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The Recovery from the Little Ice Age
(A Possible Cause of Global Warming)
and
The Recent Halting of the Warming
(The Multi-decadal Oscillation)

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Abstract

Two natural components of the presently progressing climate change are identified.

The first one is an almost linear global temperature increase of about 0.5°C/100 years (~1°F/100 years), which seems to have started at least one hundred years before 1946 when manmade CO_2 in the atmosphere began to increase rapidly. This value of 0.5°C/100 years may be compared with what the International Panel on Climate Change (IPCC) scientists consider to be the manmade greenhouse effect of 0.6°C/100 years. This 100-year long linear warming trend is likely to be a *natural change*. One possible cause of this linear increase may be Earth's continuing recovery from the Little Ice Age (1400-1800). This trend (0.5°C/100 years) should be subtracted from the temperature data during the last 100 years when estimating the manmade contribution to the present global warming trend. As a result, there is a possibility that only a small fraction of the present warming trend is attributable to the greenhouse effect resulting from human activities. Note that both glaciers in many places in the world and sea ice in the Arctic Ocean that had developed during the Little Ice Age began to recede after 1800 and are still receding; their recession is thus not a recent phenomenon.

The second one is the multi-decadal oscillation, which is superposed on the linear change. One of them is the "multi-decadal oscillation," which is a *natural change*. This particular change has a positive rate of change of about 0.15°C/10 years from about 1975, and is thought to be a sure sign of the greenhouse effect by the IPCC. But, this positive trend stopped after 2000 and now has a negative slope. *As a result, the global warming trend stopped in about 2000-2001.*

Therefore, it appears that the two natural changes have a greater effect on temperature changes than the greenhouse effects of CO_2. These facts are contrary to the IPCC Report (2007, p.10), which states that "most" of the present warming is due "very likely" to be the manmade greenhouse effect. They predict that the warming trend continues after 2000. Contrary to their prediction, the warming halted after 2000.

There is an urgent need to correctly identify natural changes and remove them from the present global warming/cooling trend, in order to accurately identify the contribution of the manmade greenhouse effect. Only then can the contribution of CO_2 be studied quantitatively.

Temperature Changes during the Last 100 Years

Figure 1a shows changes of the global average temperature from 1880 to 2000 in terms of both the annual mean and the 5-year mean. The annual mean shows large excursions, indicating that the weather is always "anomalous." In general, 5 or 10-yer running mean values are most often used in discussing the present global warming and climate change.

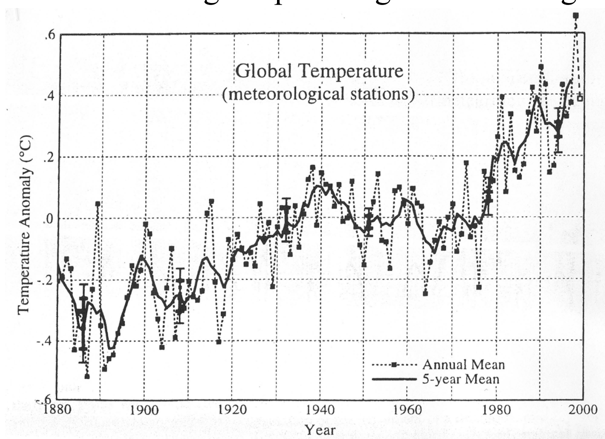

Figure 1a: The global average temperature from 1880 to 2000 (NASA:GISS). The thick line shows the 5-year running mean.

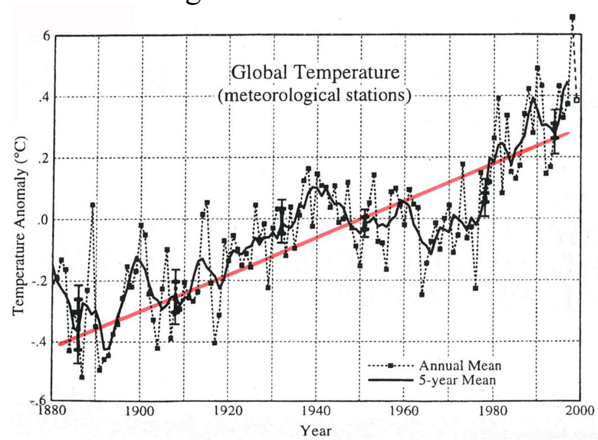

Figure 1b: An intuitive approximation of the changes shown in Figure 1a (NASA:GISS). It is shown as the red line.

When examining Figure 1a, it seems to me that it is natural for both professionals and nonprofessionals alike to consider intuitively, as a first approximation, that temperature changes may be approximated with a straight line, together with "fluctuations" superposed on it (Figure 1b). Figure 1c was found after an early version of this article was completed. This figure was constructed by Bryant (1997). In his book, he mentioned that there are only a few points outside the 95% confidence limits, but he did not elaborate further on the significance of the linear trend. His result justifies my intuition. The gradient of the straight line is close to 0.5°C/100 years, in agreement with that in Figure 1b.

Figure 1d shows the result obtained by NOAA during the same period. It can be seen that the linear increase is superposed by "fluctuations," which we identify here as the multi-decadal oscillation.

Figure 1b and Figure 1d clearly indicate that the interpretation given in Figure 1e is likely to be correct. This is because the natural fluctuation, the multi-decadal oscillation shown in Figure 1e, is now decreasing after 2000. If the upward trend after 1975 was caused by the manmade greenhouse effect of CO_2, the temperature curve should continue to swing upward. Clearly, this is not the case. For more details on the latest temperature trend, see Figures 10c, 15c, and 15d. This will be discussed in details in later sections (Summary (2).

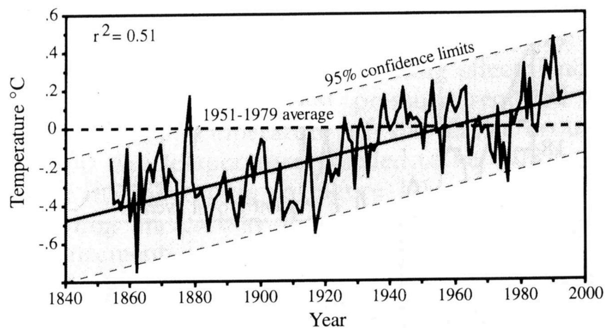

Figure 1c: The figure shows that the straight lines here and in Figure 1b are within about 95% confidence limits (Bryant, 1997). The gradient of the line is about 0.5°C/100 years.

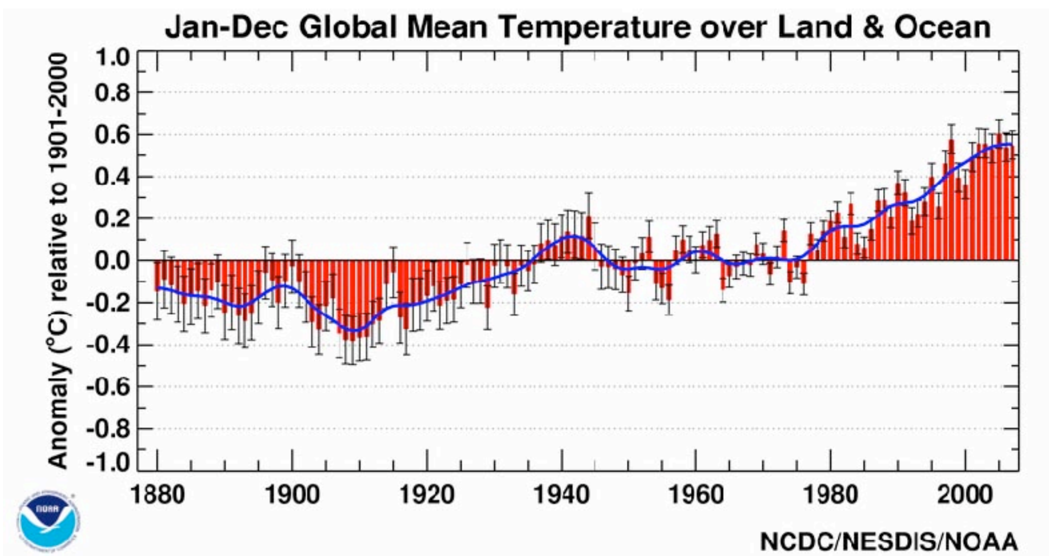

Figure 1d: Global mean temperature changes (http://www.ncdc.noaa.gov/oa/climate/research/anomalies/anomalies.html).

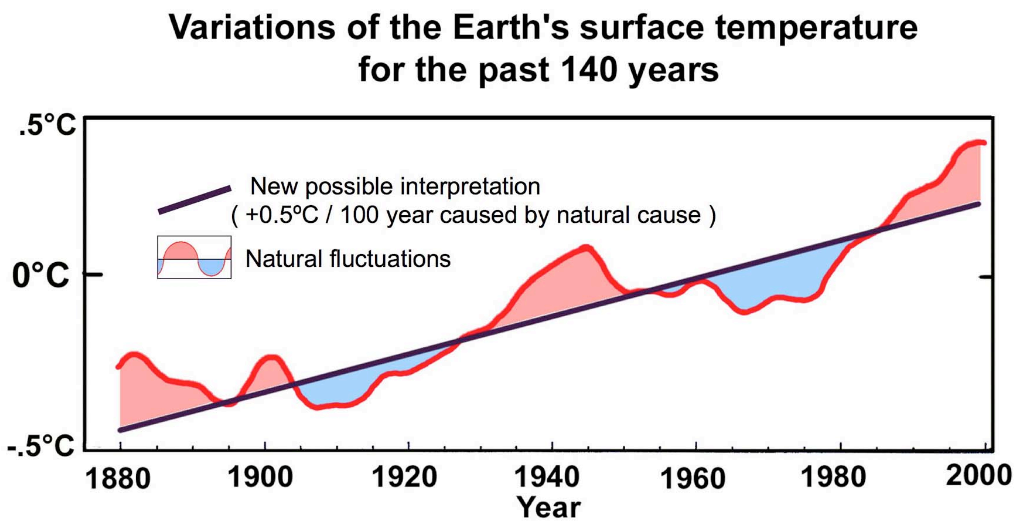

Figure 1e: An interpretation of Figures 1a, 1b, and 1d (s well as Figures 15c and 15d), showing temperature changes that consist of a linear change and "fluctuations" superposed on it. The red line is a smoothed version of the 5-year mean in Figures 1a and Figure 1b.

Figure 2 shows both the latest global average temperature and the amount of CO_2 in the atmosphere for the same period. Although the global average temperature changes can be approximated by a linear relation (T = at), CO_2 changes are more like $T = bt^2$, suggesting that the T-t relation is not simple.

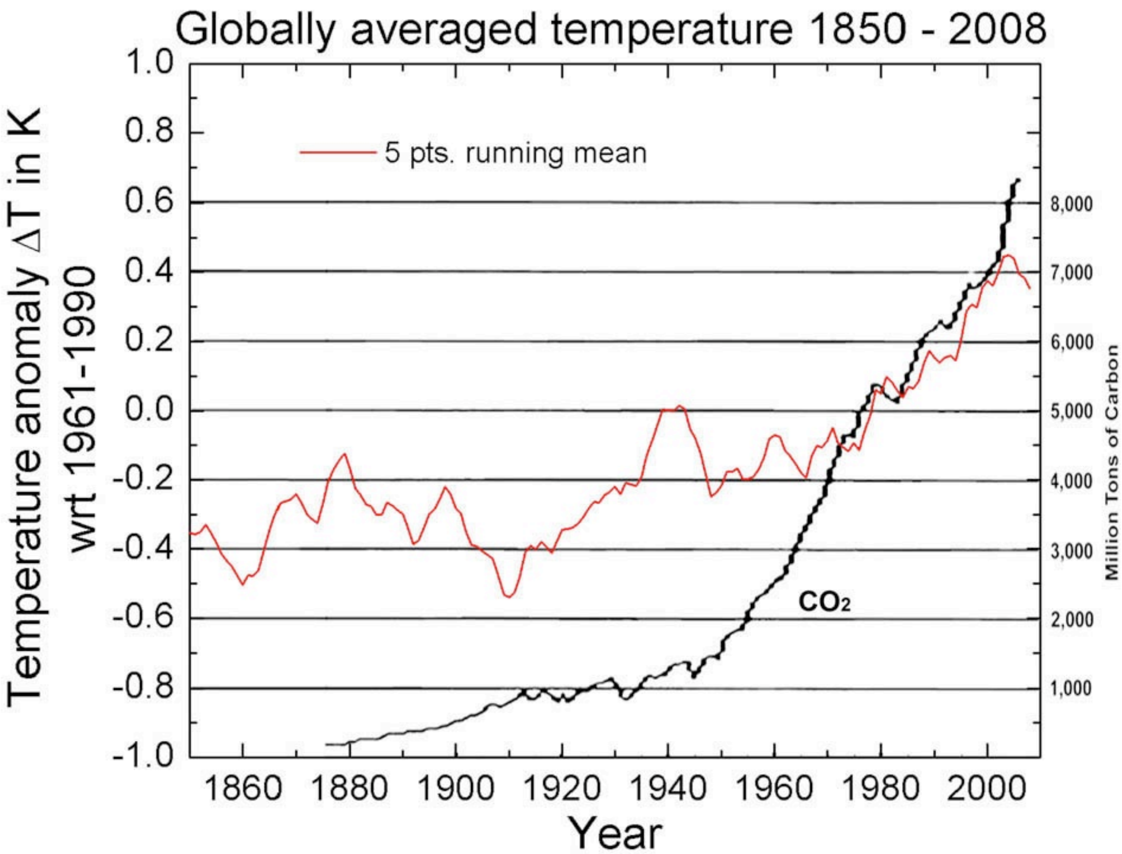

Figure 2: Global temperature changes (5-year smoothing) 1860-2005 (Hadley Center, 2008; see Figure 15d). The figure shows also the amount of CO_2 in the atmosphere during the same period

From Figure 2, it is immediately obvious that the amount of CO_2 began to increase rapidly in about 1946. Note in particular a distinct decrease of the temperature when CO_2 increased rapidly after 1946 and also after 2000. This point will become much clearer in later sections.

It is crucial to investigate the nature of the temperature rise in both the period between 1910-1940 and after 1975, in addition to the linear change. This is because *the IPCC Report (2007) emphasized that the temperature increase from 1975 was mostly caused by the CO_2 greenhouse effect. However, it is quite clear on the basis of Figures 1c and B that a significant part of the increase was caused by the multi-decadal oscillation and the linear increase, because the 5-year running average temperature stopped to increase and even began to decrease after 2000.* This point will be discussed further in later sections.

Temperature Changes during the Last 200 Years: A linear increase of the temperature

Figure 3a shows temperature changes from 1725 to 2000, which were deduced from ice cores at Severnaya Zemlya, an island in the Arctic Ocean (Fritzche et al., 2006). This figure indicates that the straight line in Figure 1b can be extended to 1775 or so. Figure 3a also includes a thermometer record from Vardo in Northern Norway. The bottom curve is temperature changes at stations along the coastline of the Arctic Ocean (Polyakov et al., 2002). The credibility of the ice core record is supported by the similarity with both thermometer records.

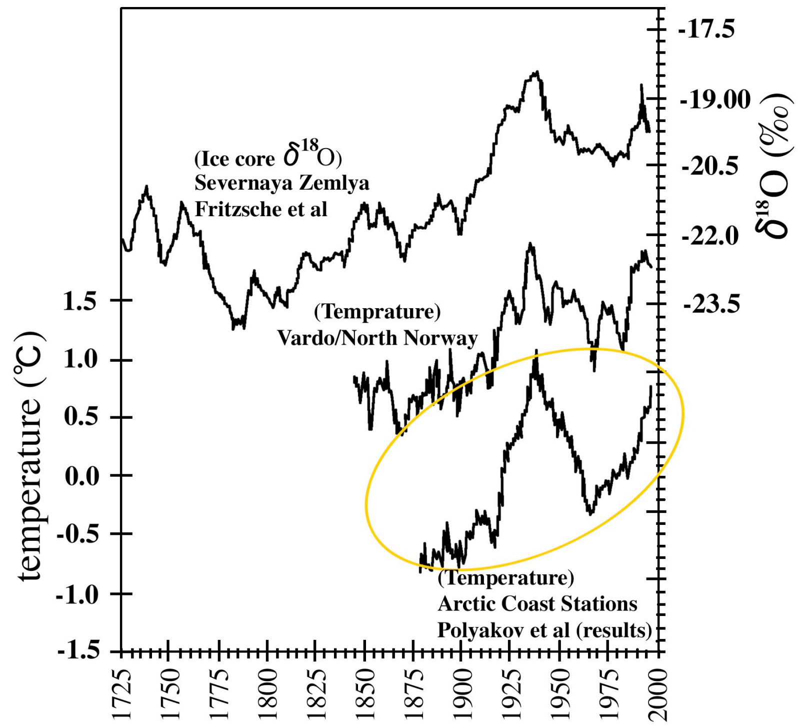

Figure 3a: Late Halocene ice core record from Akademii Nauk Ice Cap, Severnaya Zemlya, Russian Arctic, together with temperature records from Vardo, Norway, and from stations along the arctic coast (Polyakov et al., 2002); the latter is the same as the blue curve in Figure 2 (Fritzsche et al., 2006).

Figure 3b shows stable isotope time series data obtained by Asami et al. (2005) from coral in Guam (13°N, 145°E). It clearly shows a linear trend of the temperature from about 1800, in agreement with Figures 1b and 3a. Figure 3c shows temperature records during the last 200 years or so from a number of stations, indicating the general trend shown in Figures 3a and 3b. Figure 3d also shows a similar trend, although the temperature is inferred from ice break-up and rye harvest data; the absolute value of the temperature may be questioned, but the linear trend seems to be very evident.

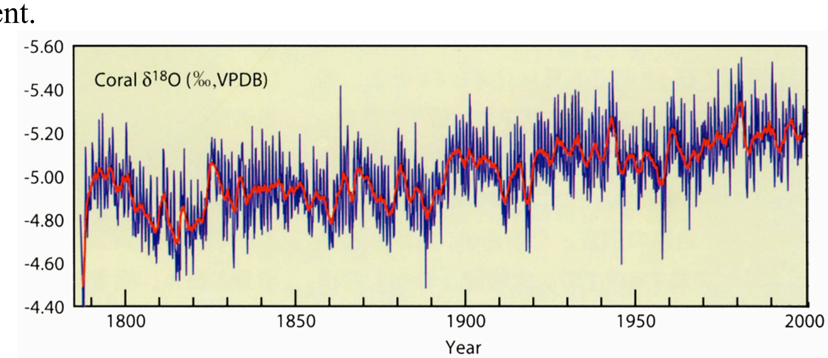

Figure 3b: Monthly time series of O^{18} isotope data from coral in Guam (13°N, 145°E) from about 1800 (Asami, R., et al., 2005).

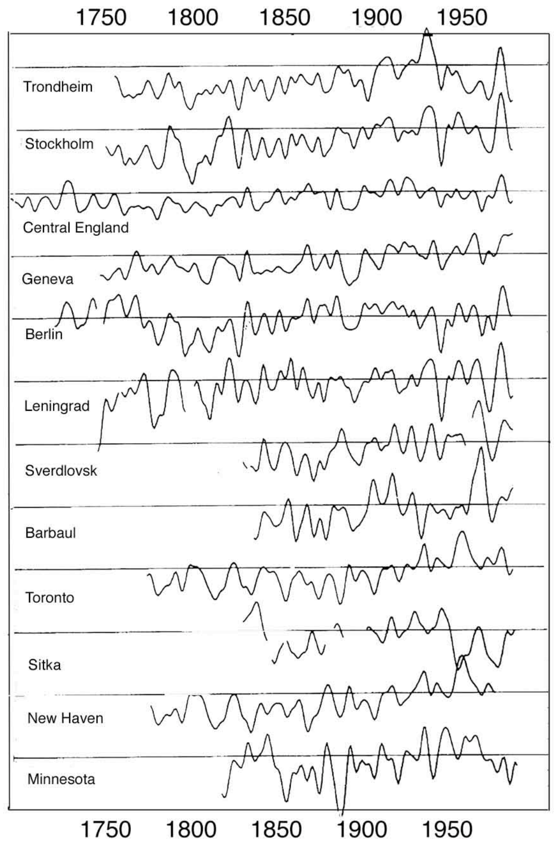

Figure 3c: Temperature change at a number of stations in the world (Jones and Braley, 1992).

