Is the Earth still recovering from the "Little Ice Age"?

A possible cause of global warming

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Abstract

There seems to be a roughly linear increase of the temperature from about 1800, or even much earlier, to the present. This warming trend is likely to be a natural change; a rapid increase of CO_2 began in about 1940. This trend should be subtracted from the temperature data during the last 100 years. Thus, there is a possibility that only a fraction of the present warming trend may be attributed to the greenhouse effect resulting from human activities. This conclusion is contrary to the IPCC (2007) Report, which states that "most" of the present warming is due to the greenhouse effect. One possible cause of the linear increase may be that the Earth is still recovering from the Little Ice Age. It is urgent that natural changes be correctly identified and removed accurately from the presently on-going changes in order to find the contribution of the greenhouse effect.

1. Introduction

There are many documents that suggest that the period between 1500 and 1900 was relatively cool, at least in Europe; the River Thames was frequently frozen in 1676 and in the later part of the 17th century (Lamb, 1982). Stories of the exploration of the Northwest Passage also hint that sea ice conditions in northern Canada in the latter part of the 1800s were much worse than conditions today. It is now possible to cruise the passage without much assistance by icebreakers. Although there is some doubt about the exact timing of the "Little Ice Age," it is possible to infer that the period between 1500 and 1900 was relatively cool in many parts of the world, including Alaska (cf. Lamb, 1982; Gribbin (ed.), 1978; Crowley and North, 1991; Burroughs, 2001; Serreze and Barry, 2005).

Climate change during the last 100 years or so has been intensely discussed over the last few decades. However, it is important to recognize that as far as the *basic* global warming data for this period are concerned, all we have is what is illustrated in the top of the diagram of Figure 1. The IPCC Reports state that the global average temperature increased about 0.6°C (~1°F) during the last 100 years. Their interpretation may be illustrated in the second diagram of Figure 1. Certainly, both the temperature and the amount of CO_2 in the air have increased during the last 100 years or so. Further, it is well known that CO_2 causes the greenhouse effect; therefore, it is natural to hypothesize that CO_2 is a cause of the present warming trend.

However, there is so far no definitive proof that "most" of the present warming is due to the greenhouse effect, as is stated in the recently published IPCC Report (2007). In fact, the relationship between air temperature and CO_2 is not simple. For example, the temperature had a cooling trend from 1940 to about 1975, in spite of the fact that atmospheric CO_2 began to increase rapidly in about 1940, as can be seen in Figure 1.

In this note, it is pointed out that it is not possible to determine the percentage contribution of the greenhouse effect that is a direct result of human activities, unless natural causes can be identified and subtracted from the present warming trend.

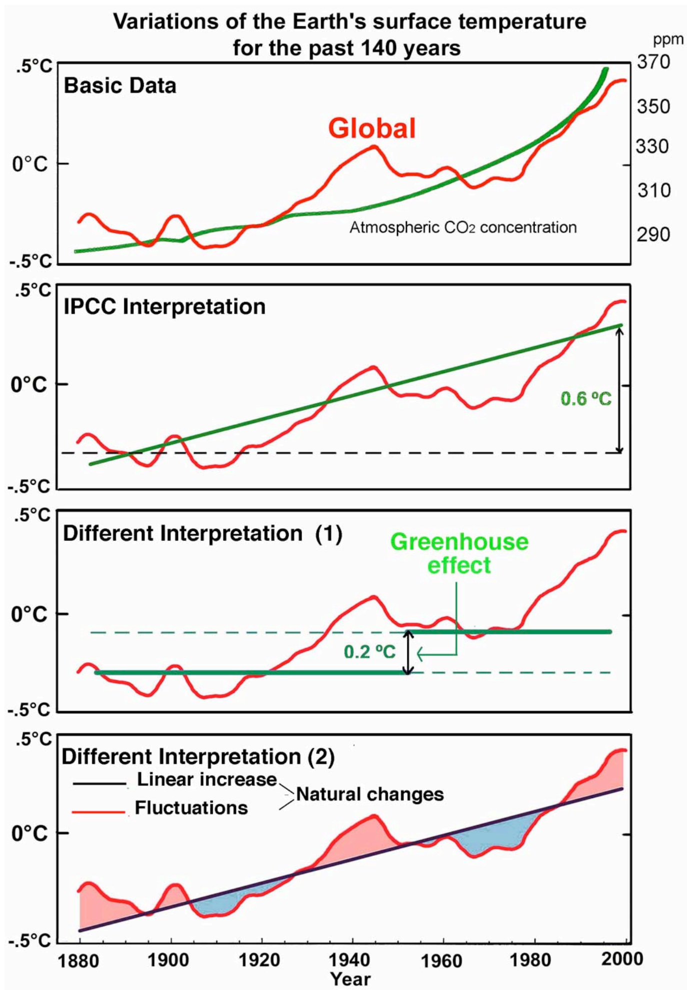

Figure 1: From the top, the basic data on global warming: the IPCC interpretation (indicating that the 0.6°C increase is caused by the greenhouse effect), another interpretation, suggesting a baseline change of 0.2°C/100 years and additional fluctuations, and yet another interpretation, a linear natural change superposed by natural fluctuations.

