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Two Natural Components of the Recent Climate Change:

(1) The Recovery from the Little Ice Age
(A Possible Cause of Global Warming)

and

(2) The Multi-decadal Oscillation
(The Recent Halting of the Warming)

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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, which seems to have started in 1800–1850, at least one hundred years before 1946 when manmade CO_2 in the atmosphere began to increase rapidly. This 150~200-year-long linear warming trend is likely to be a *natural change*. One possible cause of this linear increase may be the Earth's continuing recovery from the Little Ice Age (1400-1800); the recovery began in 1800~1850. 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.

It is also shown that various cryosphere phenomena, including 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 oscillatory (positive/negative) changes, which are superposed on the linear change. One of them is the *multi-decadal oscillation*, which is a *natural change*. This particular natural change had a positive rate of change of about 0.15°C/10 years from about 1975 (positive from 1910 to 1940, negative from 1940 to 1975), and is thought by the IPCC to be a sure sign of the greenhouse effect of CO_2. However, the positive trend from 1975 has stopped after 2000. One possibility of the halting is that after reaching a peak in 2000, the multi-decadal oscillation has begun to overwhelm the linear increase, causing the IPCC prediction to fail even during the first decade of the 21st century.

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

1. The Linear Trend: Introduction

1.1 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 thick line).

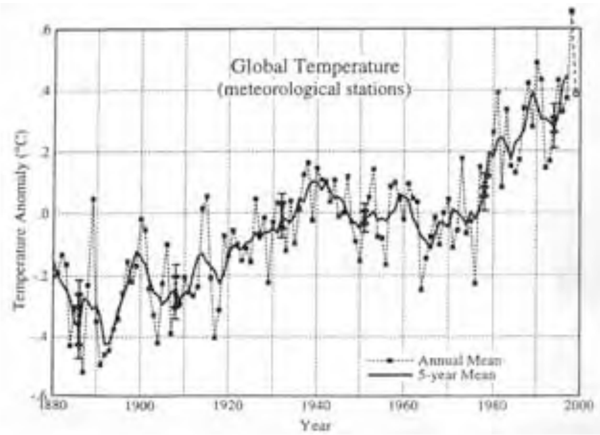

Figure 1a: The global average temperature from 1880 to 2000 (NASA:GISS). The thick line shows the 5-year running mean.

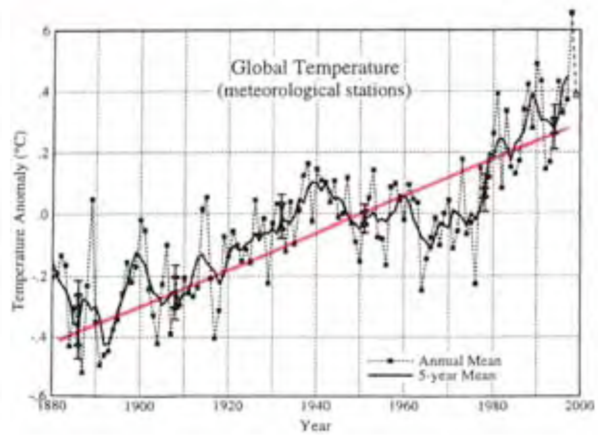

Figure 1b: An intuitive approximation of the changes shown in Figure 1a (NASA:GISS). It is shown as the red line.

When examining Figure 1a, it is natural to consider intuitively, as a first approximation, that the temperature changes may be approximated by a straight line, together with "fluctuations" superposed on it (Figure 1b). After an early version of Figure 1b was constructed in about 2003, the author found that *Bryant* (1997) approximated the changes already by a straight line and mentioned that there are only a few points outside the 95% confidence limits (Figure 1c), but he did not elaborate further on the significance of the linear trend. The gradient of the straight line is about 0.5°C/100 years, in agreement with that in Figure 1b.

Figures 1d – 1g show recent results obtained by NOAA, *Jones* (2008), the *Hadley Climate Research Center* (2008), and the Japanese Meteorological Agency. Figure 1h shows the tropospheric temperature measured by a satellite (*University of Alabama in Huntsville,* 2008); this measurement is said to be superior compared with the ground-based data in terms of uniformity of the sampling and avoiding the urban effects. The halting of the temperature rise in about 2000 can be seen clearly in figures 1d, 1e, 1f, and 1g.

From all the figures presented here, it may be possible to consider, as a first approximation, that the linear increase superposed by "fluctuations" is one of the possible interpretations of Figure 1a, among other possibilities.

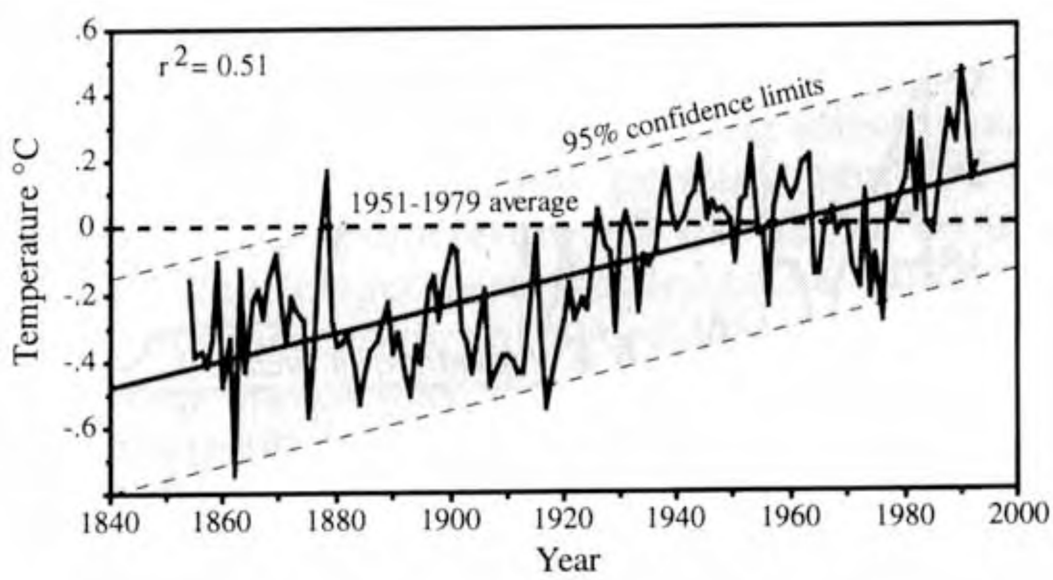

Figure 1c: The figure shows that the straight lines here and in Figure 1b are within about 95% confidence limits (*Bryant*, 1997). The gradient of the line is about 0.5°C/100 years.

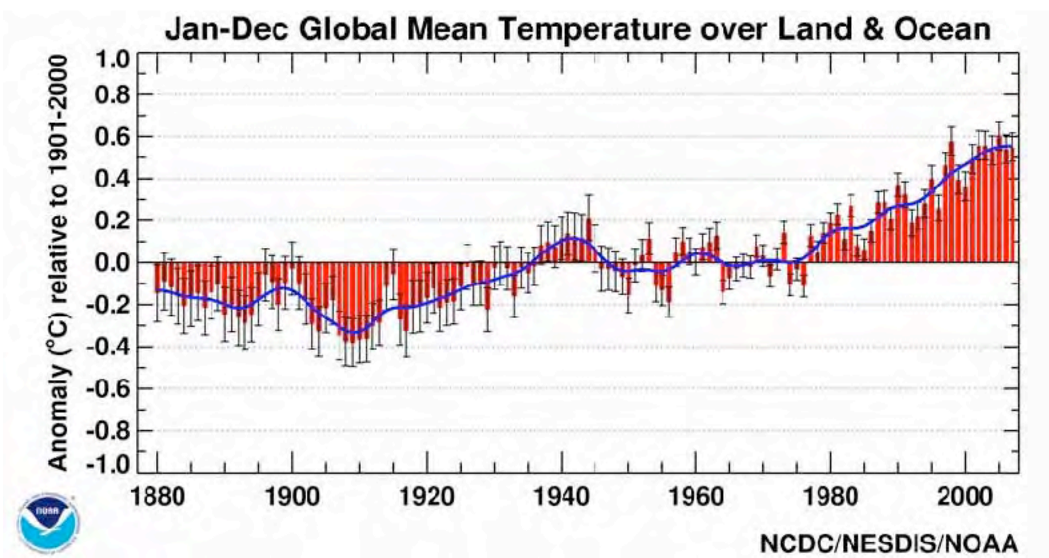

Figure 1d: Global mean temperature changes from 1880 to 2007 (NOAA). (http://www.ncdc.noaa.gov/oa/climate/research/anomalies/anomalies.html).

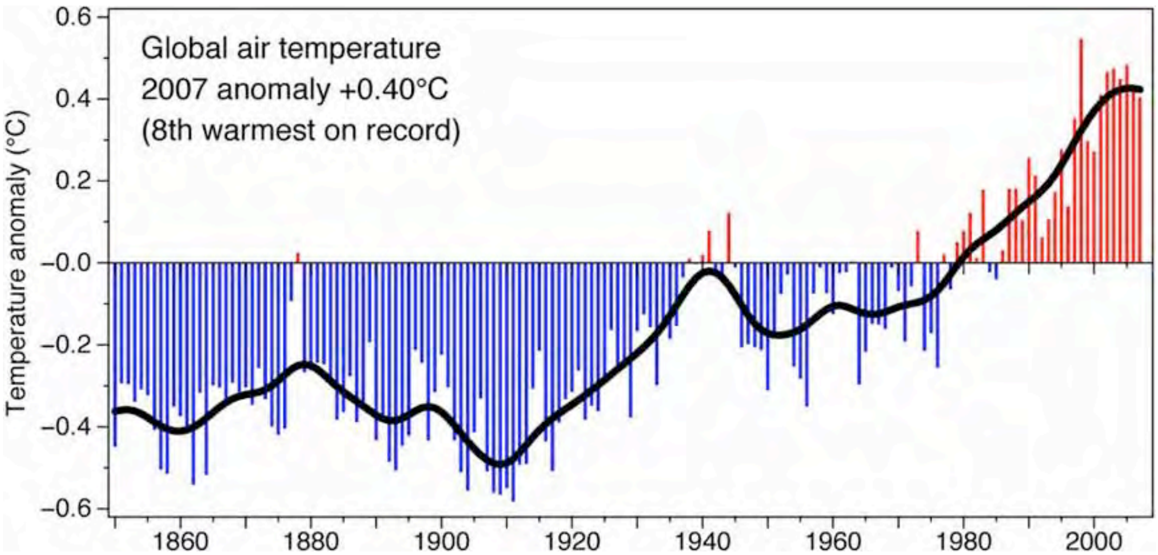

Figure 1e: The global average temperature from 1850 to 2007 (P.D. Jones, University of East Anglia, 2008). (http://www.cru.uea.ac.uk/cru/info/warming/)

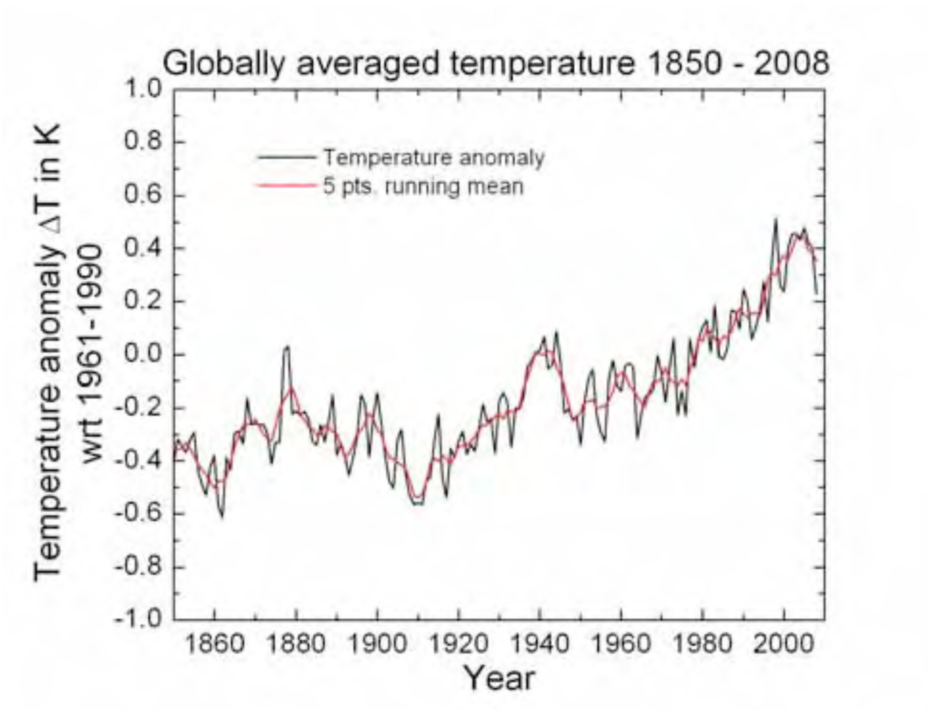

Figure 1f: Global temperature variations and their 5-year running mean (compiled from http://www.metoffice.gov.uk/research/hadleycentre/obsdata/HadCRUT3.html). Note that the warming stopped and there is a decreasing trend after 2000; see also Figures 14a and 15b.

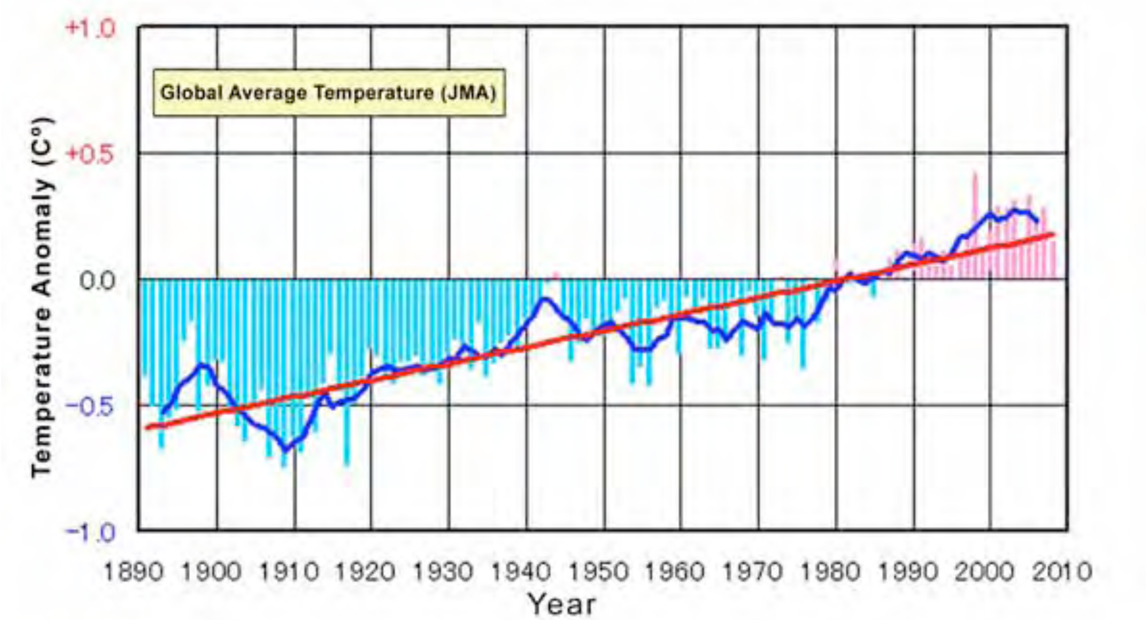

Figure 1g: Global average temperature during the month of May (Japan Meteorological Agency, JMA). The red straight line was drawn by the JMA. (http://www.data.kishou.go.jp/climate/cpinfo/temp/may-wld.html)

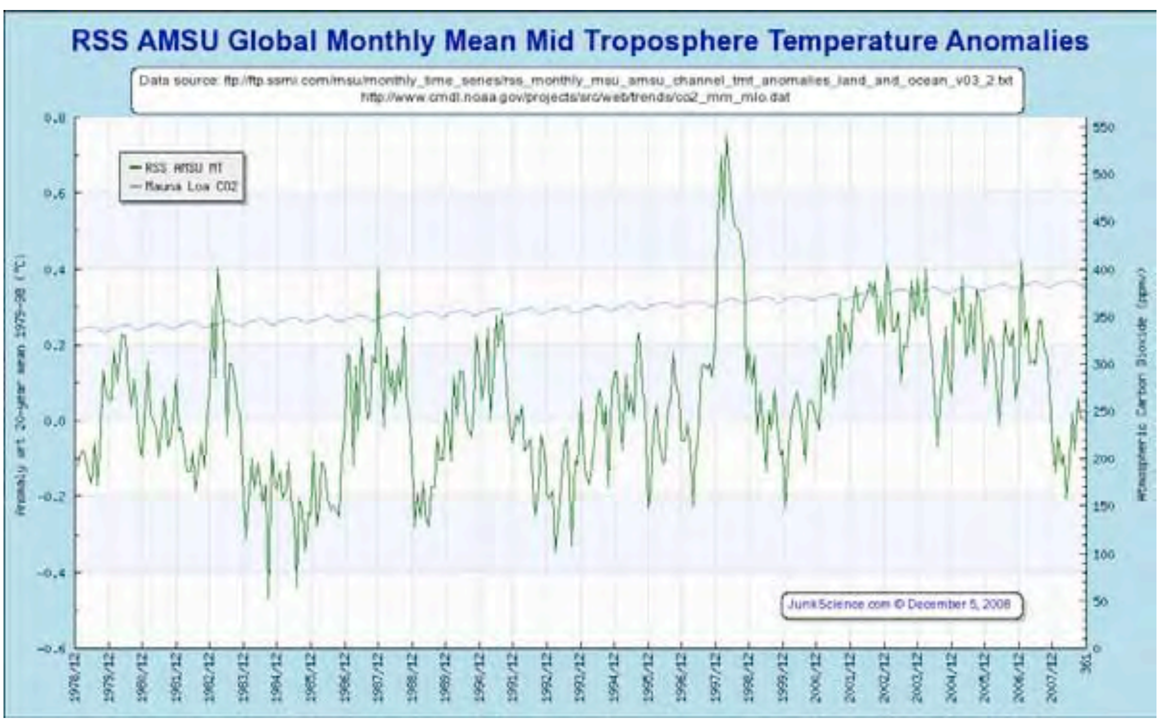

Figure 1h: Temperature variation in the middle troposphere (*University of Alabama in Huntsville,* 2008).

