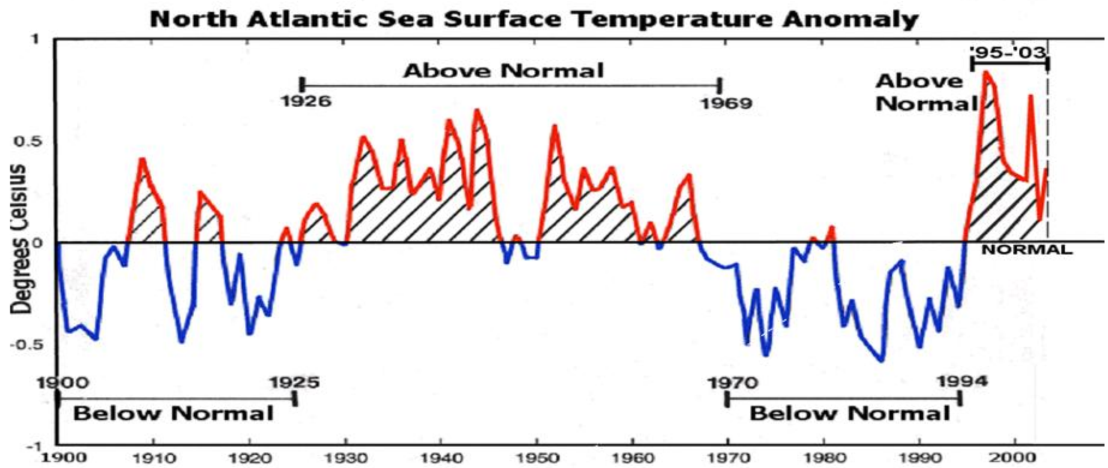
When the NAM (AO and NAO) are in their cold (negative phase) mode, high pressure is found in high latitudes and over Greenland with above normal temperatures while in the warm (positive phase), the cold polar vortex is strong and extends over Greenland.



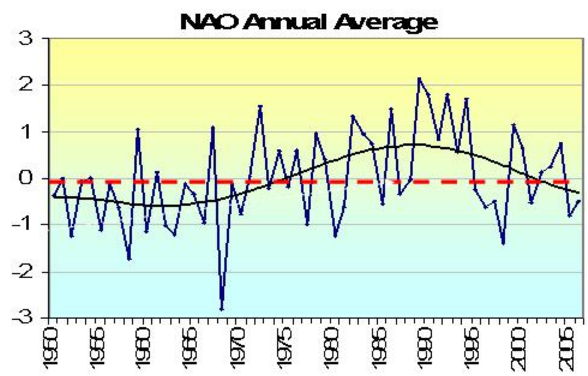
The NAM is inversely correlated with the AMO. When the Atlantic is in its cold mode (AMO negative), the AO/NAO tend to be positive and Greenland cold, when the Atlantic is in its warm mode (AMO positive), the opposite occurs with the AO/NAO more often negative. It should be always noted that there is almost always intraseasonal variability with regards to the AO/NAO and the preferred state can be overridden by stratospheric cooling or warming events that may relate to the solar/QBO relationship as Labitzke and others have shown. The tendency can be seen in the two charts that follow.



Sea Surface Temperature Anomalies
1960-1964
1965-1969
1970-1974
1975-1979
1980-1984
AO/NAO Index (Dec-Mar)
Warm Phase
Cold Phase
After Hurrell
1960
1984
Eden and Jung
Journal of Climate,
March 2001
Cold NAO driven by warm Atlantic mode!!!



North Atlantic temperatures went above normal and NAO turned more negative starting in 1995

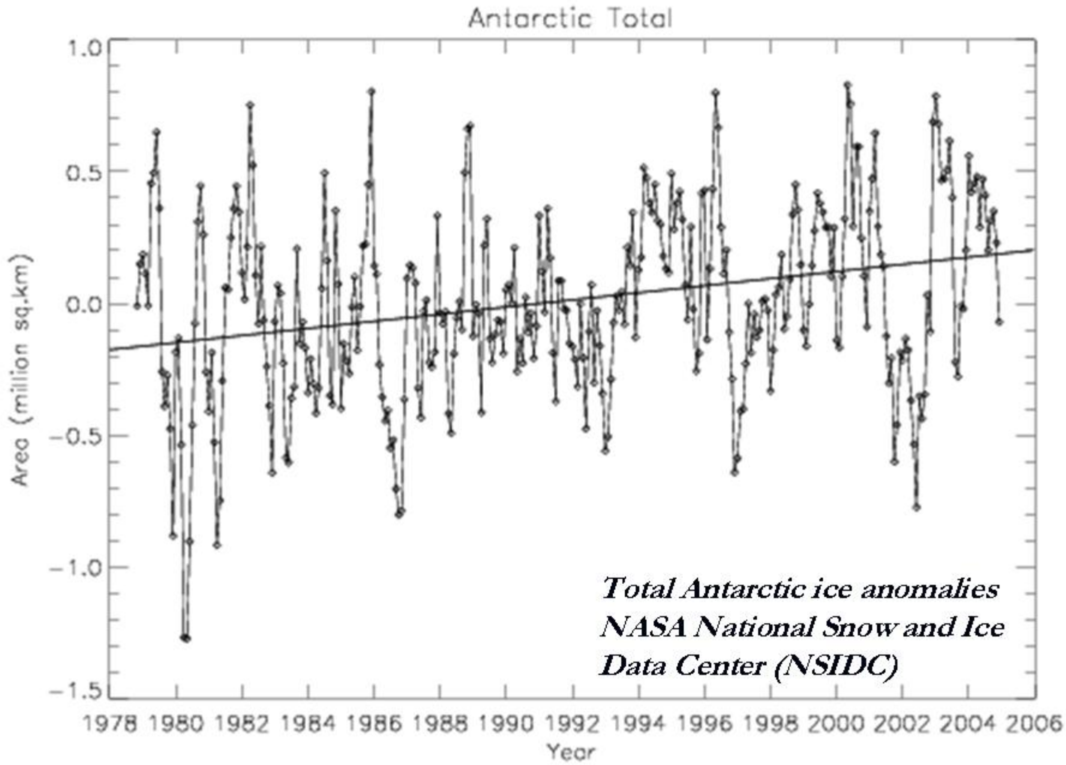


Thus the recent warming in Greenland is not unprecedented and is related to the multidecadal oscillations in the Atlantic and has precious little to do with greenhouse gases (correlation R-squared since 1900 of 0.02)

