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On the recovery from the Little Ice Age

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ABSTRACT

A number of published papers and openly available data on sea level changes, glacier retreat, freezing/break-up dates of rivers, sea ice retreat, tree-ring observations, ice cores and changes of the cosmic-ray intensity, from the year 1000 to the present, are studied to examine how the Earth has recovered from the Little Ice Age (LIA). We learn that the recovery from the LIA has proceeded continuously, roughly in a linear manner, from 1800-1850 to the present. The rate of the recovery in terms of temperature is about 0.5°C/100 years and thus it has important implications for understanding the present global warming. It is suggested on the basis of a much longer period covering that the Earth is still in the process of recovery from the LIA; there is no sign to indicate the end of the recovery before 1900. Cosmic-ray intensity data show that solar activity was related to both the LIA and its recovery. The multi-decadal oscillation of a period of 50 to 60 years was superposed on the linear change; it peaked in 1940 and 2000, causing the halting of warming temporarily after 2000. These changes are *natural* changes, and in order to determine the contribution of the manmade greenhouse effect, there is an urgent need to identify them correctly and accurately and remove them from the present global warming/cooling trend.

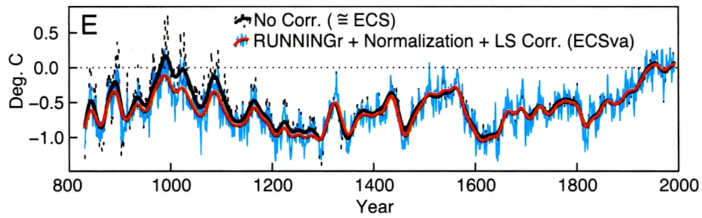
Keywords: Little Ice Age

1. INTRODUCTION: THE LITTLE ICE AGE (LIA)

The Little Ice Age (LIA) is discussed in a large number of publications, including monographs (cf. Lamb [1]; Grove [2]). Although it is generally believed that the LIA ended more than two centuries ago, there has not been much discussion about how the recovery from it. In this paper, on the basis of published papers and some openly available data, we learn that the LIA certainly ended in about 1800-1850, but the recovery has continuously progressed to the present with superposed 'fluctuations'. In this section, we briefly review data from the LIA. In Section 2, ice core data, river freeze/break-up dates, sea level changes, sea ice changes, glacier changes, tree-ring data and cosmic-ray intensity data, are examined, and we learn that the recovery progressed from 1800-1850 to the present. In Section 3, having more accurate data after 1900, we learn that temperature changes during the 20th century can be judged as a continuation of the recovery, approximated by a linear change at the rate of about 0.5 °C/100 years, with the superposed multi-decadal oscillation. In Section 4, we learn on the basis of changes of the cosmic-ray intensity from the year 1000 to the present that solar activity was relatively low during the LIA, but began to recover from about 1800-1850. In Section 5, it is suggested that the multi-decadal oscillation is halting the recovery from the LIA temporarily and that this situation is similar to the situation from 1940 to 1975. The summary is given in Section 6 and the conclusion in Section 7.

There is little doubt that the Earth experienced a relatively cool period after the Medieval Warm Period around the year 1000. In this section, we briefly review changes of temperature from about 1000 to the present before examining details of the recovery from the LIA. **Figure 1(a)** shows a typical example of tree-ring data from the middle latitudes (Esper *et al*. [3]; Frank *et al.* [4]). Compared with the mean 1961-1990 level, the temperature was relatively low from about 1100 to 1800-1850, indicating that the Earth experienced a relatively cool period, the LIA. Our particular interest here is the recovery that began in about 1800-1850, namely the temperature increase here from 1800-1850 to the present. It can be seen that the temperature rise from 1800-1850 to the present was continuous with superposed 'fluctuations' and that there is no sign of the end of the recovery before 1900.

Figure 1(b) shows temperature changes from the year 900 to the present, which combines seven (including **Figure 1(a)**) different research results (National Research



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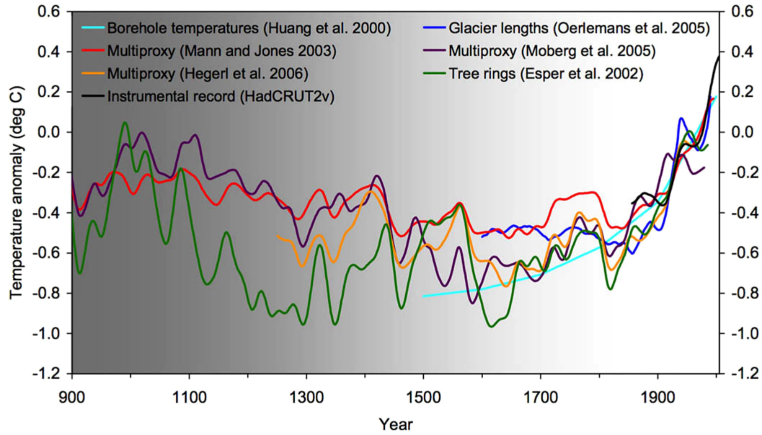

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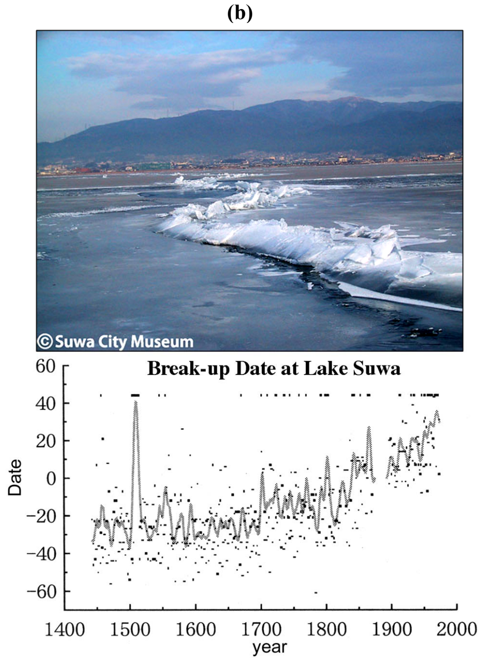


(c)

Figure 1. (a) Temperature variations deduced from tree-ring records from 14 sites from 800. It shows variance-adjusted data by Esper *et al.* [3], along with the unadjusted mean record. The dashed line shows the mean 1961-1990 anomaly reference period (Frank *et al.* [4]); (b) Reconstructions of large-scale (Northern Hemisphere mean or global mean) surface temperature variations from seven different research teams (including **Figure 2(a)**) 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 [5]); (c) Ice break-up scene at Lake Suwa in the central highland of Japan from 1450 to 2000. It produced a loud sound and it was thought that God crossed the lake. It is for this religious reason that a long record has initially been kept. The zero day refers to January 1. The dots on the top show years when the break-up did not occur (Ito [6]).

Council [5]). It is clear from **Figures 1(a) and 1(b)** that the Earth experienced a relatively cool period from about 1100 to 1800, the LIA. Again, it may be noted that all the data show clearly the continuous recovery from about 1800-1850 to the present with the superposed 'fluctuations'.