Actually, there are many other ways to interpret the temperature changes than what is shown in the second diagram of Figure 1. For example, the third diagram shows another interpretation. In this interpretation, it is assumed that there was a base increase of about 0.2°C during the last 100 years, which was superposed by fluctuations, such as multi-decadal oscillations. The fourth diagram shows yet another interpretation. In this interpretation, there was an almost linear increase of natural temperature change during the last 100 years, which is superposed by fluctuations, such as multi-decadal oscillations. The difference between the second and fourth diagrams is that the IPCC Report assumes that the warming trend is *mostly* due to human activities, while the latter assumes that a large fraction of the warming trend is caused by natural causes.

It is somewhat surprising that there has, so far, been no debate on such, and many other possibilities. Indeed, it is doubtful that the IPCC conclusion of "most" is the consensus of 250 experts in climatology. The greenhouse effect is a hypothesis to be proven quantitatively. Further, even if proven qualitatively, it is necessary to investigate, quantitatively, how large its effect is. At this stage in the development of modeling and simulation, one can test the hypothesis only qualitatively, not quantitatively, because there are too many uncertain parameters in the modelings. This point will be discussed later.

Figure 2 shows both the global average temperature and the temperature from stations widely distributed along the coast of the Arctic Ocean (Polyakov et al., 2002) during the last 100 years or so. One can see that the magnitude of temperature changes is significantly larger in the Arctic. A similar result was shown in the ACIA Report (2004); see p. 23. In particular, fluctuations, including multi-decadal oscillations, are greatly "amplified" in the Arctic. There occurred two major fluctuations, one between 1910 and 1975, and one after 1975. The arctic data indicates that the two fluctuations in the global average data should not be treated as minor fluctuations to be ignored. Indeed, it is crucial to investigate the nature of the temperature rise between 1910-1940 and also the one after 1975. As the top diagram in Figure 1 shows, CO_2 in the atmosphere began to increase rapidly after 1940, when the temperature decreased from 1940 to 1975. Thus, the large fluctuation between 1910 and 1975 can be considered to be a natural change. Therefore, unless the difference between the two changes can be understood, it is not possible to say tacitly that the rise after 1975 is mostly caused by the greenhouse effect.

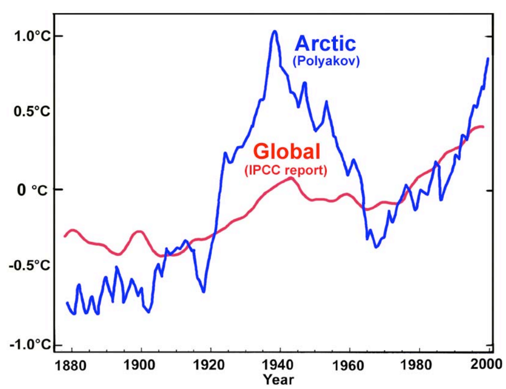

Figure 2: Red – global average change (IPCC Reports). Blue – data from stations along the coastline of the Arctic Ocean (Polyakov, et al., 2002.)

In this note, we examine first the possibility of the last case in Figure 1 and then the nature of the fluctuations.

2. Linear Increase

The basis for drawing a linear line, in the last diagram in Figure 1, is weak without additional data. Fortunately, Frizsche et al. (2006) obtained ice cores from Severnaya Zemlya, an island in the Arctic Ocean, and made the O(18) analysis. Their results are reproduced here as Figure 3. It shows the O(18) data at the top: It is possible to observe that an almost linear change is evident from about 1800 to the present in the ice core record; the red linear line is drawn by the present author; large fluctuations are also indicated as "natural changes" also by the author, since it is unlikely that CO_2 caused any major temperature fluctuations before 1940.