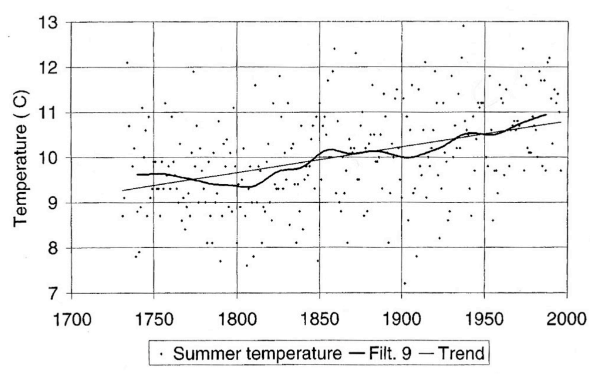

Figure 3d: Summer temperature (April to July) for Tallinn, which is based on ice break-up and rye harvest data and on instrumental observations. To ease the study of variations on a timescale of approximately 30 years, the observations are smoothed by a Gaussian filter with standard deviation of nine years in its distribution (curve). A trend line for the whole period is also shown. The trend line and curve were drawn by the original authors (Tarand and Nordli, 2001).

Figure 3e shows both the freeze dates and breakup dates of a number of lakes and rivers of the world from 1846 to 1995 (Magnuson et al., 2000). It can be seen that the breakup dates have almost steadily advanced to earlier dates; the freeze dates seemed to shift to later dates.

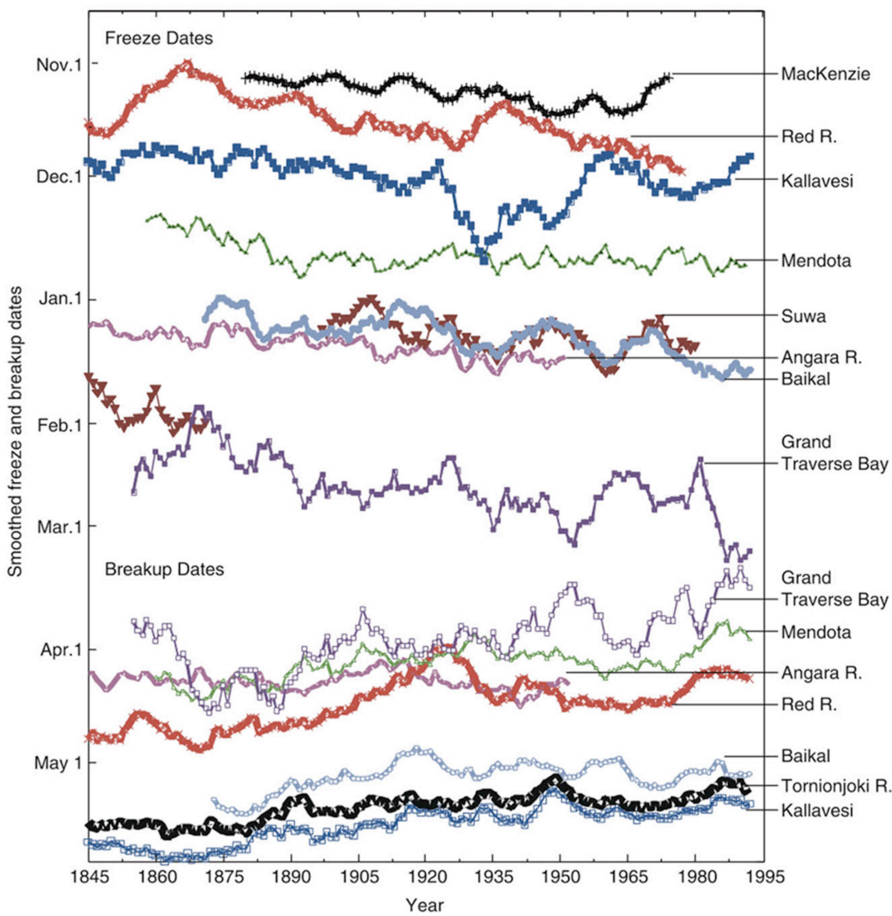

Figure 3e: The freeze dates and breakup dates of lakes and rivers in the Northern Hemisphere (Magnuson et al., 2000)

Based on Figures 3a, b, c, d, and e, there is no question that the temperature has been increasing almost linearly from 1800 (or a little earlier) to the present. In the next section, we examine temperature change before 1800 and also the linear increase after 1800.

Temperature Changes during the Last 400-500 Years: The Little Ice Age

Figure 4a shows the temperature record of central England from 1660. The temperature was significantly lower than the present by about 1°C in winter months during the period between 1600 and 1800 and further the temperature has an increasing trend toward the present time. Figure 4b shows the temperature data inferred from ice break-up (Tarand and Nordli, 2001). There was a little warming trend between 1650 and 1750; see a similar trend in the ice core data in Figure 3a. This data set extends the temperature records to about 1500.

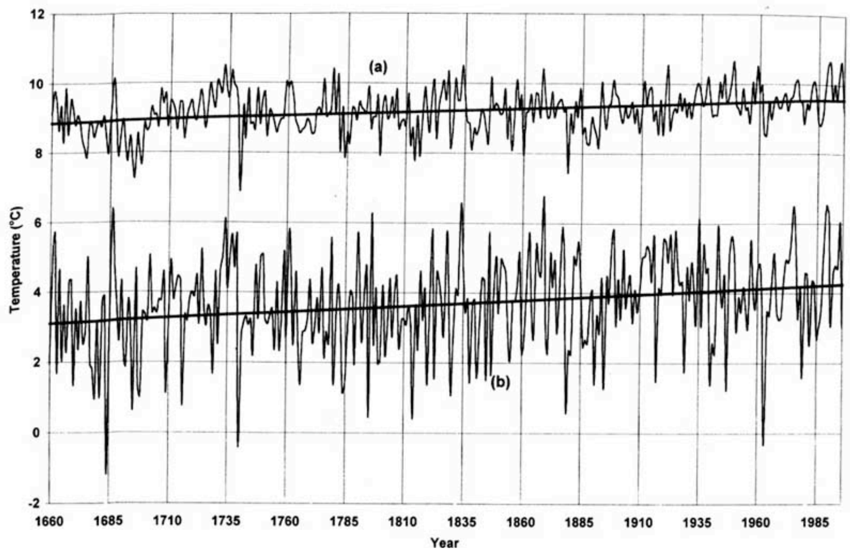

Figure 4a: The linear trends for the temperature of central England over the period 1660-1996 for (a) the annual data, and (b) the winter months (December to February), show a marked warming. In both cases, this warming is significant, but although the temperature rise is greater in winter, this trend is less significant because the variance from year to year is correspondingly greater. The trend line was drawn by the original author (Burroughs, 2001).

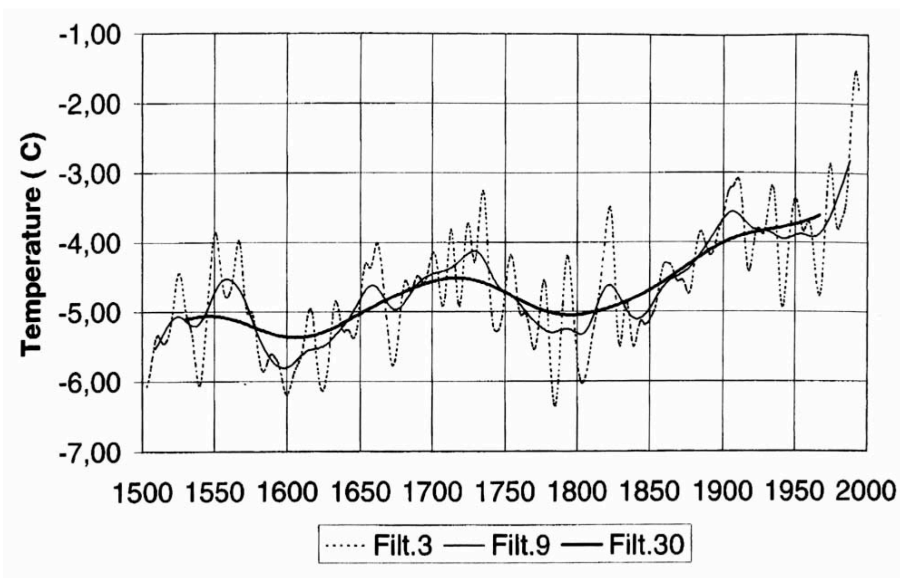

Figure 4b: Winter temperature (December-March) at Tallinn since 1500, based on ice break-up dates in Tallinn port. The series is smoothed by Gaussian filters of 3, 9, and 30 years as standard deviations in the Gaussian distribution (Tarand and Nordli, 2001).

Figure 4c shows ice core data from Quelccaya, Peru, and Dunde, China, comparing them with decadal temperature departures in the Northern Hemisphere (Thompson, 1992). This data set extends the temperature records to 1600. It is quite obvious that it was relatively cold during the period between 1600 and 1900. The Dunde record shows that the cold period between 1600 and 1800 was present in Asia.

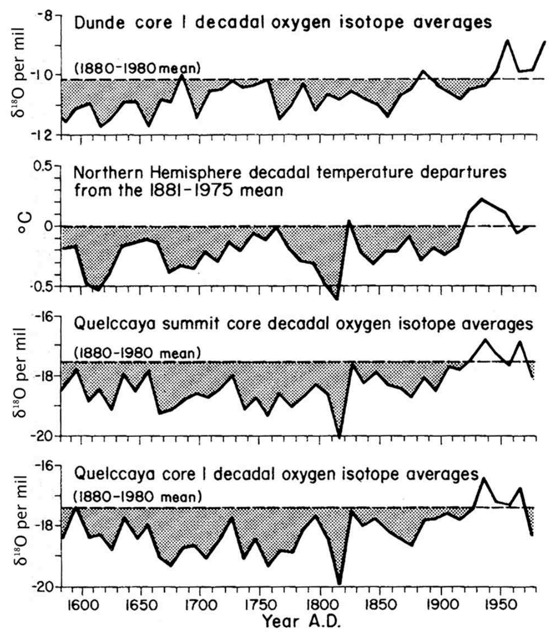

Figure 4c: Decadal temperature departures (from the 1881-1975 mean) in the Northern Hemisphere from 1580 A.D. to 1975 (second) compared with decadal average $\delta^{18}O$ values for both the Dunde, China, D-1 core (top) and Quelccaya, Peru, ice cores (third and fourth) over the same time period. For the $\delta^{18}O$ records, the dashed line is the 1880-1980 A.D. mean (Thompson, 1992).

Figure 4d shows break-up dates at Lake Suwa in the central highland of Japan from 1450 to 2000. The lake has a circular shape, and this particular break-up occurs during the early freezing period, perhaps because of the pressure exerted by the expanding ice. The delay of the break-up indicates warming from 1700 to the present (Ito, 2003).

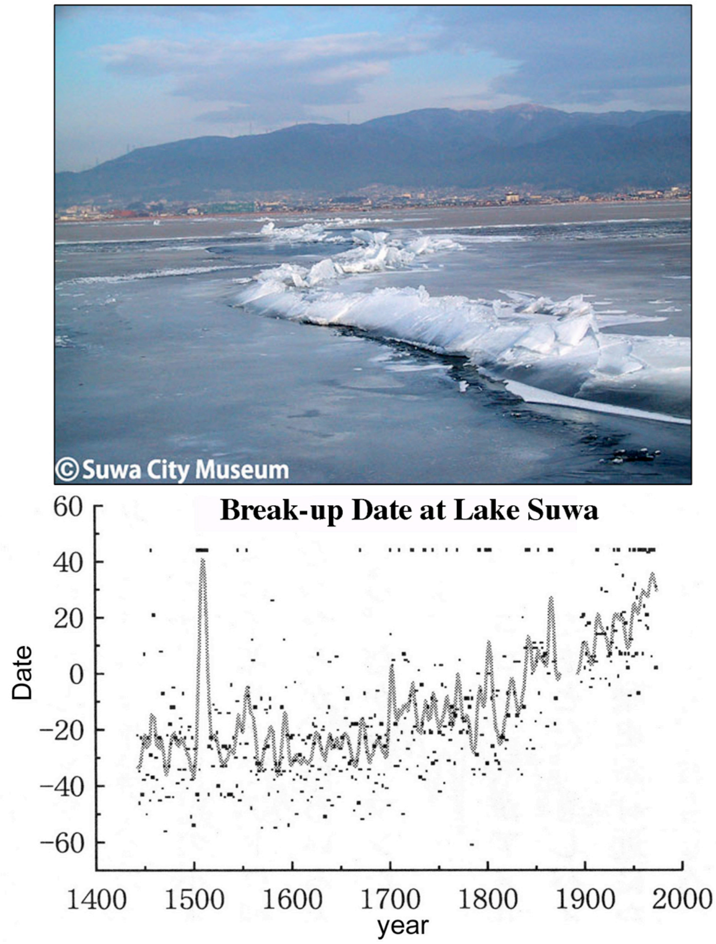

Figure 4d: Ice break-up scene at Lake Suwa in the central highland of Japan from 1450 to 2000 and the dates. The zero day refers to January 1st (T. Harada, 1977; H. Ito, 2003).

There are many documents that suggest that the period between 1500 and 1800 was relatively cold; the River Thames was frequently frozen in the later part of the 17th century (Lamb, 1982) and early stories of the exploration of the Northwest Passage also hint that sea ice conditions in Northern Canada in the 1700s and even in the latter part of the 1800s were much worse than today, when it is possible to cruise the passage without much assistance from icebreakers during short periods in summer months.

Maruyama (2008) examined various historic records from China and Japan and showed that major famines occurred in Japan between 1550 and 1750 (Figure 4e), in general associated with cool summers in the northern half of their Main Island.

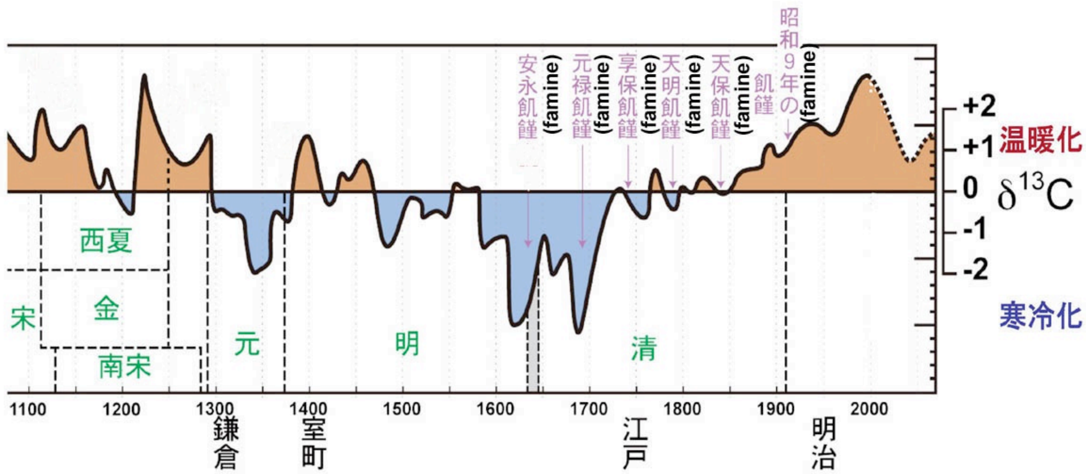

Figure 4e: Inferred temperature changes in Japan and China from 1100. A number of famines occurred during the colder period in Japan and political upheavals occurred during the cold period in China (Maruyama, 2008; modified).

Figures 4a, b, c, d, and e show different kinds of data (extending the timeline further back to 1400-1500) from the earlier ones (Figures 3a-3e), and show clearly a similar trend, namely a cold period between 1500 and 1800 in different parts of the world and an almost linear increase of the temperature after about 1800. This cold period is called the *Little Ice Age* (LIA).

Although there is some doubt about the exact timing of the LIA, and the actual values of air temperature and its changes during the LIA, it is possible to infer that the period between 1500 and 1800 was relatively cold in many parts of the world, including Europe, North and South America, and the Orient (cf. Gribbin (ed.), 1978; Lamb, 1982; Crowley and North, 1991; Fagan, 2000; Burroughs, 2001; Serreze and Barry, 2005; Nunn, 2007). In this paper, a large number of other evidences will be shown in later sections.

The fact that an almost linear change of the temperature rise has been progressing, without a distinct change of slope from 1800 or even earlier (possibly as early as 1660, long before the Industrial Revolution) to the present, suggests that the linear change is a natural change. The linear change began at least one hundred years before a rapid increase of CO_2 in the air. In the next section, we examine temperature changes during the last 1,000 years or so and also the linear increase after 1800.

Temperature Changes during the Last 1,000 Years and Earlier, including the Medieval Warm Period

Figure 5a shows climate change records in the northern Tibetan Plateau from 1150 (Holmes et al, 2007). It can be seen that the temperature was relatively lower than the present during the period between 1400 and 1800, and then it has increased from 1800 to the present.

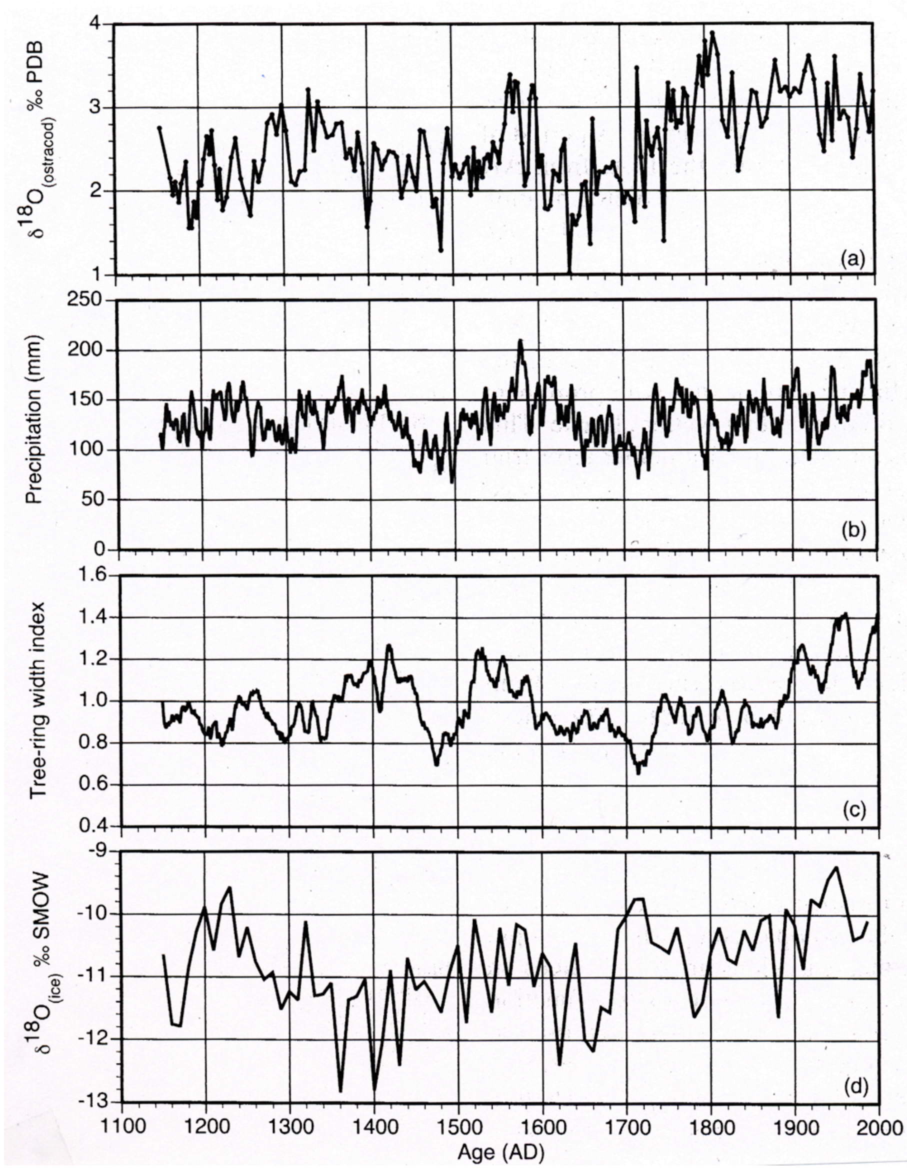

Figure 5a: Climate variability over the northern Tibetan Plateau since 1150 AD: (a) $\delta^{18}O$ of ostracodes from Sugan Lake core SG00C, (b) precipitation reconstructed from tree-rings at Delingha, (c) standard tree-ring width chronology from Sidalong. On the basis of a close correspondence between Tibetan Plateau temperature and the all-China reconstructions for the past 1,000 years, the total amplitude of ring-width change is estimated to represent a temperature variation of ≤2°C, and (d) decadally-averaged $\delta^{18}O$ values from the Dunde ice core (Holmes et al., 2007).