Figure 1(c) 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 phenomenon, called "Omiwatari", meaning 'God's crossing', 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 1800 to the present (Ito [6]). This is an example to show that the LIA occurred in Asia. The presence of the LIA in the Indo-Pacific area is documented by Nunn [7], Oppo *et al.* [8] and others (see Lamb [1]; Grove [2]; Fagan [9]). Indeed, many publications indicate that the LIA was a worldwide phenomenon. (Keigwin [10]; Tarand and Nordli [11]; van Engelen *et al.* [12]; Pollack and Smerdon [13] ; Asami *et al.* [14]; Moberg *et al.* [15]; Holmes *et al.* [16]; Liu *et al.* [17]; Richey *et al.* [18]; Aono [19]).

2. THE RECOVERY FROM THE LIA

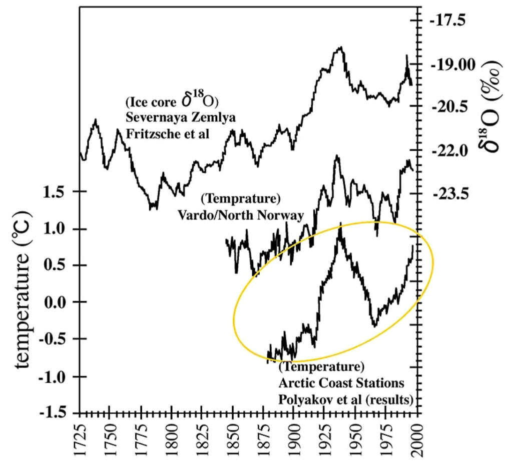
In this section, we learn about climate change from 1800-1850 to 1900. Since we have much more accurate data after 1900, climate change after 1900 will be dealt with in the next section.

2.1. Ice Core Data

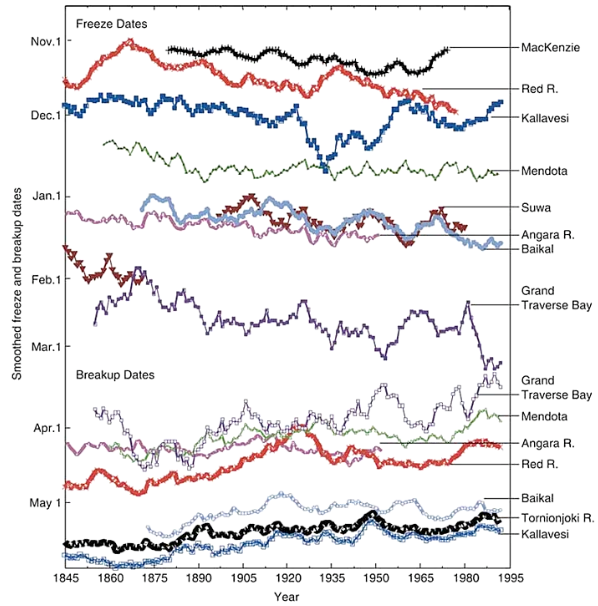
Figure 2(a) shows temperature changes from 1725 to 2000, which were deduced from ice cores at Severnaya Zemlya, an island in the Arctic Ocean (Fritzsche *et al.* [20]). This figure indicates that there occurred a continuous rise of temperature from 1775 to the present; this record is particularly valuable, because we do not expect any contamination by human activities. **Figure 2(a)** includes also 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.* [21]). The credibility of the ice core record is supported by its similarity with both thermometer records; see also a similar result by Isaksson *et al.* [22]. A large positive change from 1910 to 1975 was caused by the phenomenon called the polar amplification of the multi-decadal oscillation (Alexeev *et al.* [23]), which will be discussed in Section 5.

2.2. RIVER FREEZE/BREAK-UP DATES

Figure 2(b) shows both the break-up and freeze dates of a number of lakes and rivers of the world from 1846 to 1995 (Magnuson *et al.* [24]. It can be seen that the break-up dates have almost steadily advanced to earlier

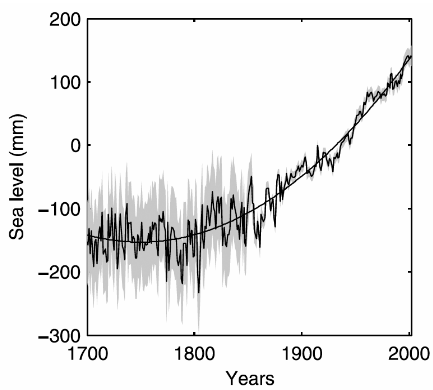


(a)



Time series of freeze and breakup dates from selected Northern Hemisphere lakes and rivers (1846 to 1995). Data were smoothed with a 10-year moving average.

(b)



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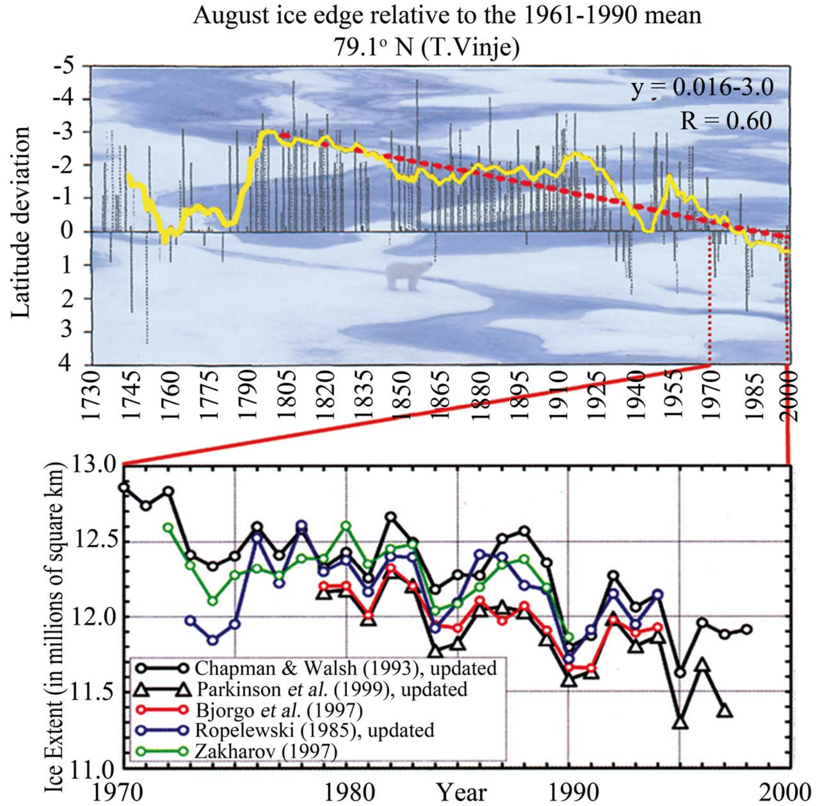