Figure 2a presents the above interpretation graphically, identifying the "fluctuations" as multi-decadal oscillation.

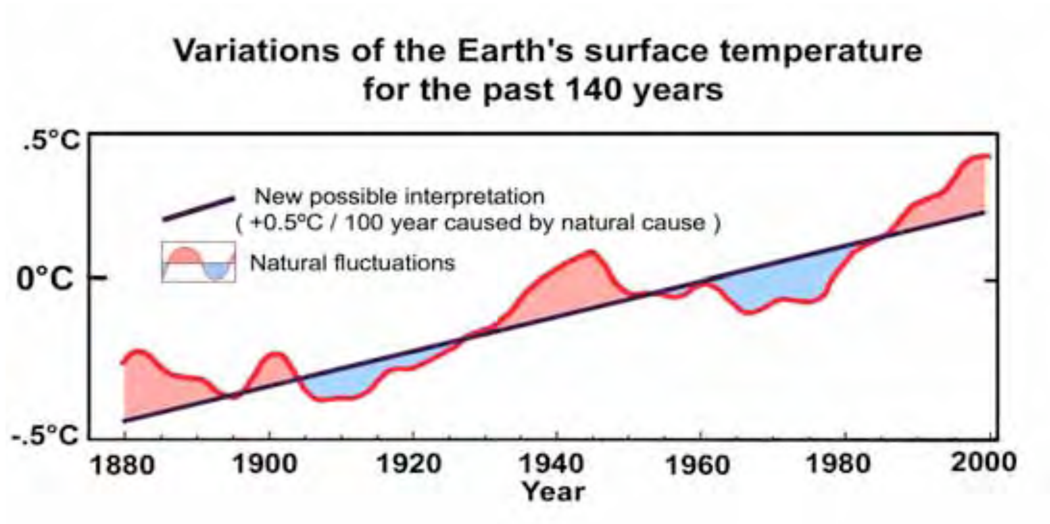

Figure 2a: An interpretation of Figures 1a, 1b, 1d, 1e, and 1f, showing temperature changes that consist of a linear change and "fluctuations" superposed on it. The red line is a smoothed version of the 5-year mean in Figures 1a and Figure 1b.

Figure 2b is made for the purpose of overview of this paper as an introduction. Figure 2a is shown in the yellow box.

Referring to Figurre 2b, the purpose of Sections 1 and 2 of this paper is to show:

(1) There existed the Little Ice Age (LIA) between 1400 and 1800, during which the Earth experienced a relatively cold period.
(2) The recovery from the LIA was gradual.
(3) This gradual recovery from 1800-1850 was, at a first approximation, linear and that the same linear change continued until about 2000.

The purpose of Section 3 of this paper is to show:

(4) The multi-decadal oscillation is superposed on the linear change.
(5) The multi-decadal oscillation peaked in about 1940 and 2000.
(6) Its negative trend after the peak overwhelmed the linear trend from 1940 to 1975, causing the warming to stop.
(7) It is suggested that the situation described in (6) may be happening after 2000.

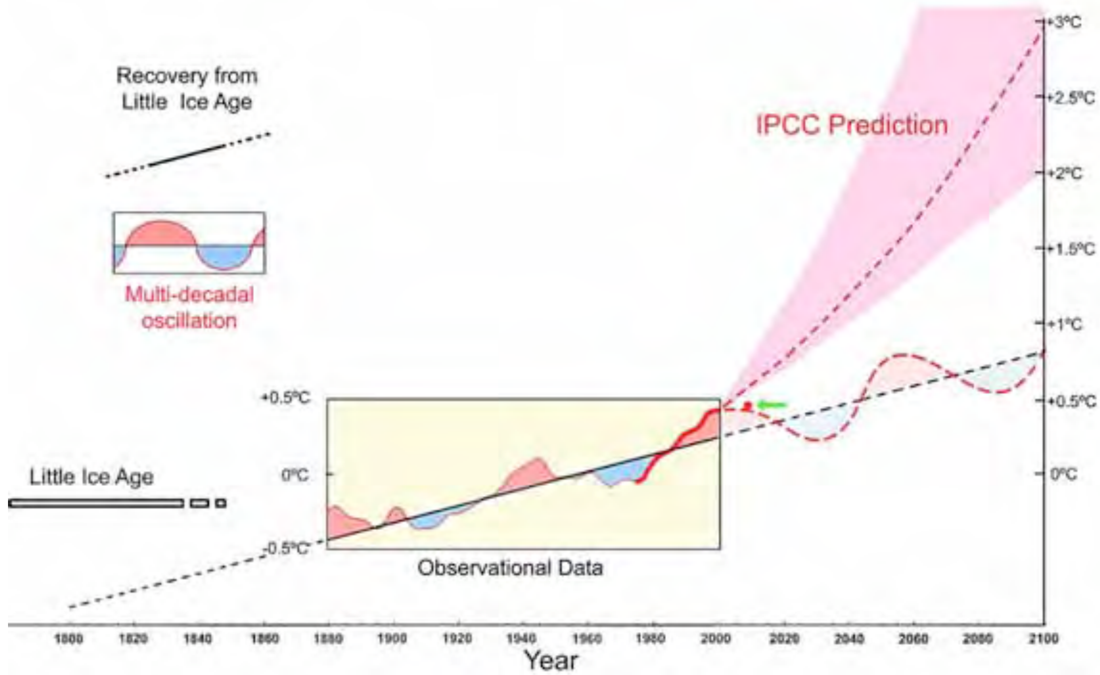

Figure 2b: The figure shows that the linear trend between 1880 and 2000 is a continuation of recovery from the LIA. It shows also the predicted temperature rise by the IPCC after 2000. Another possibility is also shown, in which the recovery from the LIA would continue to 2100, together with the superposed multi-decadal oscillation. This possibility could explain the halting of the warming after 2000. The observed temperature in 2008 is shown by a red dot with a green arrow.

Figure 2c shows both changes of the global average temperature and the amount of CO_2 in the atmosphere for the same period. Although the global average temperature (T) changes can be approximated by a linear relation as a fraction of time (t) *($T = at$)*, CO_2 changes are more like $T = bt^2$, suggesting that the *T-CO_2* relation is not simple. Note that the amount of CO_2 began to increase rapidly in about 1946 while the temperature distinctly decreased at that time; for details of this particular feature, see Section 3. The IPCC must have been concerned only with the increase of both *T* and CO_2 after 1970–1975 (*IPCC Report, 2007*).

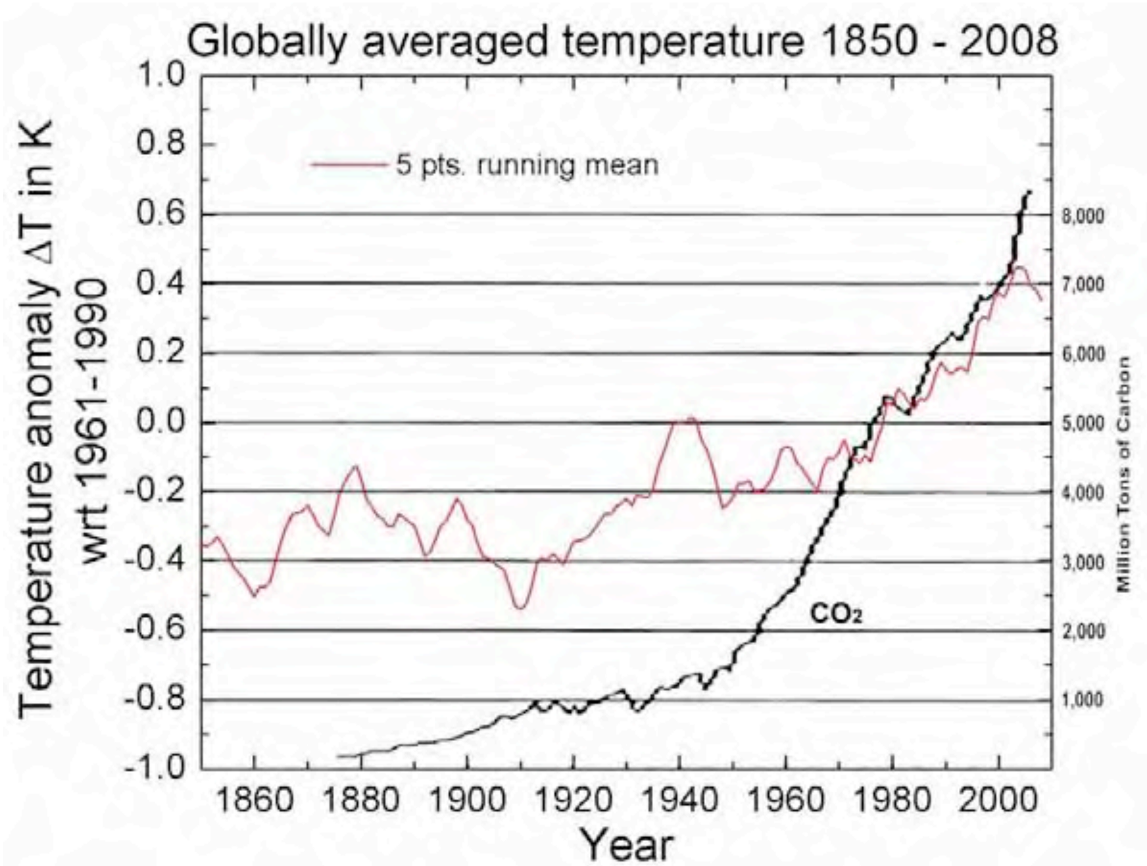

Figure 2c: Global temperature changes (5-year smoothing) 1860-2005 (*Hadley Center,* 2008; see Figure 1f). The figure shows also the amount of CO_2 released in the atmosphere during the same period (http://cdiac.esd.oral.gov/trends/emis/glo.html).

1.2 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 or vice versa; see also a similar result by *Isaksson et al.* (2003).

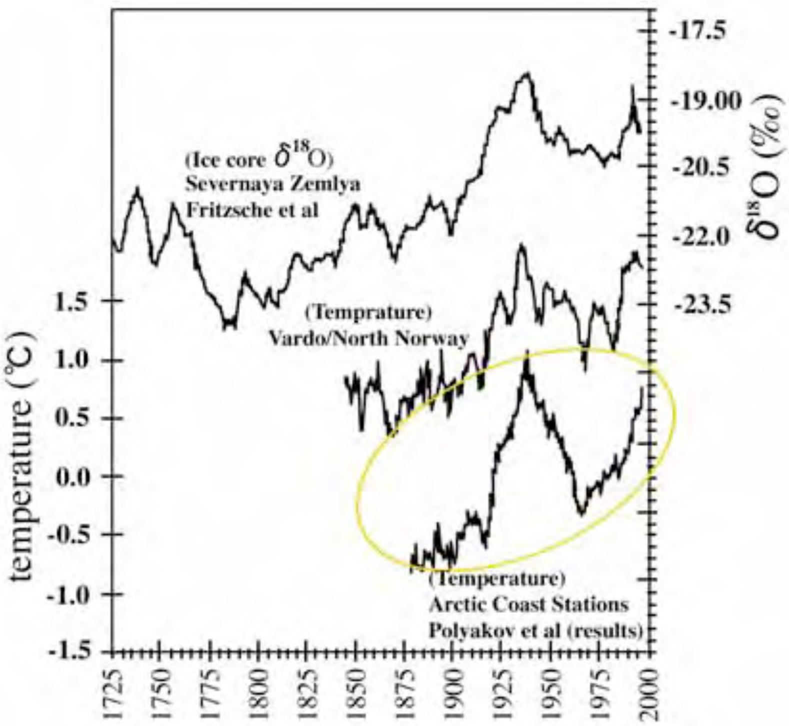

Figure 3a: Late Halocene ice core record from Akademii Nauk Ice Cap, Severnaya Zemlya, Russian Arctic, together with temperature records from Vardo, Norway, and from stations along the arctic coast (*Polyakov et al.,* 2002); (*Fritzsche et al.,* 2006).

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 linearly increasing trend of temperature from about 1800, in agreement with Figures 1b and 3a. Figure 3b 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 and positive trend from about 1800 seems to be very evident.

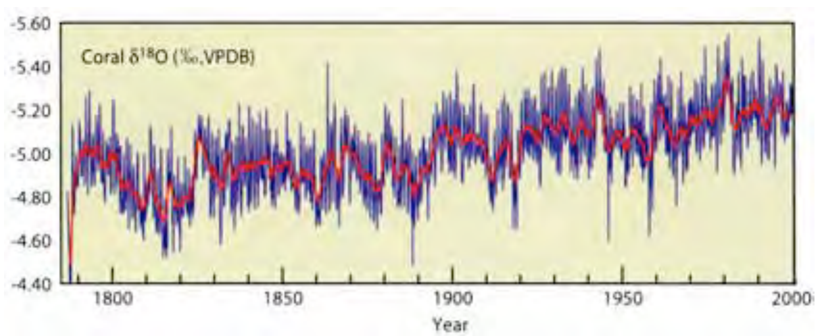

Figure 3b: Monthly time series of O^{18} isotope data from coral in Guam (13°N, 145°E) from about 1800 (*Asami, et al.,* 2005).

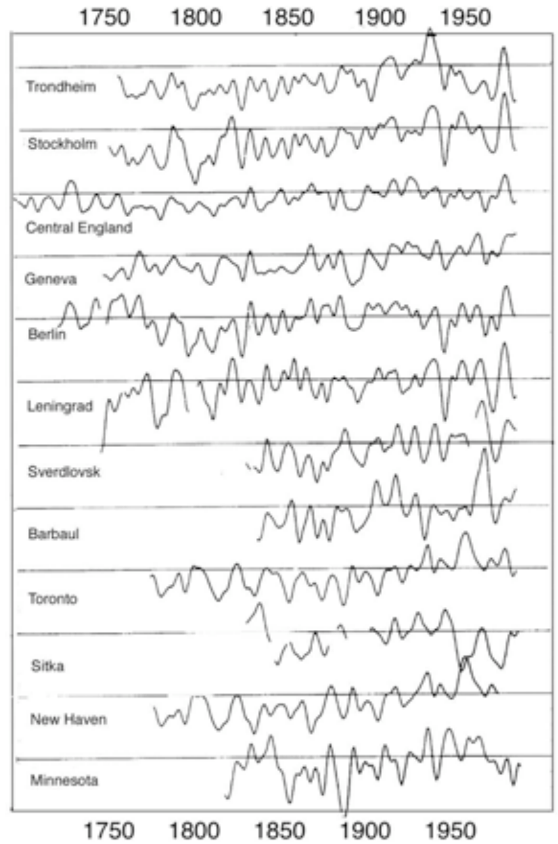

Figure 3c: Temperature change at a number of stations in the world (*Jones and Braley,* 1992).

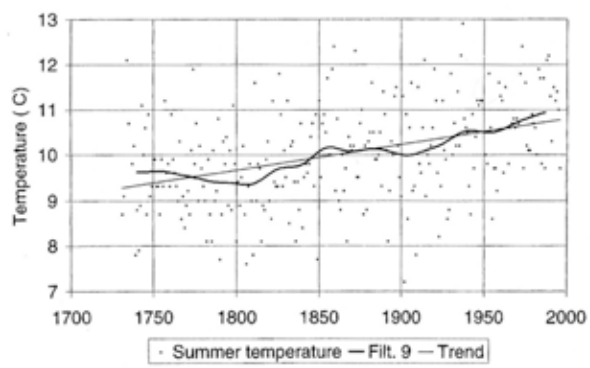

Figure 3d: Summer temperature (April to July) for Tallinn, which is based on ice break-up and rye harvest data and on instrumental observations. To ease the study of variations on a timescale of approximately 30 years, the observations are smoothed by a Gaussian filter with standard deviation of nine 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 break-up 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 break-up dates have almost steadily advanced to earlier dates, while the freeze dates seemed to shift to later dates.

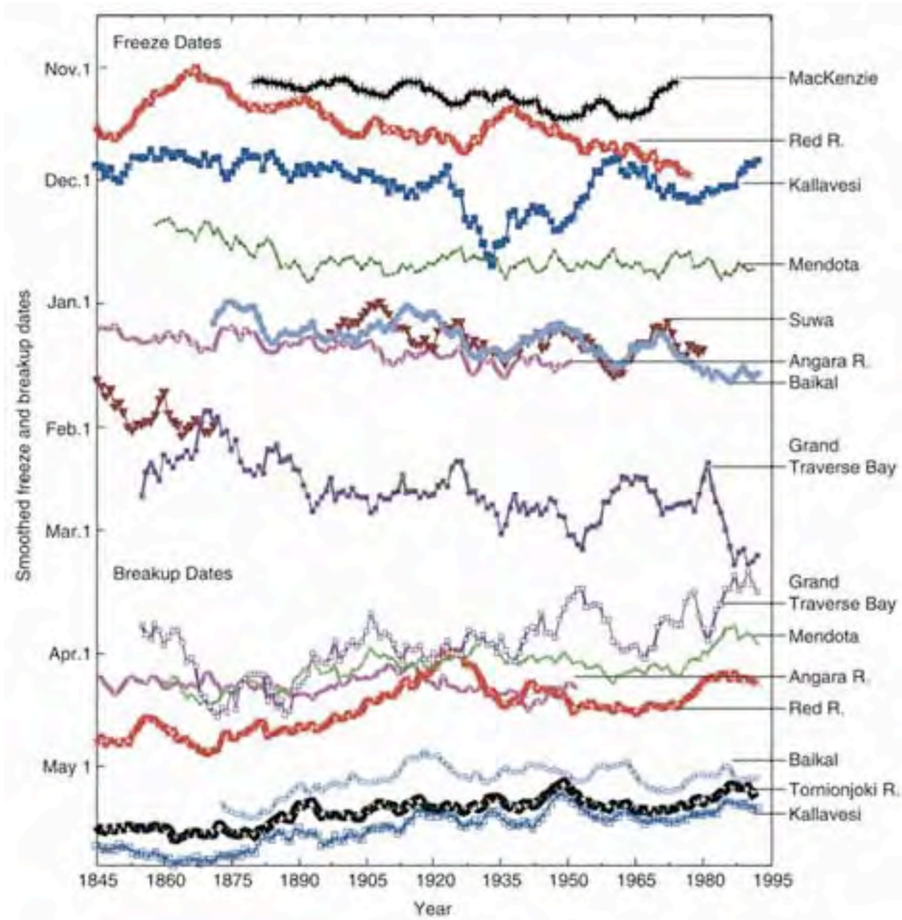

Figure 3e: The freeze dates and break-up dates of lakes and rivers in the Northern Hemisphere (*Magnuson et al.,* 2000).