The upper part of Figure 5b shows (upper) temperature variations in the middle Qilian Mountains (see the insert map) during the last 1,000 years, based on the ring width and the carbon stable isotope in tree rings (Liu et al., 2007). The lower part is shown in order to compare with the data by Espen et al. (2002), which is shown also in Figure 5c. One can see that the period between 1600 and 1800 was cold in Asia as well as the other part of the world.

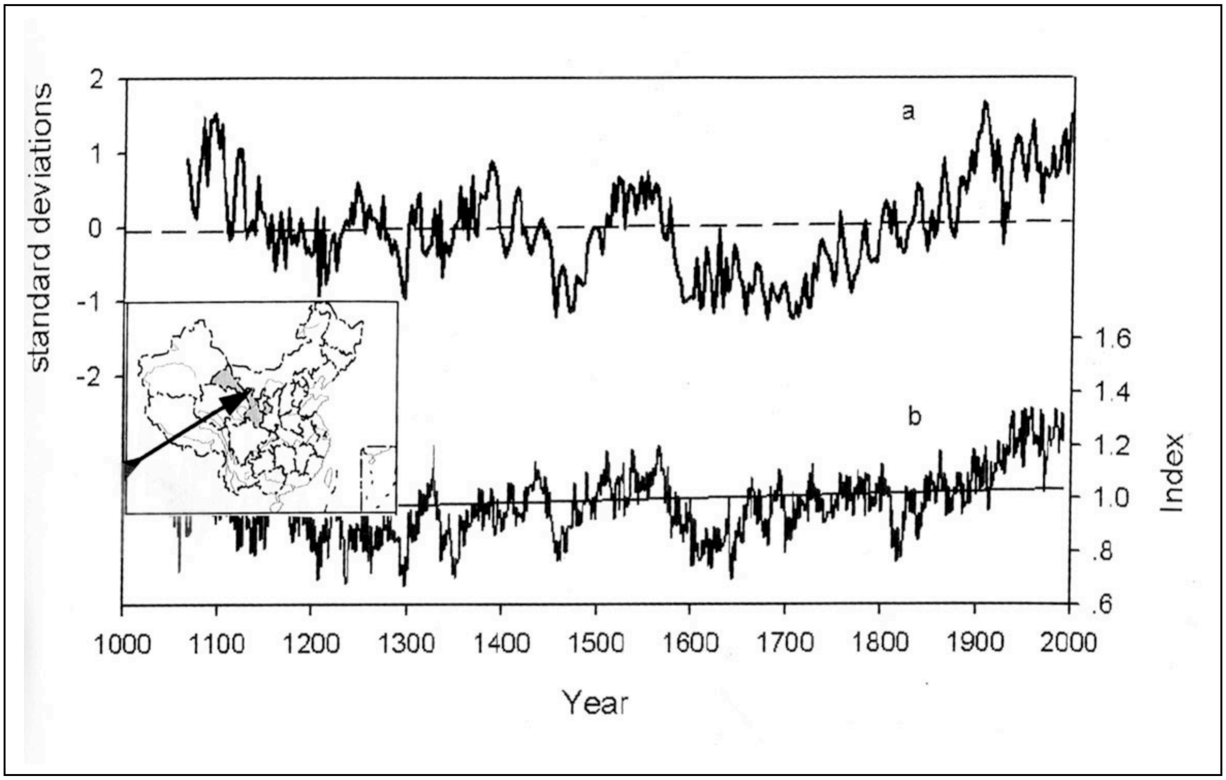

Figure 5b (upper): Temperature variations in the middle Qilian Mountains during the last 1000 years (Liu et al. 2007); (lower): The data by Espen et al (2002) for comparison (see Figure 5c).

Figure 5c shows the temperature record, which is deduced from tree-ring data at many locations in the northern hemisphere, extending the temperature record to about the year 800 (Frank et al., 2007). It shows clearly a warm period around 1000 and a cool period between 1200 and 1800, namely the LIA.

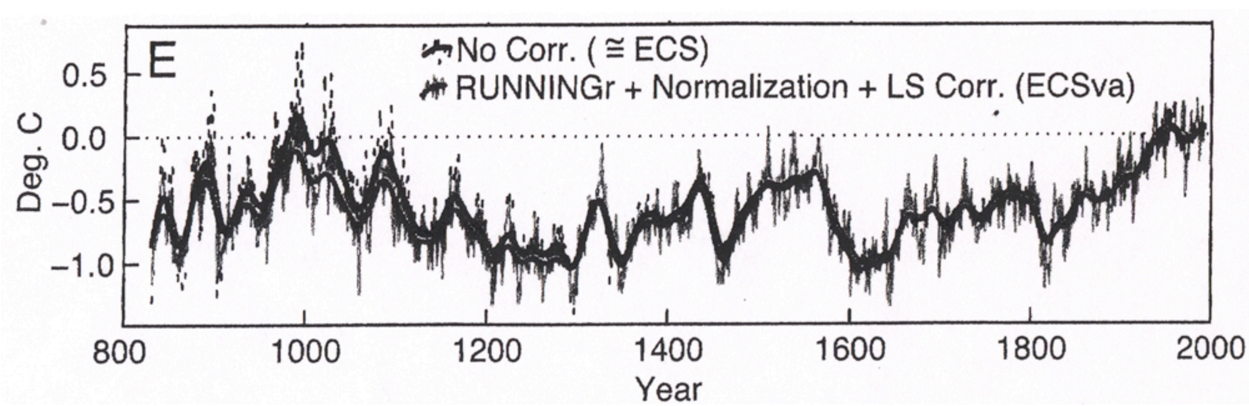

Figure 5c: Temperature variations deduced from tree-ring records from 14 sites from 800. It shows variance-adjusted data by Esper et al. (2002), along with the unadjusted mean record. The dashed line shows the mean of 1961-1990 anomaly reference period (Frank et al., 2007).

Figure 5d shows the 25-year mean winter (DJF) temperature at DeBilt (van Engelen et al, 2001). The temperature was deduced from a number of frost days, ice days, and very cold days. Figures 5a and b show the LIA and a rough linear recovery from 1800. Further, 5c and 5d show the "Medieval Warm Period" around the year 1000 as well as the LIA, although Hughes and Diaz (1994) concluded that the warming was not global.

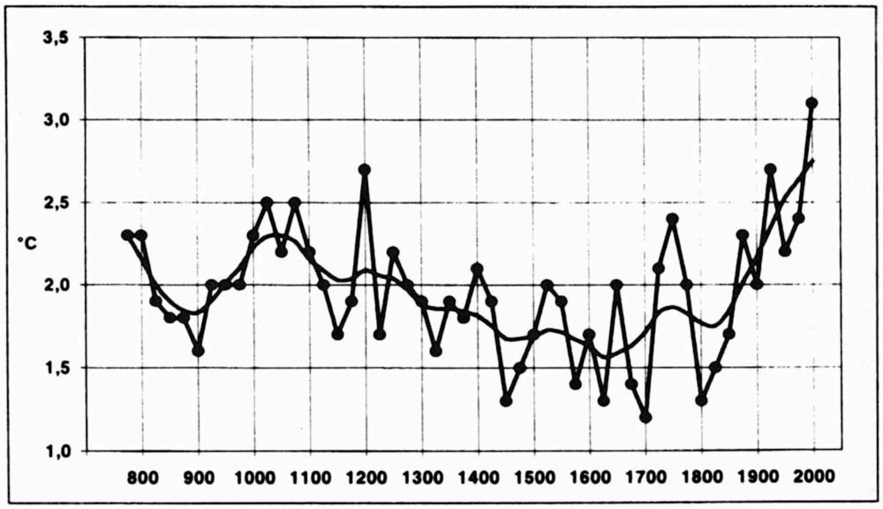

Figure 5d: 25-year mean winter (DJF) temperature at De Bilt (van Engelen et al., 2001).

Aono and Kazui (2008) obtained changes of the full-bloom date of cherry tree blossoms from the 9th Century in Kyoto, Japan (upper). It is shown in the upper part of Figure 5e(1); the date is counted from January 1. They converted the date into temperature in Figure 5e(2). They noted several cold periods, 1220-1350, 1520-1550, 1670-1700, and 1825-1830. However, the temperature began to increase almost linearly after 1830.

The exact temperatures of the Medieval Warm Period relative to the present one appear to be a point of debate at the present time (see also Figures 6a, 6b, 6c, and 6d); see also Blass et al (2007). It is hoped that this debate will be settled in the near future.

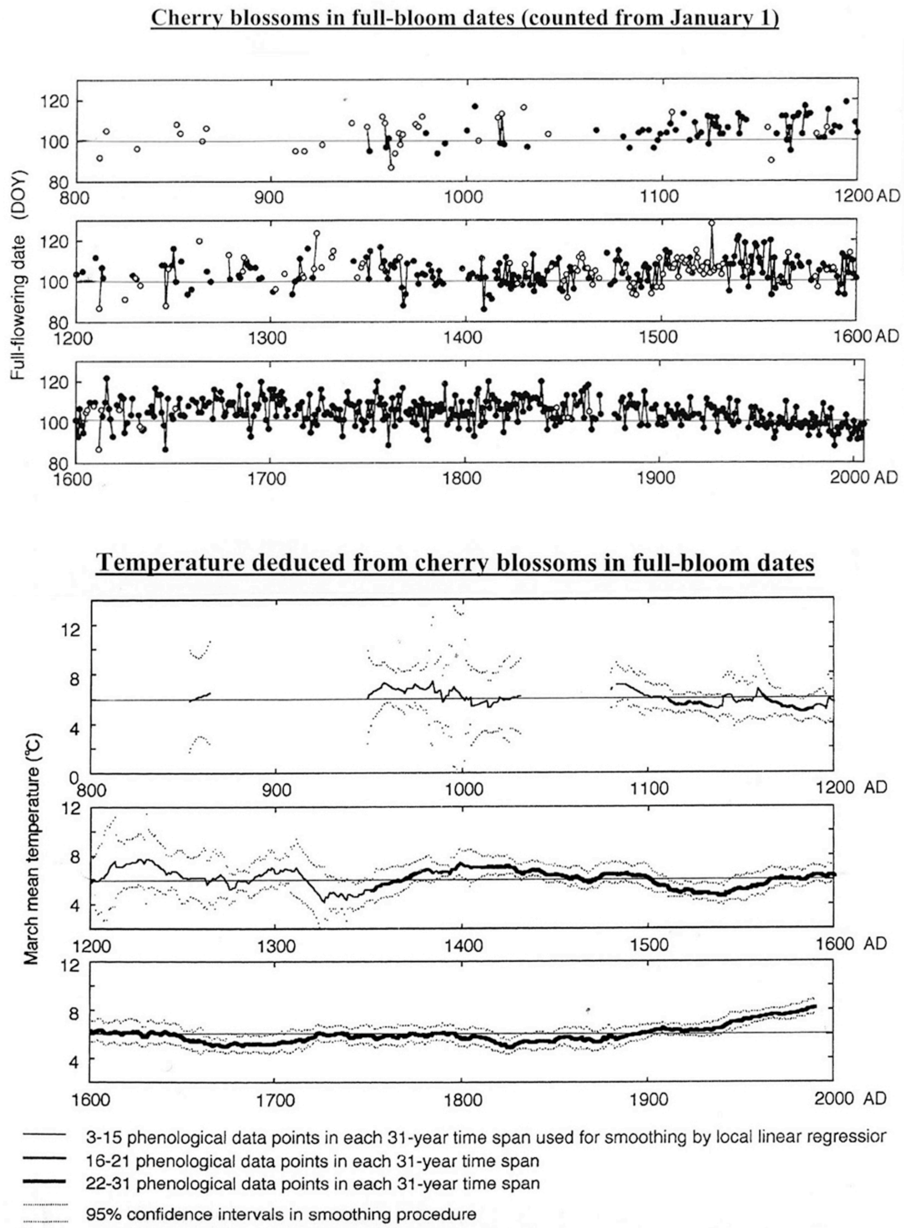

Figure 5e (1): Changes of the full-bloom date of cherry blossom trees in Kyoto, Japan, from the 9th Century; (2) The blooming date in (1) is converted into temperature (Aono and Kazui, 2008).

Temperature Changes during the Last 3,000 Years and Earlier

Figure 6a shows changes of the temperature anomalies from the year 200 reconstructed by Moberg et al. (2005); this is a very comprehensive study of temperature changes during the last 2,000 years. They added the result of a study by Mann et al. (1999); it is indicated by "MBH" in the figure; the IPCC (2001) considers that it is the most significant result, showing a very *abrupt* and *unexpected* increase of temperature in about 1900 after a slow and long decrease of the temperature after 1000. (The MBH figure is nicknamed the "hockey stick.")

An important point to make here is that the MBH result shows neither the Medieval Warming nor the LIA. The IPCC ignored (or treated as a minor side issue) the LIA in their attempt to emphasize that the abrupt increase of temperature after 1900 (illustrated by the hockey stick figure) was caused by the greenhouse effect of CO_2.

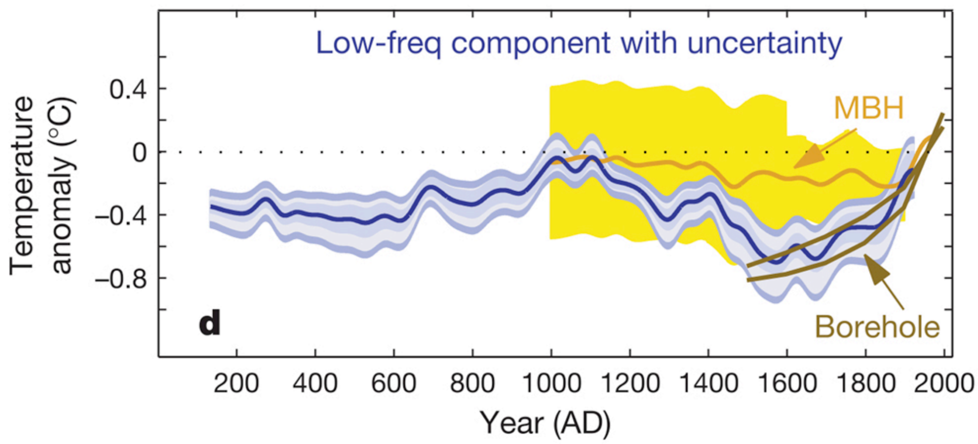

Figure 6a: Multi-proxy temperature change reconstruction from 100 to 1979 (blue), together with other data. The MBH curve indicates the so-called "Hockey stick" data (Moberg et al., 2005). The original borehole data are reproduced in Figure 6c.

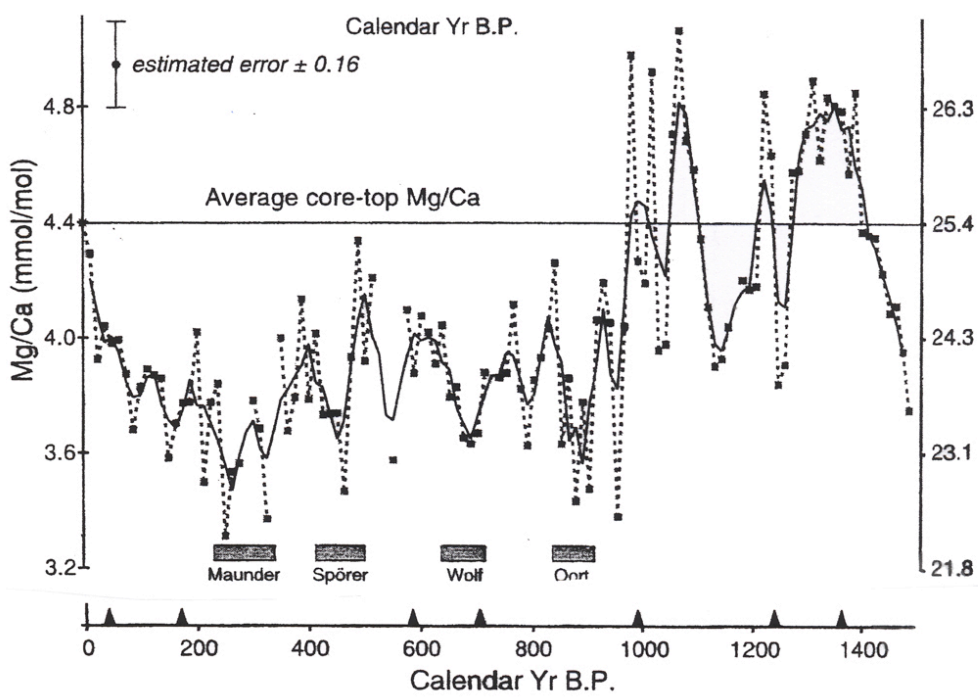

Figure 6b: Mg/Ca analyses in the white variety of the planktic forminifer delta, which were obtained from the northern Gulf of Mexico (Richey et al., 2007).

Figure 6b shows Mg/Ca analyses in the white variety of the planktic forminifer, which were obtained from the northern Gulf of Mexico (Richey et al., 2007). It shows a roughly linear recovery from the LIA about 200 years ago after a relatively cold period lasting about 800 years. The Medieval Warming Period is also clearly seen.