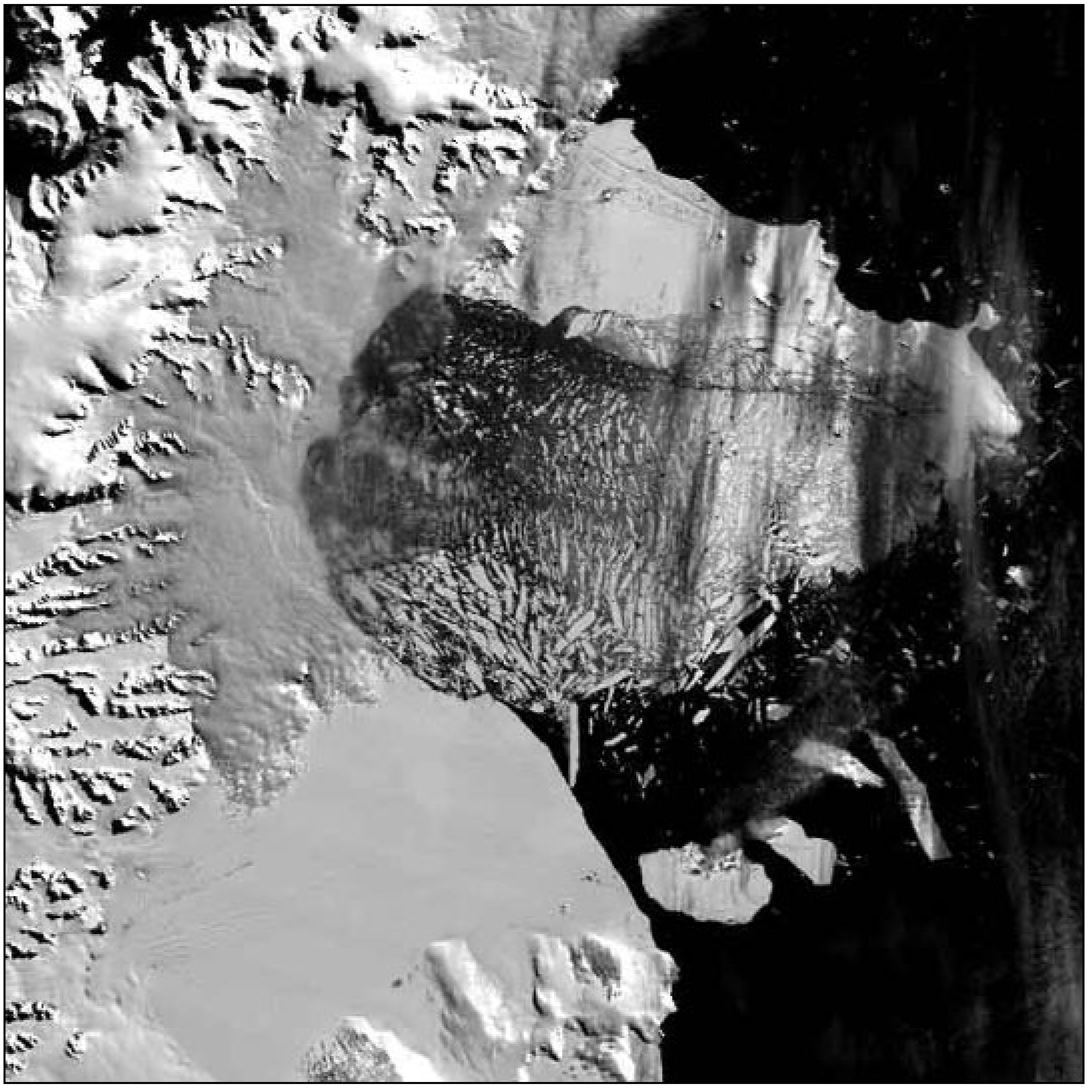
ANTARCTICA

The ice sheet in Eastern Antarctica appears to have grown while that in Western Antarctica appears to have shrunk. The overall change may be positive or negative depending on assumptions about ice dynamics.

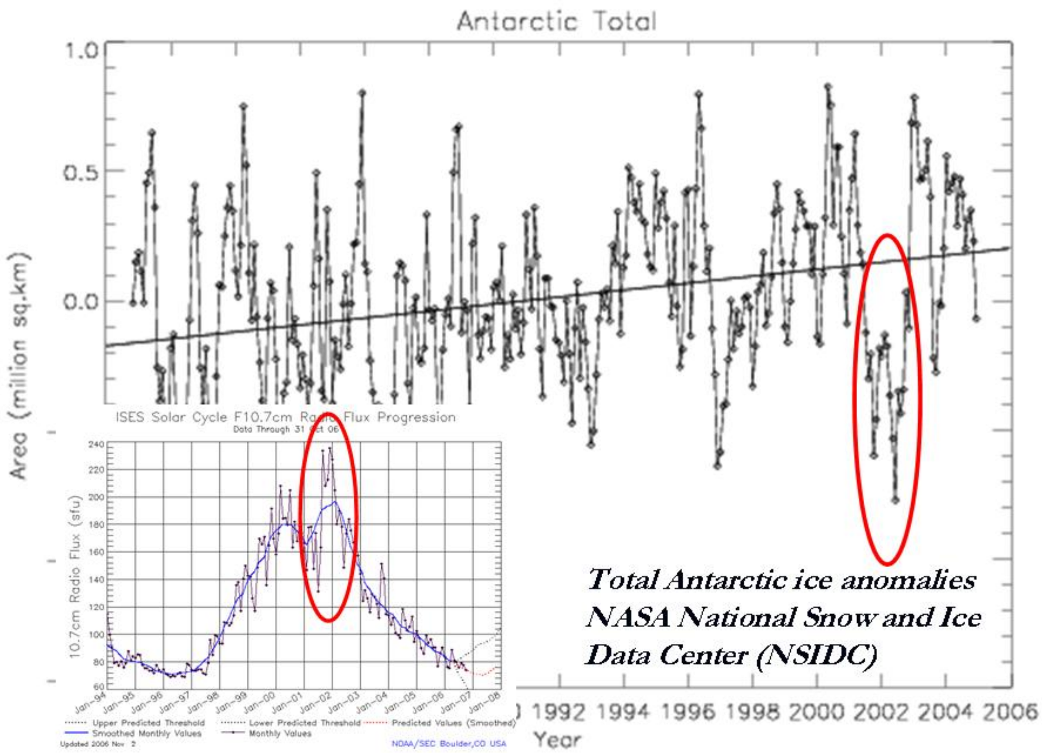
NASA NSIDC satellite derived total ice extent suggests a slow increase in ice cover since 1979.