Based on Figures 3a, b, c, d, and e, there is little doubt that the temperature has been increasing almost linearly from 1800 (or a little earlier) to the present.

1.3 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 a linearly increasing trend toward the present time. Figure 4b shows the temperature data inferred from ice break-up, showing that the period from 1500 to 1800 was colder than the present (*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.

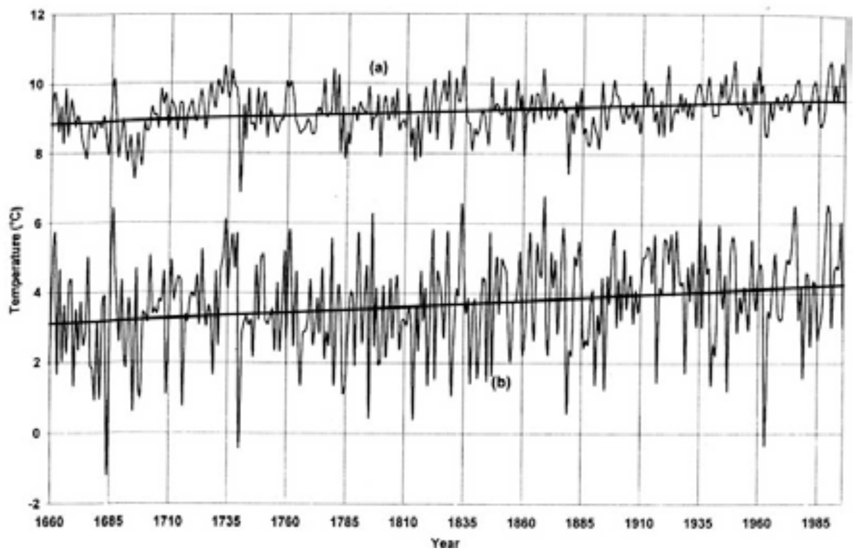

Figure 4a: The linear trends for the temperature of central England over the period 1660-1996 for (a) the annual data, and (b) the winter months (December to February), show a marked warming. In both cases, this warming is significant, but although the temperature rise is greater in winter, this trend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

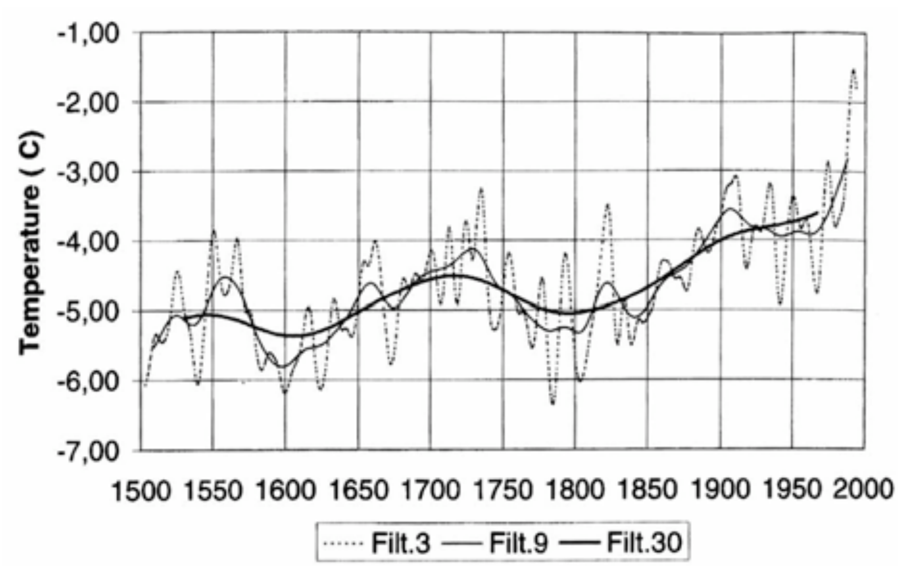

Figure 4b: Winter temperature (December-March) at Tallinn since 1500, based on ice break-up dates in Tallinn port. The series is smoothed by Gaussian filters of 3, 9, and 30 years as standard deviations in the Gaussian distribution. Both the thin and thick trend lines were drawn by the original authors (*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.

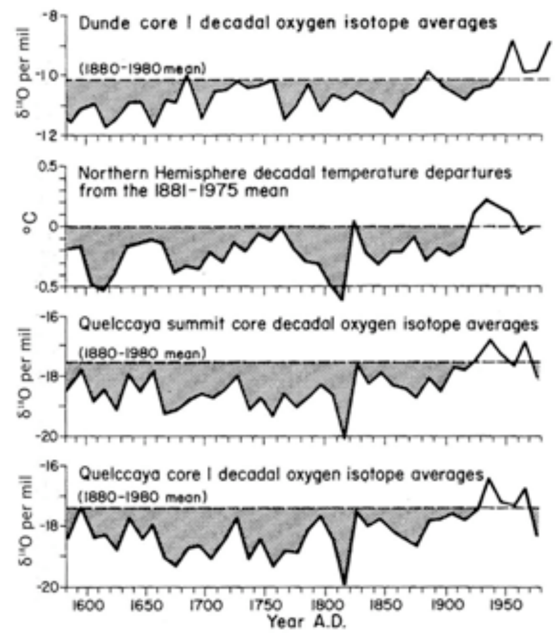

Figure 4c: The second data: Decadal temperature departures (from the 1881–1975 mean) in the Northern Hemisphere from 1580 A.D. to 1975, which can be compared with decadal average $\delta^{18}O$ values for both the Dunde, China, D-1 core (top) and Quelccaya, Peru, ice cores (third and fourth) over the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

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

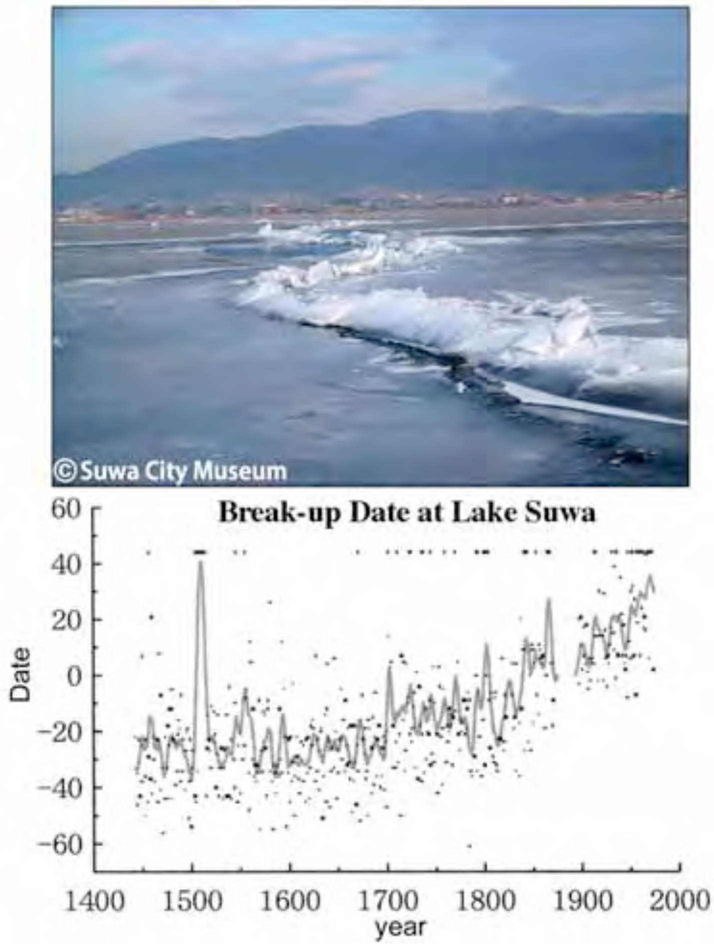

Figure 4d: Ice break-up scene at Lake Suwa in the central highland of Japan from 1450 to 2000. The zero day refers to January 1. The dots shown on the top show years when the break-up did not occur (*Harada,* 1977; *Ito,* 2003).

Many other documents suggest that the period between 1500 and 1800 was relatively cold (*Lamb, 1982; Fagan, 2000*); the River Thames was frequently frozen in the later part of the 17th century. 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. It is now 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 the Main Island.

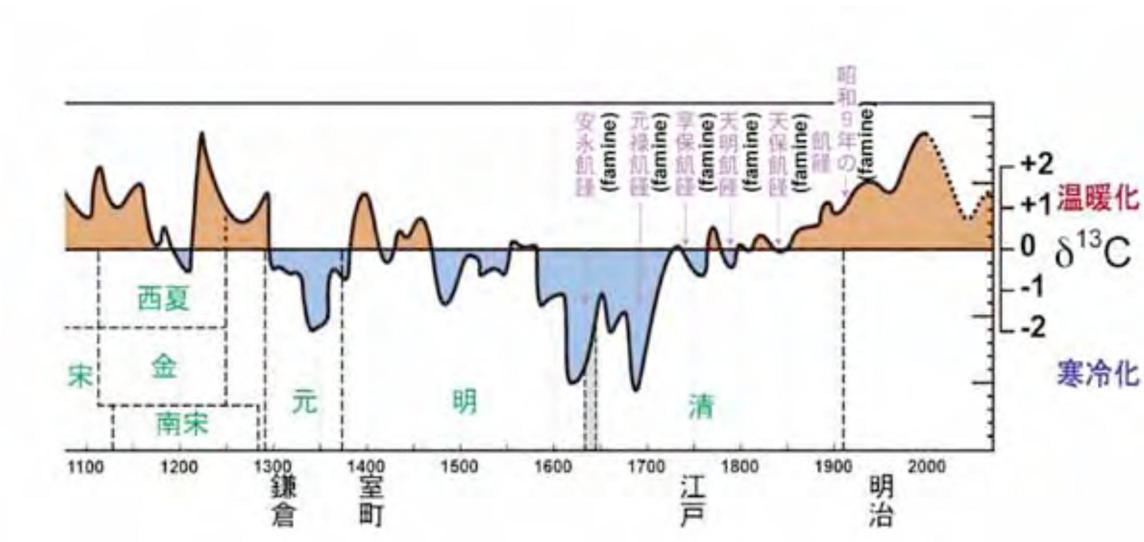

Figure 4e: Inferred temperature changes in Japan and China from 1100. A number of famines occurred during the colder period in Japan and political upheavals occurred during the cold period in China (*Maruyama,* 2008; modified).

Figures 4a, b, c, d, and e show different kinds of data (extending the timeline farther back to 1400–1500) from 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 temperature 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,* 1978; *Lamb,* 1982; *Crowley and North,* 1991; *Fagan,* 2000; *Burroughs,* 2001; *Serreze and Barry,* 2005; *Nunn,* 2007). A large amount of other supporting evidence will be shown in Section 2 of this paper.

Obviously, the LIA was caused by a natural change or changes. Further, the fact that an almost linear change of the temperature rise had been progressing until 2000 suggests that the linear change is a natural change, because the rapid increase of CO_2 began only after 1946 (Figure 2c). The linear change began from 1800~1850, at least one hundred years before a rapid increase of CO_2 in the atmosphere.

1.4 Temperature Changes during the Last 1000 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 it has increased from 1800 to the present.

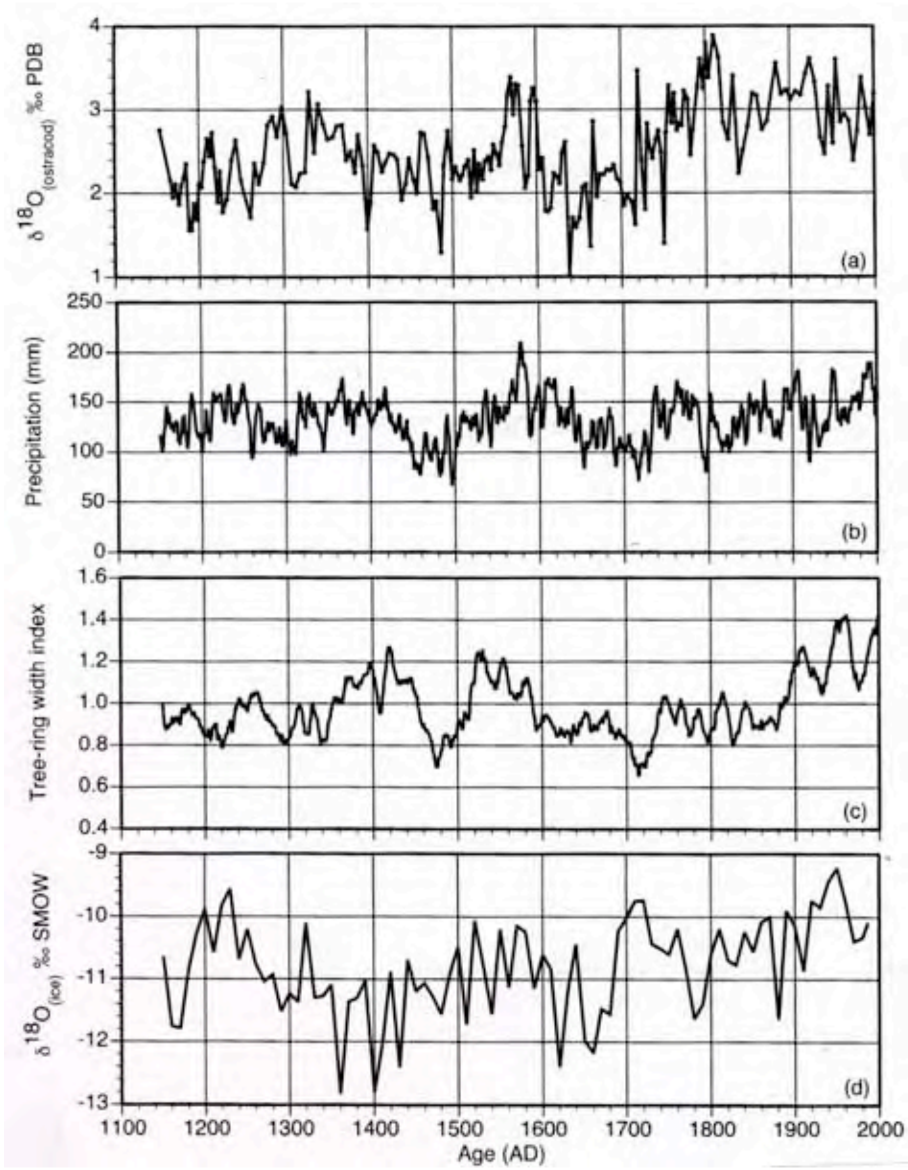

Figure 5a: Climate variability over the northern Tibetan Plateau since 1150 AD: (a) δ^{18}O of ostracodes from Sugan Lake core SG00C, (b) precipitation reconstructed from tree-rings at Delingha, (c) standard tree-ring width chronology from Sidalong. On the basis of a close correspondence between Tibetan Plateau temperature and the all-China reconstructions for the past 1000 years, the total amplitude of ring-width change is estimated to represent a temperature variation of ≤2°C, and (d) decadally-averaged δ^{18}O values from the Dunde ice core (*Holmes et al.,* 2007).

The upper part of Figure 5b shows temperature variations in the middle Qilian Mountains (see the insert map) during the last 1000 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 *Esper et al.* (2002) and *Frank et al.* (2007), which are shown also in Figure 5c. One can see that the period between 1600 and 1800 was also cold in Asia, as in the other parts of the world, and that the recovery from the LIA began in about 1800.

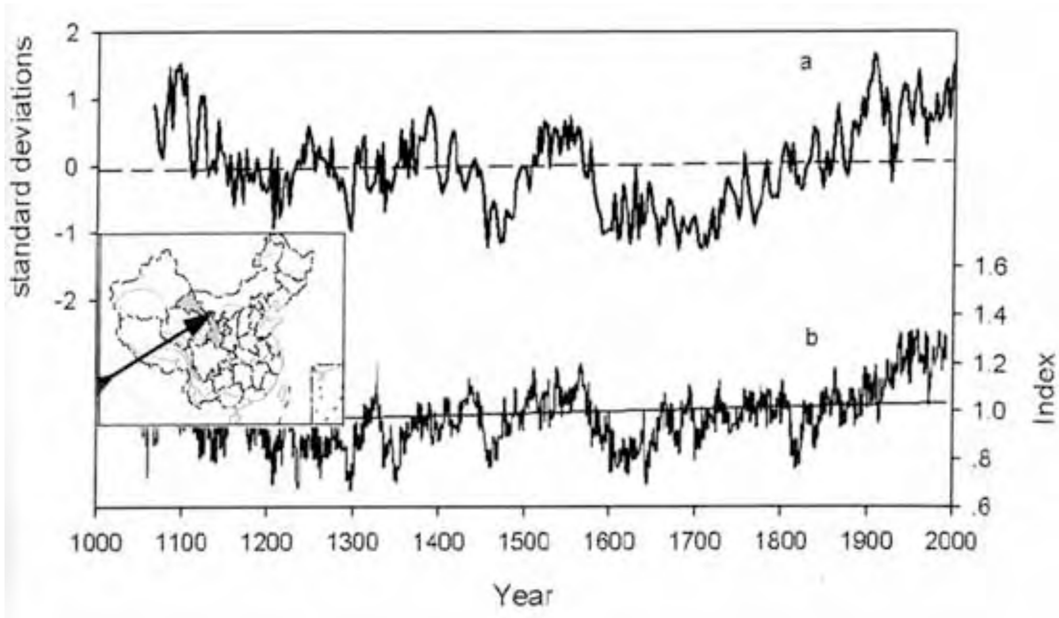

Figure 5b: Temperature variations in the middle Qilian Mountains during the last 1000 years (*Liu et al.* 2007). For comparison, the data by *Esper et al.* (2002) are also shown in the lower part (see Figure 5c).

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 (*Esper et al.,* 2002; *Frank et al.,* 2007). It shows clearly a warm period around 1000 and a cool period between 1200 and 1800, namely the LIA. Note also an almost linear recovery of the LIA after 1800.