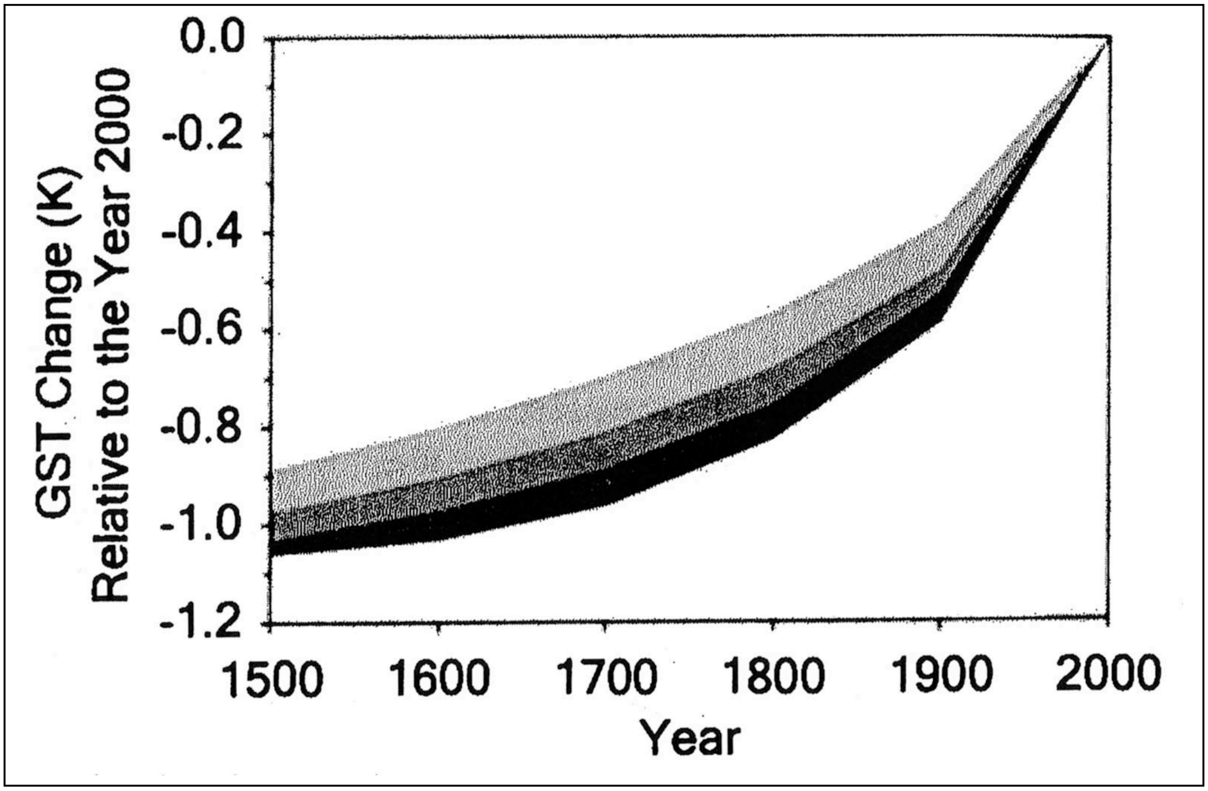

Figure 6c: Borehole data from 1500 (Pollack et al., 2004). This data set is included in Figure 6a and 7a.

Figure 6c shows borehole data from 1500 (Pollack et al., 2004). Although the inversion process from the temperature-depth to the temperature-time relationship is, in general, difficult, it is interesting to see that the warming trend began in about 1500.

Figure 6d shows temperature changes from about 1000 BC to about 2000 AD, covering a 3000-year period, extending the temperature data further to about 1000 BC (Keigwin, 1996). The temperature was deduced from cores obtained from deposits in the Atlantic Ocean. The LIA can be clearly recognized; it seems that it began in 1200 or 1400. There also occurred a broad warm period centered around 1000, the Medieval Warm Period. Thus, this record is consistent with that of Figures 5c, 5d, 6a, and 6b.

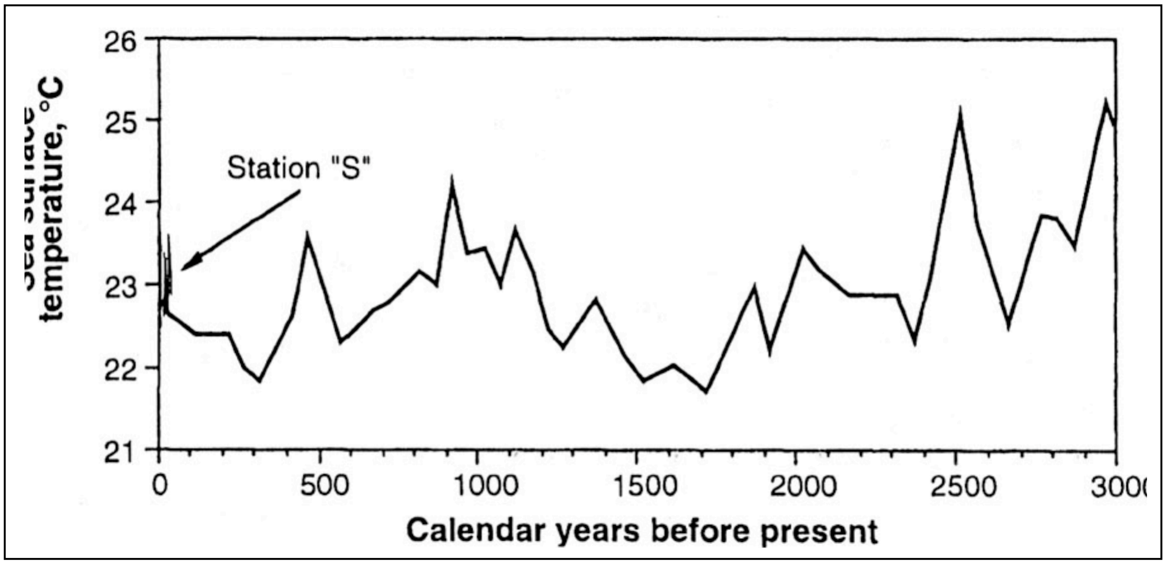

Figure 6d: Temperature changes from about 1000 BC to about 2000 AD, about 3000 years of data, deduced from cores obtained from deposits in the Atlantic Ocean (Keigwin, 1996).

Figures 6e and 6f show the ice core temperature at the GISP-2 site in Greenland (Allen, 2000). At the very least, one can recognize that the Earth experienced the LIA during the last few hundred years from 1200 to 1800 and the Medieval Warm Period from 800 to 1200. There were also large fluctuations of temperature in the past, which are obviously natural changes. Note also in both Figures 6e and 6f a number of periods in the past when the temperature was higher than the present one, about 2,500 years ago (500 BC) and 3,000 years ago (1000 BC), so that the present warm period is not at all unprecedented or unusual.

At this point, we encounter one of the fundamental problems in both climatology and meteorology. Is there any definitive evidence to conclude, as some stated, that the LIA and its recovery ended by 1800 or 1900? Permafrost that formed during the LIA still exists around Fairbanks, although it is thawing (Romanovsky, 2006). More fundamentally, how can we determine the "normal" or "standard" temperature from which deviations (warming or cooling) can be measured and also considered to be abnormal? The problem is that what is "normal" and the "standard", from which "abnormal" can be defined, depends on the chosen period and the length of the period. At the present time, there is no reference level that allows us to conclude that the Earth recovered completely from the LIA by 1900.

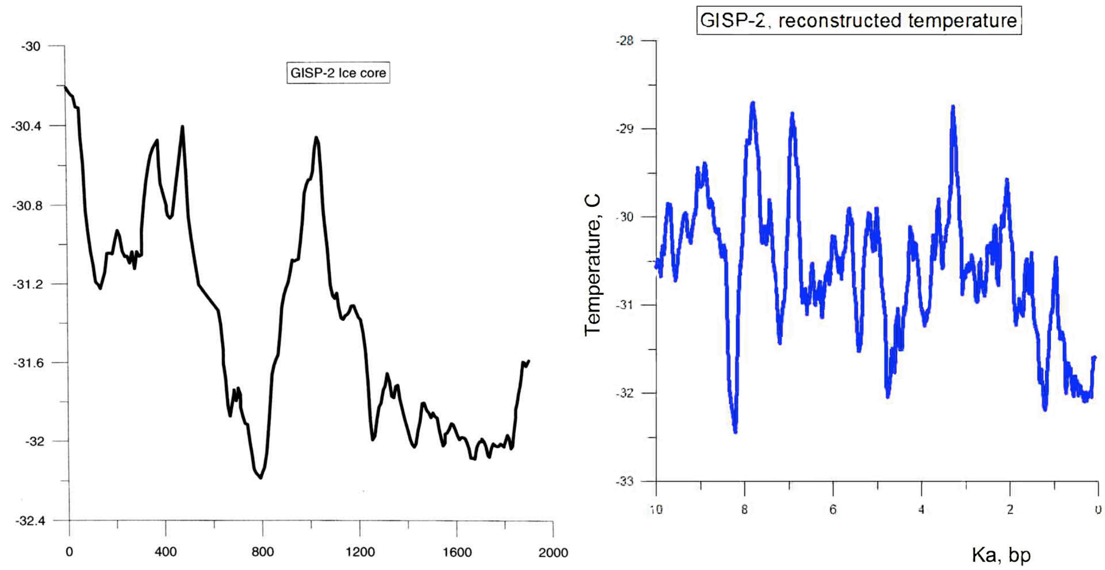

Figure 6e (left) and 6f (right): Ice core temperature at the GISP-2 site in Greenland, extending two thousand years (Ka) before present (bp) and 10 Ka bp, respectively (R.B. Alley, 2000).

Summary (1): Long-term Temperature Changes

As a summary of the above survey, Figure 7a shows changes of the temperature from the year 900 to the present, which combines six different research results (National Research Council, 2006). It is clear from this particular set of data that the present warming began in about 1825, at least 100 years before the use of fossil energy began to increase rapidly (in about 1946). This particular data set came to my attention after an earlier version of the present article was completed. It is a Summary Figure (S-1) of a National Research Council Report by an NRC committee that examined the so-called "hockey stick" diagram. However, it appears that the committee did not pay much attention to the fact that the present warming trend began in about 1800.

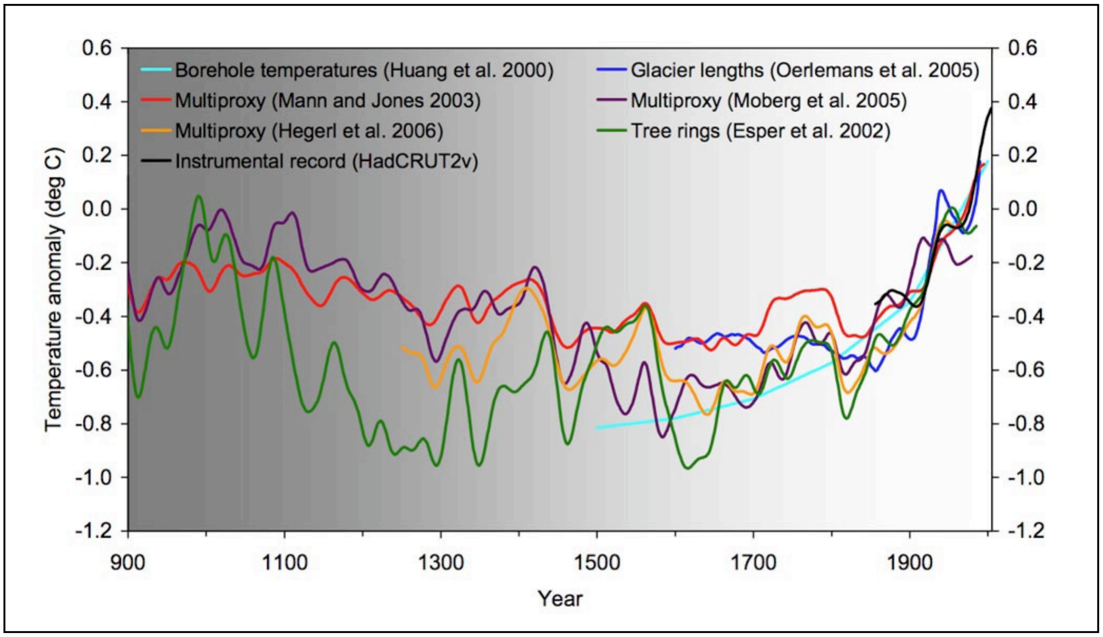

Figure 7a: Reconstructions of large-scale (Northern Hemisphere mean or global mean) surface temperature variations from six different research teams are shown along with the instrumental record of global mean surface temperature. Each curve portrays a somewhat different history of temperature variations and is subject to a somewhat different set of uncertainties that generally increase going backward in time (as indicated by the gray shading) (National Research Council, 2006).

Figure 7b shows the Greenland ice sheet data from the last part of the last ice age (Dahl-Jensen et al., 1998). The upper figure shows temperature changes during the last major ice age and a little earlier. The lower diagram shows, from the upper left (A), the recovery from the last major ice age and the beginning of the present interglacial period; the upper right (B) shows temperature changes during the early part of the present interglacial period and the Medieval Warm Period; and the lower diagram (C) shows the last 2000 years of the changes. The temperature changes shown in this figure are basically consistent with the research results quoted earlier. Note also that there was an increase/decrease around 1700, similar to those in Figures 3a and 4b. It is clear also that there were a few multi-decadal changes during the LIA, some were global, some others were (perhaps) localized.

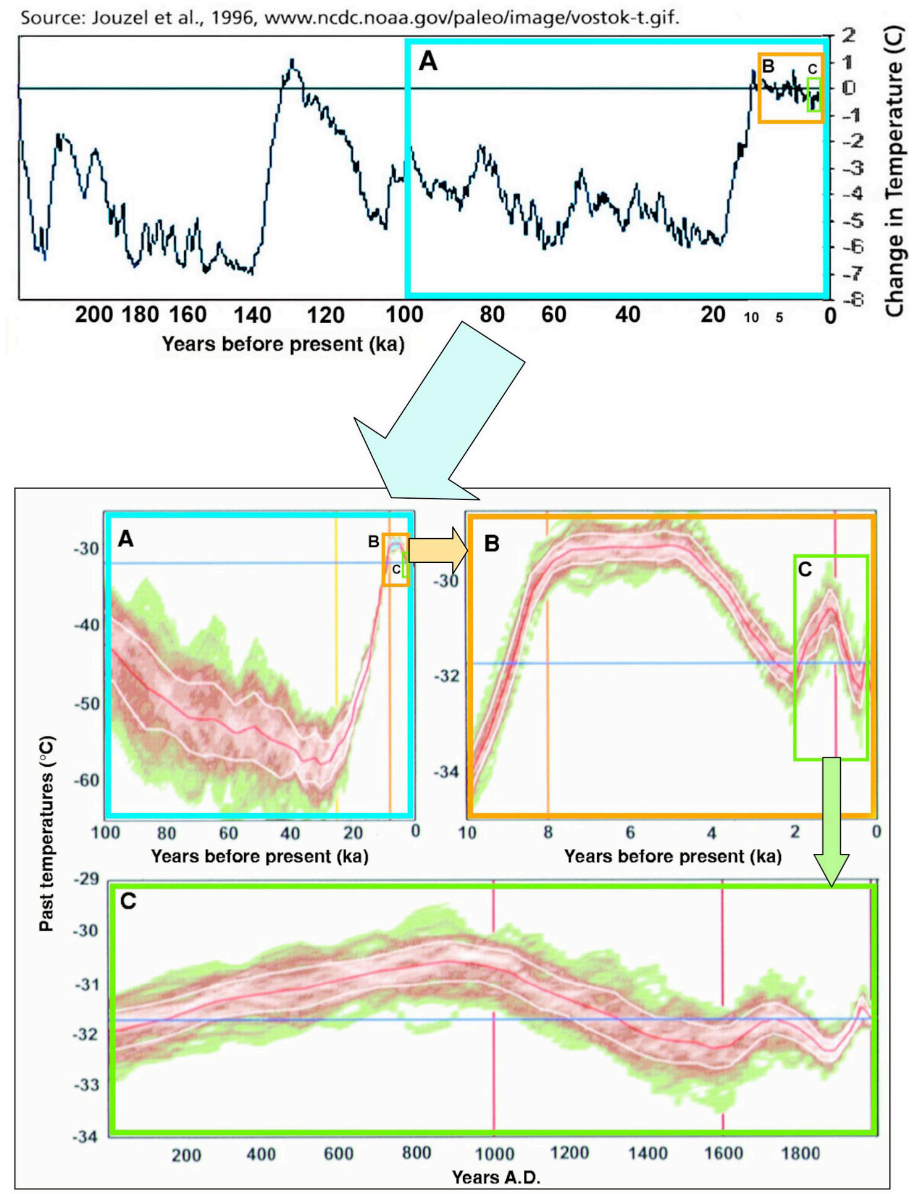

Figure 7b: The contour plots of all the GISP temperature histograms as a function of time (Dahl-Jensen et al., 1998)

There are four important points to make based on all the figures shown above.

(1) The period between 1400 and 1800 was relatively cold, confirming the LIA.
(2) The recovery from the LIA began in about 1800. The temperature has increased almost linearly from about 1800.
(3) During the last 10,000 years or so, there were warmer periods than the last century, including the Medieval Warm period, around 500 BC, 1000 BC, and many times earlier.
(4) There is nothing unusual or anomalous about the present warming trend.

Climate change during the last 100 years or so has been intensely discussed by the IPCC in terms of the manmade greenhouse effect of CO_2. However, it is unfortunate that the IPCC is focusing mainly on the temperature changes during the last 100 years or even as late as after 1975, basically ignoring the LIA.

The IPCC Reports in the past stated that the global average temperature increased about 0.6°C (~1°F) during the last 100 years and that "most" of the increase after the middle of the last century is caused by the greenhouse effect of manmade CO_2. However, on the basis of this survey, there is no definitive proof that "most" of the present warming is due to a manmade greenhouse effect. This is simply their *assumption*. The results presented in this note show that natural changes are substantial and, further, there is nothing unusual about the present temperature rise.

It is well known that CO_2 can cause the greenhouse effect, so it is natural to *hypothesize* that CO_2 is one of the causes of the present warming trend. However, it is not appropriate to conclude that the 0.6°C rise is mostly due to human causes without carefully subtracting the contributions of natural changes. This point is missing in the IPCC study on global warming.

It is natural to assume by glancing at Figure 1a that there was, as a first approximation, an almost linear increase in the natural temperature of 0.5°C/100 years from 1880. It is somewhat surprising that there has, so far, been no debate on many other possible interpretations of Figure 1a. Although the IPCC claims that the hypothesis of the manmade greenhouse effect is proven by GCM results, one can test the hypothesis only qualitatively, not quantitatively, at this stage in the present development of modeling and simulation, because there are a large number of unknown or uncertain parameters that can be adjusted or "tuned" to reproduce the 0.6°C rise. In this case, the possibility is high that a supercomputer generates a "right" answer for wrong reasons or inappropriate parameter tunings. This point will be discussed later.

As far as the gradient of the long-lasting linear change is concerned, it can roughly be estimated to be about 0.5°C/100 years based on all the records from about 1800. *It is very interesting to recognize that this gradient is almost comparable with the IPCC's claim of 0.6°C/100 years.* Therefore, the linear change, which is likely to be a natural change, should be subtracted from the observed increase in order to identify and estimate the manmade greenhouse effect: (0.6°C/100 years) - (0.5°C/100 years) = 0.1°C/100 years. Since the maximum decrease of temperature during the LIA is estimated to be about 0.5°C (Wilson et al., 2000) to 1.5°C (Crowley and North, 1991; Grove, 2005, and many figures shown earlier), it is worthwhile to speculate that the Earth is still recovering from the LIA. Another possibility is that the Earth is experiencing a new warming trend of unknown causes. One possible cause is the increasing solar output (cf. Soon, 2005; Scafetta and West, 2006), which I do not investigate in this note.

It is not the purpose of this note to attempt an accurate estimate of the gradient of the linear change or explore causes of natural changes. Such an estimate is beyond the scope of this note, and it is a task for professional climatologists, although Bryant (1997) showed that the gradient is about 0.5°C/100 years, as shown in Footnote A on p. 3. Here, I emphasize only that a significant part of the 0.6°C increase during the last 100 years must contain substantial natural changes, contrary to the statement by the IPCC Report (2007), so that natural changes must be subtracted before estimating manmade effects.

The linear change is only a rough first approximation. An accurate examination is expected to show deviations from the linear trend (an upward swing after 1946), if the greenhouse effect is significant, namely an upward deviation from the linear change after 1946. Such a study is a task for climatologists.