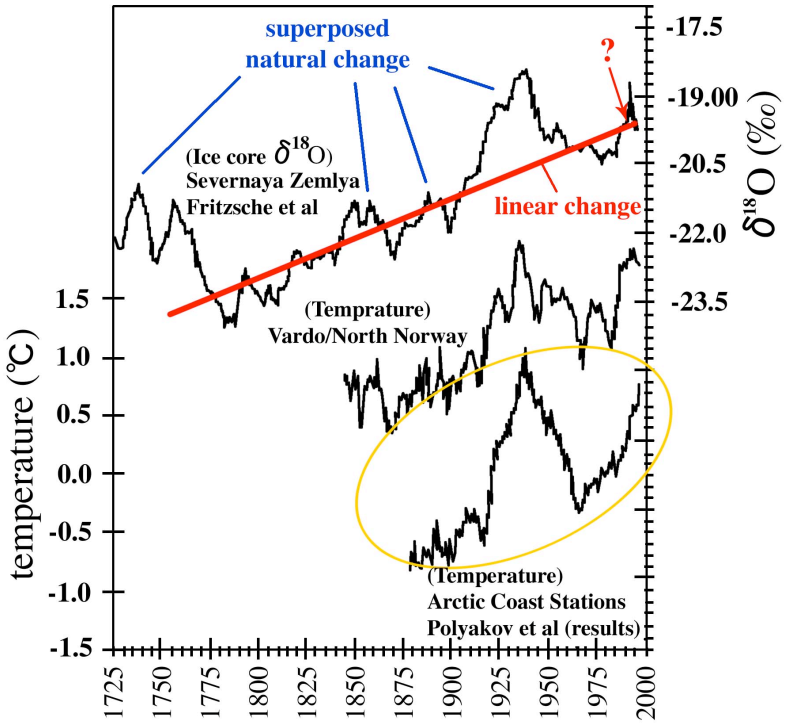

Figure 3: Late Halocene ice core record from Akademii Nauk Ice Cap, Severnaya Zemlya, Russian Arctic, together with temperature records at Vardo, Norway, and along the artic coast stations (Polyakov et al., 2002), the last one is the same as that in Figure 2 (blue).

Their figure shows also a thermometer record from Vardo in Northern Norway. The bottom diagram is the same as the "Arctic" one of Figure 2. The credibility of the ice core record is supported by the similarity with the Norwegian temperature record and the data by Polyakov et al. (2002), or vice versa.

The ACIA Report (2004) took the *average* of 100-year records as the baseline (their figure on page 23), namely, a line parallel to the horizontal axis, with the average value as the zero line. However, the ice-core record shows that such a practice may not be appropriate. There is clearly a linear increase of temperature from about 1800. Similar linear trends can be inferred in the Norwegian data and the data by Polyakov et al. (2002) in Figure 3 based on the core record. There are several other supporting studies that suggest that there has been a linear change from about 1800 or earlier. For example, Figures 4, 5, 6, and 7 suggest a roughly linear change of temperature from the earliest recordings by Burroughs (2001), Tarand and Nordli (2001), and van Egelen et al. (2001).

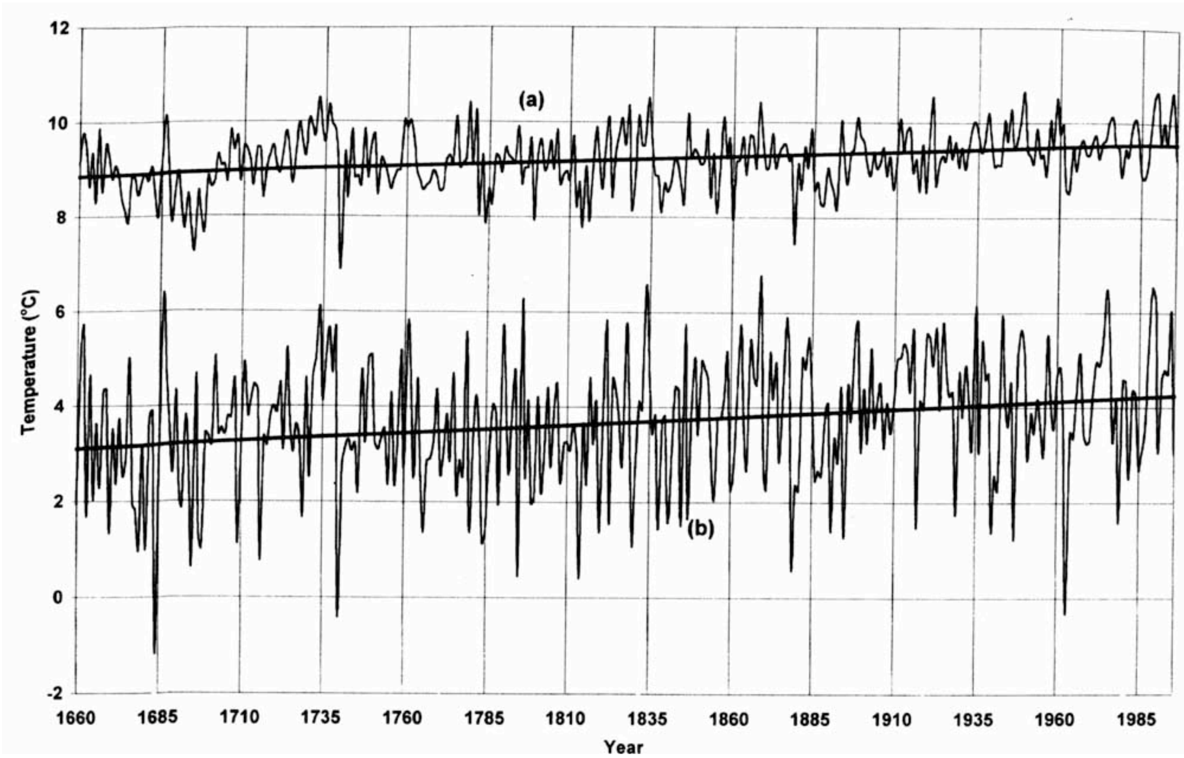

Figure 4: The linear trends for the temperature of central England over the period 1660-1996 for (a) the annual data, and (b) the winter months (December to February), show a marked warming. In both cases, this warming is significant, but although the temperature rise is greater in winter, this trend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