The much publicized break-up of the Larsen Ice Sheet was likely due to the very strong second solar maximum in cycle 23 between September 2001 and April 2002.

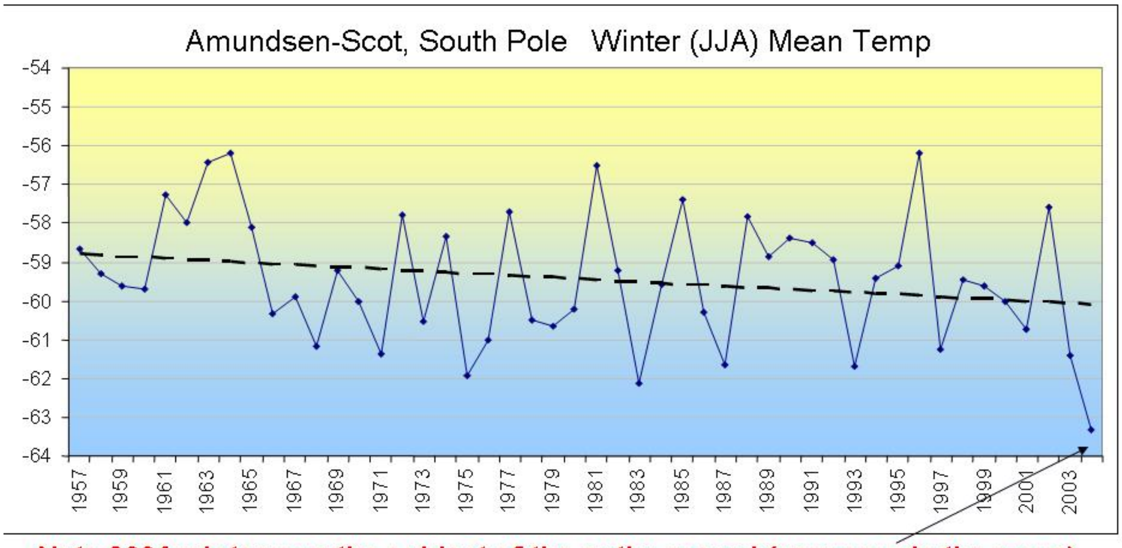


Strong ultraviolet radiation caused significant warming of the high atmosphere in low and middle latitudes with dynamical and radiative coupling down into the troposphere. This caused a shrinking of the polar vortices in both hemispheres and reportedly for the first time ever, a break up of the southern summer polar vortex into two centers for a time. Changes in the circulation and perhaps increased solar heating may have contributed to the temporary break-up.



Temperatures over Antarctica except near the Antarctic Peninsula have been steady or falling. The winter readings for example at the South Pole have been falling now for the last half century. The coldest winter on record was 2004.

Winters are colder over the continent (more than 1F in the last 50 years)



Note 2004 winter was the coldest of the entire record (never made the news)

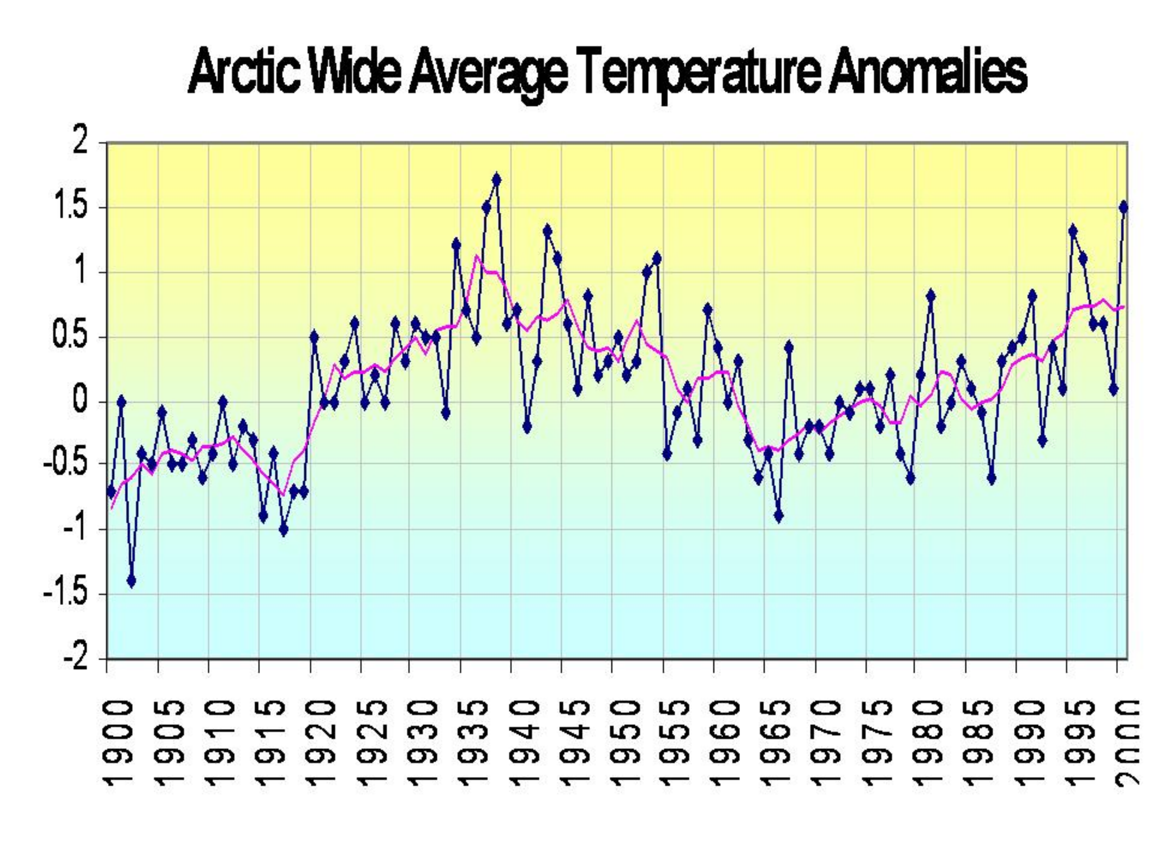
Data from Monthly NASA GISS data for Amundsen-Scot 1957-2005
http://data.giss.nasa.gov/work/gistemp/STATIONS//tmp.700890090008.1.1/station.txt