In addition to the linear change, various fluctuations are superposed on it. One of them is the multi-decadal oscillation, which will be discussed in detail in the Section "Multi-decadal change and others." The identification of this component is crucial in the present discussion of global warming. This is because the IPCC claims that the temperature increase after 1975 is mostly caused by the greenhouse effect of CO_2, while the multi-decadal oscillation has been strongly positive (0.15°C/10 years) from 1975 to 2000.

The verification of the presence of the multi-decadal oscillation had to wait until very recently. Figure 1c suggests that the temperature will begin to decrease, after reaching a maximum value in about 2000. Indeed, as shown in Figure 2 and Footnote B, the temperature has begun to decrease after 2000. Since the multi-decadal oscillation has a gradient of about 0.15°C/10 years, it could overcome the linear change of 0.5°C/100 years, either positively or negatively. The positive case occurred from 1975 to 2000, superposed on the linear increase. As Figure B on p. 4 shows, it seems that the decline of the multi-decadal oscillation (or a change from a positive rate change to a negative rate change) is beginning to happen; note that we are examining a 5-year smoothing data, instead of annual means. This point will be discussed further in the section on "Multi-decadal Change and Others."

Further, the IPCC Report (2007) states that the present high temperature is "unusual" except for about 125,000 years ago (p. 10 of their Report). However, if we examine temperature records during all the other interglacial periods (240,000, 330,000, 400,000 years ago), and Figures 6d and 6e and 7a and 7b, there were periods during which the temperature was comparable to, or higher than, the present one. Actually, it could be said that the present interglacial period was an abnormally cool one compared with the earlier interglacial periods, and there is nothing unusual or abnormal about the present warming trend and the temperature.

One lesson here is that it is not possible to study climate change without long-term data. In fact, one way to learn about natural changes is to examine climate change before the greenhouse effect of CO_2 became significant in about 1946, as attempted in this note. Unfortunately, it is very easy to discredit the results of the traditional paleoclimate change studies in terms of accuracy. However, it is important to recognize that a study of climate change cannot avoid some aspect of anthropology or archaeology. Indeed, archaeological data are quite useful in climate change. Unlike the activities of people in the Tropics, the activity of people in the Arctic was greatly influenced by climate change in the past. The temperature changes shown in Figure 7c were deduced from archeological data collected in high latitude regions (McGhee, 1941, similar to the data shown earlier). Climatologists must face such data because there was no thermometer data before the 17th Century. It may be said that in some ways the "*inaccurate" data (compared with modern data) available for the last few hundred years are more valuable than accurate, but instant, satellite data after 1970 in our study of global warming.*

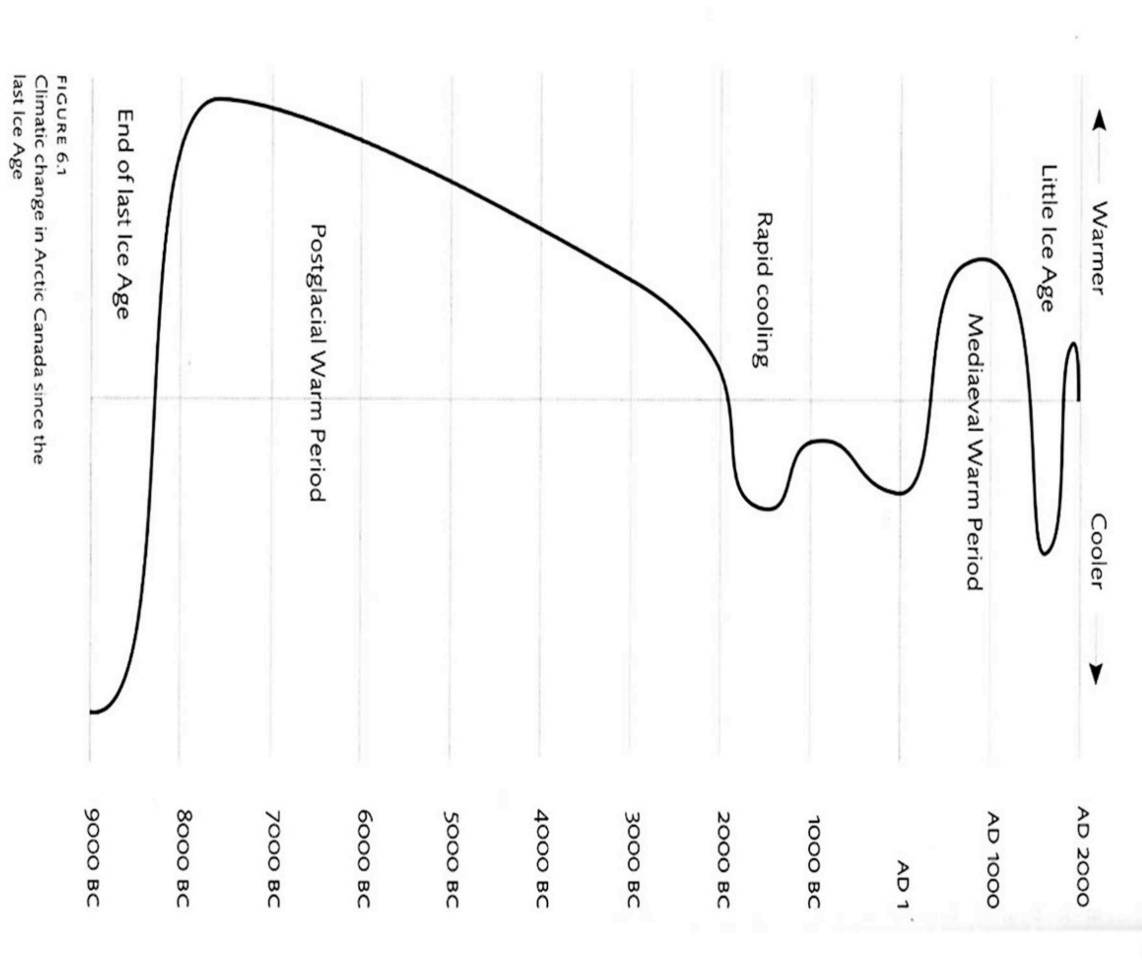

Figure 7c: Climate change in arctic Canada after the last major ice age (McGhee, 1941).

Observed Phenomena supporting the Rebound from the Little Ice Age

Sea ice

It is clear from all the figures shown earlier that the Earth has been in the process of recovering from the LIA since about 1800. Figure 8a shows changes of the southern edge of sea ice in the Norwegian Sea. It has been continuously receding from about 1800 to the present (Vinje, 2001), at least 100 years before the use of fossil energy began to increase rapidly in 1946. Further, there is a possibility that the present recession is related to an intense inflow of warm North Atlantic water; this phenomenon is known as the North Atlantic Oscillation (NAO), which is a natural phenomenon (Polyakov et al., 2002, 2007); this issue will be discussed in later sections. In fact, sea ice in the Arctic Ocean is not shrinking uniformly. The largest shrinkage is taking place where warm North Atlantic water is flowing along the Siberian coast. This phenomenon will be discussed in detail later.

It is important to note that the sea ice surrounding the Antarctic continent has had no definite sign of major change during the last several decades, in spite of the fact that it is expected the greenhouse effect should cause similar effects on sea ice in both hemispheres, but this is not the case. Therefore, the shrinking ice cover in the Arctic Ocean is a feature unique to Arctic Ocean ice, namely not present in the Antarctic Ocean. The North Atlantic flow may be one cause of this unique change; for more details, see the next section. Both winds and currents are also important in explaining shorter (monthly or weekly) period changes. This particular sea ice change will be discussed further in connection with Figures 12a and 12b.

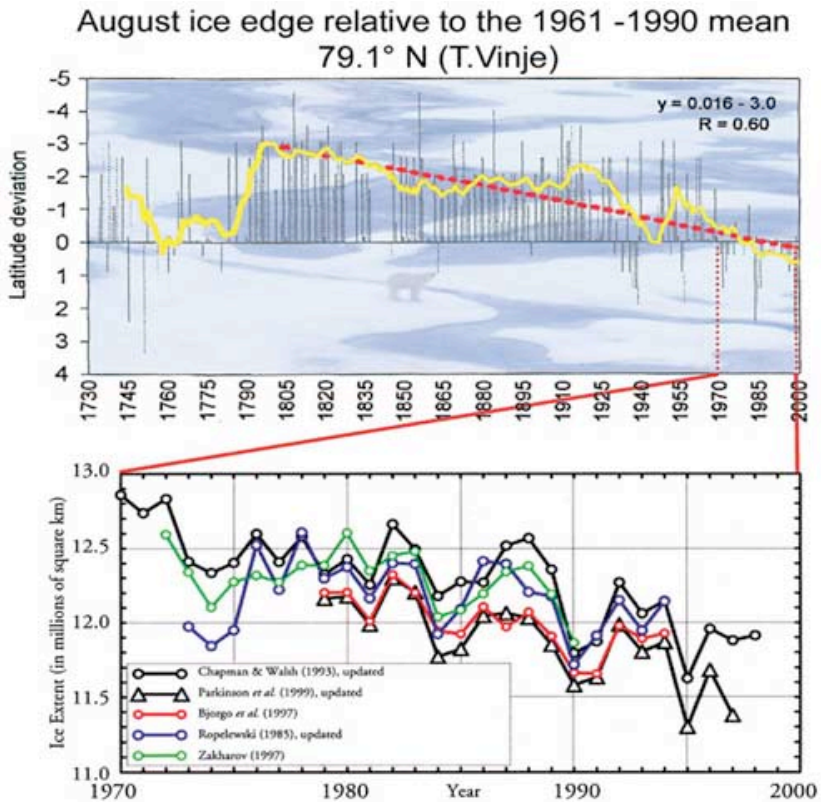

Figure 8a: Upper, retreat of sea ice in the Norwegian Sea (Vinje, 2001). Lower, satellite data corresponding to the period between 1970 and 1998.

Figure 8b shows variations of the occurrence of sea ice at the coasts of Iceland (see the figure caption for the reference). The decline after 1800 corresponds to the variations shown in Figure 8a, supporting the evidence that the receding began well before 1946. Another important evidence is that, as Figure 8b shows, there was a gradual build-up of sea ice beginning in 1200 or after 1400, at the beginning of the LIA.

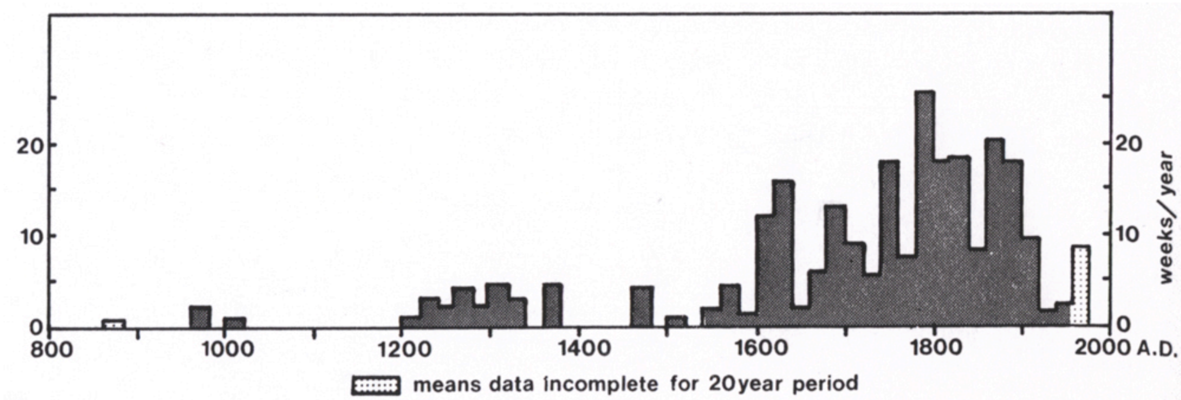

Figure 8b: Variations of the occurrence of sea ice at the coast of Iceland from the year 800. This work was made by L. Koch; Lamb (1982).

Glaciers

Figures 9a, 9b, 9c, 9e, and 9f show records of glaciers in Alaska, New Zealand, the European Alps, and Himalaya, respectively, which have been receding from the time of the earliest records, about 1800. There are also a large number of similar records from the European Alps and elsewhere (Grove, 1988). It is clear that the retreat is not a phenomenon that began only in recent years, or after CO_2 emission increased in1946. Therefore, the retreat of glaciers cannot be used as a supporting evidence of the greenhouse effect of CO_2. Some glaciers are receding rapidly, but some others are advancing rapidly, too (so that it is wrong to pay attention only to rapidly receding glaciers). These short-time phenomena should not be confused with long-term climate change phenomena.

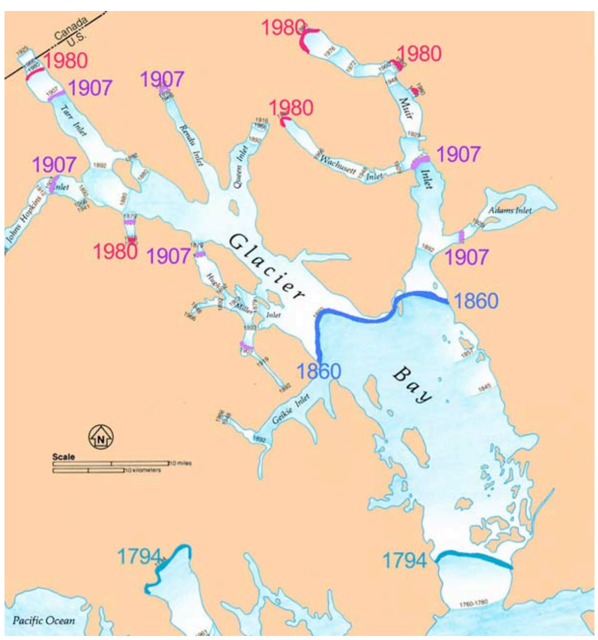

Figure 9a: Retreat of glaciers in Glacier Bay, Alaska (*Alaska Geographic*, 1993).

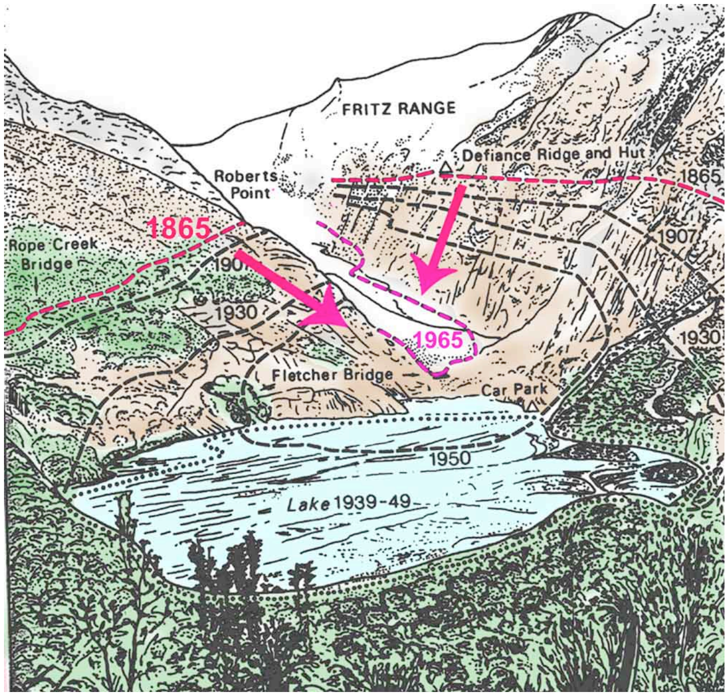

Figure 9b: Retreat of the Franz Josef Glacier in New Zealand; the coloring is added by the present author for emphasis (Grove, 1988).

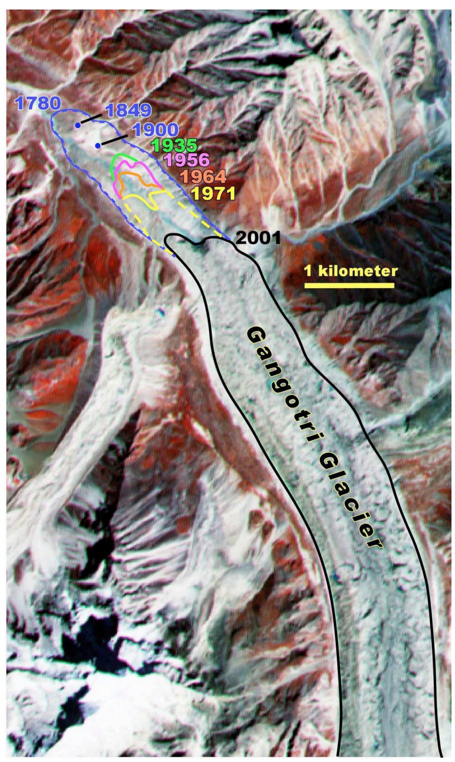

Figure 9c: The Gangotri Glacier in the Himalayas (Kargel, 2007). It shows clearly that the retreat began even before 1800 AD.

It is interesting to examine glacier changes before 1800. Figure 9d shows radiocarbon dates related to glacial advances in some of the Juneau outlet glaciers (Grove, 2001). Each advance killed trees and left in-situ stumps. Figure 9a shows the advance of glaciers near Glacier Bay during the LIA before they began to recede around 1800.

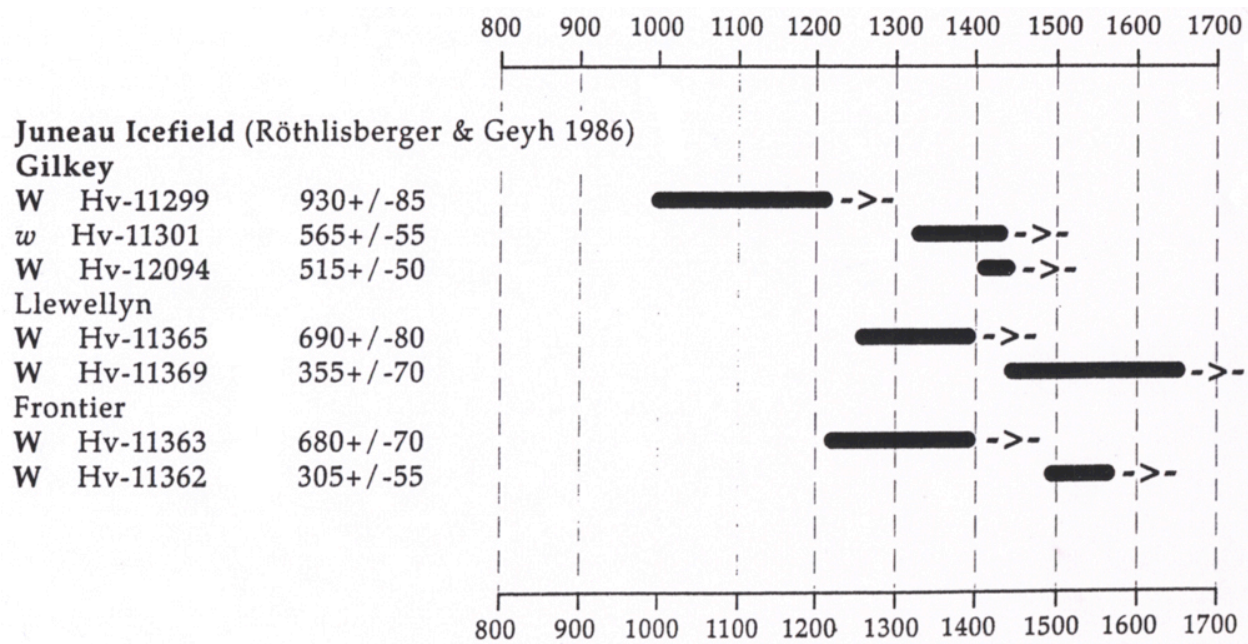

Figure 9d: Radiocarbon dates related to glacial advances in the Juneau glaciers (Grove, 2001).