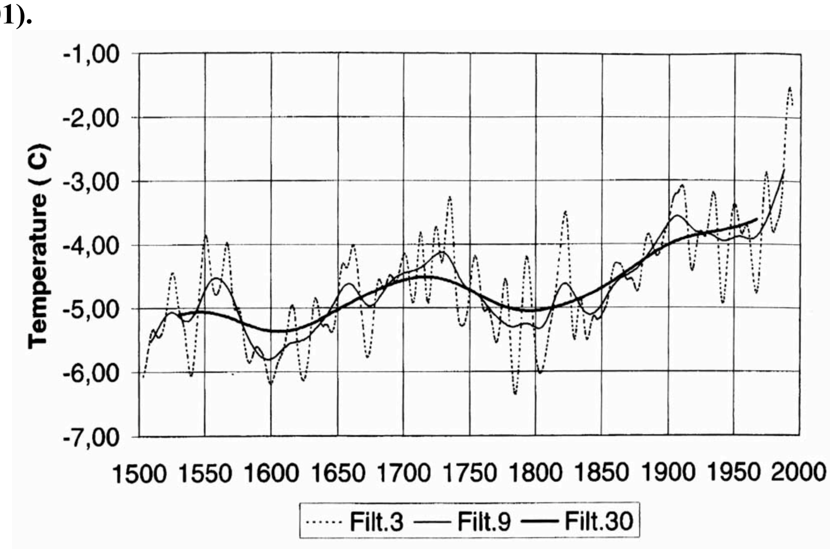

Figure 5: Winter temperature (December-March) at Tallinn since 1500, which are based on ice break-up dates in Tallinn port. The series is smoothed by Gaussian filters of 3, 9, and 30 years as standard deviations in the Gaussian distribution (Tarand and Nordli, 2001).

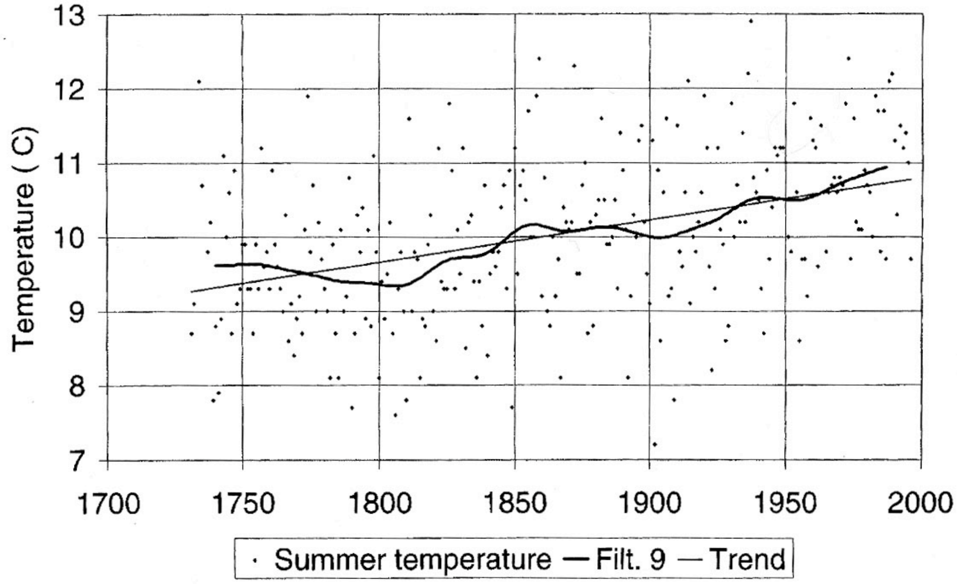

Figure 6: Summer temperature (April to July) for Tallinn, which is based on ice break-up and rye harvest data and of instrumental observations. To ease the study of variations on a timescale of approximately 30 hours, the observations are smoothed by a Gaussian filter with standard deviation of 9 years in its distribution (curve). A trend line for the whole period is also shown; Tarand and Nordli (2001)