The reduction in the forecast rise in sea level in the IPCC SPM reflects uncertainty as to how much melting will take place of the major ice sheets. Given the very cyclical and explainable behavior of the Greenland Ice and temperatures and the continued cooling over Antarctica where greenhouse theory predicts the greatest warming suggests this prudence is wise.

ARCTIC SEA ICE

Sea ice thickness is one of the most difficult geophysical parameters to measure on large-scales. Ice thickness varies considerably from year to year at a given location and so the rather sparse temporal sampling provided by submarine data makes inferences regarding long term change difficult.

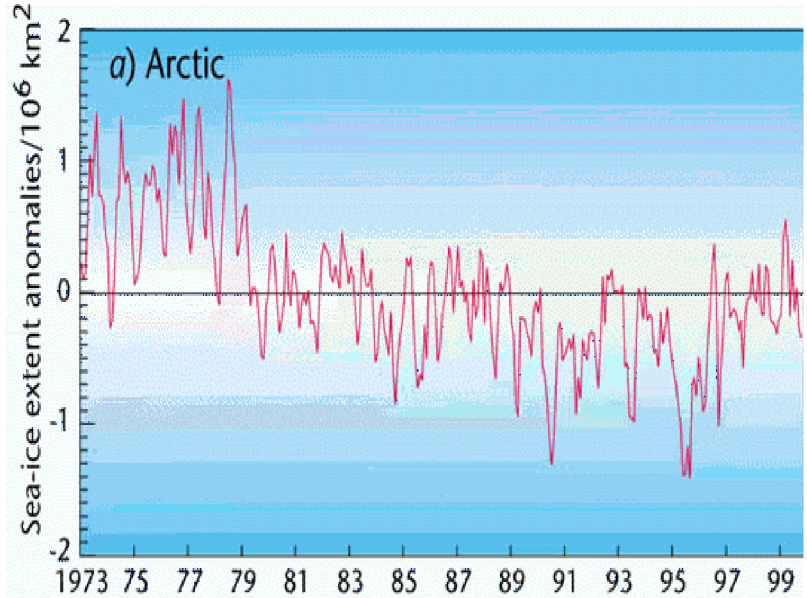
Temperature have behaved cyclically very much like Greenland in the arctic with a warm period, acknowledged by the IPPC SPM in the 1930s and 1940s at least comparable to the recent warming.



Arctic wide average annual temperature anomalies from 1900 to 2000 (Polyakov)

Arctic Ice, the PDO and AMO

Changes in arctic ice may be partially related to decadal changes in the oceans, in this case both oceans. The arctic ice began to decrease rapidly in the late 1970s when the Great Pacific Climate Shift took place, which warmed the water in the North Pacific and Alaska. The predominance of the positive PDO and warm north Pacific coastal water may have contributed to reduced ice cover at least in the western Arctic Ocean.