Figure 9e shows changes of the Mer de Glace glacier in the Alps. It began to retreat in about 1852, and Figure 9f shows its changes in more details (von Michael Kuhn, 2007). This particular glacier was built up after 1550 (namely during the LIA) and began to retreat after 1850.

Figure 9e: The location of the terminus of the Mer de Glace glacier after 1644 (von Michael Kuhn, 2007)

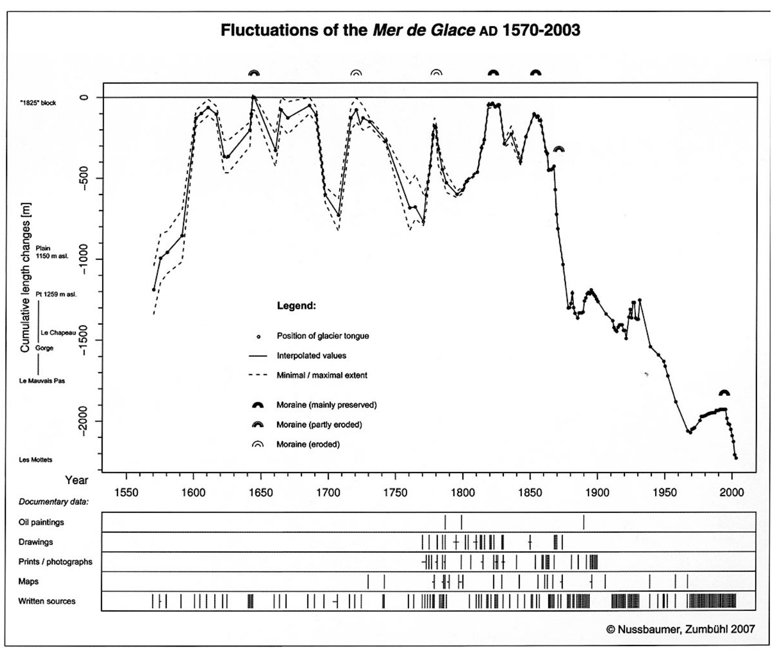

Figure 9f: Details of the changes of the Mer de Glace glacier after 1550 (von Michael Kuhn, 2007).

Figure 9g shows advances/retreats of glaciers in the west-central Alps from 1500 BC. It is clear that glaciers in the Alps grew during the LIA and retreated greatly after 1850 (Holzhausen et al, 2005).

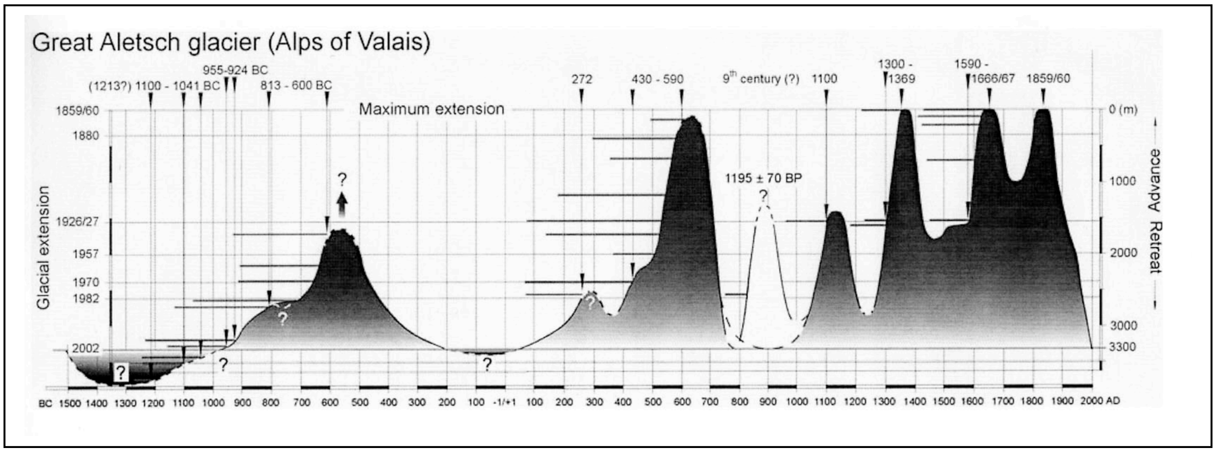

Figure 9g: Advances/retreats in the west-central Alps from BC 1500 (Holzhausen et al., 2005)

There are also various reports about the advancing glaciers during the LIA in Scandinavia. Therefore, it is clear that many glaciers advanced during the LIA before retreating in about 1800.

Sea Level

A recent study of sea level changes is shown in Figure 10a (Holgate, 2007). During the period of his study, Holgate (2007) noted that the rate of sea level rise was about 1.7 mm/year, not tens of meters as suggested in some earlier reports. Although the data cover only the period after 1907, this coverage is sufficient to examine an indication of any accelerated sea level increase after 1946. The sea level change should reflect the expected rise associated with the thermal expansion of seawater (which depends on the depth) and glacier melting during the last half century, as warned in the IPCC Reports. Figure 10a shows that there is no clear indication of an accelerated increase of sea level after 1946, even if some individual glaciers in the world are receding. In fact, comparing the slope between 1907-1960 and 1960-2000, there occurred even a slightly smaller gradient (1.4 mm/year) in the latter period.

Figure 10b shows the global sea level from 1800 and its rate of change. It is clear that the sea level began to increase in about 1850 and continued to the present, approximately with the same rate as that which is shown in 10a (Jevrejeva et al., 2006 and 2008), namely 100 years before 1946. The recovery of sea level from the LIA was delayed compared with the air temperature for the obvious reason. For the rate of change, see the next section.

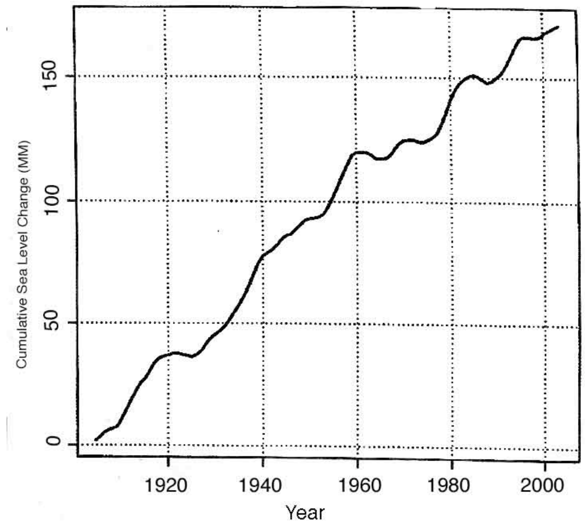

Figure 10a: The mean sea level record from nine tide gauges over the period 1904-2003 based on the decadal trend values for 1907-1999. The sea level curve here is the integral of the rates (Holgate, 2007).

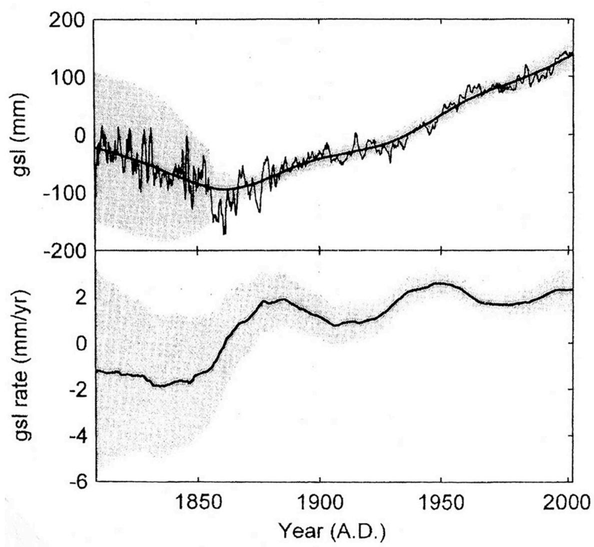

Figure 10b: Global sea level change and its rate from 1800 to the present (Jevrejeva et al., 2006).

Figure 10c shows a satellite study of sea level changes (Nerem and Choe, 2008, and Mitchum and Chambers, 2008). After increasing from 1993, the sea level began to decrease after 2006.

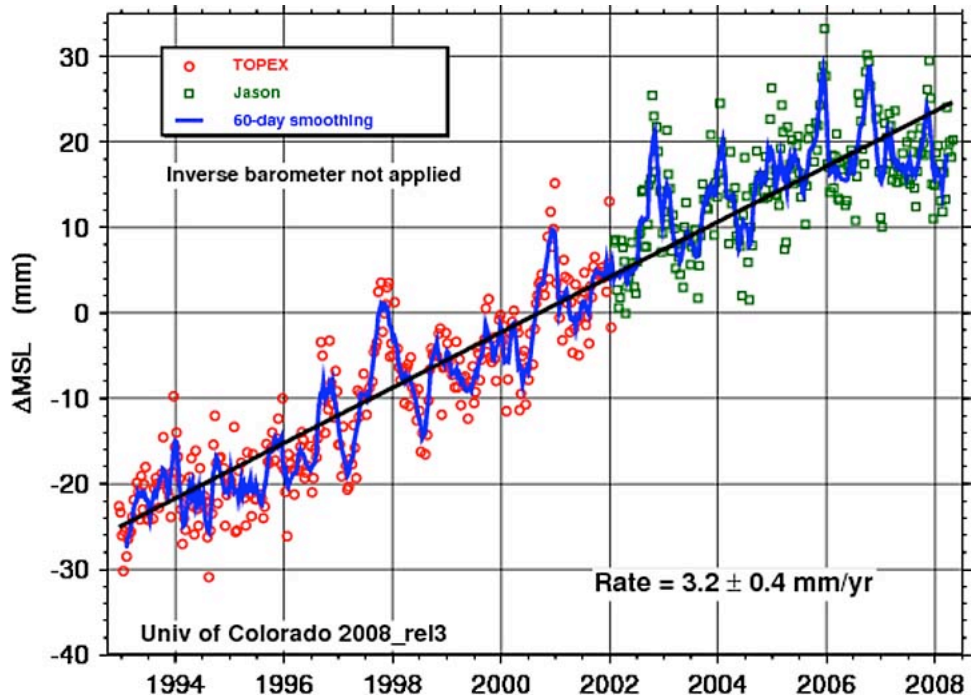

Figure 10c: Sea level changes from 1993 to 2008 (Nerem and Choe, 2008, and Mitchum and Chambers, 2008). (http://sealevel.colorado.edu/current/sl_noib_global.jpg, and http://sealevel.colorado.edu/results.php).

Multi-decadal Change and Others

Temperature

As shown in Figures 1a and 1c, three prominent fluctuations occurred during the last 100 years. The first was a temperature rise from 1910 to 1940 and the subsequent decrease from 1940 to about 1975. The last is the present rise between 1975 and 2000. As stated earlier, it is crucial to examine whether both rises are due to the same, similar, or entirely different causes. Until such a study can prove the causes of this particular phenomenon convincingly, we should not claim that the rise after 1975 is mostly due to the greenhouse effect, as stated in the IPCC Report.

It is important to note that the present global warming after 1975 is not uniform over the Earth. Although a single number, namely +0.6°C/100 years, is used in discussing global warming, the geographic distribution of "warming" is quite complex. The upper part of Figure 11a shows the "warming" pattern during the last half of the last century, from about 1950 to about 2000 (Hansen et al., 2005). One can see that the most prominent change occurred in Siberia, Alaska, and Canada. In the continental Arctic, the warming rate was several times more than the global average of 0.6°C/100 years or 0.3°C/50 years. There is no doubt that such a prominent change contributed to the global average change in Figure 1a. On the other hand, it may also be noted that cooling was in progress in Greenland over the same time period.

It is of great interest to ask if GCMs can reproduce this geographic distribution of the observed changes shown in the upper part of Figure 11a, since they claim to be able to reproduce the 0.6°C/100 years rise. Thus, we asked the IPCC arctic group (consisting of 14 sub-groups headed by V. Kattsov) to “hindcast” geographic distribution of the temperature change during the last half of the last century. To “hindcast” means to ask whether a model can produce results that match the known observations of the past; if a model can do this at least qualitatively, we can be much more confident that it is reliable for predicting future conditions. Their results are compiled by Bill Chapman, of the University of Illinois, and are shown in the right side of Figure 11b. The left side of the figure is taken from the ACIA Report (2004), which shows a trend similar to that shown in the upper part of Figure 11a, namely the prominent warming in the continental Arctic and cooling in Greenland. This comparison was undertaken in an attempt to reduce differences between the observations and modeling results, because they are expected to be similar, but imperfect.

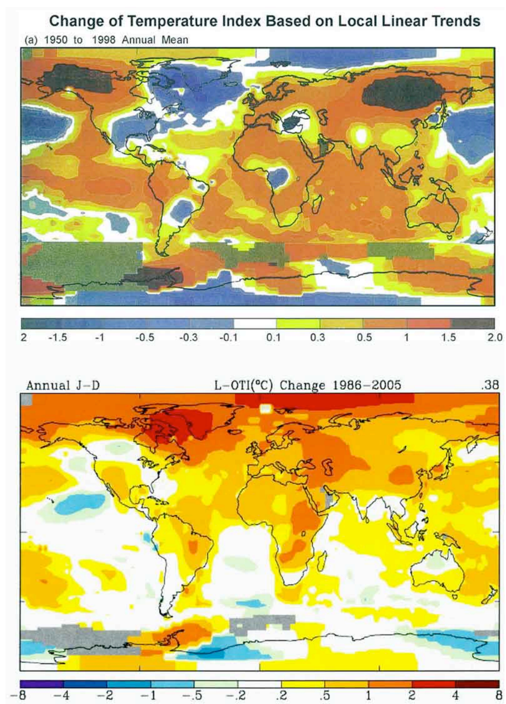

Figure 11a: Upper – the geographic distribution of temperature change between 1950 and 1998 (Hansen et al., 2005). Lower – the geographic distribution of temperature change between 1986 and 2005 (Hansen, 2006).

We were surprised at the difference between the two diagrams in Figure 11b. If both were reasonably accurate, they should look alike. Ideally, the pattern of change modeled by the GCMs should be identical or very similar to the pattern seen in the measured data. We assumed that the present GCMs would reproduce the observed pattern with at least reasonable fidelity. However, we found that there was no resemblance at all, even qualitatively.

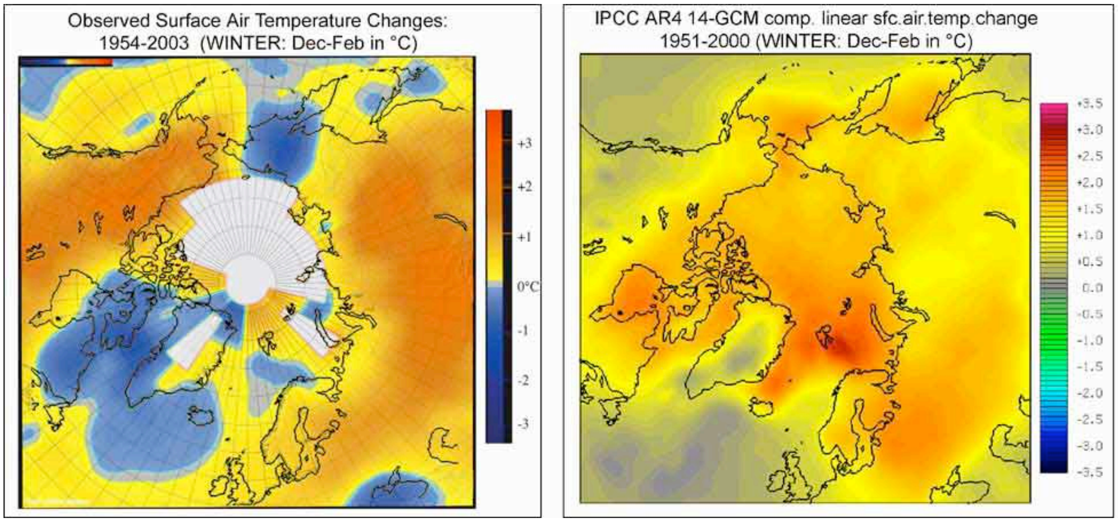

Figure 11b: Comparison of the observed distribution of temperature changes (ACIA, 2004) and the simulation (hindcasting) by the IPCC arctic group (Chapman 2005).

Our first reaction to this surprising result was that GCMs are still not advanced enough for hindcasting. However, this possibility is inconceivable, because the increase of CO_2 measured in the past is correctly used in the hindcasting, and everything we know is included in the computation. The IPCC arctic group's result is the best result based on our present knowledge. If the greenhouse effect caused the warming, it should be reproducible at least qualitatively by these models, even if the reproduction is not perfect.

It took a few weeks or so before we began to realize another possible implication of this discrepancy: If 14 GCMs cannot reproduce prominent warming in the continental Arctic even qualitatively, perhaps much of this warming is not caused by the greenhouse effect at all. That is to say, because it is not caused by the greenhouse effect, the warming of the continental Arctic cannot be reproduced even qualitatively by the GCMs. This is because 14 GCMs do not contain processes that caused the continental Arctic warming and cooling. How do we examine that possibility?

If the prominent warming in the continental Arctic (Figure 11a, upper, and Figure 11b, left) is due to the greenhouse effect, the prominent trend should continue after 2000. That is, we should observe an amplification of continental Arctic warming in this century that will be even greater than the amplification that was observed during the last half of the last century, since the amount of CO_2 continues to increase at an exponential rate. Thus, we examined the warming trend during just the last 20 years or so, provided by Hansen (2006). To our surprise, the prominent continental Arctic warming almost disappeared in those results; the Arctic warmed at a rate about like that of the rest of the world, while Greenland showed a strong warming (the lower part of Figure 11a), instead of cooling during the last half of the last century. Actually, in Fairbanks, Alaska, the temperature shows a cooling trend between 1977 and 2001, as can be seen in Figure 11c (Hartman and Wendler, 2005). The sudden increase of temperature in 1975 is another indication that this particular warming is not likely to be due to the greenhouse effect of CO_2. It is likely that such a change is caused by shifts of the atmospheric pressure patterns due to unknown causes; Figure 14 shows clearly this trend. In fact, the cause of the LIA may be partially related to such a shift of the pressure pattern. Therefore, our conclusion at the present time is that much of the prominent continental Arctic warming and cooling in Greenland during the last half of the last century is due to natural changes, perhaps to multi-decadal oscillations like the Arctic Oscillation, the Pacific Decadal Oscillation, and the El Niño. This trend is shown schematically in Figure 1c as positive and negative fluctuations. If this is indeed the case, the IPCC Report is incorrect again in stating that the warming after 1975 is particularly caused by the greenhouse effect. The steep increase of the temperature after 1975 is likely to be a combined effect of the linear change and the oscillatory change, which had been positive during the recent few decades. In any case, this comparison gave us a new way to use GCM results to identify natural changes of unknown causes.

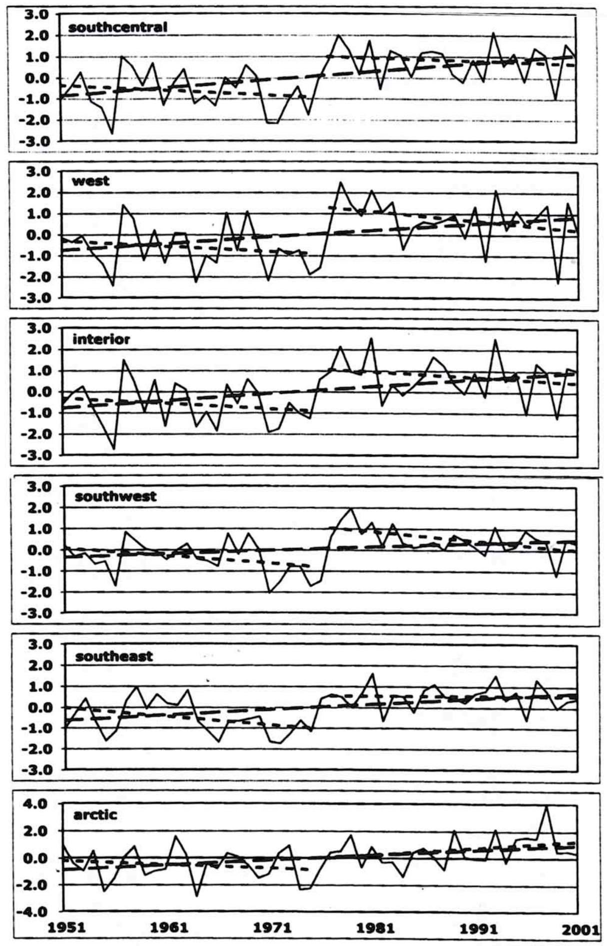

Figure 11c: The transition from the period of declining temperature (1940-1975) to the period of rising temperature after 1975. The transition is a step-function-like change, unlike the Greenland effect. Further, after a step-function-like increase, the trend appears to be negative (B. Hartmann and G. Wendler, 2005).