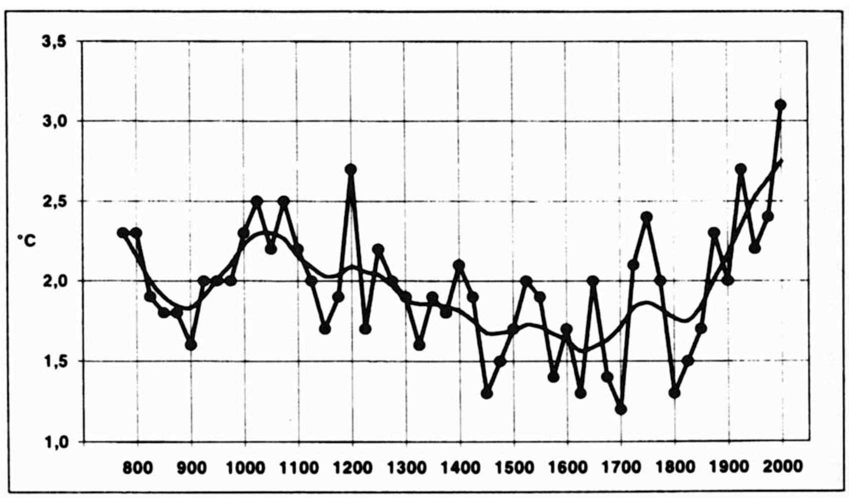

Figure 7: 25-year mean winter (DJF) temperature at De Bilt; van Egelen, Buisman and Ijnsen (2001). This figure includes a longer period data than Figures 4, 5, and 6.

There is further supporting evidence of a continuous climate change from about 1800. Figure 8 shows that the southern edge of sea ice in the Norwegian Sea has been continuously receding from about 1800. Figure 9 shows examples of glaciers in Greenland and Alaska, which have been receding from the time of the earliest records (about 1800 for Greenland and 1900 for Alaska). There are a large number of similar records from the European Alps and elsewhere (Grove, 1982). Therefore, it can be assumed that many glaciers advanced during the Little Ice

Age and have been receding since then. Thus, the retreat is not something that happened only in recent years.

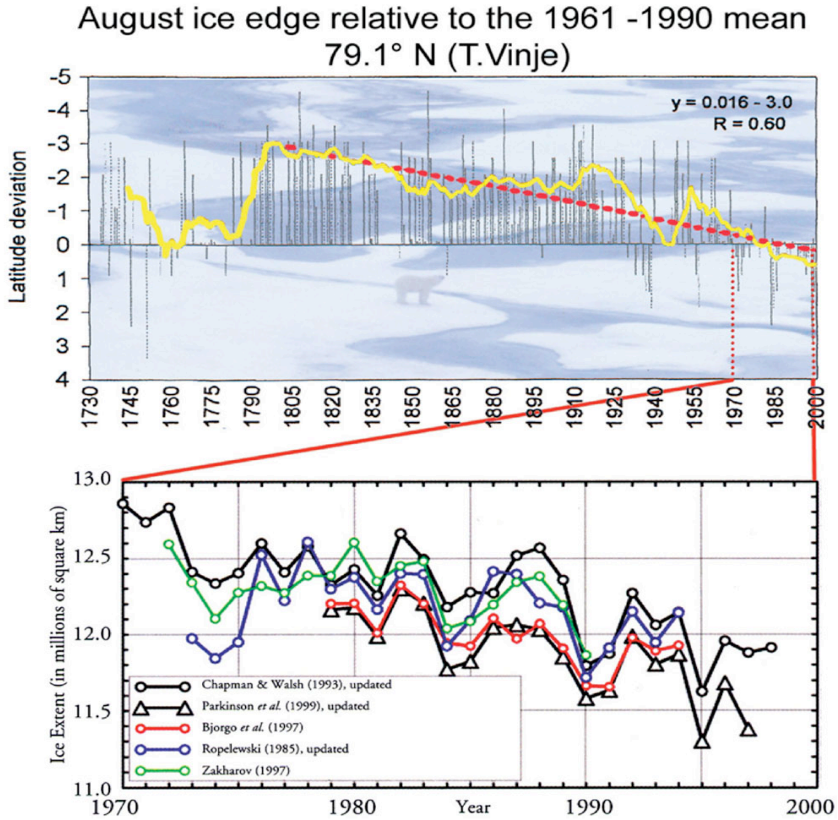

Figure 8: Retreat of sea ice in the Norwegian Sea (Vinje, 2001).