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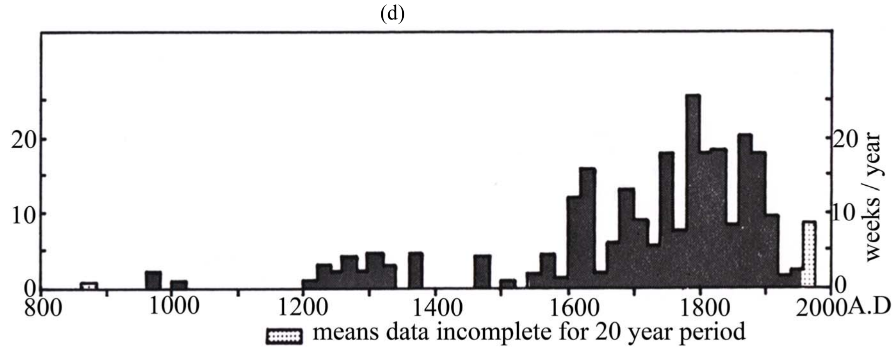


(e)

Figure 2. (a) Late Holocene ice core record from Akademii Nauk Ice Cap, Severnaya Zemlya, Russian Arctic, by Fritzsche [20], together with temperature records from Vardo, Norway, and from stations along the arctic coast (Polyakov *et al* [21]); (b) Freeze dates and break-up dates of lakes and rivers in the Northern Hemisphere from 1845~1993 (Magnuson *et al* [24]; (c)Global sea level change from 1700 to the present (Jevrejeva *et al* [26]; (d) Upper, retreat of sea ice in the Norwegian Sea (Vinje [27]; note that the downward slope indicates a northward shift. Lower, satellite data corresponding to the period between 1970 and 1998; (e) Variations of the occurrence of sea ice at the coast of Iceland from the year 800. This work was done by L. Koch (Lamb [1].).

dates in the year, while the freeze dates seemed to shift steadily to later dates. Similar ice break-up data are also available by Tarand and Nordlie [11] and van Engelen *et al.* [12].

2.3. Sea Level Changes

The linear trend of the recovery from the LIA can also be seen in sea level changes (Jevrejena *et al.* [25,26]. **Figure 2(c)** shows the global sea level from 1800. It is clear that the sea level began to increase in about 1850 and continued rising almost linearly to the present.

2.4. Sea Ice Changes

There is no accurate Arctic Ocean data until satellite observations became available in the 1970s. The only long-term observation of sea ice is available from the Norwegian Sea. **Figure 2(d)** shows changes in 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 [27]. In the lower part, satellite data are shown. Although a drastic decrease in 2007 (not shown here) was widely reported, it is found that winds and many other factor were responsible for it (Zhang *et al.* [28,29]; in fact, the ice has shown a steady recovery since then (Muskett [30]. The large 'fluctuations' between 1910 and 1975 are likely related to the multi-decadal oscillation, which is discussed in Section 5.

Figure 2(e) shows variations of the occurrence of sea ice on the coasts of Iceland (see the figure caption for the reference). The decline after 1800 corresponds to the northward shift shown in **Figure 2(d)**. Another important piece of evidence to notice is that, as **Figure 4(b)** shows later, there was a gradual build-up of sea ice, beginning in about 1200 or after 1400, at the beginning of the LIA.

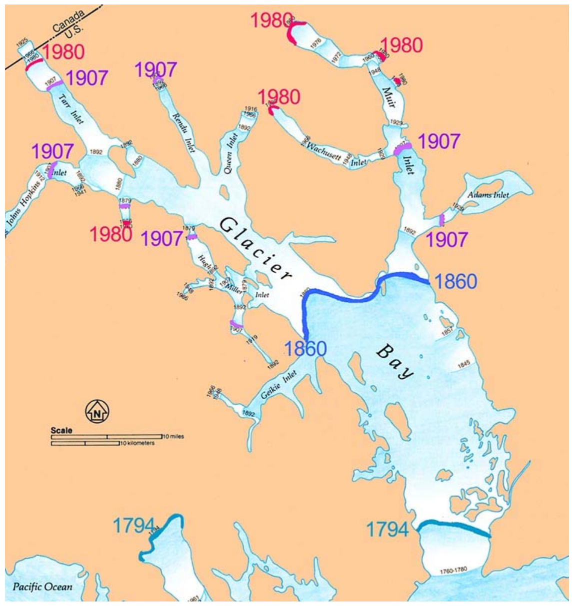
2.5. Glaciers

Figures 3(a-f) show records of glaciers in Alaska, New Zealand, the European Alps, and the Himalayas. These glaciers have been receding from the time of the earliest available records, about 1800 and an accurate terminus records. There are also a large number of similar records from the European Alps, Alaska, and elsewhere (Grove [2]; Molnia [31]). Molnia's examples are shown in his figures 33, 34, 81, 107 (same as **Figure 3(a)**) and 301. Thus, it may be said that many glaciers in the world have been retreating from 1800-1850 to the present; the retreat is not a phenomenon that began only in recent years. In a large number of recent publications, photograph sets of the same glaciers taken early and late in the 1900s are shown as evidence of the effect of CO_2 (cf. ACIA [32]; Strom [33]). However, **Figure 3(a-f)** demonstrate that those recent photographs are misleading as evidence of the sudden warming after 1900 and of the greenhouse effect. Therefore, such a set of photographs cannot be used as evidences supporting the greenhouse effect of CO_2.

It is interesting to examine glacier changes before 1800. **Figure 3(d)** shows radiocarbon datings related to glacial advances in some of the Juneau outlet glaciers (Grove [34]. Each advance killed trees and left in situ stumps for analyses. These advances occurred before Glacier Bay glaciers began to recede in about 1800 (**Figure 3(a)**).

Figure 3(e) shows changes of the Mer de Glace glacier in the Alps. It began to retreat in about 1852. **Figure 3(f)** shows its changes in more detail (von Michael Kuhn [35]. This particular glacier began to build up after 1550 (namely during the LIA) and began to retreat after 1850 (Holzhausen *et al.* [36]).