Sea Ice in the Arctic Ocean

As mentioned earlier, the present rapid retreat of sea ice in the Arctic Ocean, particularly in 2007, is caused by the inflow of the warm North Atlantic water into the Arctic Ocean and the effects of winds. Figures 12a and 12b show results of the ocean monitoring effort by an international group, led by the International Arctic Research Center. This warm water is melting sea ice from the bottom. The resulting thin ice tends to break up easily by stormy water and is easily forced to flow by winds; nothing can move sea ice (which covers an area of the United States) in the Arctic Ocean, if it is a single plate. This was exactly what happened in the fall of 2007, resulting in a large recession of sea ice toward the Canadian side (some expected further shrinking in 2008, but that is unlikely). It was shown by Polyakov (2006) that this inflow is a quasi-periodic phenomenon, as shown in Figure 12c.

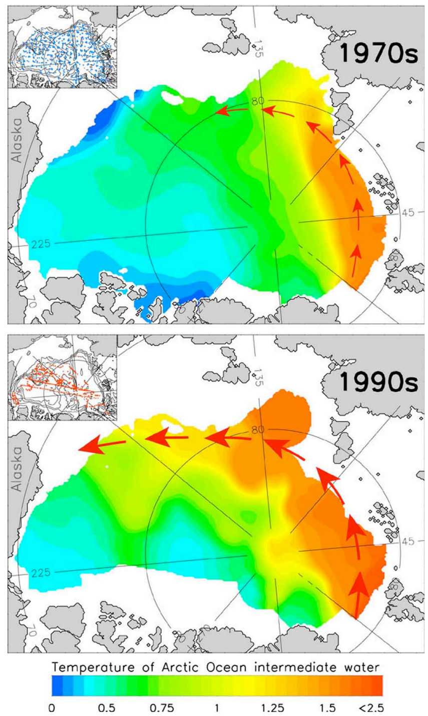

Figure 12a: Inflow of warm North Atlantic water into the Arctic Ocean (Polyakov, 2006).

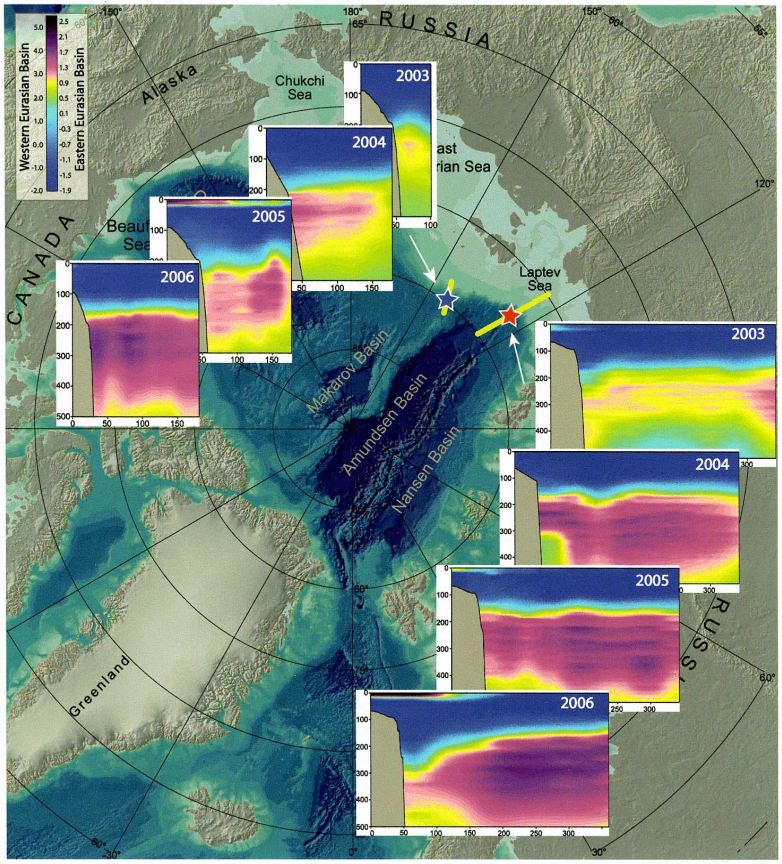

Figure 12b: Changes of seawater temperature at two locations in the Arctic Ocean. The warm water from the North Atlantic Ocean is flowing deeply into the Arctic Ocean (Polyakov et al., 2007).

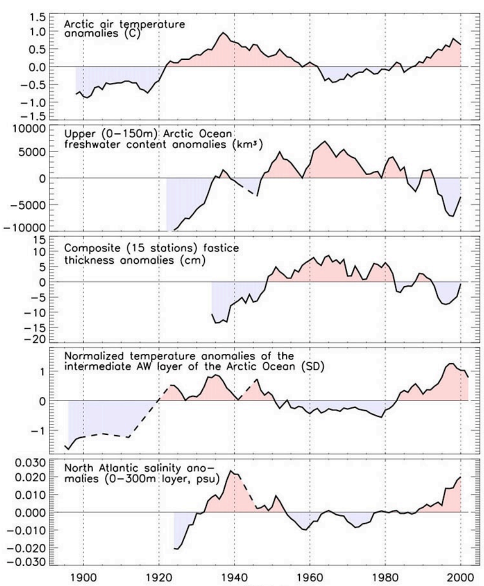

Figure 12c: Air temperature and various conditions of the Arctic Ocean between 1895 and 2000 (Polyakov et al., 2008).

We have another example to show that GCM results can be used to examine warming processes other than the greenhouse effect of CO_2. Figure 13 shows results of various models on the shrinking sea ice in the Arctic Ocean, together with data from satellite observations (DeWeaver, 2007). Both model results and satellite data show a shrinking trend. However, the satellite data show a much steeper decline than all the model results. Since the models take into account the observed amount of CO_2 during the observation period, some processes other than the CO_2 greenhouse effect must have been in progress that are not considered at this time or not properly taken into account in GCMs. It may well be that the inflow of warm North Atlantic water shown in 8b and 8c is one such process. It is well known that winds or ocean currents can move massive sea ice. In fact, sea ice around the Antarctic continent shows no clear sign of decrease, and is actually growing a little.

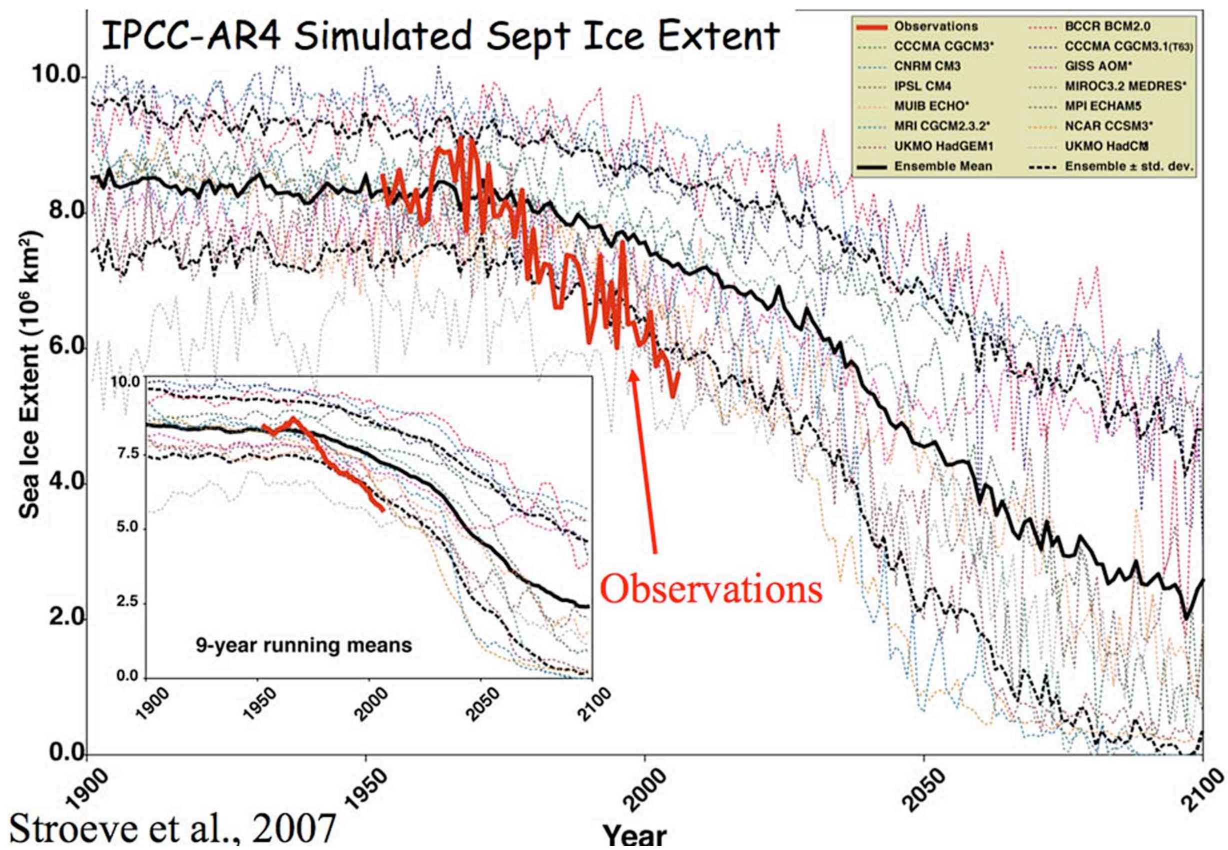

Figure 13: Changes in the area of Arctic Ocean sea ice; comparison of computer modeling results with observations (DeWeaver, 2007).

Figure 14 shows the Pacific Decadal Oscillation (PDO), which is a natural phenomenon, together with Figure 1c. In the top part, it shows the observed wind pattern over the Pacific Ocean; note the reversal of the wind direction as the PDO changes its sign. The middle part shows the PDO index. In the bottom part, Figure 1c is reproduced for comparison with the PDO index. It is interesting to note a striking resemblance of changes between the multi-decadal oscillation and the Pacific Decadal Oscillation (PDO).

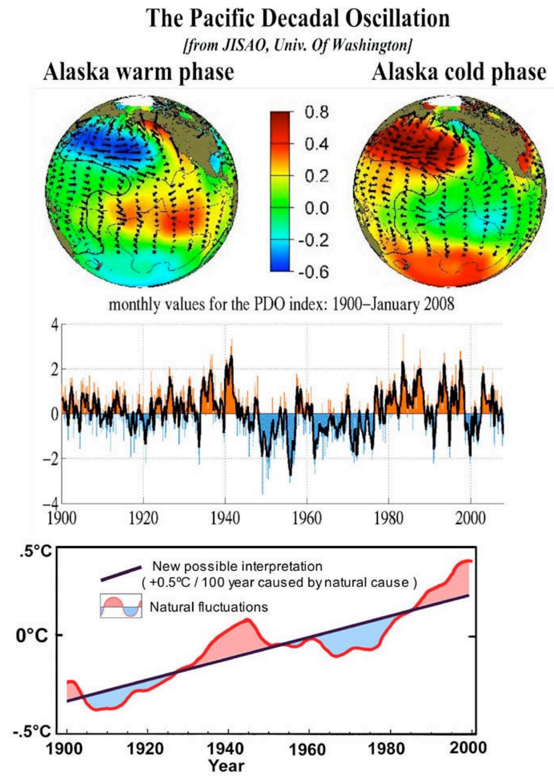

Figure 14: The PDO wind pattern, the PDO index. Figure 1e is shown at the bottom for comparison with the PDO index.

Summary (2): Multi-decadal Oscillation and Others

In this summary, it is interesting to examine Figure TS.6 in the IPCC Report (2007) reproduced here as Figure 15a. They drew several straight lines, including the one (red) from 1860 (gradient being ~ 0.5°C/100 years). However, the IPCC has been interested only in the one that began in 1955 (orange) and the that began in 1980 (yellow), as their Summary for Policy Makers noted. It is important to note that the temperature rise from 1910 to 1940 was as steep as the one that started in 1975 or 1980. If they are interested in the rise after 1975, they should have also paid serious attention to the temperature rise between 1910 and 1940, because the amount of increase and the rate of change are similar to those after 1975, as stressed earlier a few times. We are going to show that the so-called 'unprecedented' increasing rate of the temperature shown by the yellow line in Figure 14 is mostly due to effects of the multi-decadal oscillation. If there is a possibility that the increase after 1910 (but before 1946) was caused by natural changes, there is a good possibility that the rise after 1975 or 1980 contains also natural changes.

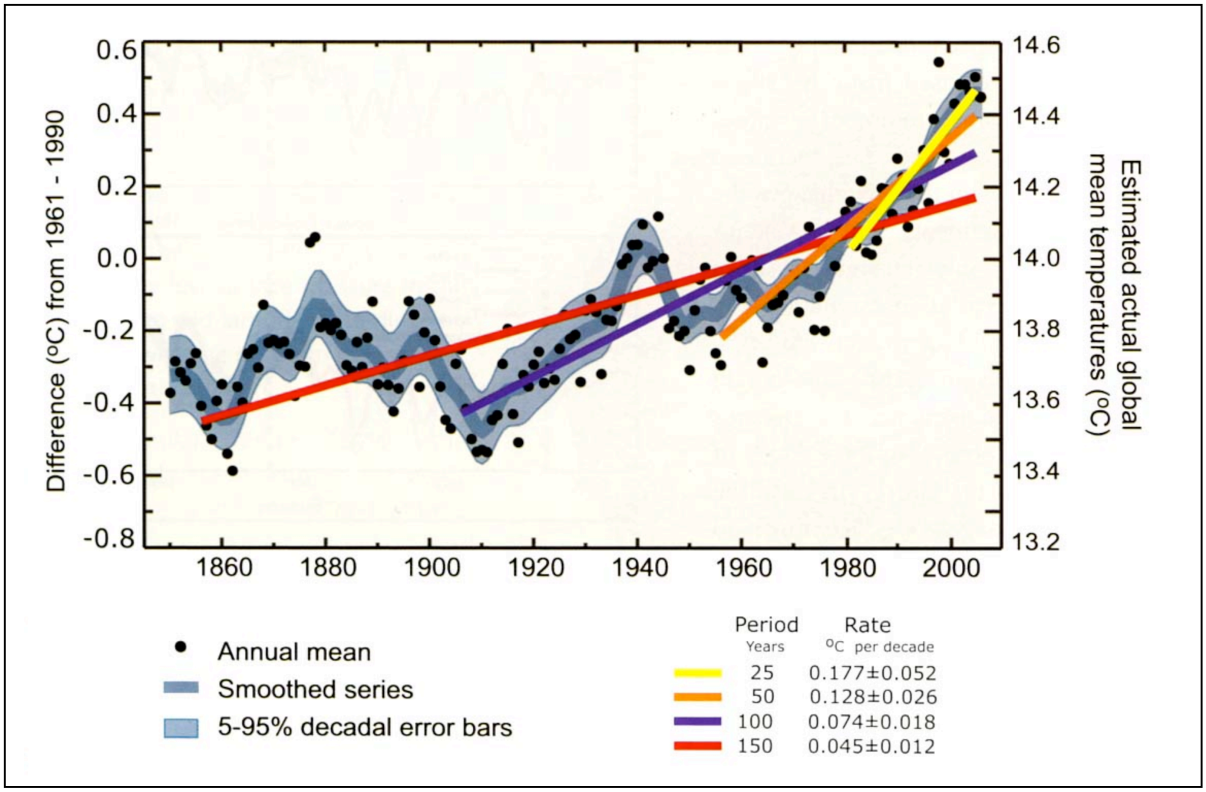

Figure 15a: Temperature changes from 1850; several gradient lines are drawn (IPCC Report, 2007). The red gradient is about 0.5°C/100 years.

It is important to note that the yellow line is specifically identified by the IPCC as the greenhouse effect of CO_2. However, as pointed out earlier (Figure 1c), a very significant part of the yellow line must be caused by the combination of both the linear change (the recovery from the LIA) and the multi-decadal oscillation. In fact, although the IPCC Report (2007) emphasized that the temperature increase from 1975 was mostly caused by the CO_2 greenhouse effect, the multi-decadal oscillation must have contributed greatly to the increase, as shown in Figure 15b (the thick red line). Figure 15c shows the latest temperature trend presented by Jones (2008). Figure 15d shows a similar trend (Hadley Climate Research Center, 2008). From these results, it is clear that the multi-decadal oscillation has reached a maximum in about 2001 or 2002, and the rate of change is shifting toward negative values. The future trend depends on the combination of the recovery from the LIA (0.5°C/100 years) and the multi-decadal change that tends to have a greater rate change than the former. It is also interesting to note that the PDO appears to shift toward a negative period (Figure 14).

For those reasons, there is little doubt that natural changes are greater than the greenhouse effect of CO_2.

At least, the IPCC should have tried to identify natural changes from the yellow line, before claiming that the temperature rise shown by the yellow line is mostly due to the greenhouse effect of CO_2.

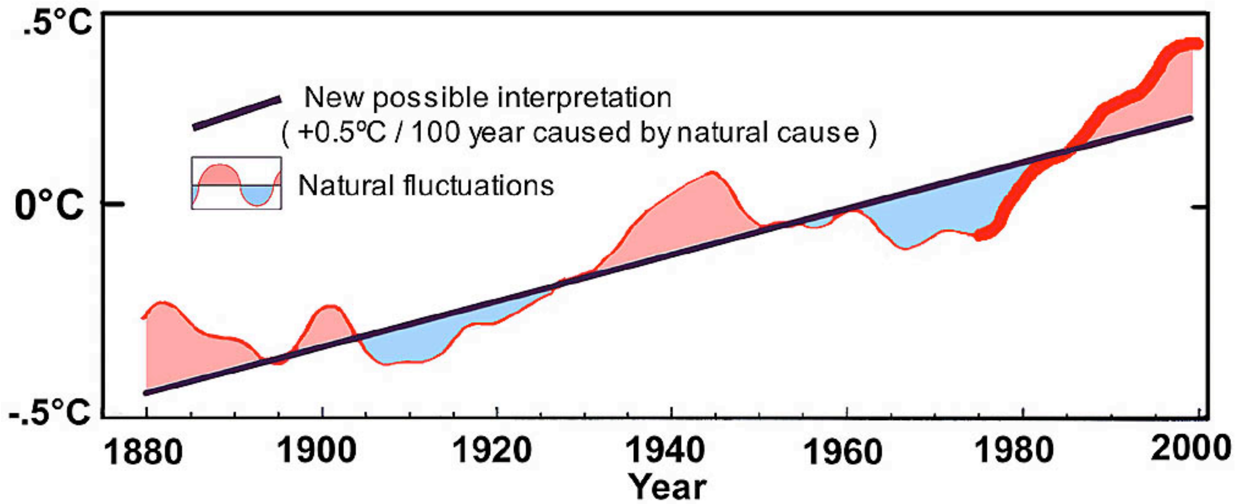

Figure 15b: Figure 15b is the same as Figure 1e, except that the last part of the multi-decadal oscillation after 1975 is emphasized by a thick red line.