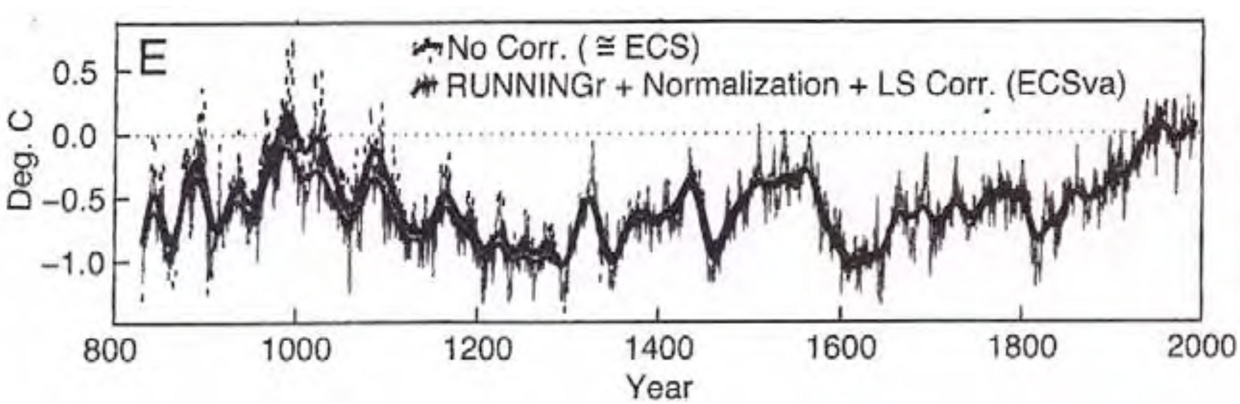

Figure 5c: Temperature variations deduced from tree-ring records from 14 sites from 800. It shows variance-adjusted data by *Esper et al.* (2002), along with the unadjusted mean record. The dashed line shows the mean of 1961-1990 anomaly reference period (*Frank et al.,* 2007).

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.

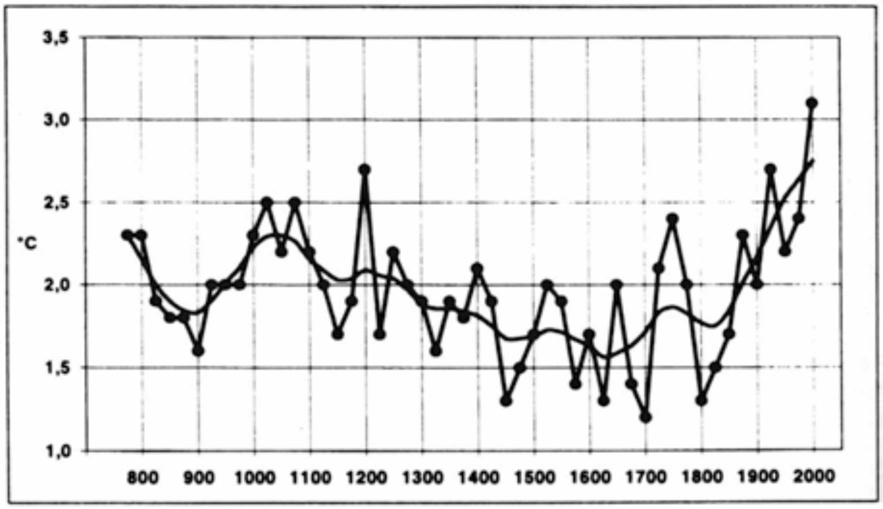

Figure 5d: 25-year mean winter (DJF) temperature at De Bilt (van Engelen et al., 2001).

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

Figures 5a-e 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. 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.

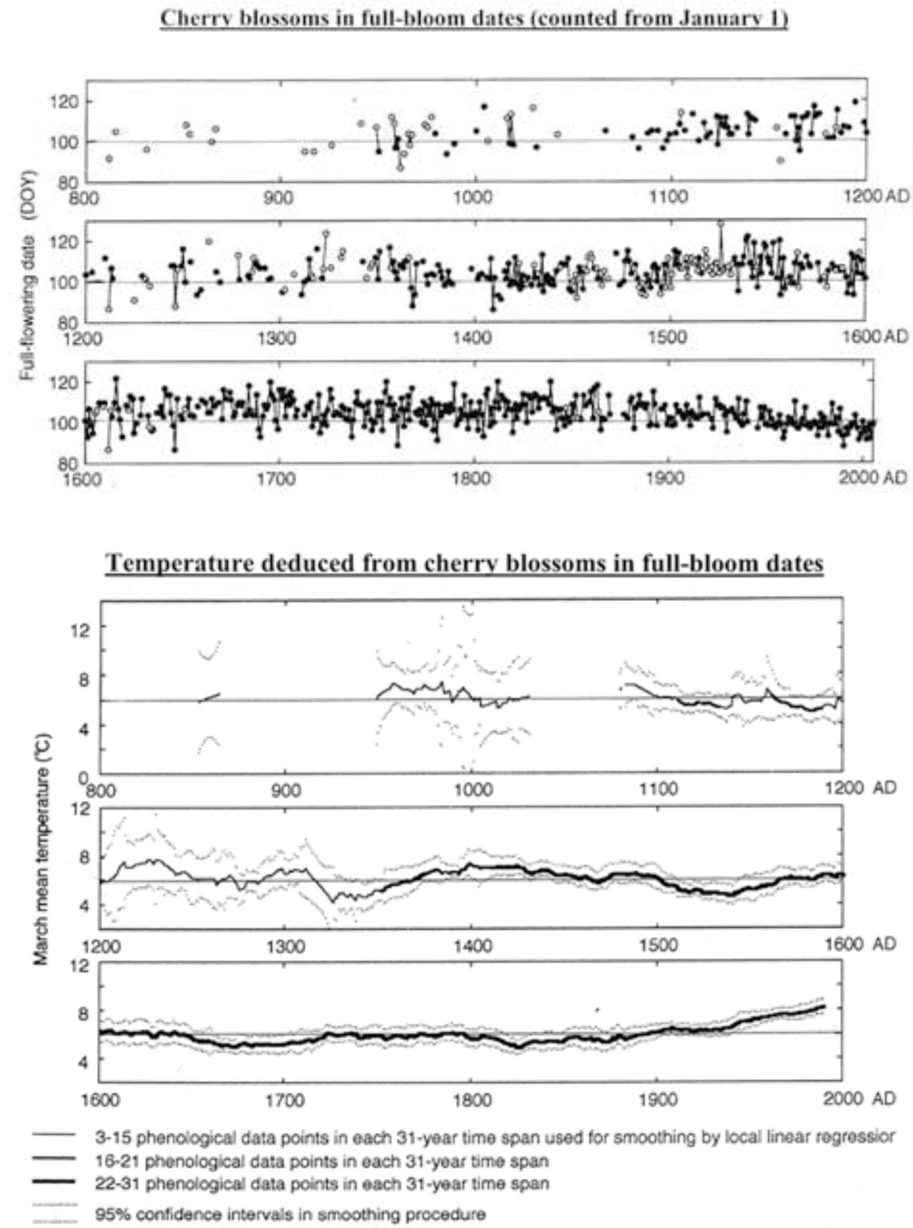

Figure 5e (1): Changes of the full-bloom date of cherry blossom trees in Kyoto, Japan, from the 9th Century. The date is counted from January 1. (2) The blooming date in (1) is converted into temperature (*Aono and Kazui,* 2008).

1.5 Temperature Changes during the Last 3000 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 2000 years. They added the result by *Mann et al.* (1999); it is indicated by "MBH" in the figure. The *IPCC* (2001) considered that the "MBH" result is the most representative result of their work, prompting to show a very *abrupt* and *unexpected* increase of temperature by the CO_2 effect in about 1900 after a slow and long decrease of the temperature from 1000. An important point to make here is that the MBH result shows neither the Medieval Warming Period nor the LIA.

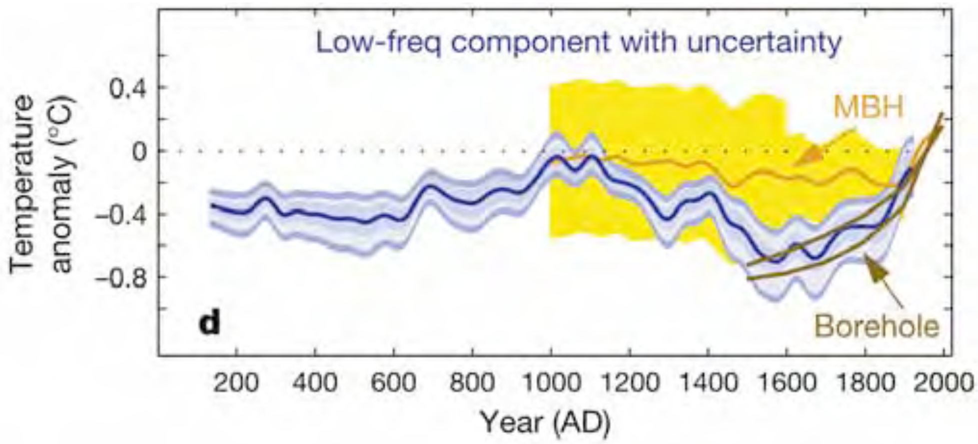

Figure 6a: Multi-proxy temperature change reconstruction from 100 to 1979 (blue), together with other data. The MBH curve indicates the so-called "Hockey stick" data (*Moberg et al.,* 2005). The original borehole data are reproduced in Figure 6c.

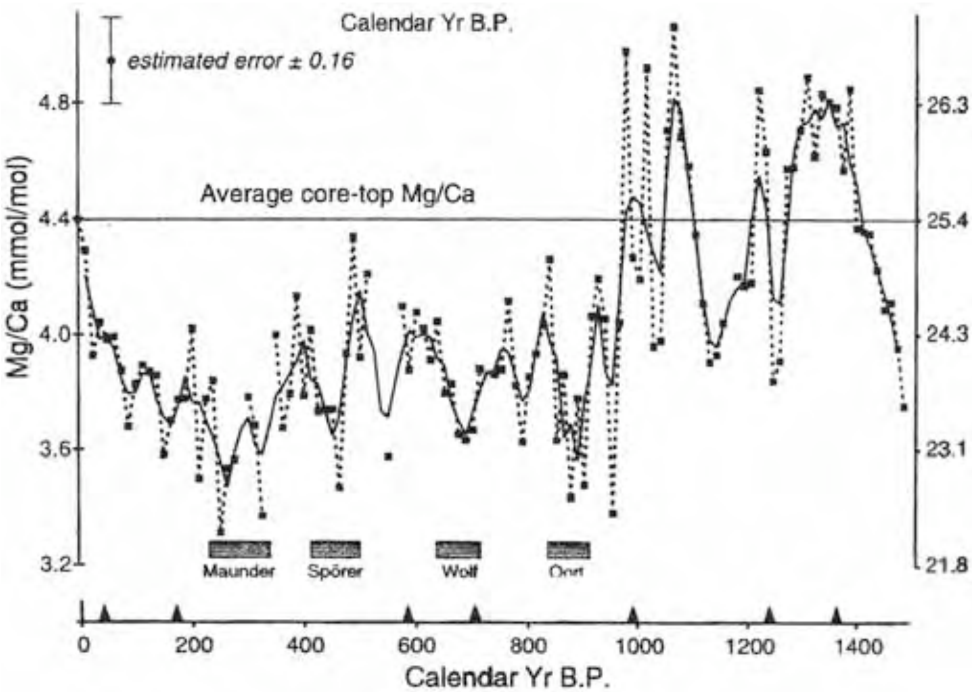

Figure 6b: Mg/Ca analyses in the white variety of the planktic forminifer delta, which were obtained from the northern Gulf of Mexico (*Richey et al.,* 2007).

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.

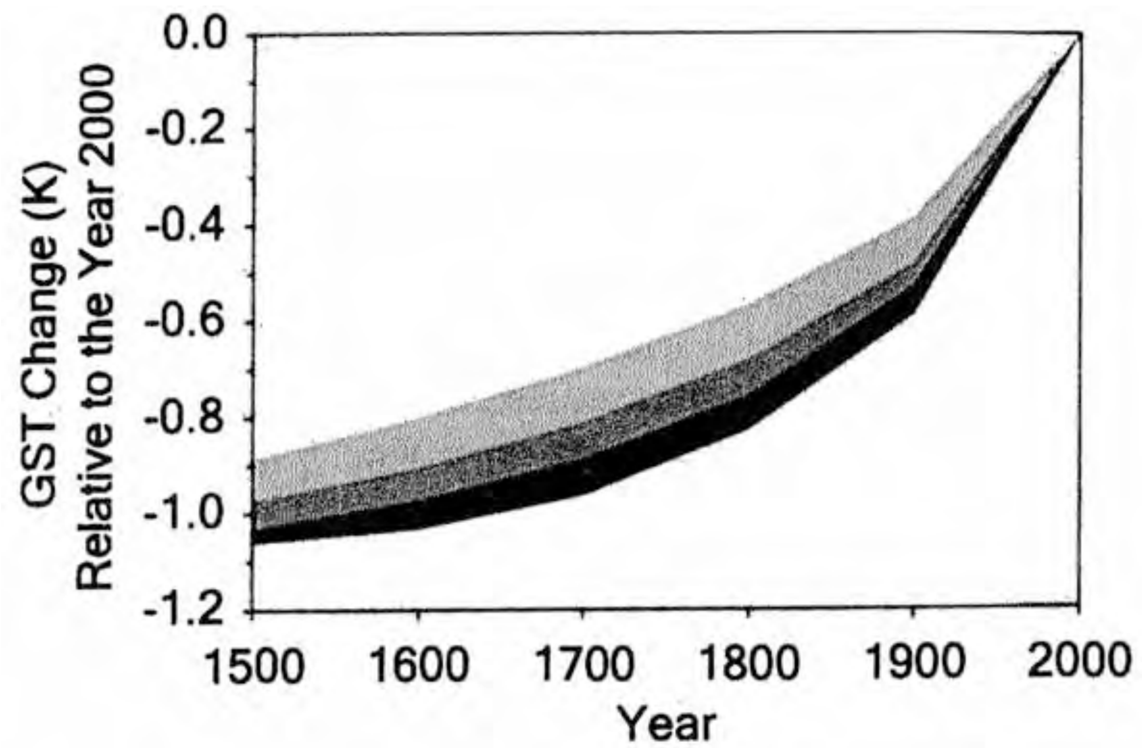

Figure 6c: Borehole data from 1500 (*Pollack et al.,* 2004). This data set is included in Figure 6a and 7a.

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; see also Figure 6a.

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 about 400 years ago (1600). 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. Note also at least two warm periods, 2500 and 3000 years ago, which were warmer than the present.

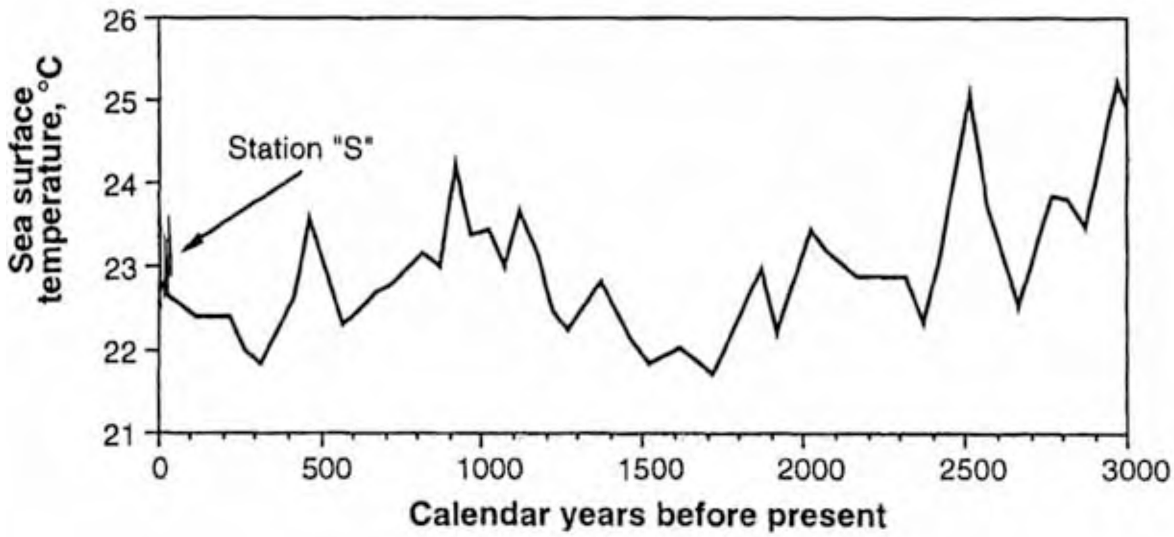

Figure 6d: Temperature changes from about 1000 BC to about 2000 AD, about 3000 years of data, deduced from cores obtained from deposits in the Atlantic Ocean (*Keigwin,* 1996).

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, as well as the recovery from the LIA (beginning in about 1800) and the Medieval Warm Period from 800 to 1200.

At this point, we encounter one of the fundamental problems in both climatology and meteorology. Can we tell when the LIA ended or will end? 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. Rather, it appears that the linear trend began in 1800–1850 and continued until about 2000. In Section 3, it will be shown that a number of cryospheric phenomena support this conclusion.

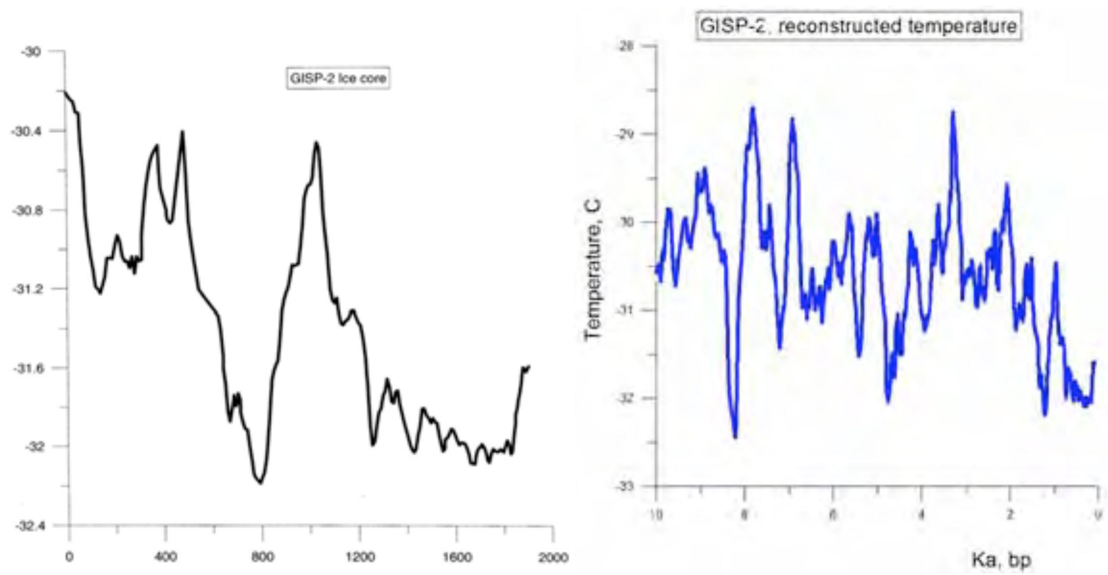

Figure 6e (left) and 6f (right): Ice core temperature at the GISP-2 site in Greenland, extending two thousand years (Ka) before present (bp) and 10 Ka bp, respectively (*Alley,* 2000).