There are also various reports about advancing glaciers during the LIA in Scandinavia (cf. Lamb [1]). Therefore, it is clear that many glaciers advanced during the LIA before starting to retreat in about 1800-1850. Altogether, *long-term* glacier data presented here show that glaciers advanced from about 1400 and began to retreat rather steadily after 1800-1850. These facts confirm that the Earth experienced the LIA and began to recover from it as evidenced by a number of natural phenomena, such as retreating glaciers and sea ice from about 1800-1850 to the present. A large number of his-



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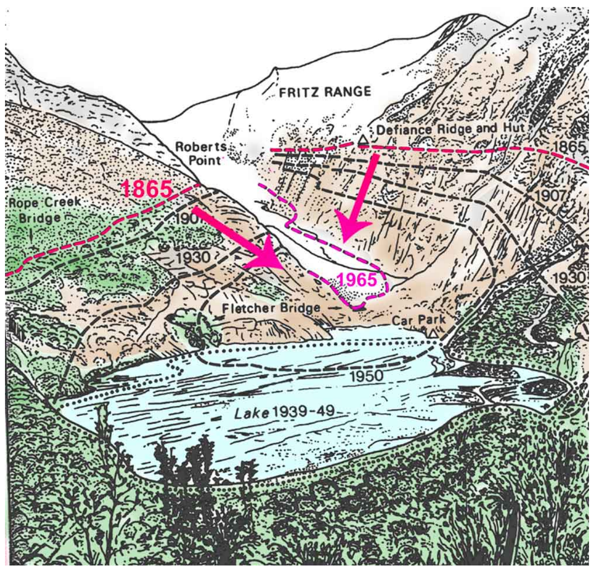

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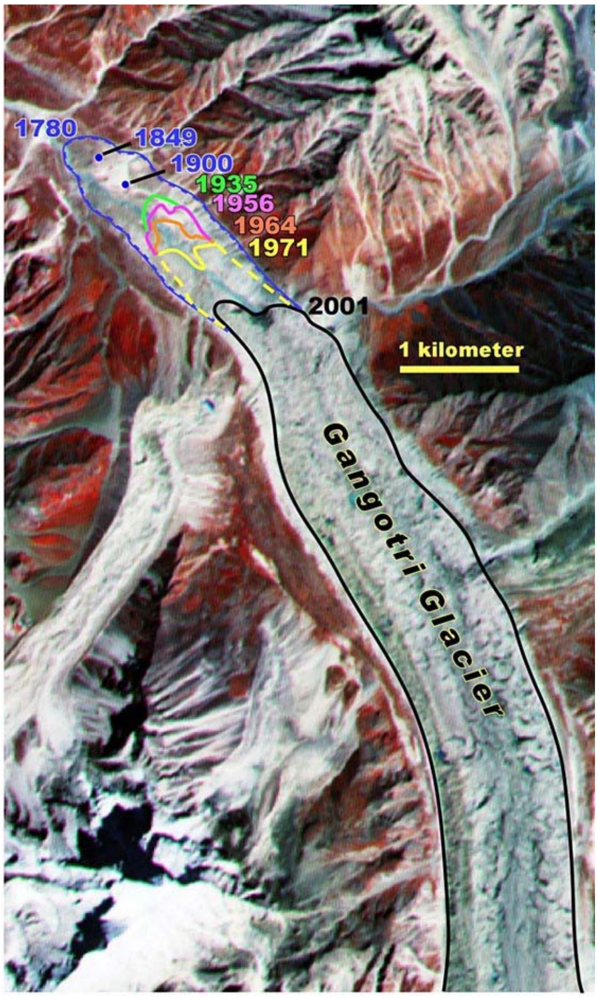
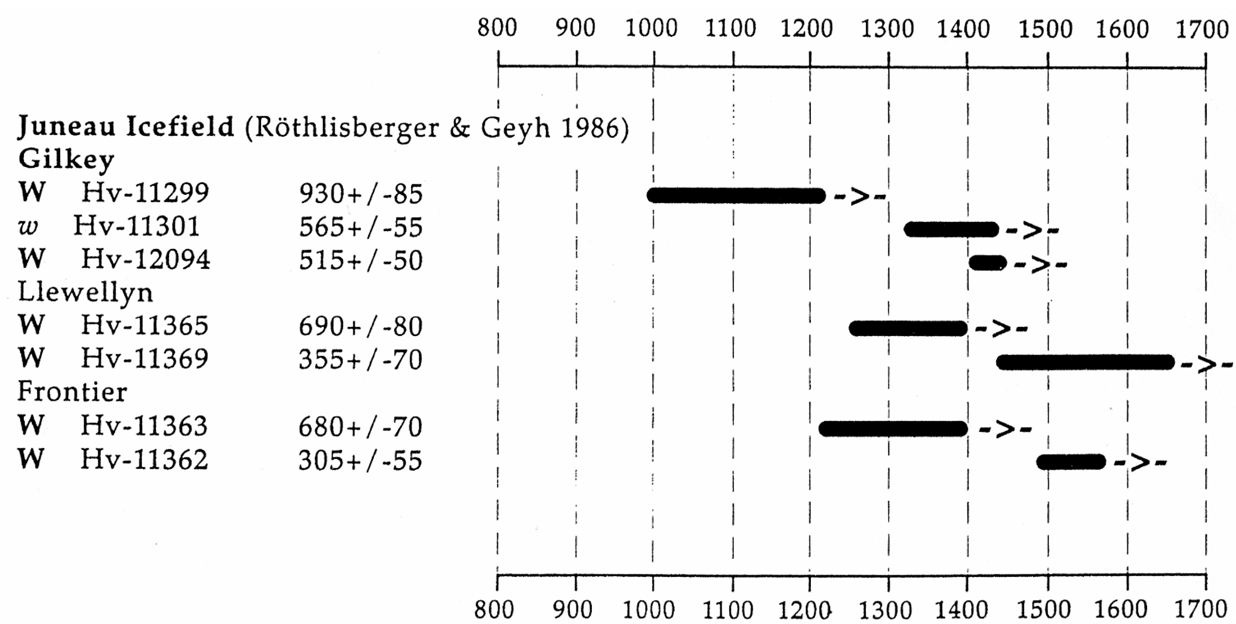

1780
1849
1900
1935
1956
1964
1971
2001
1 kilometer
Gangotri Glacier

(c)


800 900 1000 1100 1200 1300 1400 1500 1600 1700
Juneau Icefield (Röthlisberger & Geyh 1986)
Gilkey
W Hv-11299 930+/-85
w Hv-11301 565+/-55
W Hv-12094 515+/-50
Llewellyn
W Hv-11365 690+/-80
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Frontier
W Hv-11363 680+/-70
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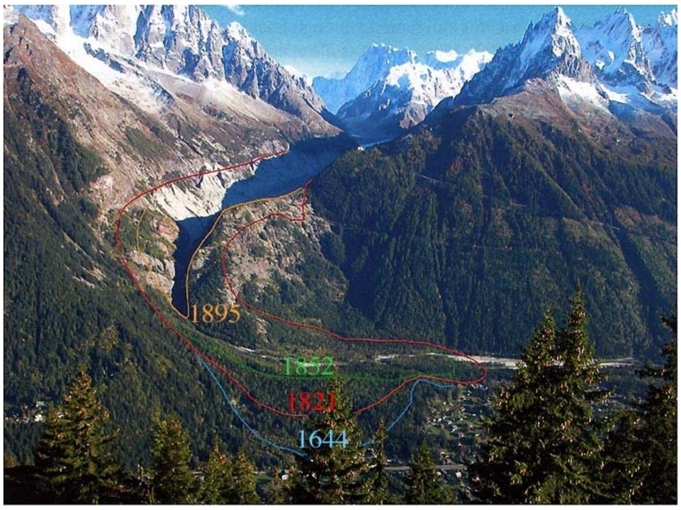
(d)