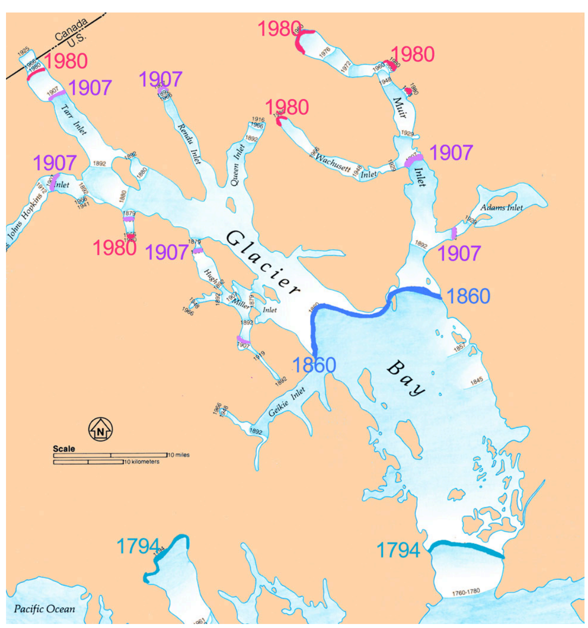

Figure 9: Retreat of glaciers in Glacier Bay (Alaska Geographic, 1993)

The fact that an almost linear change has been progressing, without a distinct change of slope, from as early as 1800 or even earlier (about 1660, even before the Industrial Revolution), suggests that the linear change is natural change. As shown at the top diagram of Figure 1, a rapid increase of CO_2 began only after 1940.

As far as the gradient of the linear change is concerned, it can roughly be estimated to be about 0.5°C/100 years based on Figures 3, 4, 5, 6, and 7. *It is very interesting to recognize that this gradient is almost comparable with the IPCC's estimate of 0.6°C/100 years.* Since the maximum decrease of temperature during the Little Ice Age is estimated to be about 0.5°C (Wilson et al, 2000) – 1.5°C (Crowley and North, 1991; Grove, 2005), it is worthwhile to speculate that the Earth is still recovering from it. Another possible additional cause may be changes in solar output (cf. Scafetta and West, 2006), which we did not investigate in this note.

Therefore, the linear change, which is likely to be a natural change, should be subtracted from the top diagram of Figure 1 in order to identify and estimate the greenhouse effect.

However, this note is not intended to evaluate an accurate estimate of the gradient of the linear change. There is a great uncertainty in obtaining early data corresponding to the accuracy of the top of Figure 1 in terms of the geographic distribution of the stations, seasons, etc. Here, I emphasize only that a significant part of the 0.6°C increase includes natural changes, contrary to the statement by the IPCC Report (2007).

At this point, we encounter one of the fundamental problems in climatology and also meteorology. Is there any definitive evidence to conclude that the Little Ice Age ended by 1900? More fundamentally, how can we determine the "normal" or "standard" temperature from which deviations (warming or cooling) are considered to be abnormal? At this time, there is no reference level to conclude that the Little Ice Age was over by about 1900.

Further, the IPCC Report (2007) states that the present high temperature is "unusual" except for about 130,000 years ago (p. 10). However, if we examine the temperatures during all the other interglacial periods (240,000, 330,000, 400,000 years ago), each period was warmer than the present one. Thus, it could be said that the present interglacial period was abnormally a cool one. In fact, even during the present interglacial period, the temperature was a little warmer than the present one for a few thousand years at its beginning (cf. Wilson et al., 2000).

3. How Linear is the Linear Change?

It is reasonable to expect that the linear change is only a rough first approximation. An accurate examination is expected to show deviations from the linear trend, if the greenhouse effect is significant, namely an upward deviation after 1940. However, this may be hard to examine because the linear change is superposed by large fluctuations.

In this respect, it is interesting to note a recent study of sea level changes (Holgate, 2006); it is shown in Figure 10. Although the data covers only the period after 1910, it is sufficient to view any indication of accelerated increase of sea level after 1940. The sea level change should reflect the expected changes associated with the thermal expansion of seawater and glacier melting changes during the last half century that were mentioned in the IPCC Reports. Figure 10 shows that there is no clear indication of an accelerated increase of sea level after 1940, even if some individual glaciers in the world show accelerated receding.

As will be discussed in the next section, the most prominent warming during the last half of the last century has ceased during the last twenty years. In this connection, it might be added that both seawater (Lynn et al., 2006) and permafrost temperatures (Richter-Menge et al., 2006), as well as the amount of CH_4, have ceased to increase from about 2000. It is puzzling why they do not show an accelerated increase if their increase before 2000 was due to the greenhouse effect; they may be temporal fluctuations.

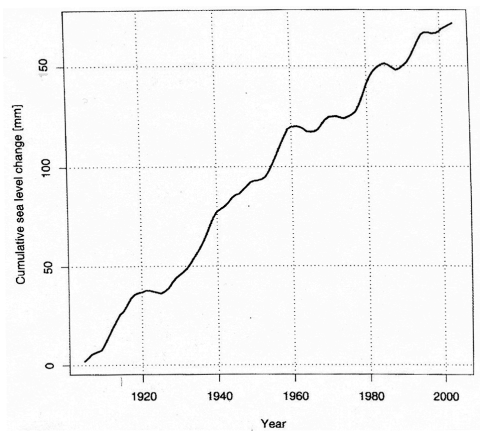

Figure 10: The mean sea level record from the nine tide gauges over the period 1904-2003 based on the decadal trend values for 1907-1999. The sea level curve here is the integral of the rates; (Holgate, 2007).