1.6 Summary: The Recovery from the Little Ice Age

As a summary of the survey in Section 1, 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, namely in about 1946, and that the rate of warming can be approximated by a straight line. This particular data set came to the author's attention after an earlier version of the present article was completed. It is the Summary Figure (S-1) of a report by an NRC committee. Unfortunately, however, it appears that the committee did not pay much attention to the fact that the recovery from the LIA began in about 1800 and that the recovery had continued to 2000.

From the review in Section 1, it may be concluded that the straight line in Figures 1b and 2a can roughly be extended to about 1800–1850. This is an important indication that the linear warming during the last century is not caused by the CO_2 effect. It is difficult to find clear indications that the T-t relation was given roughly by $T=bt^2$, rather than $T=at$. In fact, it will be shown in Section 3 that the warming has halted in about 2000.

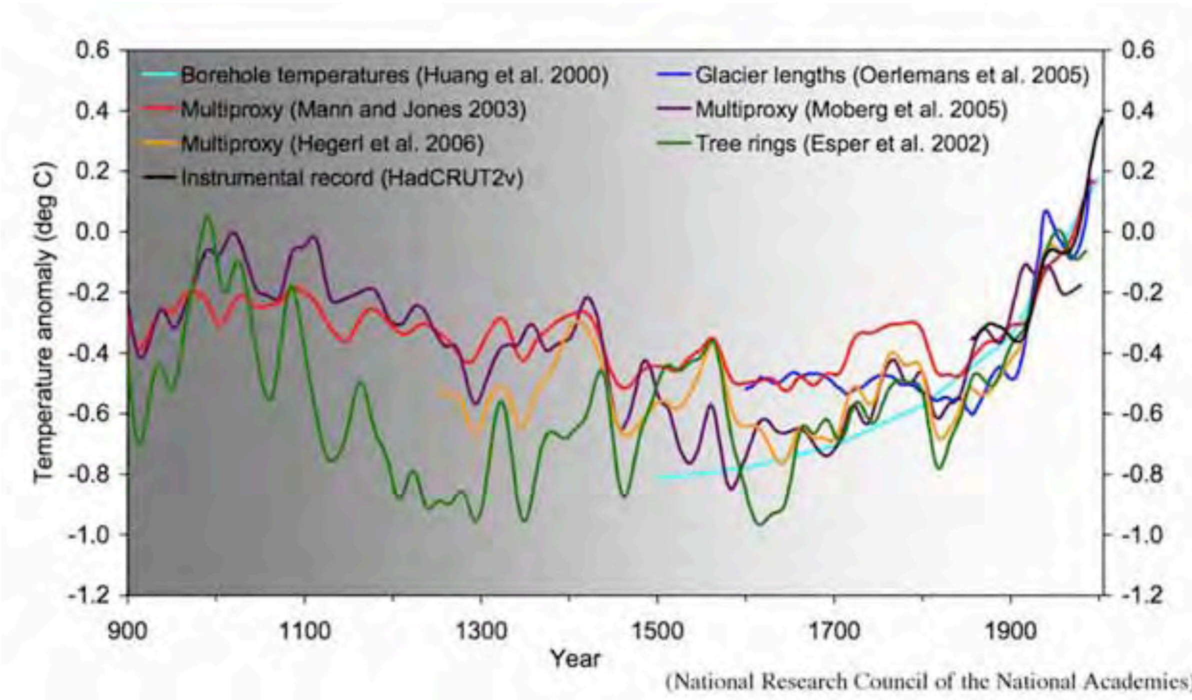

Figure 7a: Reconstructions of large-scale (Northern Hemisphere mean or global mean) surface temperature variations from six different research teams are shown along with the instrumental record of global mean surface temperature. Each curve portrays a somewhat different history of temperature variations 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 Big Ice Age (*Dahl-Jensen et al.,* 1998). The upper figure shows temperature changes during the last Big 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 in this section. Note also that there was an increase/decrease around 1700, similar to those in Figures 3a and 4b. It seems that there were a few multi-decadal changes during the LIA.

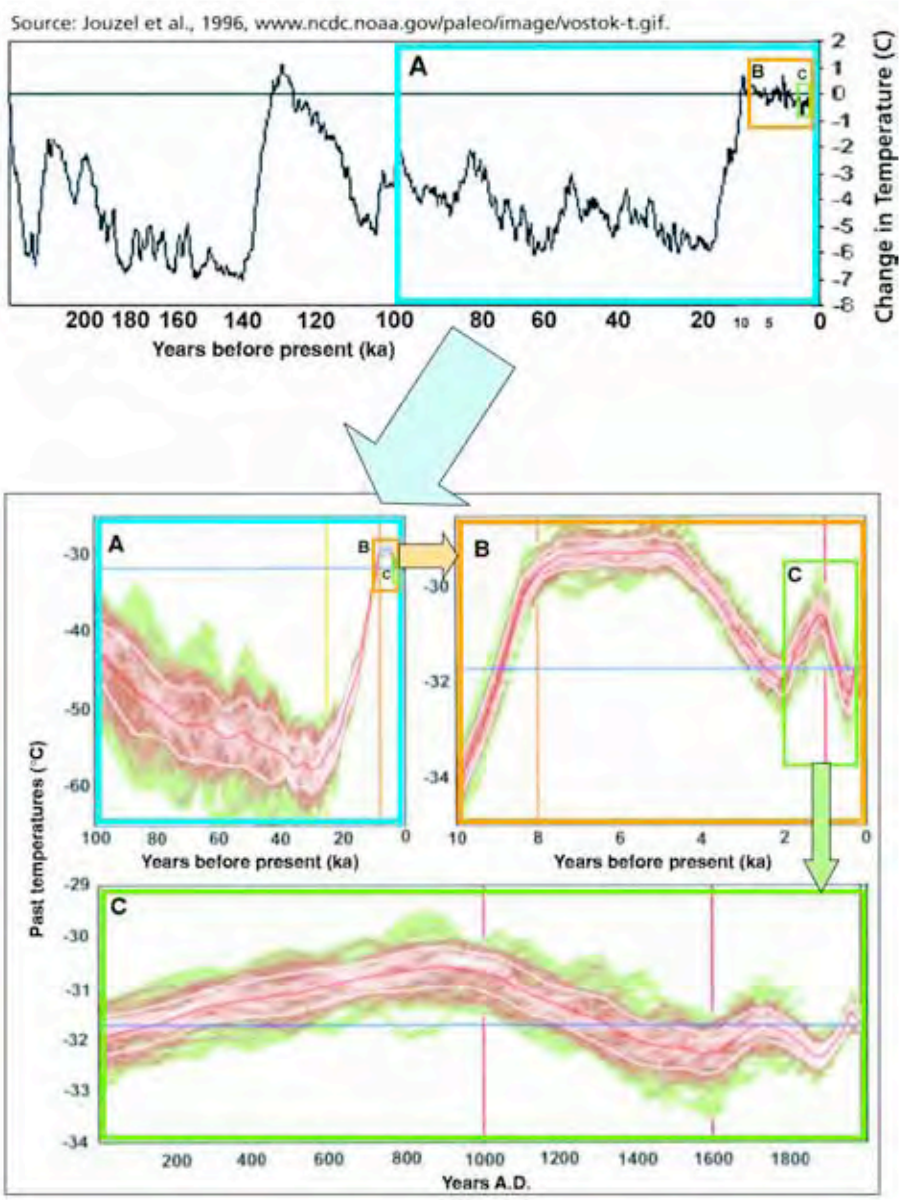

Figure 7b: The contour plots of all the GISP temperature histograms as a function of time (*Dahl-Jensen et al.,* 1998).

There are six important points to make on the basis of results in this section.

(1) The period between 1400 and 1800 was relatively cold worldwide, confirming the LIA.

(2) The recovery from the LIA began in about 1800-1850. The temperature has increased almost linearly from about 1800–1850 to 2000.

(3) During the last 10,000 years or so, there were warmer periods than the present, including the first 4000 years of the interglacial period.

(4) The Earth has experienced many warmer and colder periods. Thus, there is nothing unusual or anomalous about the present warming trend even during the current interglacial period.

(5) Changes, including the linear increase from 1800–1850, are likely to be due to *natural changes.*

(6) Thus, it is not possible to learn about the warming during the last century (1900–2000) without carefully examining natural changes from 1000.

One lesson here is that it is not possible to examine climate change without very carefully studying long-term data. In fact, one way to learn about natural changes is to examine climate change before the greenhouse effect of CO_2 was said to become significant (namely after 1946), as attempted in this paper. 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 anthropological or archaeological aspects simply because intrinsic temperature (digital) data were not available before 1600.

Actually, archaeological data in the Arctic are quite useful in studying climate change. Unlike the activities of people in the Tropics, activities of people in the Arctic were critically 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).

It may be said that in a study of global warming the "*inaccurate"* paleoclimate data available during the last few hundred years are in some sense equally or more valuable than accurate digital but *"short-period"* data after 1970.

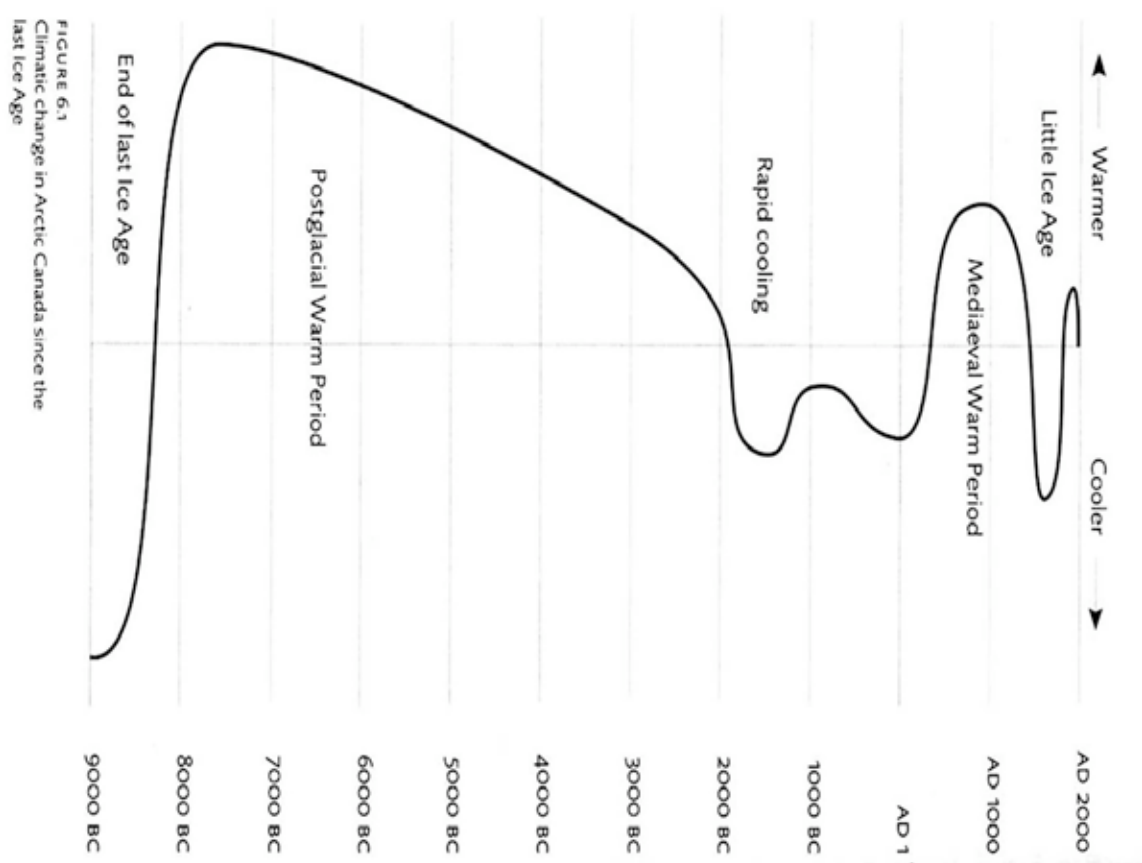

Figure 7c: Climate change in Arctic Canada after the last major ice age (*McGhee,* 1941).

2. Observed Phenomena Supporting the Recovery from the Little Ice Age

2.1 Sea ice

It is clear from all the reports compiled in Section 1 that the Earth has been in the process of recovering from the LIA since about 1800–1850. In this section, several natural phenomena are presented to support the fact that the LIA was present and the recovery from it began in about 1800–1850, and it is still continuing.

Figure 8a shows changes of the southern edge of sea ice in the Norwegian Sea. It has been receding from about 1800 to the present at almost the same rate (*Vinje,* 2001), at least 100 years before the use of fossil energy began to increase rapidly in 1946. Note also large changes between 1910 and 1970, which will be discussed in Section 3.

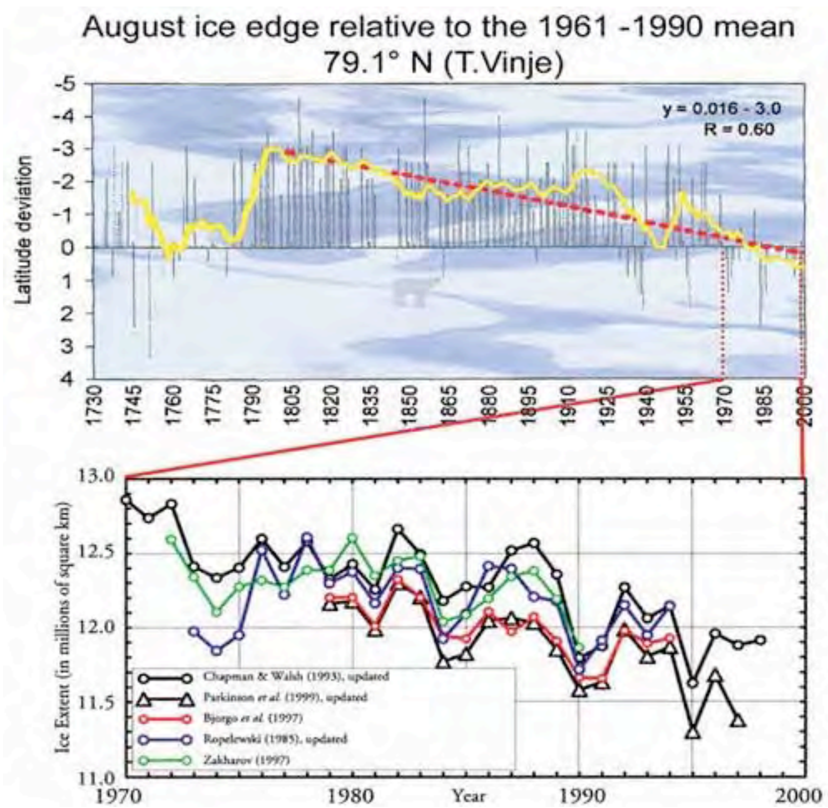

Figure 8a: Upper, retreat of sea ice in the Norwegian Sea (*Vinje,* 2001); note that the downward slope indicates a northward shift. Lower, satellite data corresponding to the period between 1970 and 1998.

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 northward shift shown in Figure 8a. Another important piece of evidence to notice is that, as Figure 8b shows, there was a gradual build-up of sea ice, beginning in about 1200 or after 1400, at the beginning of the LIA. A large number of historical documents are available that describe ice conditions during this ice-build-up period.

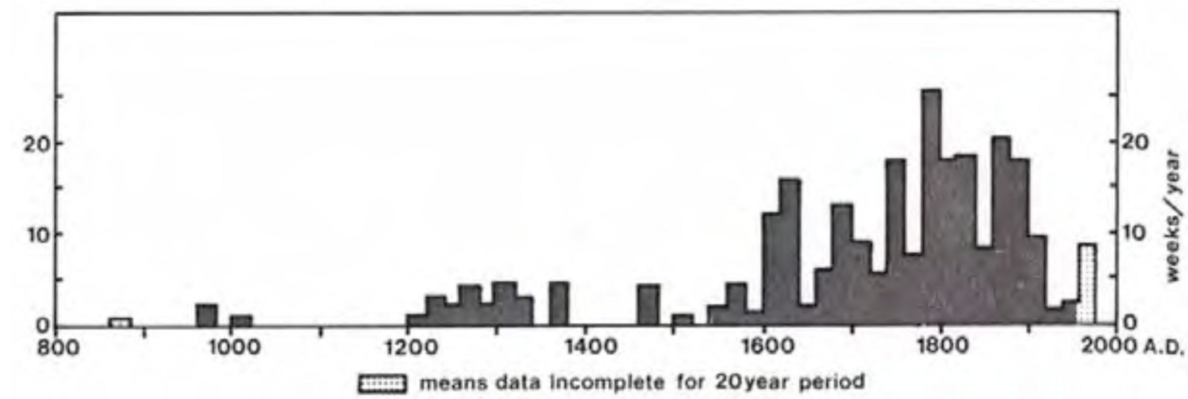

Figure 8b: Variations of the occurrence of sea ice at the coast of Iceland from the year 800. This work was made by L. Koch; *Lamb* (1982).

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 (*Cavalieri and Parkinson,* 2008). Even though it is expected that the greenhouse effect should cause similar effects on sea ice in both hemispheres, this is not the case. Shrinking ice cover is a feature unique to Arctic Ocean ice and is not present in the Antarctic Ocean (see Section 3.2).

2.2 Glaciers

Figures 9a-9f show records of glaciers in Alaska, New Zealand, the European Alps, and the Himalayas, 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; *Molina,* 2008). Molina's examples (2008) are shown in his figures 33, 34, 81, 107 (same as 9a), and 301; some exceptions are shown in figures 89 and 259. It is clear that the retreat is not a phenomenon that began only in recent years, or after CO_2 emission increase in1946. Therefore, the retreat of glaciers cannot be used as supporting evidence of the greenhouse effect of CO_2.