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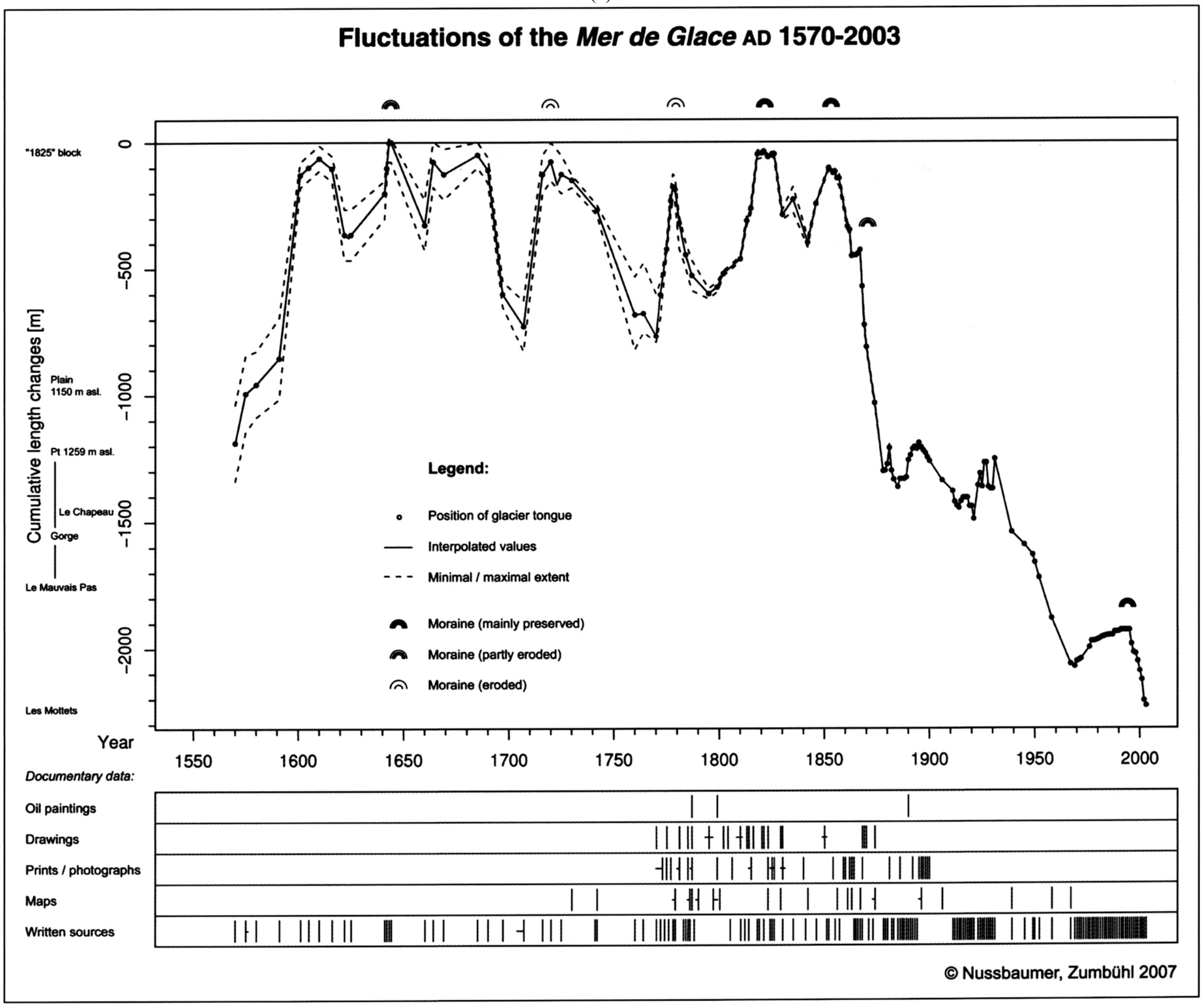


(f)

Figure 3. (a) Retreat of glaciers in Glacier Bay, Alaska (Molina [31]; (b) Retreat of the Franz Josef Glacier in New Zealand; the coloring is added by the present author for emphasis (Grove [2]); (c) The Gangotri Glacier in the Himalayas (Kargel [37]). It shows clearly that the retreat began even before 1800; (d) Radiocarbon dates related to glacial advances in the Juneau glaciers (Grove [34]); (e) The location of the terminus of the Mer de Glace glacier after 1644 (von Michael Kuhn [35]); (f) Details of the changes of the Mer de Glace glacier after 1550 (von Michael Kuhn [35]).

torical documents are also available that describe cool weather conditions during the LIA, such as freezing of the River Thames in the 1600 (Lamb [1]; Crowley and Nort [38]; Fagan [9]).

3. CONTINUATION OF THE RECOVER

3.1. The Linearity of the Recovery

In the previous section, we learned that the recovery from the LIA was continuous, although there are superposed 'fluctuations', which will be discussed in Section 5. In this section, we learn, on the basis of more accurate data gathered during the last century, that climate change examined in the previous section has continued to the present. With these data, we can examine more carefully the changes and, specifically the linearity of the changes.

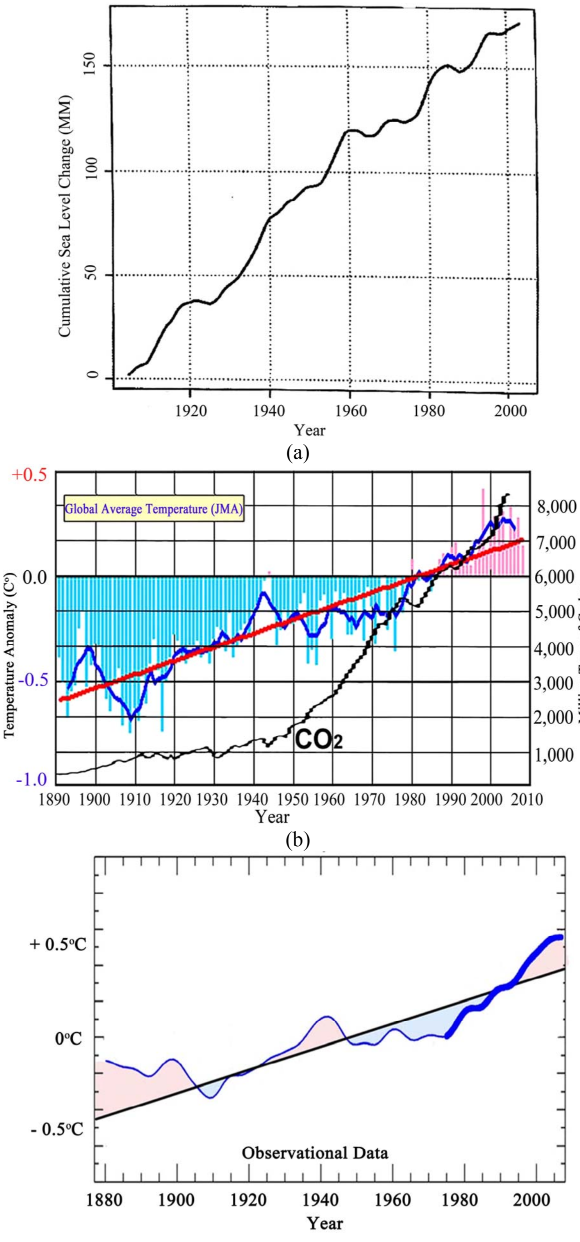
A recent study of sea level changes by Holgate [39] is shown in **Figure 4(a).** It shows the last part of **Figure 2(c)**. First of all, Holgate noted that the rate of sea level rise was about 1.7 mm/year. The sea level change is known to reflect the thermal expansion of seawater and glacier melting during the last half century. Comparing **Figure 4(a)** and **Figure 2(c),** it can be seen that the recovery from the LIA is a continuous process, without major change of the rising rate. This coverage is sufficient to show the linearity of the change from 1900 to 2000. Actually, comparing the slope between 1907–1960 and 1960–2000, the gradient has become smaller (1.4 mm/year) in the latter period (Holgate [39]). In fact, the rise of sea level nearly stopped after 2005 (Nerem *et al.* [40]). This point will be discussed in Section 5.