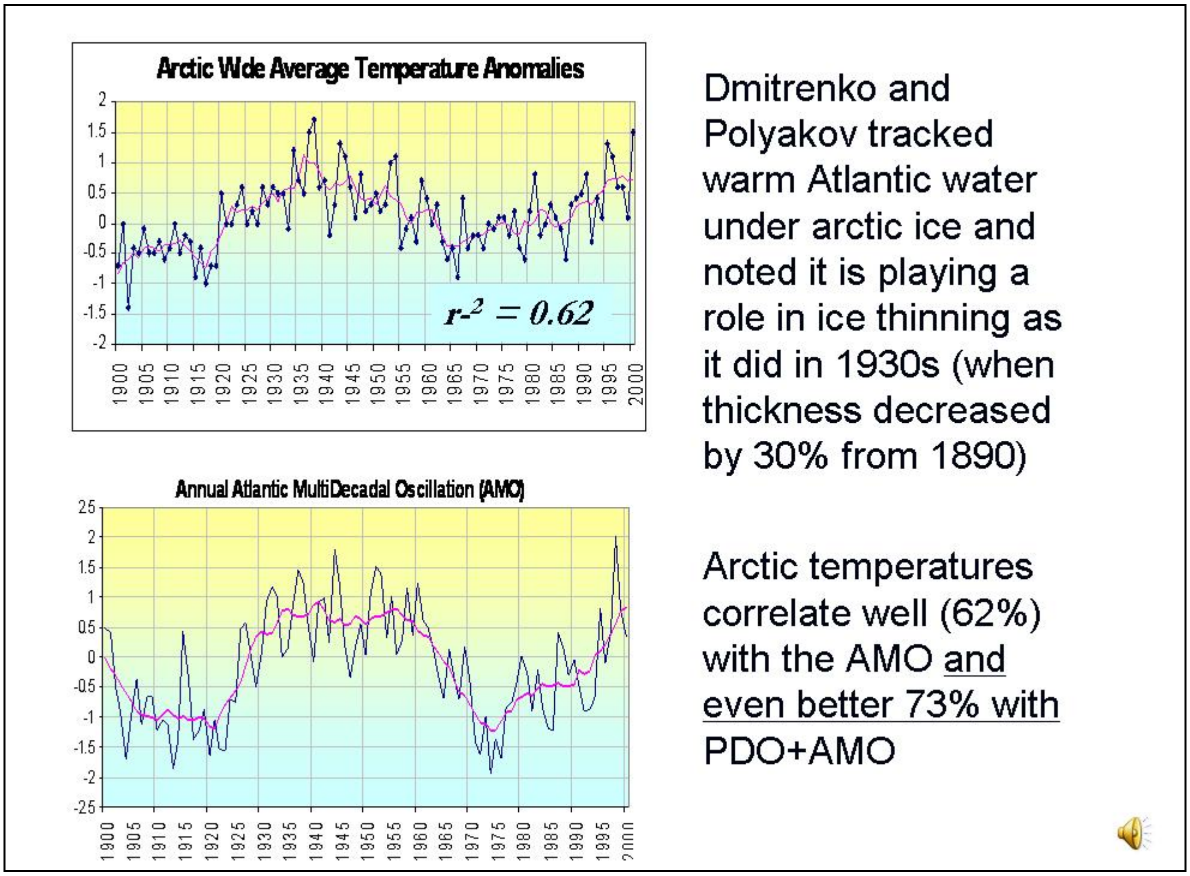


Data from Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change National Assessment Synthesis Team USGRCP, June 2000

The Japan Agency for Marine-Earth Science and Technology in Yokosuka, Kanagawa Prefecture observed a drastic ice shrinkage in the western Arctic Ocean from 1997 to 1998 that was triggered *"... by the flow to the area of warm water from the Pacific Ocean, not by atmospheric impact as previously thought"*. This was related to the super El Nino of 1997/98. JAMSTEC's Koji Shimada, the group's sub-leader, said the shrinkage was particularly severe in the Pacific side of the Arctic Ocean. The ocean's ratio of area covered with ice during the summer stood at about 60-80 percent from the 1980s to mid-1990s, but it went down to 15-30 percent after 1998, he said.

In addition, Dmitrenko and Polyokov observed warm Atlantic water from the warm AMO had made its way under the ice to off of the arctic coast of Siberia where it thinned the ice by 30% much as it did when it happened in the last warm AMO period from the 1880s to 1930s (r-squared correlation of AMO with arctic wide temperatures since 1900 of 0.62).

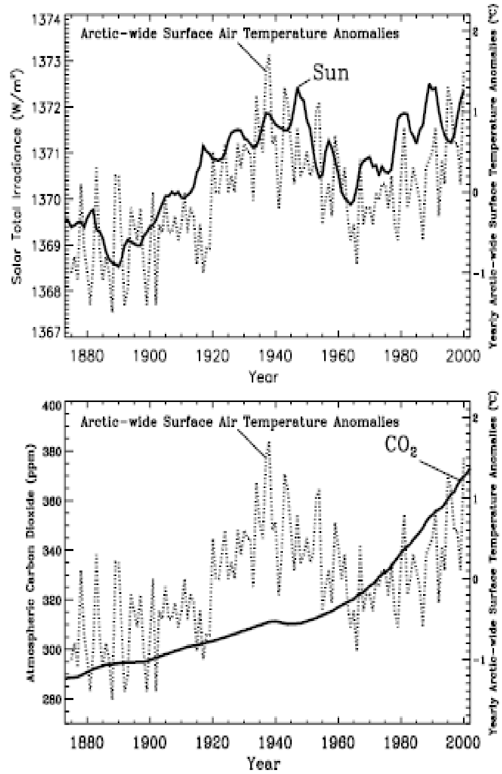
The combination of PDO and AMO (PDO+AMO) correlates even stronger with an r-squared of 0.73.



Polyakov arctic wide temperatures and NOAA CDC AMO Climate Indices

Arctic Temperatures/Ice and Solar

Soon (GRL 2005) showed how the Arctic temperatures (Polyakov) correlated extremely well with the total solar irradiance (Hoyt-Schattem) (r-squared of 0.79). This compared to an r-squared correlation of just 0.22 with the CO^2.



Arctic Basin wide air temperatures (Polyakov) correlated with Hoyt Schatten Total Solar Irradiance (TSI) and with annual average CO^2 (Soon 2005)

Addendum by George Taylor on the Arctic

It has long been recognized by climate modelers that CO2-induced global warming should be most noticeable in the polar regions. In most of the world, there is enough of the earth's dominant greenhouse gas -- water vapor -- to absorb the heat that radiates from the surface. Water vapor is scarcest where the air is coldest, however, because cold air can "hold" much less water vapor than warm air can. Since temperatures are coldest in the polar regions, the driest air on earth occurs there.

In those regions, the other greenhouse gases, especially CO2 and methane, take on a potentially much stronger role, and we would expect that increases in those gases would have their biggest impacts in those regions. As some scientists have said, the Arctic is "the canary in the coal mine" when it comes to global warming, and we should be watching there for early warnings of impending climate change.

Sure enough, we're hearing plenty of media reports from American media and abroad suggesting that big changes are already happening. Here are a few examples:

"Since the industrial revolution, human activity has released ever-increasing amounts of carbon dioxide and other greenhouses gases into the atmosphere, leading to gradual but unmistakable changes in climate throughout the world--especially at the higher latitudes.

Average surface temperatures in the Arctic Circle have risen by more than half a degree Celsius (0.9 degrees Fahrenheit) per decade since 1981. The extent of Arctic sea ice cover has decreased by 7 - 9 percent per decade. And the three smallest extents of summer ice ever seen there have all occurred since 2002. According to the latest forecasts, the Arctic could be ice-free in the summer by the end of this century." Earth Policy Institute, February 26, 2005

"The Arctic sea ice has receded by about 40 percent since 1979. By the end of this century the region could be ice free during the summer months, according to Michael Oppenheimer, a geoscientist at Princeton University in New Jersey." National Geographic News, February 25, 2005

"Up to 60% of Arctic sea ice could vanish in about half a century if climate change continues, a scientist warned today. Over the last 20 years, the Arctic's perennial sea ice sheet has reduced by about 15%, said Dr Mark New of the University of Oxford. 'That could go up to 50% or 60%, say by the 2050s, if current trends continue,' Dr New told an international conference in Exeter, Devon, on avoiding dangerous climate change." PA News, February 2, 2005

"Global warming will hit the Arctic harder and faster than the rest of the world and could cause the extinction of polar bears and other Arctic wildlife within 20 years, conservationists warn. 'If we don't act immediately the Arctic will soon become unrecognizable,' said Tonje Folkestad, climate change officer with WWF's International Arctic Program." Environmental News Service, February 1, 2005

Let's see what science, rather than the press, tells us about sea ice in the Arctic.