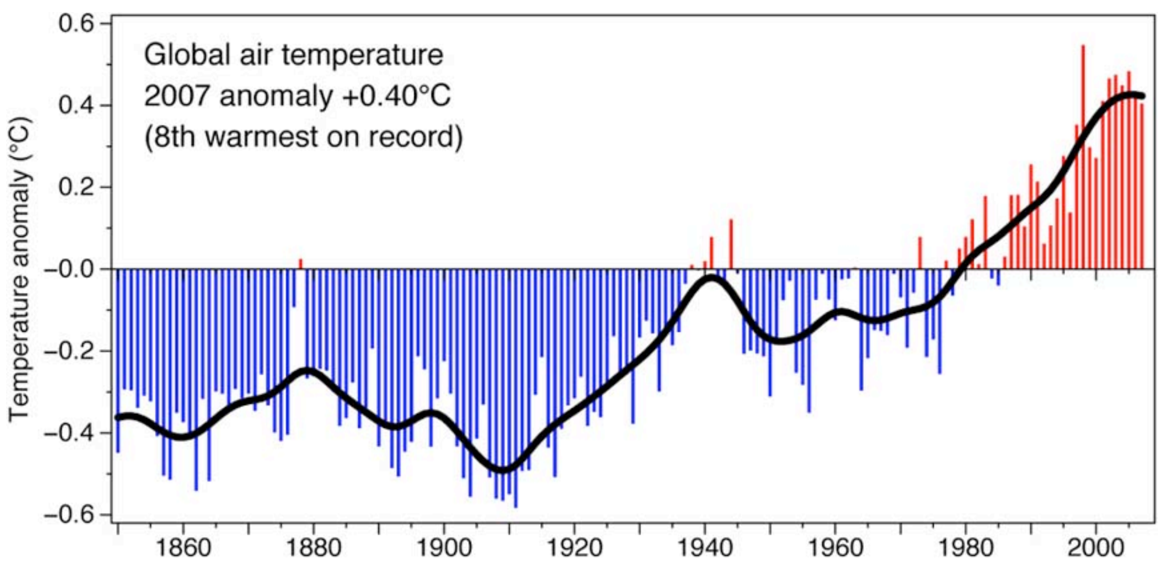

Figure 15c: The global average temperature from 1850 to 2007 (P.D. Jones, University of East Anglia, 2008). (http://www.cru.uea.ac.uk/cru/info/warming/)

Unfortunately, at this time, many studies are focused only on climate change after 1975, because satellite data have become so readily available. A study of climate change based on satellite data is a sort of "instant" climatology. Based on satellite data, it is often reported that climate change is "unprecedented." For example, although there are a number of reports on the condition of ice in Greenland these days, implying unprecedented changes, Chylek et al. (2006, 2007) reported that present changes of the Greenland ice sheet are smaller than changes observed during the 1920-1940 period. Their results are reproduced as Figure 16. This feature can also be seen in the sea level change in Figure 10b; the multi-decadal oscillation can be recognized in the lower half of the figure, in which the rate of change of sea level is shown.

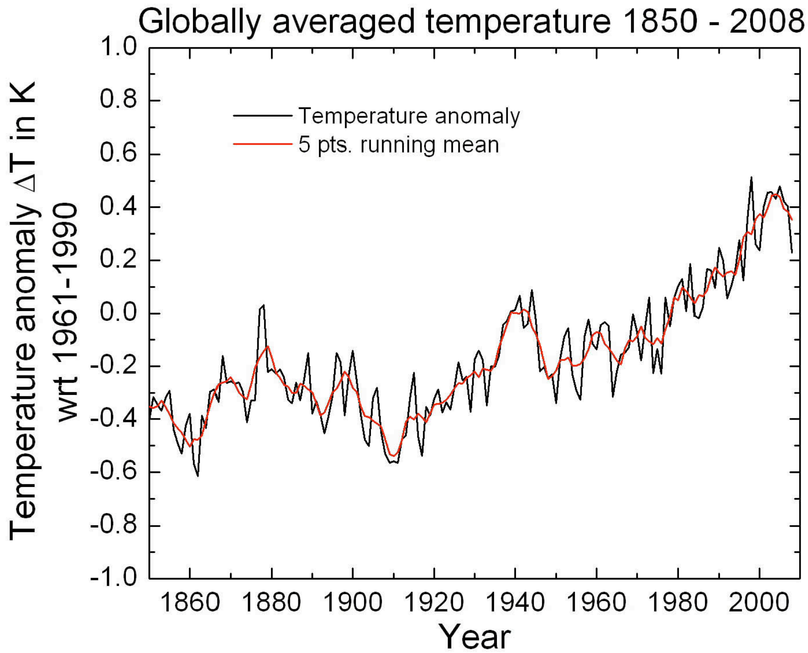

Figure 15d: Global temperature variations and their 5-year running mean (compiled from http://www.metoffice.gov.uk/research/hadleycentre/obsdata/HadCRUT3.html). Note that the warming stopped and there is a decreasing trend after 2000; see also Figures 15c and 15d.

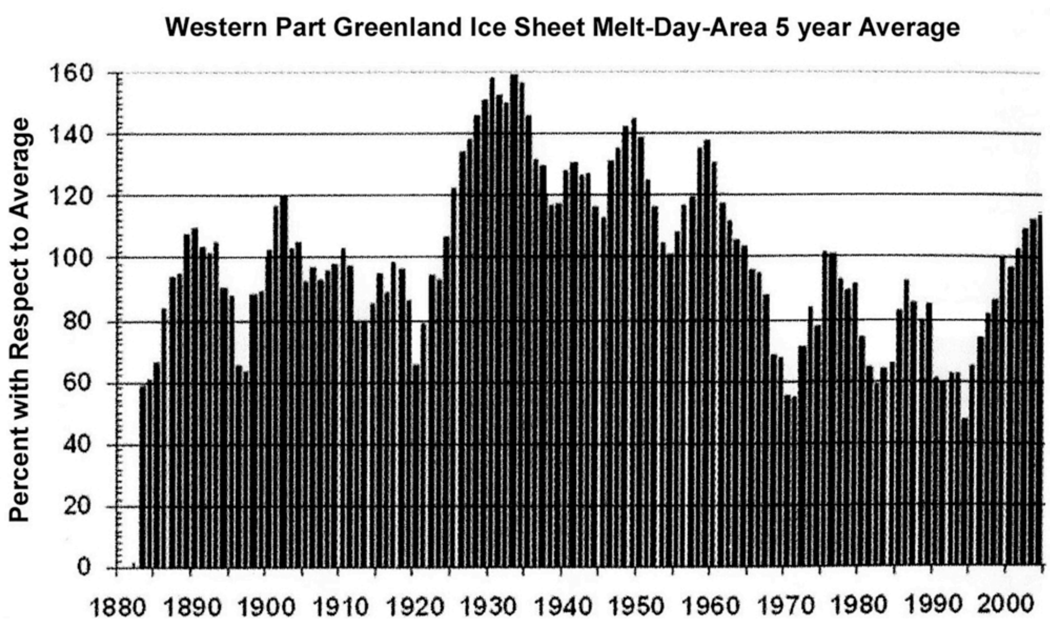

Figure 16: The melt day area of the western part of the Greenland ice sheet. It is reconstructed from the temperature record and melt area sensitivity of 3.8% per 0.1°k temperature change (Chylekm et al., 2007).

In this connection, it might be added that permafrost temperatures have stopped rising during the last several years (Richter-Menge et al., 2006); see Figure 17. It is puzzling why permafrost temperatures do not show an accelerated increase after 2000, if the increase from 1986 to 2000 was due to the greenhouse effect. It seems that the snow depth has the most important effect on permafrost temperature (Osterkamp, 2007a, b). The amount of methane (CH_4) is known to have ceased to increase since about 2000.

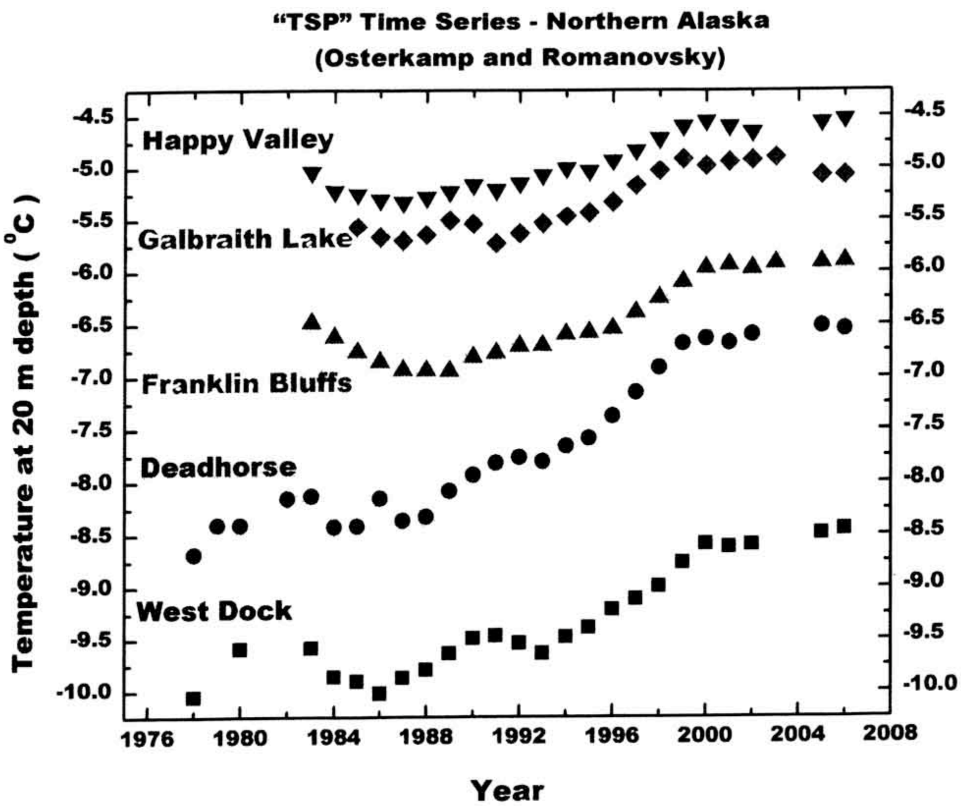

Figure 17: Permafrost temperature variations in Northern Alaska from 1976 to 2006. Note that the temperature increase starting in about 1988 stopped in about 2000 (Richter-Menge et al., 2006).

Conclusions:

I would like to emphasize:

(i) Natural components are important and significant, so they should not be ignored in studying global temperature changes.

(ii) Two natural changes after 1800 are identified in this note: an almost linear increase of about +0.5°C/100 years and multi-decadal oscillation of ±0.15°C/10 years superposed on the linear change.

(iii) The Earth as a whole experienced a relatively cold period, the Little Ice Age (LIA), between 1400 and 1800. The Earth is still recovering from the LIA.

(iv) The reason why the global warming trend stopped in 2000-2001 is likely to be due to the fact that after peaking in about 2000-2001, the multi-decadal oscillation has started a negative trend.

(v) There is nothing unusual or abnormal about the present global warming trend and temperature. There were a number of periods when the temperature was higher than the present after the recovery from the last Big Ice Age.

(vi) It is insufficient to study climate change on the basis of data from only the last 100 years or so.

(vii) It is quite likely that a significant part of the temperature rise after 1975 is due to the multi-decadal oscillation, not the greenhouse effect as hypothesized by the IPCC.

(viii) Two examples are presented in which GCM results can be used to identify natural changes of *unknown* causes.

(ix) Computers are incorrectly "taught," "instructed," or "tuned," to adjust to the observed 0.6°C rise during the last hundred years by hypothesizing by the IPCC that it is caused by the CO_2 effect and ignoring the recovery from the LIA.

(x) Because of these deficiencies of the global warming studies by the IPCC, the GCMs cannot prove that the warming (0.6°C/100 years) is caused by the greenhouse effect.

(xi) The predicted temperature in 2100 by the IPCC is not reliable, because the present GCMs are adjusted or "tuned" to result in the 0.6°C/100 years increase by hypothesizing the CO_2 effect.

If most of the present rise is caused by the recovery from the LIA (a natural component) and if the recovery rate does not change during the next 100 years, the expected temperature rise by 2100 would be 0.5°C. This rough estimate is based on the recovery rate of 0.5°C/100 years during the last 200 hundred years. The contribution of the greenhouse effect is much less than what is predicted by GCMs and the IPCC and is expected to be 0.1°C by 2100. Multi-decadal oscillation could be either positive or negative in 2100. Since its rate of change is about 0.15°C/10 years, the temperature in 2100 depends greatly on the phase of the multi-decadal oscillation.

Causes of the Little Ice Age

It is likely that the multi-decadal oscillation of periods of 50 years or so may be explained in terms of changes of the atmospheric pressure pattern. However, it is likely that a cold period lasting for several hundred years may be difficult to explain by such changes.

In order to understand the radiation balance during the Little Ice Age, it may be interesting to consider it during the Big Ice Age. It is generally considered that the present mean temperature of 15°C is the normal condition and that something unusual happened during the Big Ice Age. Figure 18a shows this situation.

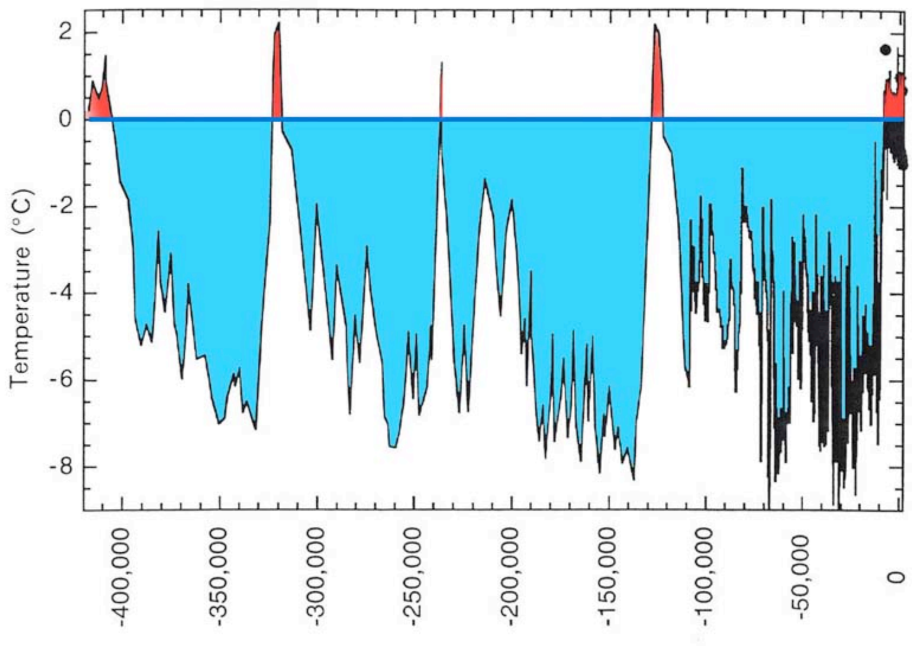

Figure 18a: The Big Ice Age temperature changes assuming that the present condition is normal.

However, it seems more likely from the pattern of the temperature changes during the last four Big Ice Ages that the basic level of the radiative balance of the Earth is 8° to 10°C lower than the present one. On the basis of this consideration, it is interesting to speculate that some unknown process causes impulsive warmings every 10,000 years or so, but it cannot maintain its effect (namely, the condition of higher temperature and the interglacial period) too long, and thus such an abnormal condition gradually subsides, so that the radiative balance goes back to the basic level (Figure 18b).

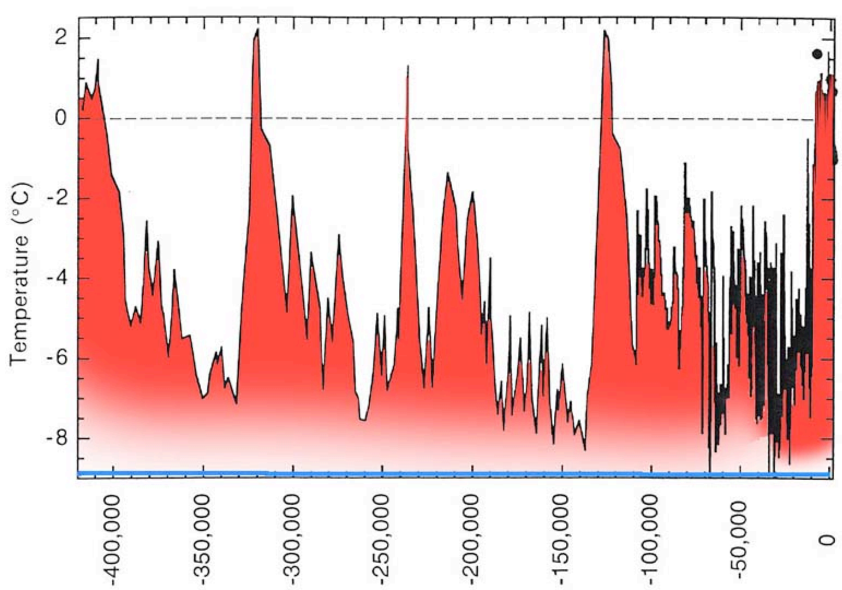

Figure 18b: Big Ice Age temperature changes, which assume that the warming (including the interglacial changes) is abnormal.

The radiative balance for the supposedly normal condition (the present) and for the proposed Big Ice Age condition are shown in Figures 18c and 18d, respectively.

- **Solar <u>Input</u> to the top of the atmosphere = <u>100</u> (257 kcal/cm^2/years)**
  - **Reflection = 30**
  - **Earth surface absorbs = 47**
  - **Greenhouse effect = 96**
  - **Total = 47 + 96 = <u>143</u>**
- **Output from the earth surface**
  - **Evaporation = 24**
  - **Transpiration = 6**
  - **Surface radiation (15°C) = 113**
  - **Total = 24 + 6 + 113 = <u>143</u>**
- **100 – (30: Reflection) = 70**
  - **Stefan-Holtzman equation (T^4) → -18°C**
- **Total = 143 → +31°C**
- **143 – 6 (Transpiration) = 137 → +28°C**
- **137 – 24 (Evaporation) = 113 → +15°C**
- **100 → +5°C**

Figure 18c: The present radiative balance (Tsuchida, 2008). Most text books on this subject show similar numbers within ±2.

- **Solar <u>Input</u> to the top of the atmosphere = <u>100</u> (257 kcal/cm^2/years)**
  - **Reflection = ~~30~~** 20
  - **Earth surface absorbs = ~~47~~** 57
  - **Greenhouse effect = ~~96~~** 43
  - **Total = ~~47~~ + ~~96~~ = ~~<u>143</u>~~** 100
    57 43
- **Output from the earth surface**
  - **Evaporation = ~~24~~** 0
  - **Transpiration = ~~6~~** 0 (5°C)
  - **Surface radiation ~~(15°C)~~ = ~~113~~** 100
  - **Total = ~~24~~ + ~~6~~ + ~~113~~ = ~~<u>143</u>~~** 100
    0 0 100
- **100 – (30: Reflection) = 70**
  - **Stefan-Holtzman equation (T^4) → -18°C**
- **Total = 143 → +31°C**
- **143 – 6 (Transpiration) = 137 → +28°C**
- **137 –24 (Evaporation) = 113 → +15°C**
- **100 → +5°C**

Figure 18d: The inferred radiative balance during the Big Ice Ages. The numbers are not based only on intuitive consideration.

During the Big Ice Age, humidity was much less (resulting in less greenhouse effect) than at the present. During the Little Ice Age it can be inferred that the greenhouse effect was less than the present one.

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