Figure 4(b) shows changes of the global average temperature from 1890 to 2007 (the Japan Meteorological Agency (JMA) [41]); the red line is added by the JMA. Very similar figures have been published by NASA (GISS), NOAA, and others. In **Figure 4(b)**, the amount of CO_2 released in the atmosphere is added; it can be seen that it began to rise rapidly in 1946. Although the global average temperature (T) changes can be approximated by a linear relation as a function of time (t) ($T = at$), CO_2 changes are more like $T = bt^2$.

Figure 4(c) presents schematically the above interpretation of global average temperature changes from 1880, indicating that the linear increase is superposed by 'fluctuations'. Changes above the linear line are shown in red and below in blue.

In examining the linearity of temperature changes during the last century, Bryant [43] noted that there are only a few points outside the 95% confidence limits of the linear approximation. The gradient of the straight line is about 0.5 °C/100 years. A much more detailed analysis of the trend was conducted by Wu *et al.* [44]; N.E. Huang, Research Center for Advanced Data Analysis, National Central University, Taiwan, called my attention to their paper after a draft of this paper was nearly completed. **Figure 4(d)** shows their results. The solid line indicates what we approximated by a linear line. Note that the gradient of the solid line from 1900 to 2000 is approximately 0.5 °C/100 years. The dashed line will be discussed in Section 5.

There have been a number of discussions of the temperature during the LIA. It ranges from 0.5 °C to 1.5 °C below the present temperature (see Lamb [1] 1982; Grove [2]). If we take it to be 1.0 °C mainly on the basis of Figures 1a and 1b, the rate of increase during the last 200 years, namely between 1800 and 2000, is about



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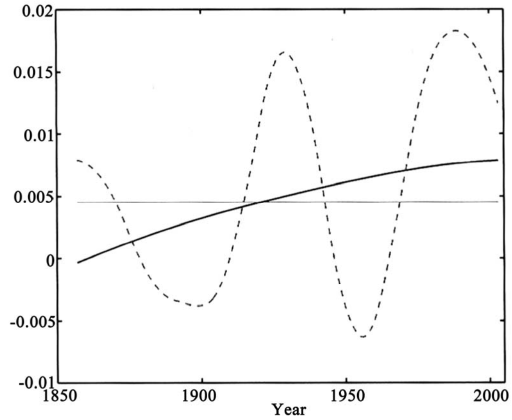

Rates of change (temporal derivative of a trend ,in degrees Kelvin per year) for the overall trend (thick solid line) and the multidecadal trend (the sum of C5 and C6 ,thick dashed line).

(d)

Figure 4. (a) The mean sea level record from nine tide gauges over the period 1904-2003 based on the decadal trend values for 1907-1999 (Holgate [39]); (b) Global average temperature (the Japan Meteorological Agency, JMA, [41]). The red straight line was drawn by the JMA. The amount of CO_2, which began to rise rapidly in 1946, is added for comparison; (c) An interpretation of **Figure 4(b)**, showing temperature changes that consist of a linear change and 'fluctuations' superposed on it. The temperature record (thin blue line) is taken from the NOAA report [42] (see the insert in **Figure 9**), which is basically a smoothed version of the 5-year mean in **Figure 4(b)**. The thick blue line from 1975 to 2000 will be discussed in Section 6; (d) The rates of temperature changes (per year) for the gradual increase (solid line) and the multi-decadal changes (dashed line) from 1850 to 2000 (Wu *et al.* [44]).

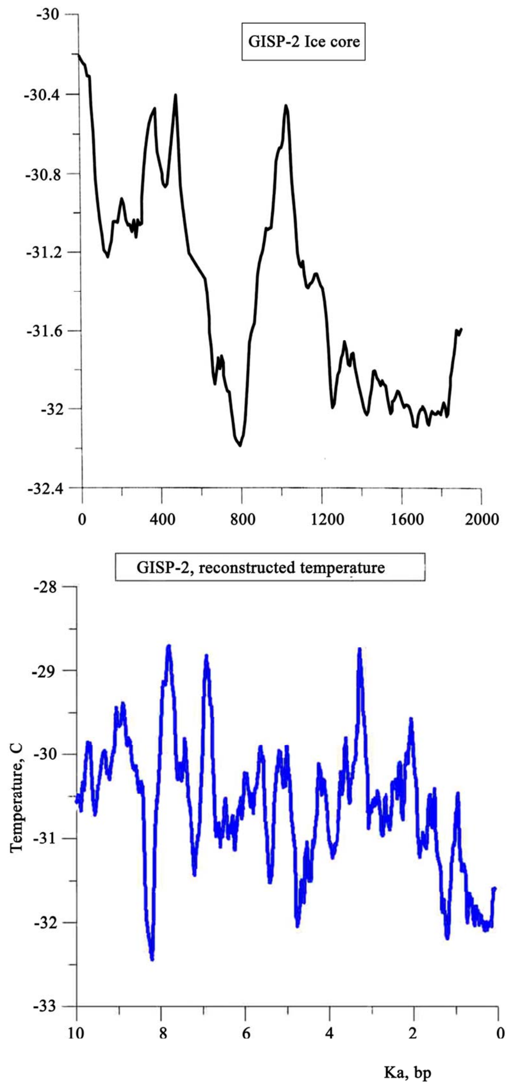

Figure 5. Ice core temperature at the GISP-2 site in Greenland, extending to 2000 years (left hand side and 10,000 years (right hand side), respectively (Alley [46].

0.5°C/100 years.

3.2. Did the Recovery from the LIA End before 1900 ?

On the basis of the above studies, we have learned that the recovery has continued to the present. The next question is " Did the recovery end before 1900?" A casual inspection of **Figures 1(a) and 1(b)** might give an impression that the Earth has recovered from the LIA, if we consider that the present level is the normal level. However, in meteorology and climatology, it is not possible to define the *absolute* normal level (baseline) from which deviations (warming or cooling) can be measured or the end of the LIA can be determined. When one examines data over a longer period (say, 2000 and 10,000 years), the present temperature can be below the average temperature for chosen periods. In **Figure 5**, one can see clearly that the average temperature of the 20th century is not useful in examining our question in this subsection. Similar long-period records were obtained by Keigwin [10] and Dale-Jensen *et al.* [45].