Sea Ice in the Sub-Arctic, According to Scientific Journals

Grumet *et al*. (2001) created a record of sea ice conditions in the Baffin Bay region of the Canadian Artic going back 1,000 years. They concluded that the 11th through 14th centuries saw reduced sea ice, but that ice extent was greater over the next six centuries. The last century has shown that "sea-ice conditions in the Baffin Bay/Labrador Sea region, at least during the last 50 years, are within 'Little Ice Age' variability," despite several periods of warmer temperatures. The authors added an interesting statement, as well, stating that the sea ice cover history of the Arctic "can be viewed out of context because their brevity does not account for interdecadal [decade to decade] variability, nor are the records sufficiently long to clearly establish a climate trend."

For an area in the Greenland Sea, Comiso *et al*. (2001), used satellite images to assess the size and character of the Odden ice tongue, a 1,300 km long feature, from 1979 to 1998. They were also able to infer its character back to the early 1920s using temperature measurements. The authors stated that there has been no statistically significant change in any of the parameters studied over the past 20 years. However, the proxy record several decades further into the past reveals that the ice tongue was "a relatively smaller feature several decades ago," apparently as a result of warmer temperatures.

Omstedt and Chen (2001) identified a proxy record of the annual maximum coverage of Baltic sea from 1720 through 1997. They stated that there was a sharp decline in sea ice in about 1877. There was also greater variability in sea ice extent in the first 150 years of the record, which was colder, than in the warmer period of the last 100 years.

Jevrejeva (2001) reported on a longer Baltic sea ice data set from 1529 to 1990 for the port of Riga, Latvia. The time series included four climate eras: (1) 1530-1640, with warming accompanied by earlier ice break-up (by 9 days/century); (2) 1640-1770, a cooler period with later ice break-up (5 days/century); (3) 1770-1920, with warming and a tendency toward earlier ice break-up (15 days/century); and (4) 1920-1990, a cooling period with later ice breakup (by 12 days/century).

Moving Poleward

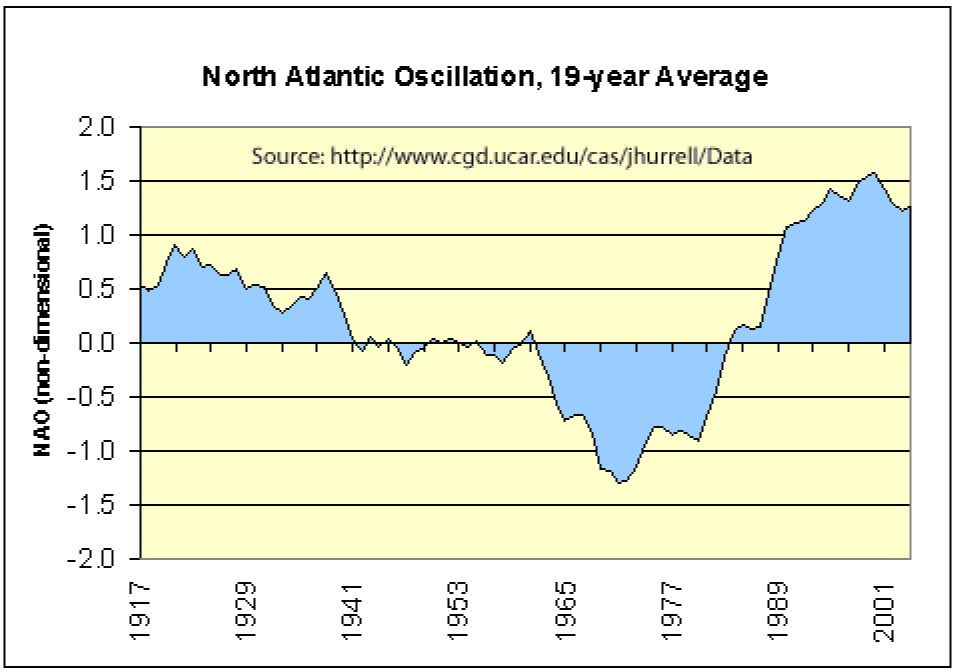
Laxon, et al (2003) were motivated by a "mismatch between the observed variability and that predicted by models." The actual variability and model predictions appear to be very different, and this casts doubts on the models' ability to predict future changes. Unfortunately, the "sparseness of sea ice thickness observations" in the Arctic means that the "regional and interannual variability of sea ice thickness is entirely based on models of the Arctic." Since too few observations exist, scientists resort to very imperfect models, which perform poorly. In conclusion, "Until models properly reproduce the observed high-frequency, and thermodynamically driven, variability in sea ice thickness, simulations of both recent, and future, changes in Arctic ice cover will be open to question."

Okay, so if we need to be cautious about models perhaps we should just see what the data say.

Polyakov, et al (2002) studied sea ice cover over the Kara, Laptev, East Siberian and Chukchi Seas north of Russia. Sea ice cover trends were "smaller than expected" and "do not support the hypothesized polar amplification of global warming." In a later report, Polyakov et al (2003b) stated that "long-term ice thickness and extent trends are small and generally not statistically significant"; in fact, "over the entire Siberian marginal-ice zone the century-long trend is only 0.5% per decade," or 5% per century."