In a large number of publications, photograph sets of the same glaciers taken early and late in the 1900s are shown as evidence of the CO_2 effects (cf. *ACIA,* 2005; *Strom,* 2007). The figures in this section demonstrate that those photograph sets are inadequate as evidence of the greenhouse effect.

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

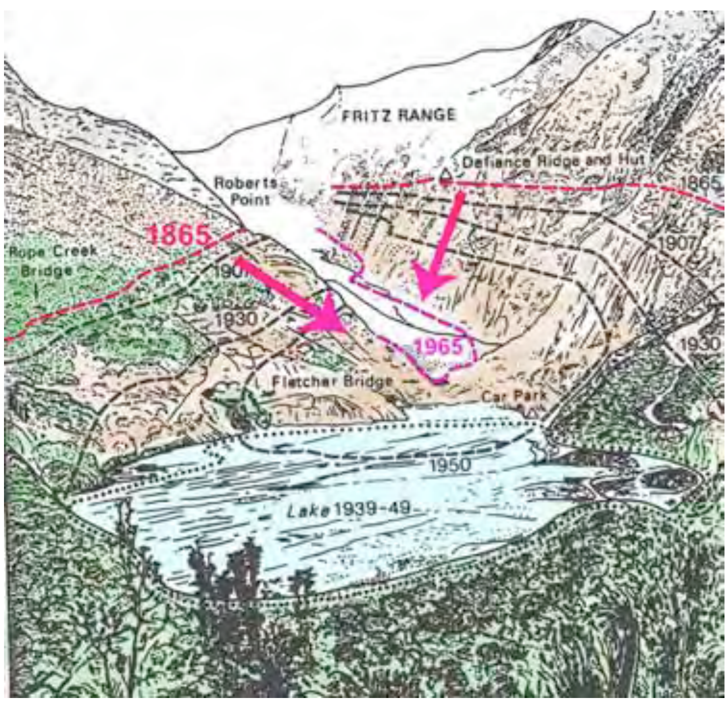

Figure 9b: Retreat of the Franz Josef Glacier in New Zealand; the coloring is added by the present author for emphasis (*Grove,* 1988).

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 datings related to glacial advances in some of the Juneau outlet glaciers (*Grove,* 2001). Each advance killed trees and left in situ stumps. These advances occurred before Glacier Bay glaciers began to recede in about 1800 (Figure 9a).

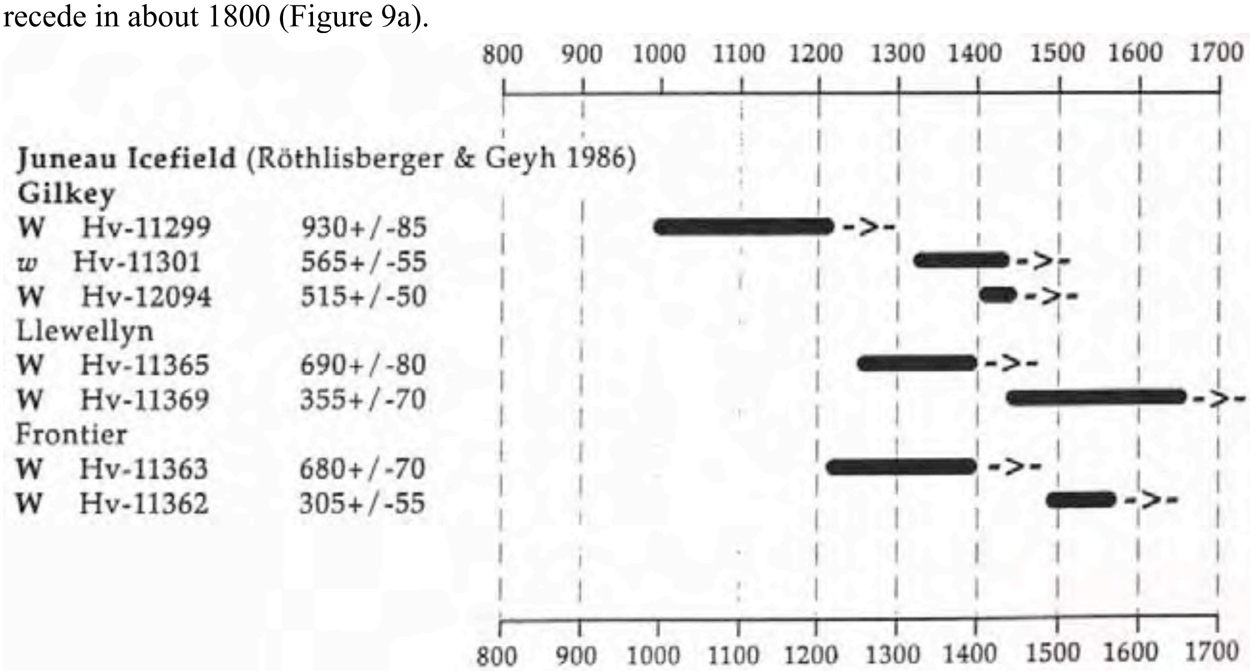

Figure 9d: Radiocarbon dates related to glacial advances in the Juneau glaciers (*Grove,* 2001).

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

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

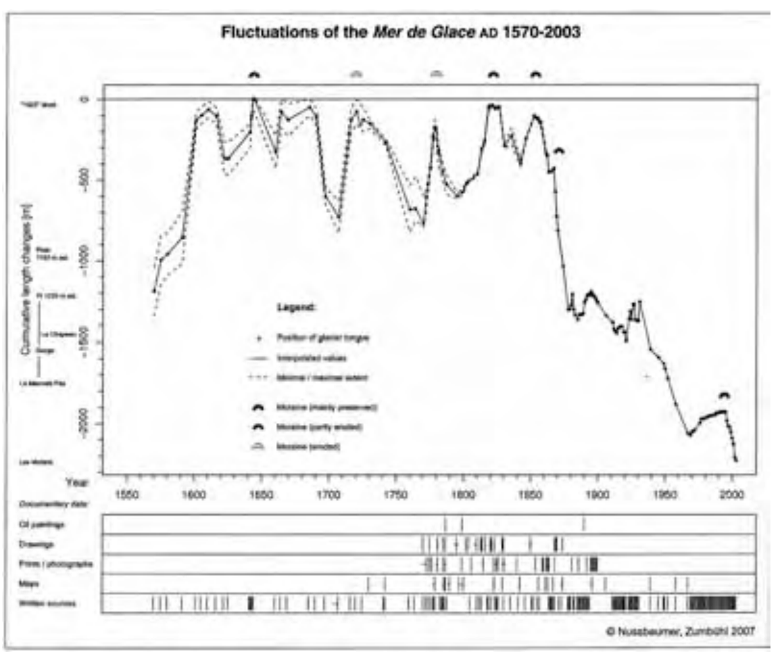

Figure 9f: Details of the changes of the Mer de Glace glacier after 1550 (*von Michael Kuhn,* 2007).

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 (*Holzhauser et al.,* 2005).

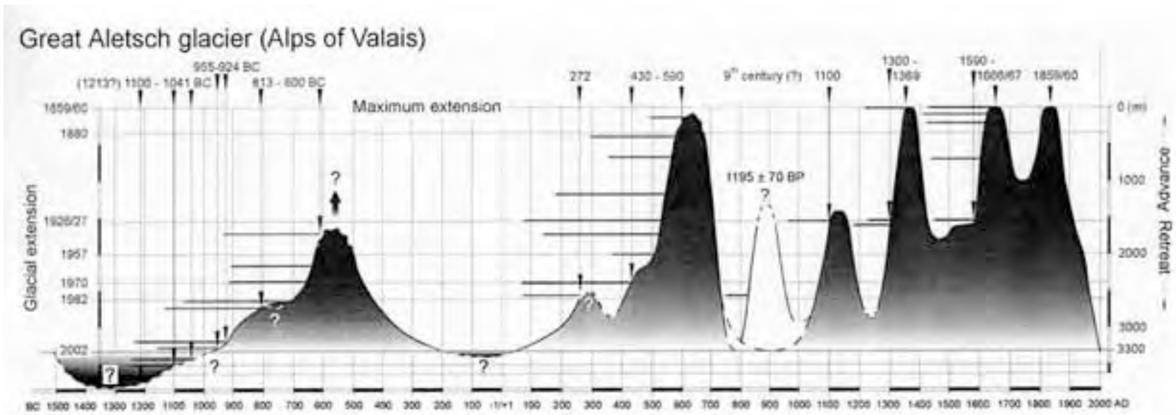

Figure 9g: Advances/retreats in the west-central Alps from BC 1500 (Holzhausen et al., 2005).

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 starting to retreat in about 1800.

Altogether, long-term glacier data presented here show that glaciers advanced from about 1400 and began to retreat after 1800 (cf. *Akasofu,* 2008). These facts confirm that the Earth experienced the LIA.

2.3 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. 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. Although the data cover only the period after 1907, this coverage is sufficient to find the absence of accelerated sea level increase after 1946. 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 a satellite study of sea level changes (*Nerem and Choe,* 2008; *Mitchum and Chambers,* 2008). After increasing from 1993, the sea level rise began to decrease after 2004. *Pilke* (2008) showed that the heat content of the oceans has been decreasing from 2004.

Figure 10c shows the global sea level from 1800 (the upper diagram) and its rate of change (the lower diagram). It is clear that the sea level began to increase in about 1850 and continued almost linearly to the present, approximately with the *same rate* as that which is shown in 10a (see also *Jevrejeva et al.,* 2006, 2008), namely 100 years before 1946. The rate of increase/decrease during the 1920–1960 period will be discussed in Section 3; it should be noticed also that the increase during that period was much more noticeable than that after 1975; see Section 3 and Figure 16.

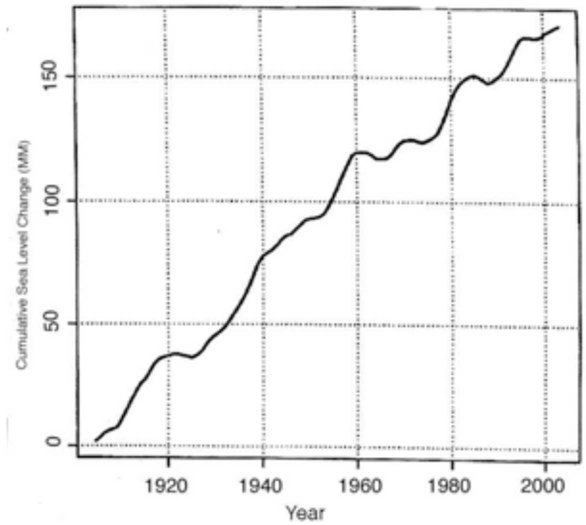

Figure 10a: The mean sea level record from nine tide gauges over the period 1904-2003 based on the decadal trend values for 1907-1999. The sea level curve here is the integral of the rates (*Holgate,* 2007).

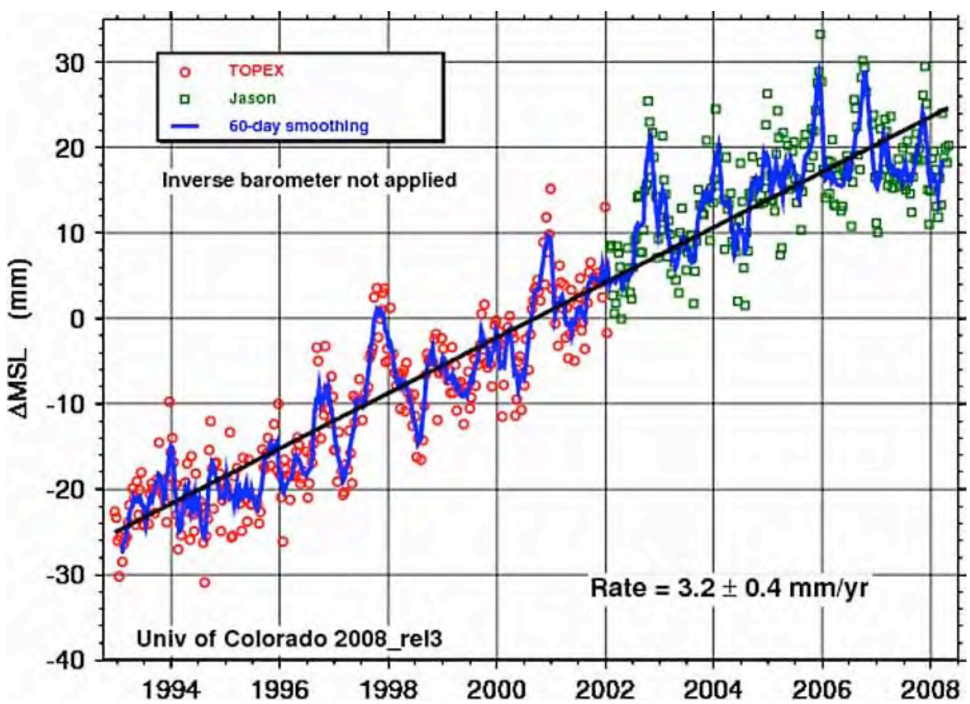

Figure 10b: Sea level changes from 1993 to 2008 (*Nerem and Choe,* 2008; *Mitchum and Chambers,* 2008). (http://sealevel.colorado.edu/current/sl_noib_global.jpg, and http://sealevel.colorado.edu/results.php)

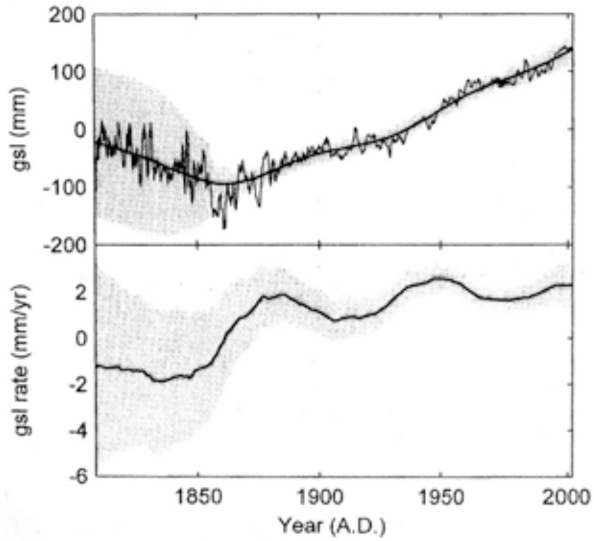

Figure 10c: Global sea level change and its rate from 1800 to the present (*Jevrejeva et al.,* 2006).

2.4 Summary: The Supporting Phenomena of the LIA and a Linear Recovery from it

The cryospheric phenomena presented in this section support the presence of the LIA and a linear recovery from it. All the data presented here show that climate change cannot be properly discussed without a variety of records, particularly arctic ones, for at least the past 1000 years.

3. Multi-decadal Change and Others

3.1 Temperature

As shown in Figures 1a–1g and Figure 2a, three prominent fluctuations superposed on the linear trend 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 rise was between 1975 and 2000, leveling off after 2000. It is crucial to examine whether both rises (1910–1940) and (1975–2000) are due to the same, similar, or entirely different causes. Until such a study can find the causes of this particular phenomenon convincingly, it is not possible to claim, as stated in the IPCC Reports, that the rise after 1975 is mostly due to the greenhouse effect. This point has become very crucial, because the temperature rise stopped in about 2000. There is a possibility that this situation is similar to the one in 1940, when the increase from 1910 stopped in 1940 and began to decrease; it was considered by some at the time that a new Big Ice Age was on its way.

It is important to note that the global warming after 1950 is not uniform over the Earth. Although a single number, namely +0.6°C/100 years or +0.3°C/50 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. Thus, in the continental Arctic, the warming rate was several times greater 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 statistically to the global average change in Figure 1a. On the other hand, contrary to the general trend of warming, note 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 the IPCC seems to claim to be able to reproduce the 0.6°C/100 years rise caused by the greenhouse effect of CO_2. The IPCC arctic group (consisting of 14 sub-groups headed by V. Kattsov) "hindcasted" geographic distribution of the temperature change during the last half of the last century. To "hindcast" means to ask whether a model can reproduce results that match the known observations of the past; if a model can do this at least qualitatively, we can be much more confident about the present GCMs and their prediction of 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 the 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 at the International Arctic Research Center, University of Alaska, actually in an attempt to reduce differences between the observations and modeling results, because they are expected to be similar but not the same.

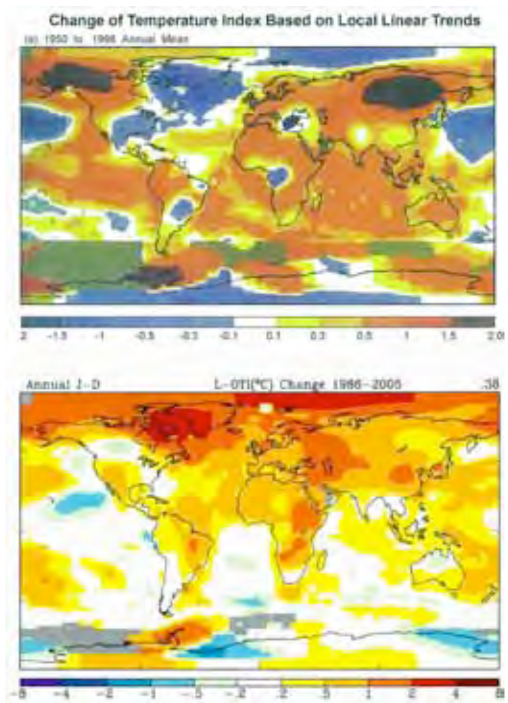

Figure 11a: Upper – the geographic distribution of temperature change between 1950 and 1998 (Hansen et al., 2005). Lower – the geographic distribution of temperature change between 1986 and 2005 (*Hansen,* 2006).

It was a great surprise to find significant differences between the two diagrams in Figure 11b. If both were reasonably accurate, they should at least 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. It was expected that the present GCMs would reproduce the observed pattern with at least reasonable fidelity. However, as can be seen in Figure 11b, there was no resemblance at all between the two, even qualitatively. In particular, the GCMs could not reproduce the warming in the continental Arctic, the most prominent feature in both Figure 11a (the upper part) and Figure 11b (the left side).