4. Fluctuations

As shown in Figure 2, two prominent fluctuations occurred during the last 100 years. The first one was a temperature rise from 1910 to 1940 and the subsequent decrease from 1940 to about 1975 (Figures 1 and 2). The second one is the present rise after 1975. As stated earlier, it is crucial to examine if both rises are due to the same, similar, or entirely different causes. Until some study can provide convincing results on this problem, we should not claim that the rise after 1975 is mostly due to the greenhouse effect.

It is interesting to note from the original paper from Jones (1987, 1994) that the first temperature change from 1910 to 1975 occurred only in the Northern Hemisphere. Further, it occurred in high latitudes above 50° in latitude (Serreze and Francis, 2006). The present rise after 1975 is also confined to the Northern Hemisphere, and is not apparent in the Southern Hemisphere; there may be a problem due to the lack of stations in the Southern Hemisphere, but the Antarctic shows a cooling trend during 1986-2005 (Hansen, 2006).

Thus, it is not accurate to claim that the two changes are a truly *global* phenomenon, even if *averaging* the data from both hemispheres can provide Figure 1. Since the greenhouse effect is supposed to be global, the two prominent changes may be considered to be regional changes. Thus, there is a possibility that both increases are natural changes, unless it can be shown definitely that such regional changes are caused by the greenhouse effect.

If so, it may not be very difficult, after all, to remove the two prominent fluctuations from the changes during the last 100 years. As a *very rough* first approximation, fluctuations above and below the linear change can also be regarded as natural changes.

It is important to note that the present global warming after 1975 is not uniform over the Earth. Although a single number, namely +0.6°C/100 years, is used in discussing global warming, the geographic distribution of "warming" is quite complex. The upper part of Figure 11 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, namely in the continental arctic. In the continental arctic, the warming rate was several times more than the global average of 0.6°C/100 years (0.6°C/2=0.3°C/50 years). It may be also noted that cooling was in progress in Greenland over the same time period.

It is of great interest to ask if GCMs can reproduce this geographic distribution of the observed changes shown in the upper part of Figure 11. Thus, we asked the IPCC arctic group (consisting of 14 sub-groups headed by V. Kattsov) to "hindcast" geographic distribution of the temperature change during the last half of the last century. To "hindcast" means to ask whether a model can produce results that match the known observations of the past; if a model can do this, we can be much more confident that the model is reliable for predicting future conditions Their results are compiled by Bill Chapman, of the University of Illinois, and are shown in the right side of Figure 12. The left side of the figure is taken from the ACIA Report (2004), which shows a similar trend as that of the upper part of Figure 11, namely the prominent warming in the continental arctic and cooling in Greenland. This comparison was undertaken to reduce differences between them, because both are expected to be imperfect.

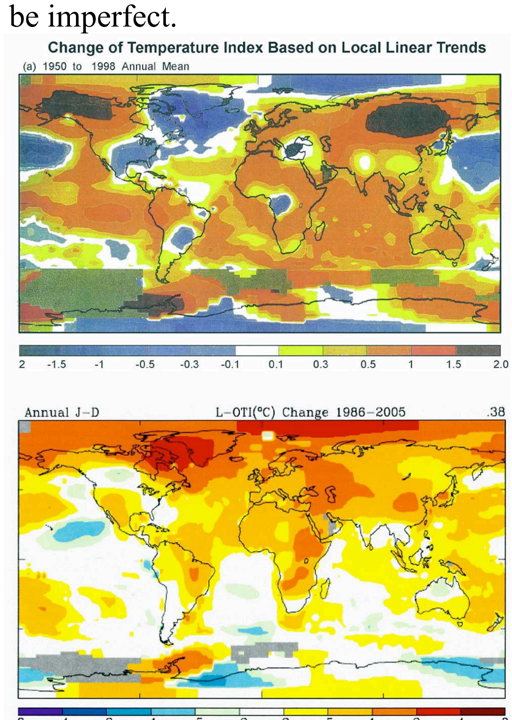

Figure 11: Upper – the geographic distribution of temperature change between 1950 and 1998 (Hansen et al., 2005). Lower – the geographic distribution of temperature change between 1986 and 2005 (Hansen, 2006).

We were surprised at the difference between the two diagrams in Figure 12. If both were reasonably accurate, they should look alike. Ideally, the pattern of change modeled by the GCMs should be identical or very similar to the pattern seen in the measured data. We assumed that the present GCMs would reproduce the observed pattern with at least reasonable fidelity. However, we found that there was no resemblance at all.