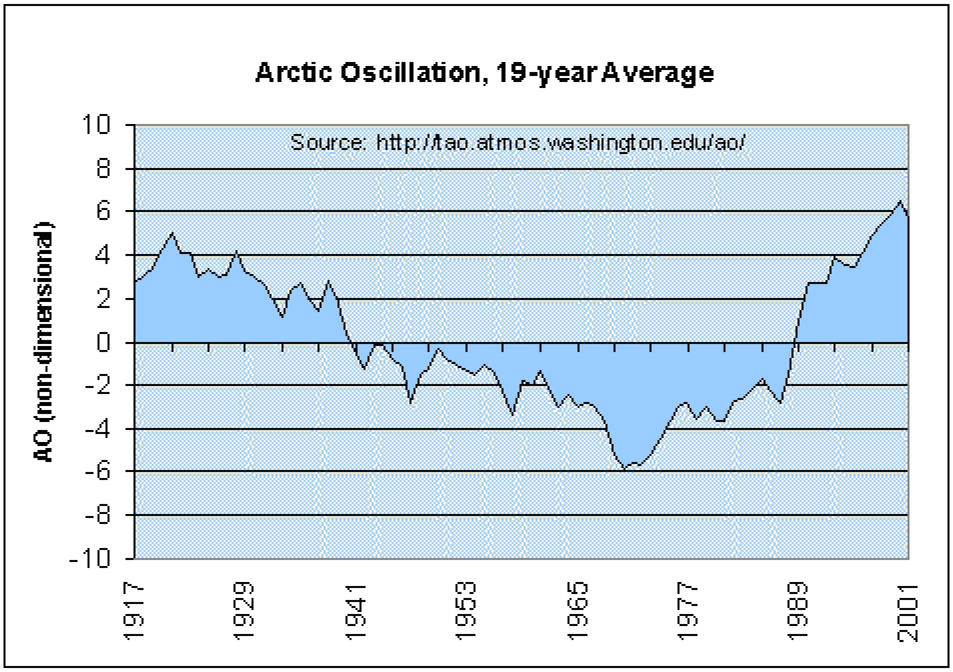
A number of researchers have suggested that inflows of Atlantic water into the Arctic profoundly affect temperatures and sea ice trends in the latter ocean. Polyakov, et al (2004) are among these. The first sentence of their paper states "Exchanges between the Arctic and North Atlantic Ocean have a profound influence on the circulation and thermodynamics of each basin." The authors attributed most of the variability to multidecadal variations on time scales of 50-80 years, with warm periods in the 1930s-40s and in recent decades, and cool periods in the 1960s-70s and early in the twentieth century. These are associated with changes in ice extent and thickness (as well as air and sea temperature and ocean salinity). The most likely causative factor involves changes in atmospheric circulation, including but not limited to the Arctic Oscillation.

It is tempting to employ satellite data to estimate sea ice trends (see, for example, Parkinson, et al, 1999; and Parkinson, 2000) because satellites give us broad coverage (and prevent us from having to trek to the Arctic to make measurements!). Satellite data are limited to only the last several decades, however. According to Schmith and Hansen (2003), trend studies of Arctic sea ice conditions "should be regarded with some care" since the period of satellite observations coincided with but one phase of a clear multidecadal oscillation (alternating climate periods several decades long). Instead, the authors studied sea ice observations for the period 1820-2000 for waters off Greenland. One parameter which shows multidecadal variability is the correlation between ice export and the North Atlantic Oscillation (NAO); see trends below. In recent decades there has been a strong correlation between the two, as there was in the 1930s-40s. During the 1960s-70s and from about 1870-1920 there were much lower correlations. This "casts doubt on the hypothesis of enhanced greenhouse effect being the cause" for recent NAO-sea ice correlations, according to the authors.



North Atlantic Oscillation, 19-year average

Rigor, et al (2002) suggest that the Arctic Oscillation (AO) affects surface air temperatures and sea ice thickness over the Arctic in a profound way. Ice thickness responds primarily to surface winds changes caused by the AO, whose long-term trends are shown below. Positive AO values (as have been observed in recent years) correspond to higher wind speeds (and generally thinner ice).



Arctic Oscillation, 19-year average

Parkinson (2000) seems to have identified decadal or longer trends as well. The analysis described in that paper divided the Arctic into nine regions. In seven of the nine the sign of the trend "reversed from the 1979-1990 period to the 1990-1999 period," which is another reason to be cautious when evaluating relatively short data sets.

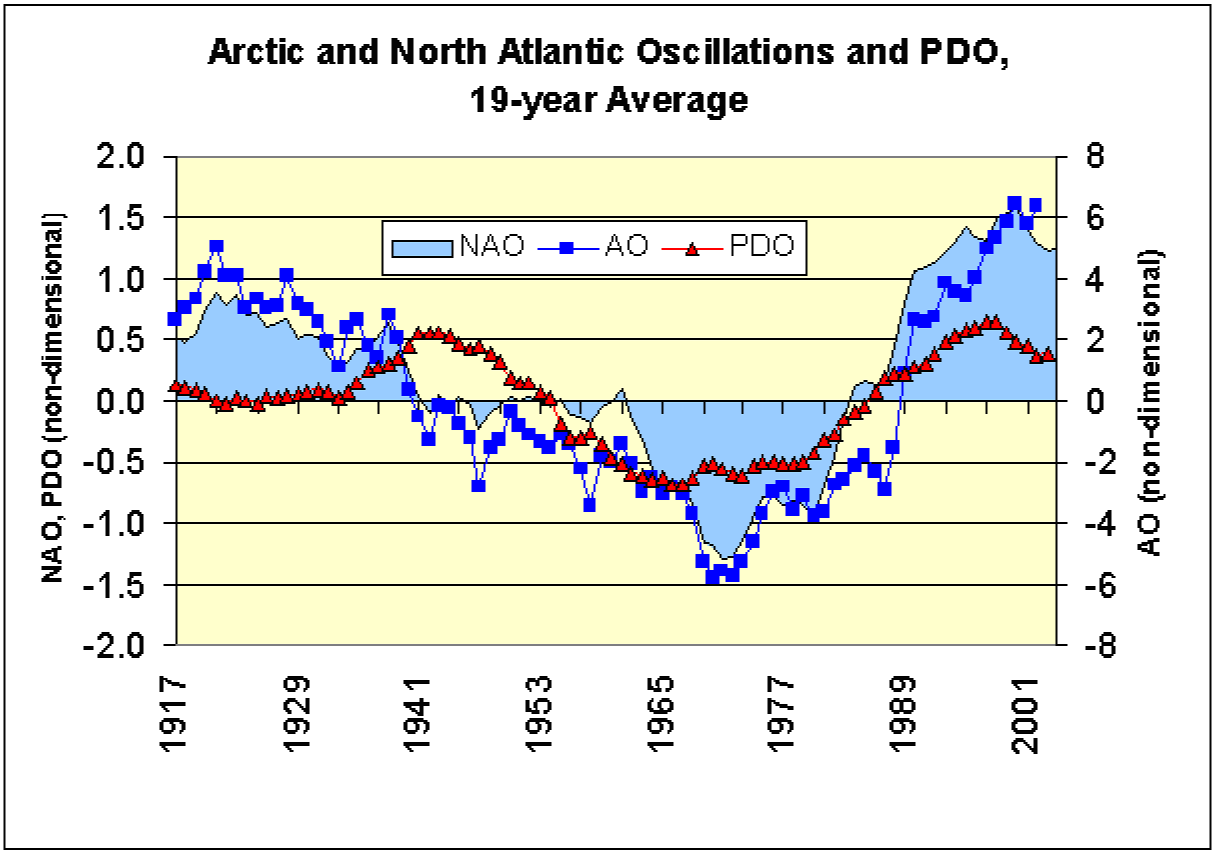
Holloway and Sou (2002) used data from "the atmosphere, rivers and ocean along with dynamics expressed in an ocean-ice-snow model." The authors warn against using any linear trend longer than 50 years due to multidecadal variability, which included "increasing volume to the mid-1960s, decadal variability without significant trend from the mid-1960s to the mid-1980s, then a loss of volume from the mid-1980s to the mid-1990s. They also suggest that changes in wind patterns play a large role in ice thickness changes and that "Arctic sea ice volume has decreased more slowly than was hitherto reported." In fact, "the volume estimated in 2000 is close to the volume estimated in 1950."