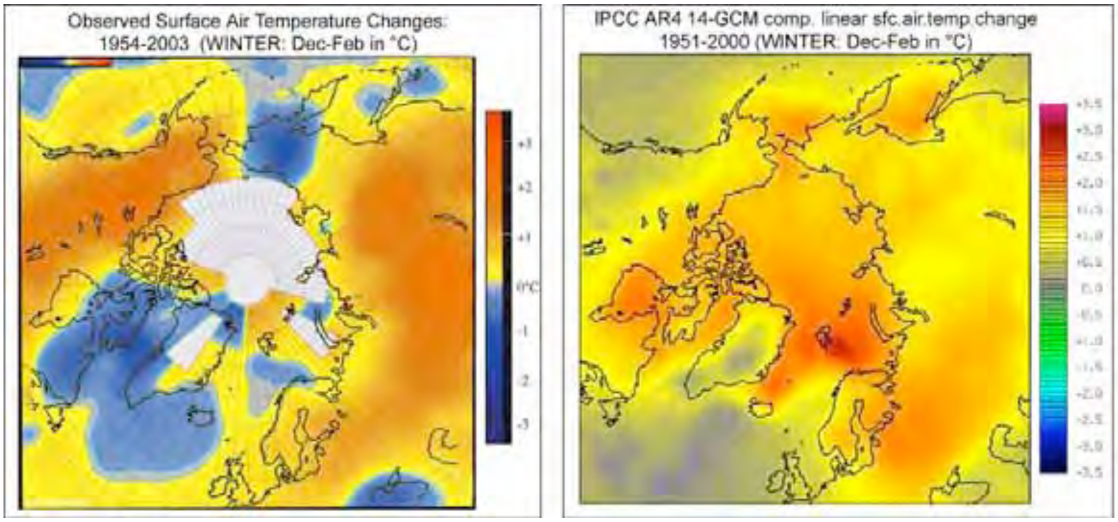

Figure 11b: Comparison of the observed distribution of temperature changes (*ACIA,* 2004) and the simulation (hindcasting) by the IPCC arctic group (*Chapman,* 2005).

It is natural to consider that this surprising result was due to the fact that the GCMs might 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 about the CO_2 effects so far is included in the computation. If the greenhouse effect caused the warming, the observed pattern should be reproducible at least qualitatively by these models, even if the reproduction is not perfect. It was a great puzzle for several weeks in figuring out the great differences.

After some consideration, 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 particular warming is not caused by the greenhouse effect of CO_2 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/cooling. How do we examine that possibility?

If the prominent warming in the continental Arctic (Figure 11a, upper, and Figure 11b, left) were due to the greenhouse effect, the prominent trend should continue and strengthen after 2000. That is, we should observe an accelerated 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 (Figure 11a, the lower one), provided by *Hansen* (2006). However, it was found that the prominent continental Arctic warming in Figures 11a (the upper diagram) and 11b (the left diagram) were almost absent in Figure 11a (the lower one); the Arctic warmed at a rate about like that of the rest of the world, while Greenland showed a strong warming after cooling during the last half of the last century.

Actually, in Fairbanks and many parts of Alaska, the temperature shows a cooling trend between 1977 and 2001 (except on the arctic coast line), as can be seen in Figure 11c (*Hartman and Wendler,* 2005). Note also a rather sudden increase of temperature in about 1975. This is another indication that this particular warming is not likely to be due to the greenhouse effect of CO_2; the greenhouse effects are supposed to cause a gradual change. It is likely that such a change is caused by shifts of the atmospheric pressure patterns (see Section 3.3 and Figure 14). Therefore, it may be concluded 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, and the Pacific Decadal Oscillation (PDO). (The PDO will be discussed in connection with Section 3.3 and Figure 14a.) This trend is shown schematically in Figure 2a as positive and negative fluctuations. If this is indeed the case, the IPCC Report (2007) is incorrect in stating that the warming after 1975 is mostly caused by the CO_2 greenhouse effect. The steep increase of the temperature after 1975 is likely to be the oscillatory change superposed on the linear change. This point will be further discussed in Section 3.4. This comparison gave us a new way to use GCM results to identify natural changes of unknown causes; another example is shown in connection with Figure 13.

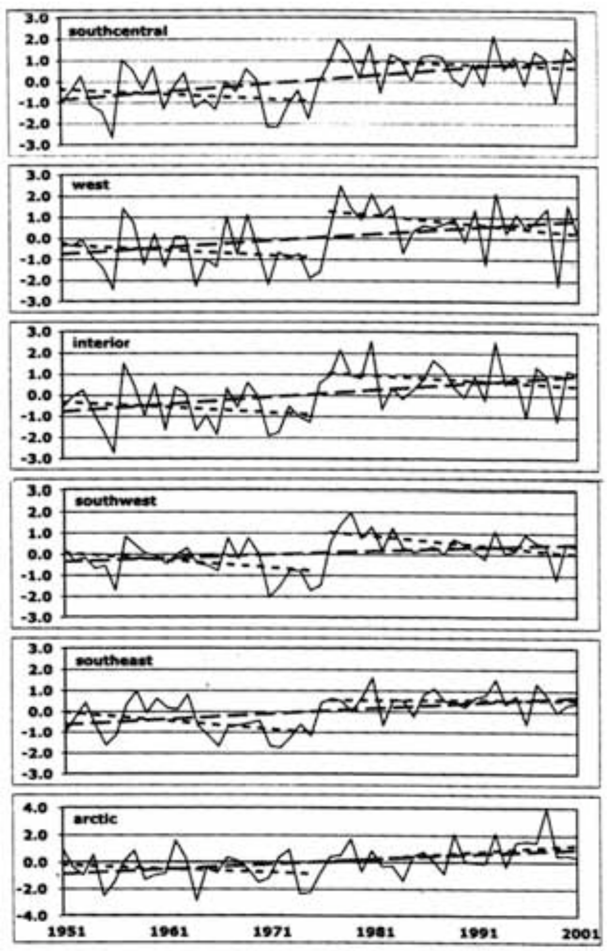

Figure 11c: The transition from the period of declining temperature (1940–1975) to the period of rising temperature after 1975. The transition is a step-function-like change, unlike the Greenland effect. Further, after a step-function-like increase, the trend appears to be negative (*Hartmann and Wendler,*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

3.2 Sea Ice in the Arctic Ocean

The recent rapid retreat of sea ice in the Arctic Ocean, particularly in 2007, is partly caused by the inflow of warm North Atlantic (*Karcher et al.,* 2003; *Polyakov,* 2006) and North Pacific (*Shimada and Kamoshida,* 2008) waters into the Arctic Ocean and also the effects of winds and currents. Figures 12a and 12b show results of the ocean monitoring effort by an international group led by the International Arctic Research Center. It was shown by *Polyakov* (2006) that this inflow is a quasi-periodic phenomenon, as shown in Figure 12c. This warm water was melting sea ice from the bottom until 2007, but sea temperature in 2008 was significantly colder than in 2007 (*Polyakov,* 2008). Thin ice tends to break up easily in stormy water and is then easily forced to flow by winds and currents. This was exactly what happened in the fall of 2007. The wind pattern in 2007 and 2008 was different (cf. *Zhang et al.,* 2008). Some researchers expected further shrinking in 2008, but the area increased by about 7% compared with that of 2007 (cf. *Muskett,* 2008).

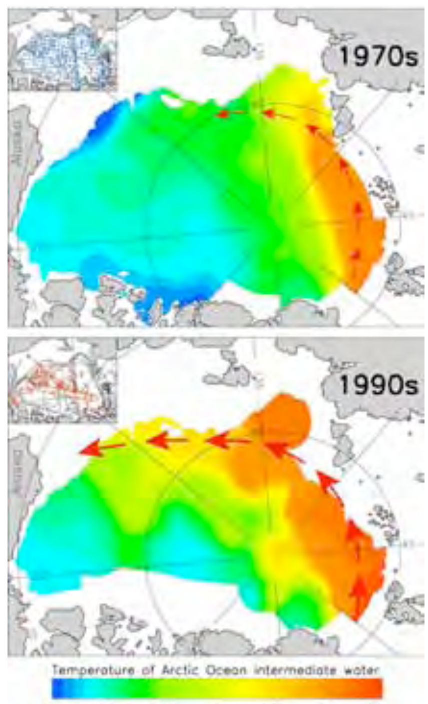

Figure 12a: Inflow of warm North Atlantic water into the Arctic Ocean (*Polyakov,* 2006).

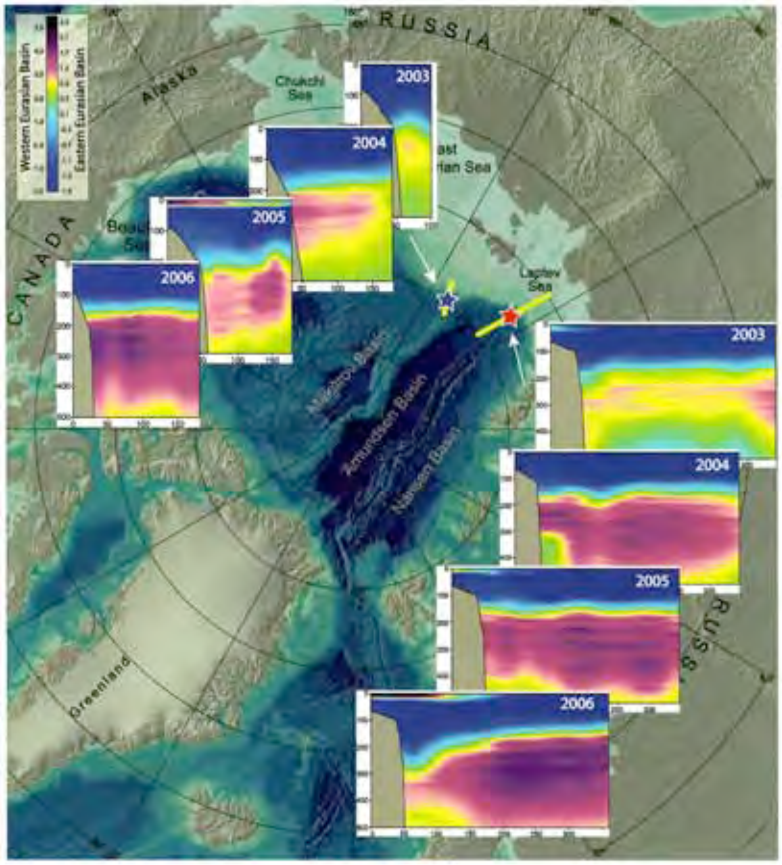

Figure 12b: Changes of seawater temperature at two locations in the Arctic Ocean. The warm water from the North Atlantic Ocean is flowing deeply into the Arctic Ocean (*Polyakov et al.,* 2007).

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

Here is 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, it is interesting to speculate that some processes other than the CO_2 greenhouse effect must have been in progress that are not considered or not properly taken into account in GCMs. Indeed, the inflow of warm North Atlantic water shown in 12a and 12b can be one such process that can melt sea ice from below (cf. *Haas et al.,* 2008). It is well known that winds or ocean currents can also move sea ice once it is broken up (cf. *Zhang et al.,* 2008). Thus, it may be concluded that processes other than the CO_2 effect have a greater influence on sea ice in the Arctic Ocean than the greenhouse effects of CO_2. The Arctic Ocean is special in this respect. In fact, as mentioned earlier (Section 2.1), sea ice around the Antarctic continent shows no clear sign of a similar decrease, and is actually growing a little.

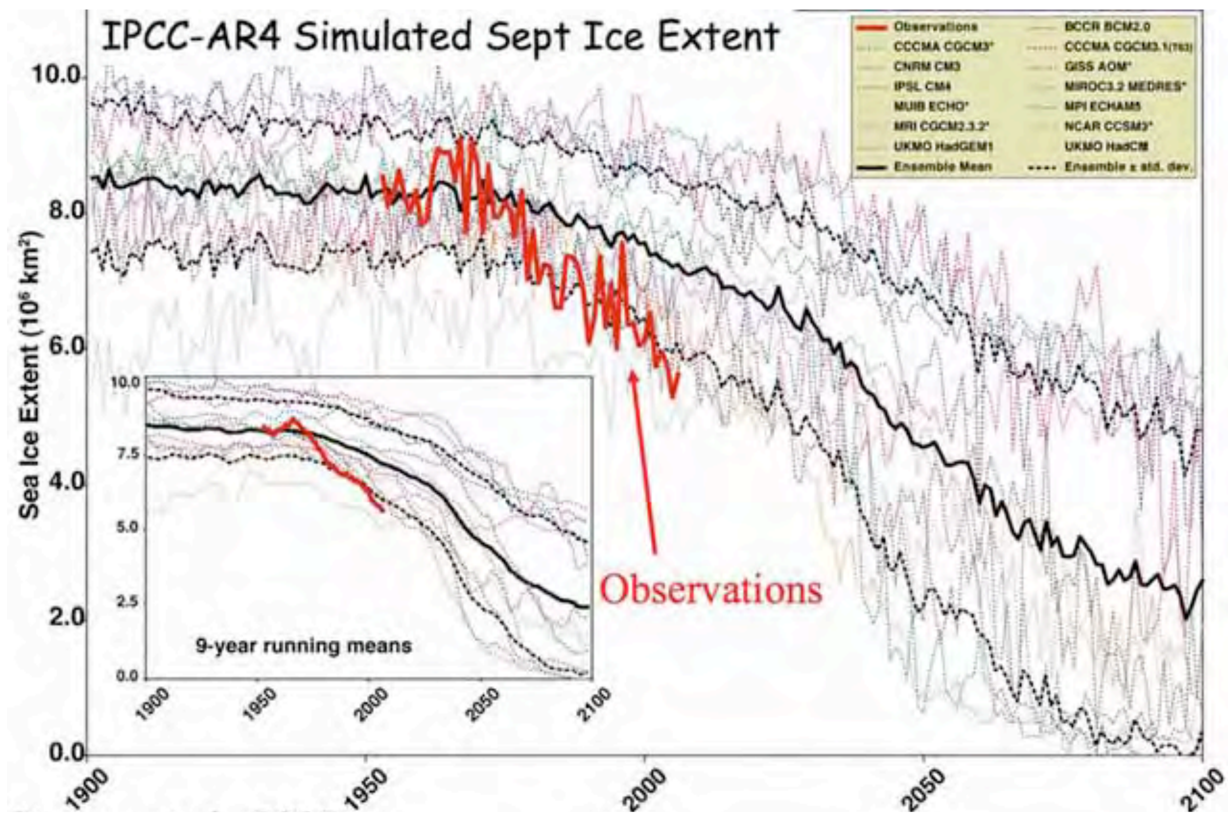

Figure 13: Changes in the area of Arctic Ocean sea ice; comparison of computer modeling results with observations (*DeWeaver,* 2007).

3.3 The Pacific Decadal Oscillation (PDO)

Figure 14a shows the pattern of the Pacific Decadal Oscillation (PDO), which is a natural phenomenon. 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 (*University of Washington,* 2008). The middle part shows the PDO index. In the bottom part, Figure 2a 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); note that the baseline is different for the PDO and the bottom diagram, so that an accurate comparison between them is difficult. This similarity supports the assumption that the superposed fluctuations on the linear change (the recovery from the LIA) are in part the multi-decadal *oscillation*.

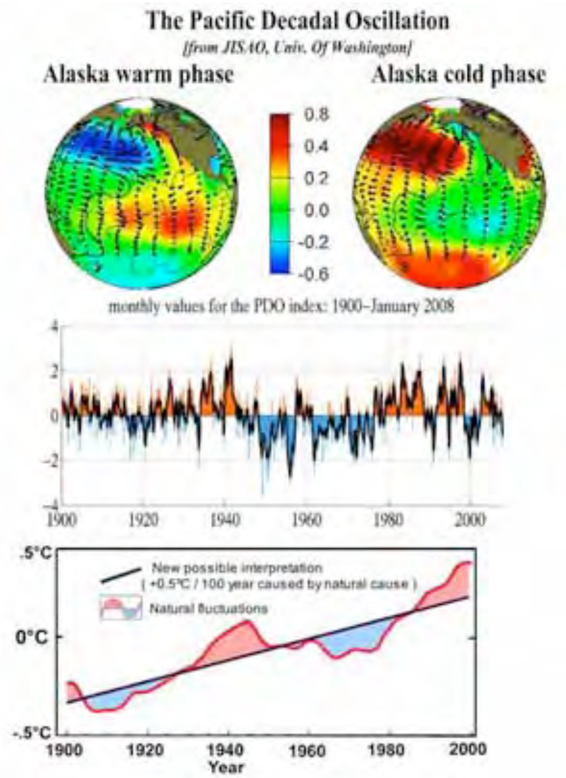

Figure 14a: The PDO wind pattern, the PDO index (*University of Washington,* 2008). Figure 2a is shown at the bottom for comparison with the PDO index.

It is important to mention here that the present halting of global warming is not likely to be a temporal event like La Niña. The Jet Propulsion Laboratory (*JPL/NASA,* 2008) announced recently that the Pacific Ocean remained locked in a strong cool phase of the PDO. Figure 14b shows their result. The JPL/NASA result is based on observations from 1993 through 2008.

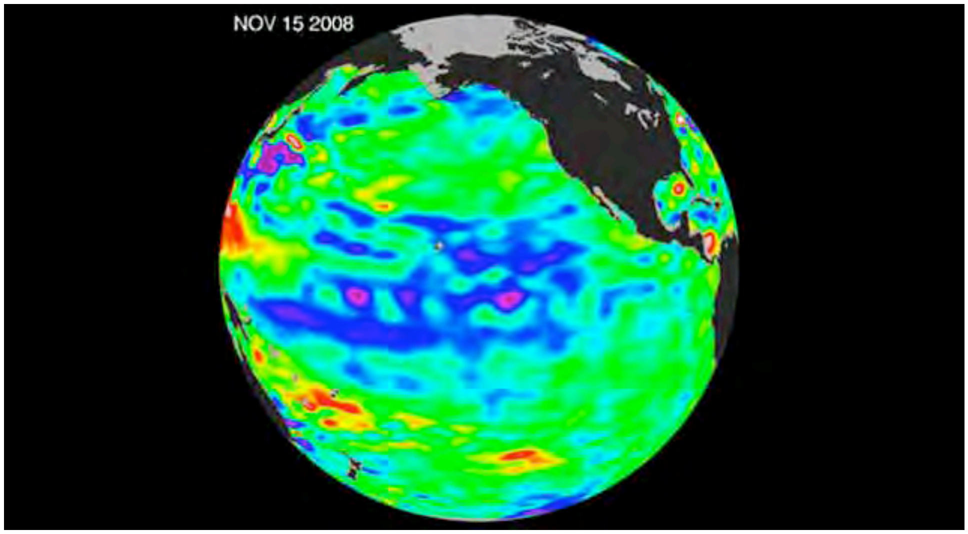

Figure 14b: A recent image of sea surface height measurements from the U.S./French Jason-1 oceanography satellite. The yellow/red area is higher (warmer) and the blue/purple is lower (cooler) than the normal (green).