Further, it is very important to note that the temperature is in a rising trend in the last part. Thus, although it is generally believed that the recovery from the LIA ended some time ago, there is no basis to define the ending year of the LIA. It is more likely that the Earth is still in the process of recovery. What we have learned so far has a significant implication for understanding the temperature rise in the 20th century. This point will be discussed in Section 6 (see **Figure 9**).

4. POSSIBLE SOLAR CAUSES.

It is not the purpose of this section to discuss any major causes of climate change. We learn only, on the basis of the valuable cosmic-ray intensity data, that solar activity was low in general during the LIA and *began to recover about* 1800. A number of studies have suggested that the LIA coincided with the Maunder Minimum period (cf. Burroughs [47]). This is because the Maunder Minimum happened to occur during the LIA. We see here a much longer period record.

The fact that the cosmic-ray intensity varied during the LIA suggests that non-terrestrial forces, more specifically solar activity, are involved in some components of climate change (cf. Lang [48]; Burroughs [47]). **Figure 6** shows the solar modulation function deduced from 10Be and 14C records from 1000 to 2000 (Muscheler *et al.* [49]). When the solar modulation function is low, solar activity is low (but, the cosmic-ray intensity is high), while it is high, solar activity is high (but, the cosmic-ray intensity is low). It is known that solar activity is represented by the sunspot number and its changes are well correlated with changes of the solar irradiance (Lean *et al.* [50]).

Therefore, **Figure 6** represents the trend of changes of solar activity from 1000 to 2000, which may be compared with **Figure 1(a) or 1(b)**. It can be seen that solar activity was relatively low during the LIA and *began to recover* in about 1800. Therefore, it may be speculated that solar irradiance is involved in causing the LIA and its recovery.

Changes of the solar irradiance during the sunspot cycle are rather small (1.3W/m2). However, the difference between the LIA period and the present may be a few times greater than 1.3W/m2 (Lean et al. [50]. Therefore, although Nozawa *et al.* [51] showed that the solar effect on temperature changes during the 20th century was small, this subject requires much more detailed study with newer Global Climate Models by taking into account a *prolonged period* of a low solar irradiance (Scafetta and West [52]), at least as its triggering effects. Note that as **Figure 1(a) and 1(b)** show, the LIA began in about 1200 or 1300, and such a prolonged period of low solar irradiance may cause a significant climate change (cf. Scafetta and West [52,53]). In this paper, we are mainly interested in possible causes of a long period change like the LIA. On the other hand, Soon [54] examined the solar effect of a shorter period (130 years) and found a significant correlation with arctic temperature variations.

In **Figure 6**, several minima, the Oort Minimum (1000-1100), the Wolf Minimum (1250-1350), the Spoer Minimum (1380-1510), and the Maunder Minimum (1620-1720), may be noted (cf. Dehau and de Jager [55]). Intermittent increases of the solar modulation function (thus, low cosmic-ray intensities) were caused by a high solar activity. In fact, as **Figure 1(a) and 1(b)** suggest, the LIA was not a continuously cool period (see Lamb [1] and Fagan [9]). Since it is known that the solar activity represented by the sunspot number correlates well with

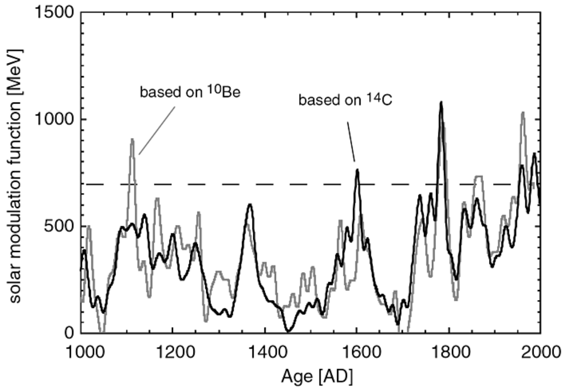

Figure 6. The solar modulation function of cosmic rays deduced from 10Be and 14C records (Muscheler *et al.* [49]).

the solar irradiance, **Figure 6** represents the general trend of changes of the solar irradiance among others.

5. MULTI-DECADAL CHANGE

It is not the purpose of this section to discuss the multi-decadal changes in detail. The sole purpose is to explain why the warming has halted after 2000, despite the fact that we concluded in the previous sections that the Earth is still in the recovery process from the LIA. **Figure 7** shows this halting (Kerr [56]).

In Section 3, we suggested that the prominent 'fluctuations' superposed on the linear recovery are the multi-decadal oscillation. **Figure 4(d)** shows its rate of changes. From **Figures 4(c) and 4(d)**, the multi-decadal oscillation peaked in 1940, and the temperature actually decreased from the level of the linear increase from 1940 to 1975 and then increased after 1975 to 2000. Thus, it may be speculated that the situation in 2000 is similar to that in 1940, so that it is predicted that the temperature change will be flat or in a slightly declining trend during the next 30 years or so (see Section 6 and **Figure 9**). That is to say, the halting does not mean the end of the recov-

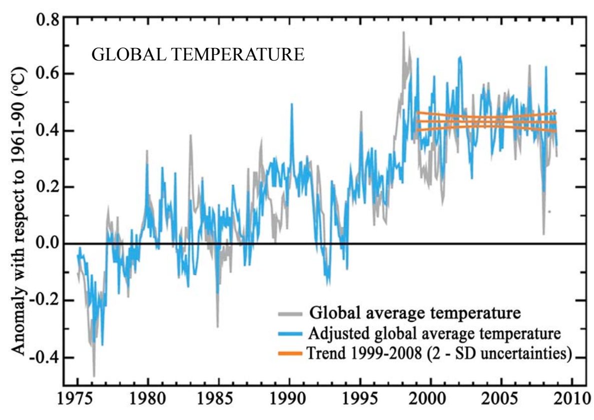

Figure 7. The global average temperature changes during the last several decades (Kerr [56]).

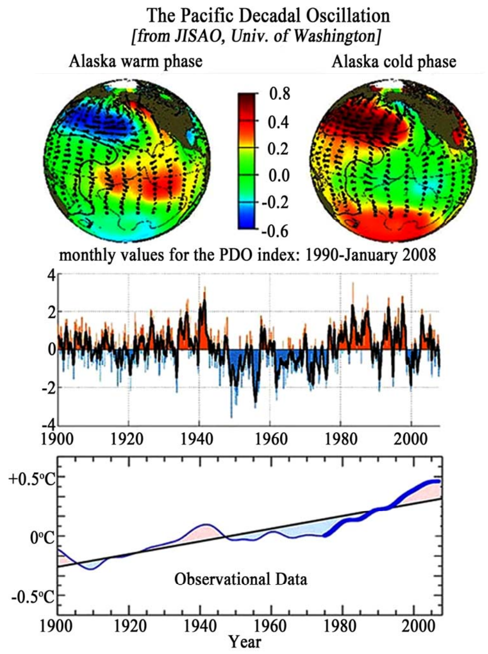

Figure 8. The PDO wind pattern and the PDO index (University of Washington [57]). The bottom diagram is the same as **Figure 4(c)**.

ery from the LIA. The halting after 2000 can be observed in sea level change (Nerem *et al*. [40]), a decrease of the heat content of the oceans (Pielke, Sr. [58]) and other factors.