Interdecadal Variability

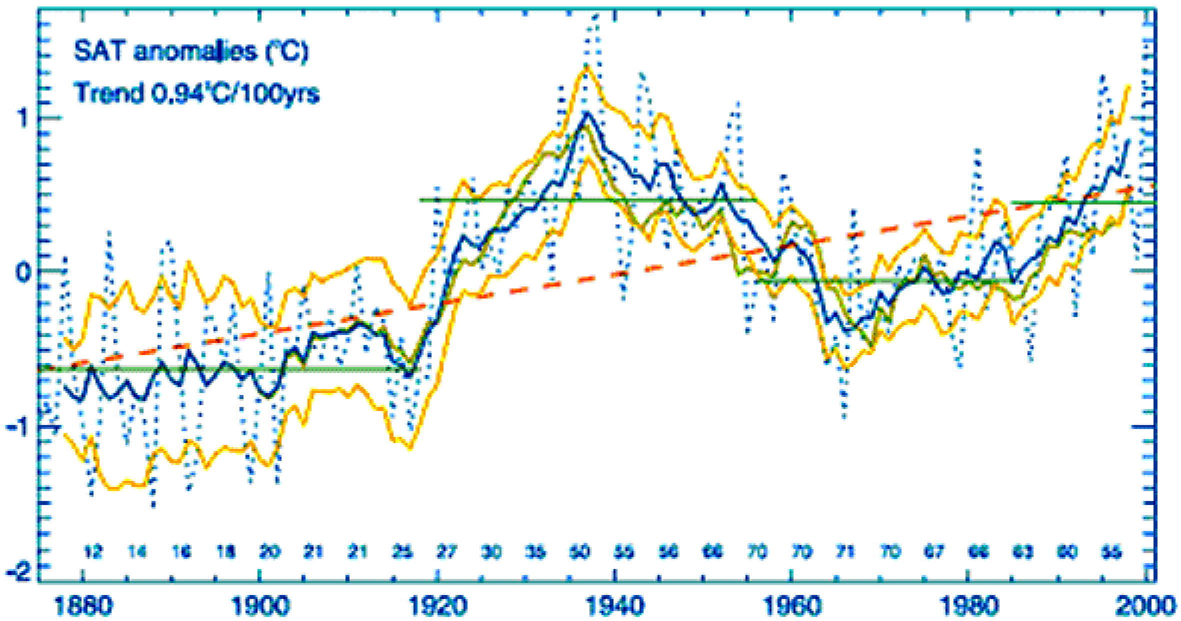
Again and again we see terms "decadal," interdecadal" or "multi-decadal" in describing Arctic sea ice conditions. You have seen the similarity of the NAO and AO and can view the long-term variability. Note that in the NAO and AO charts the year 1970 (a starting point for many of the time series being mentioned) occurred at a time of minimum NAO and AO value.

Now consider a data set from the Pacific -- the Pacific Decadal Oscillation (PDO), an index which correlates strongly with ocean conditions in the tropical Pacific - positive values correlating with El Nino conditions, negative with La Nina. Below are annual values of the PDO. In the following chart I have plotted the NAO, AO and PDO together, with 19-year smoothing to show long-term trends.

And then take a look at the final chart, showing surface air temperature in the Arctic, from Polyakov, et al (2002). Notice how closely the temperatures match the NAO-AO-PDO chart: negative values of the latter match up with cooler temperatures (such as in the 1960s and 70s), while positive values of the indices correlate with warmer Arctic temperatures -- in recent years, and in the 1930s-40s.



North Atlantic, Arctic, and Pacific Decadal Oscillations, 19-year average



Surface air temperature anomalies in the Arctic, from Polyakov, et al (2002)

What This Tells Us

If we want to understand variability of Arctic sea ice (and, for that matter, sea and air temperature) we should take our eyes off greenhouse gases, at least for a moment, and study multidecadal phenomena. We should also avoid the temptation of taking the last 20-30 years of data, computing a trend, and assuming that that trend will continue for 50-100 years. History tells us that long-term linear trends will not occur. In the words of Santayana, "Those who cannot remember the past are condemned to repeat it." Or make bad forecasts.

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