3.4 Summary: 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. The report shows 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 one that began in 1980 (yellow), as the Summary for Policy Makers (2007) noted.

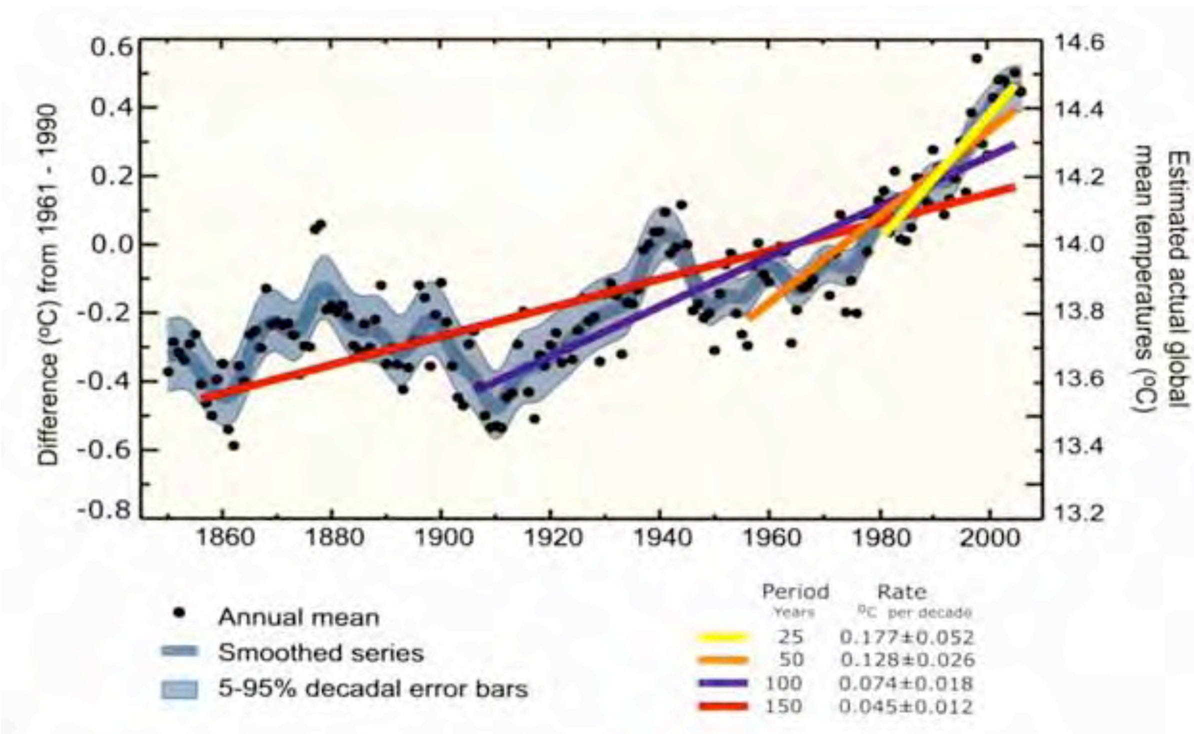

Figure 15a: Temperature changes from 1850; several gradient lines are drawn (*IPCC Report,* 2007). The red gradient is about 0.5°C/100 years.

The orange and yellow lines are specifically identified by the IPCC as the greenhouse effect of CO_2. However, as pointed out in Sections 1, 2, and 3, a very significant part of the orange and yellow lines 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, which is the same as Figure 2a, except that the change after 1975 is shown by the thick red line. At least, the IPCC should have tried to identify natural changes and subtract them from the orange and yellow lines in Figure 15a.

From Figure 15b, it is clear that the multi-decadal oscillation has reached a maximum in about 2000, and the rate of change is shifting toward a negative trend after that time. It is also interesting to note that the PDO appears to shift toward a negative period (Figure 14a), suggesting also that the multi-decadal oscillation starts the negative trend. This negative trend is unlikely to be a very short period phenomenon such as La Niña.

Figure 15b suggests also that the temperature in the future depends on the combination of the recovery from the LIA and the multi-decadal change. The latter tends to have a greater rate change than the former, as illustrated in Figure 2b.

Figure 2b was constructed on the basis of the above conclusion. It is assumed that both the linear change and the multi-decadal oscillation are continued until 2100. In this view, the halting of the temperature after 2000 can easily be understood. As mentioned earlier, the linear change has the gradient of +0.5°C/100 years, thus +0.05°C/10 years. On the other hand, the multi-decadal oscillation has an amplitude of 0.2°C and period of 50~60 years, so that the expected change after 2000 to 2010 is -0.07°C, causing the linear increase to stop, resulting in a slight decline; the year 2008 was the coolest year during the first decade of this century.

The difference of the opinion between the IPCC and the present author can be put simply as how to interpret the temperature rise from 1975 to 2000. The IPCC considered it to be unprecedented and anomalous and thus assumed it to be the effect of CO_2, while the present author considers it as a positive phase of the multi-decadal oscillation (the thick red line in Figure 15b and Figure 2b). If the orange and yellow lines in Figure 15a are caused by the CO_2 effect, these trends should continue after 2000, since CO_2 is still rapidly increasing. However, as already noted several times, the warming is halted after 2000. Thus, the present author's interpretation in Figure 2b agrees with the observations.

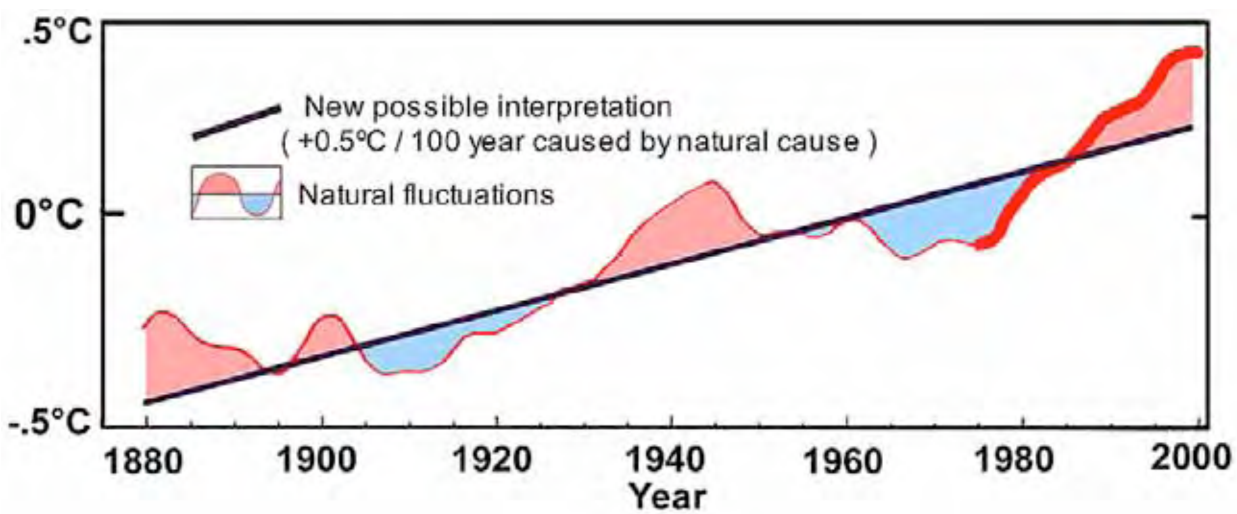

Figure 15b: Figure 15b is the same as Figure 2a, except that the last part of the multi-decadal oscillation after 1975 is emphasized by a thick red line.

It is important to note that the temperature rise from 1910 to 1940 was as steep as the one that started in 1975; the range of change was also similar. Although the IPCC was interested only in the rise after 1975, they should have also paid serious attention to the temperature rise between 1910 and 1940 and should have tried to understand its cause before deciding that the rise after 1975 was mostly due to the effect of CO_2. The situation in 2000 might be similar to that in 1940 when the temperature began to decrease.

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 such data, it is often reported that the recent climate change is "unprecedented." For example, although there are a number of reports on "unprecedented changes" of ice in Greenland these days, *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. Such features can also be seen in the sea ice change in Figure 8a and in the sea level change in Figure 10c, in which the rate of changes to the sea level from 1920 to 1960 is greater than that after 1970.

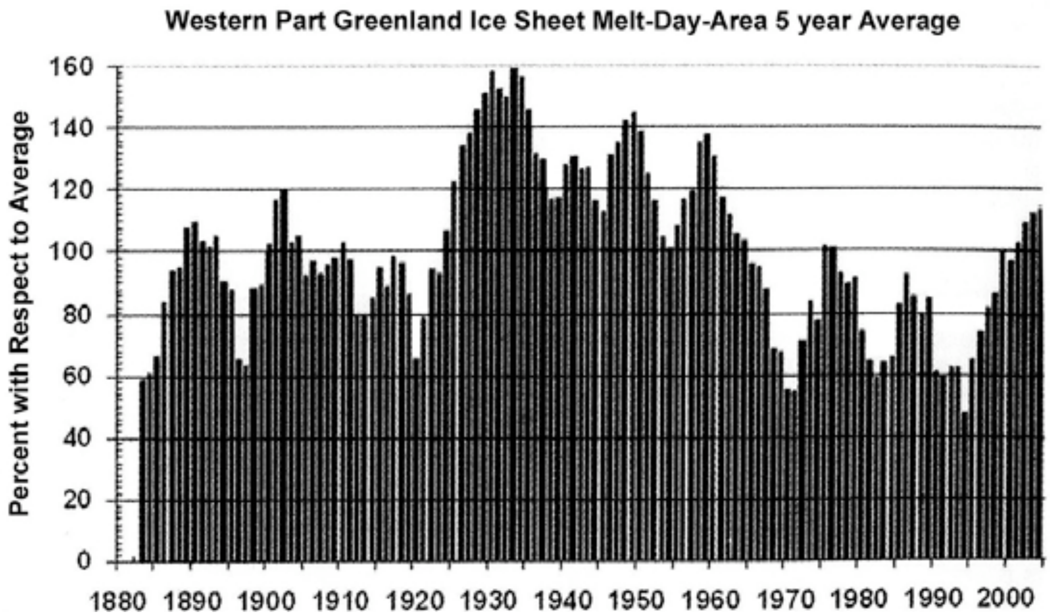

Figure 16: The melt day area of the western part of the Greenland ice sheet. It is reconstructed from the temperature record and melt area sensitivity of 3.8% per 0.1°k temperature change (*Chylek et al.,* 2007).

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 snow depth has the most important effect on permafrost temperature (*Osterkamp,* 2007a, b). It should also be mentioned that although there are a number of reports of collapsing buildings caused by the CO_2 effects of thawing permafrost (cf. *ACIA,* 2005), this is actually the result of poor construction (houses built directly on permafrost). *Froese et al.* (2008) showed that permafrost formed 740,000 years ago survived a few interglacial periods that were warmer than the present one.

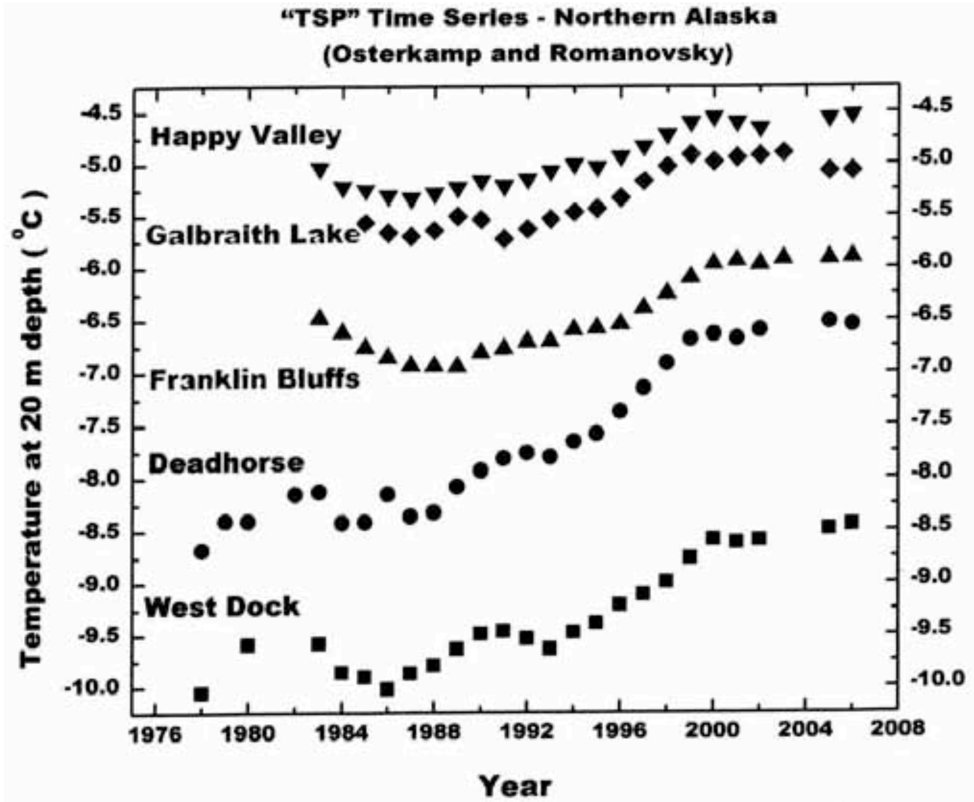

Figure 17: Permafrost temperature variations in Northern Alaska from 1976 to 2006. Note that the temperature increase starting in about 1988 stopped in about 2000 (*Richter-Menge et al.,* 2006).

4. Conclusions

Climate change during the last 100 years or so has been intensely discussed by the IPCC and many others 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 only as late as after 1975, basically ignoring the LIA, the linear recovery from the LIA, and the superposed multi-decadal oscillation.

The IPCC Reports have stated that the global average temperature increased about 0.6°C 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, it is shown that the Earth has been warming from about 1800–1850 to 2000 with approximately the same rate, so that there is no definitive proof that "most" of the warming after 1975 is due to a manmade greenhouse effect (Figure 2b). This is simply their *hypothesis*. It is well known that CO_2 molecules can cause the greenhouse effect and its amount in the atmosphere is increasing, so it is natural to *hypothesize* that CO_2 is one of the causes of the warming trend. However, it is not appropriate to conclude *a priori* that the 0.6°C rise is mostly due to human causes without carefully subtracting the contributions of natural changes. Natural causes are almost ignored in the IPCC study except for some obvious causes (cf. solar changes and volcano effects). The results presented in this paper show that natural changes are substantial and, further, there is nothing unusual about the present temperature rise.

It is natural to assume by glancing at Figures 1a and 2b that there was, as a first approximation, an almost linear increase in temperature of 0.5°C/100 years from 1880 to 2000. It is somewhat surprising that there has, so far, been no debate on many other possible interpretations of Figure 1a. Some modelers claim that without including the CO_2 effect, they cannot reproduce the present warming (cf. *Nozawa et al.,* 2005). This is partly because (1) natural causes, such as the recovery from the LIA and the multi-decadal oscillation are not included in their models, and (2) their models are tuned to reproduce the warming by the CO_2 effect. Their deficiency in this regard is demonstrated by the fact that the IPCC prediction after 2000 has already failed during the first decade of the present century. This is a clear indication that some process other than the CO_2 effects are at work (Figure 2b).

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). Assuming it to be ~ 1.0°C, we can interpret it to mean that the Earth has been recovering from the LIA during the last 200 years with the rate of 0.5°C/100 years.

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 to 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. However, it is not the purpose of this paper to attempt an accurate estimate of the gradient of the linear change or explore causes of natural changes. It is a task for professional climatologists. It is emphasized 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 the extent of 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 also a task for climatologists. The present study could not find obvious signs of such a trend. Instead, contrary to such an expectation of an upward swing, the warming trend has stopped after 2000. Even if the halting is temporary, this fact indicates that there are natural or some unknown processes that can overcome the CO_2 effect.

In addition to the linear change, various fluctuations are superposed on it. One of them is the multi-decadal oscillation. 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 exceptional and is mostly caused by the greenhouse effect of CO_2, while the multi-decadal oscillation has been strongly positive from 1975 and peaked in about 2000. It is suggested that the present halting of warming is caused by the fact that the multi-decadal oscillation had reached the maximum stage in about 2000 and has begun to decrease (Figure 2b).

In this paper, we did not discuss causes of the LIA and its recovery. It has been noted by several researchers that the Earth is experiencing cooling and warming trends because of changing solar output (cf. *Soon,* 2005; *Scafetta and West,* 2006; *Mazzarella,* 2007; *Svensmark and Calder,* 2007). However, this subject is beyond the scope of this paper.

Important findings in this paper are:

(i) Natural components are important and significant in climate change, so they should not be ignored in studying global temperature changes.
(ii) Two natural changes after 1800–1850 are identified in this paper: an almost linear increase of about +0.5°C/100 years and a multi-decadal oscillation of amplitude 0.2°C and period of 50~60 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) 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.
(v) The reason why the global warming trend stopped in about 2000 is likely to be due to the fact that after peaking in about 2000, the multi-decadal oscillation has started to have a negative trend. There are other signs of the haltings (Figures 10b, 14, and 17 as well as the ocean heat content). The halting is not due to La Niña.
(vi) 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 even after the recovery from the last Big Ice Age.
(vii) It is insufficient to study climate change on the basis of data only from 1975.
(viii) Two examples are presented in which GCM results can be used to identify natural changes of *natural* causes.
(ix) Computers are incorrectly “taught,” “instructed,” or “tuned” to adjust to the observed temperature rise during the last hundred years, and particularly after 1975, ignoring the recovery from the LIA and the multi-decadal oscillation. Thus, the present GCMs do not include processes associated with the LIA and the multi-decadal oscillation.
(x) The predicted temperature in 2100 by the IPC is simply an extension of the warming trend between 1975 and 2000.
(xi) As a result, the IPCC prediction during the first decade of the present century has already failed.
(xii) 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. Multi-decadal oscillation could be either positive or negative in 2100. Since its amplitude change is about 0.2°C, the temperature in 2100 depends greatly on the combination of both effects, 0.5°C ± 0.2°C.

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