The multi-decadal oscillation can be seen in other phenomena. **Figure 8** shows the pattern of the Pacific Decadal Oscillation (PDO), which is a natural phenomenon (University of Washington [58]). Top part shows the observed wind pattern over the Pacific Ocean. The middle part shows the PDO index. It is interesting to note a striking resemblance of changes between PDO and the multi-decadal oscillation (at the bottom, **Figure 4(c)** is reproduced for comparison.). Although there is some phase difference between them, this similarity supports the inference that the fluctuations superposed on the linear change (the recovery from the LIA) are in part the multi-decadal oscillation. The Pacific Ocean is large enough to contribute to the global average temperature. Polyakov *et al.* [59] showed that the Arctic Ocean shows a similar trend.

6. Summary

It may be appropriate to summarize results in sections

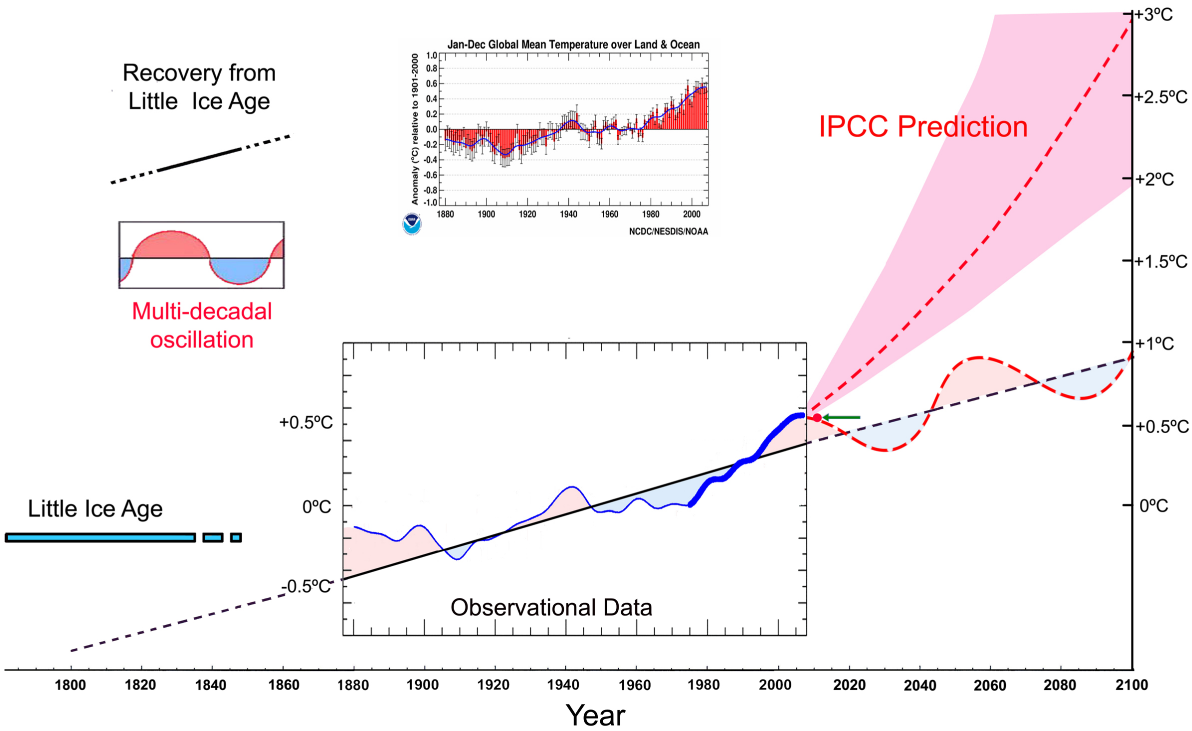

Figure 9. The figure shows that the linear trend between 1880 and 2000 is a continuation of recovery from the LIA, together with the superposed multi-decadal oscillation. It shows also the predicted temperature rise by the IPCC after 2000. It is assumed that the recovery from the LIA would continue to 2100, together with the superposed multi-decadal oscillation. This view could explain the halting of the warming after 2000. The observed temperature in 2008 is shown by a red dot with a green arrow. It has been suggested by the IPCC [60] that the thick blue line portion was caused mostly by the greenhouse effect, so their future prediction is a sort of extension of the blue line.

1-5 on the basis of **Figure 9.** The large box is the same as **Figure 4(c).** The figure suggests that temperature changes from 1800 to 2000 can be explained mainly as a combination of the linear increase from about 1800-1850 and the multi-decadal oscillation. The blue line is taken from the NOAA data shown in a small box above the large box. The meaning of the *linearity* of the recovery from 1800-1850 is crucial in considering the cause of the warming in the last century (the amount of CO_2 in 2000 was at least 14 times greater than that in 1900 and was even much greater in 1850), so it is difficult to associate the linear warming only with CO_2. The temperature rise from 1800-1850 to the present is fairly steady. Therefore, it is not unreasonable to assume the rise after 1900 is a continuation of the same process, namely the recovery from the LIA. Assuming that the recovery from the LIA and the multi-decadal oscillation would continue during the next 100 years or so, the future trend until 2100 is predicted in **Figure 9.** The observed temperature in 2008 is shown by a red dot with a green arrow. It has been suggested by the IPCC [60] that the thick blue line portion was caused mostly by the greenhouse effect, so their future prediction is a sort of extension of the blue line.

7. CONCLUSIONS

In this paper we learned:

1) The Earth experienced the Little Ice Age (LIA) between 1200-1400 and 1800-1850. The temperature during the LIA is expected to be 1°C lower than the present temperature. The solar irradiance was relatively low during the LIA.

2) The gradual recovery from 1800-1850 was approximately *linear*, the recovery (warming) rate was about 0.5°C/100 years. The same linear change continued from 1800-1850 to 2000. In this period, the solar irradiance began to recover from its low value during the LIA.

3) The recovery from the LIA is still continuing today.

4) The multi-decadal oscillation is superposed on the linear change. The multi-decadal oscillation peaked in about 1940 and also in 2000, causing the temporal halting of the recovery from the LIA.

5) The negative trend after the peak in 1940 and 2000 overwhelmed the linear trend of the recovery, causing the cooling or halting of warming.

6) The view presented in this paper predicts the temperature increase in 2100 to be 0.5°C ± 0.2°C, rather than 4° C ± 2.0°C predicted by the IPCC.

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