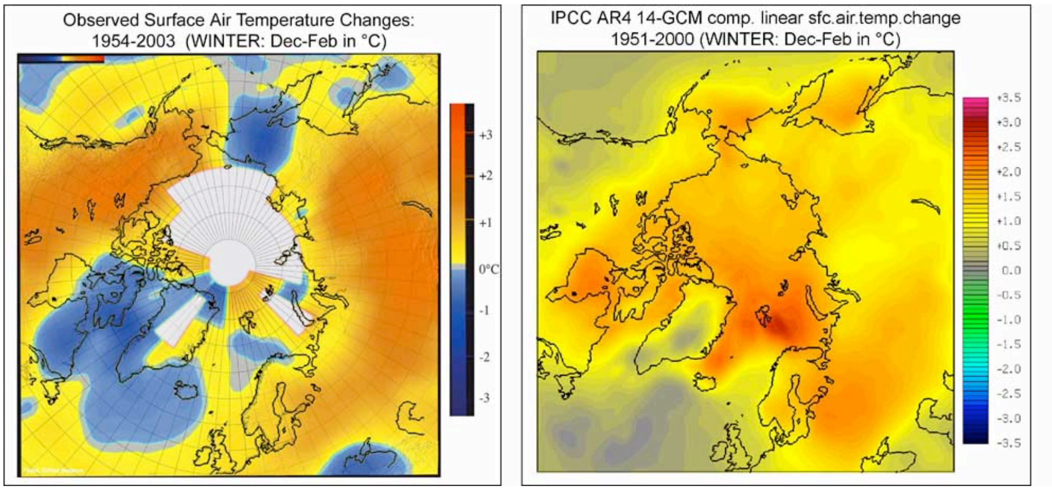

Figure 12: Comparison of the observed distribution of temperature changes (ACIA, 2004) and the simulation ("hindcasting") by the IPCC arctic group.

Our first reaction to this surprising result was that GCMs are still not advanced enough for hindcasting. However, this possibility is inconceivable, because the increase of CO_2 measured in the past is correctly used in the hindcasting, and everything we know is included in the computation. The IPCC arctic group's result is the best result that is possible based on our present knowledge. If the greenhouse effect caused the warming, it should be reproducible to some extent by these models, even if the reproduction is not perfect. It took a week or so before we began to realize another possibility of this discrepancy: If 14 GCMs cannot reproduce prominent warming in the continental arctic, perhaps much of this warming is not caused by the greenhouse effect at all. That is to say, because it is not caused by the greenhouse effect, the warming of the continental arctic cannot be reproduced by our GCMs. How do we examine that possibility?

If the prominent warming in the continental arctic is due to the greenhouse effect, the prominent trend should continue after 2000. That is, we should observe an amplification of continental arctic warming in this century that will be even greater than the amplification that was observed during the last half of the last century, because the amount of CO_2 continues to increase at an exponential rate. Thus, we examined the warming trend during just the last 20 years or so, provided by Hansen (2006). To our surprise, the prominent continental arctic warming almost disappeared in those results; the Arctic warmed at a rate about like that of the rest of the world, while Greenland showed a strong warming (the lower part of Figure 11). Actually, the temperature shows a cooling trend in Fairbanks between 1977 and 2001 (Hartman and Wendler, 2005). Therefore, our conclusion at the present time is that much of the prominent continental arctic warming and cooling in Greenland during the last half of the last century is due to natural change, perhaps to multi-decadal oscillations like Arctic Oscillation, the Pacific Decadal Oscillation, and the El Niño – Southern Oscillation. This trend is shown at the bottom of Figure 1 as positive and negative fluctuations.

5. Summary

From the data provided in the earlier sections, it is quite obvious that the temperature change during the last 100 years or so includes significant natural changes, both the linear change and fluctuations. It is very puzzling that the IPCC Reports state that it is mostly due to the greenhouse effect Radiative and other forcings are considered to explain the present warming of 0.6°C/100 years, so that they cannot be a confirmation of the term "most." Further, unfortunately, computers are already incorrectly "taught" that the 0.6°C rise during the last hundred years was caused by the greenhouse effect, so they cannot prove the greenhouse effect and cannot predict accurately the degree of future warming.

It is suggested here that the linear change may be due to the fact that the Earth is slowly recovering from the Little Ice Age, although the cause of the Little Ice Age is unknown at the present time.

It is urgent that natural changes should be correctly identified and removed accurately from the present on-going changes in order to find the contribution of the greenhouse effect. Only then will an accurate prediction of future temperature changes become possible.

One lesson here is that it is not possible to study climate change without long-term data. This is understandable from the fact that it is not possible to draw the linear line in the fourth diagram of Figure 1 without the data shown in Figures 3, 4, 5, 6, 7, and 8. It is very easy to discredit the results of the traditional climate change studies (Figures 4, 5, 6, and 7) in terms of accuracy. However, this is what climatologists must face. In some sense, inaccurate data during the last few hundred years are more important than accurate satellite data after 1970 in our study of global warming. Unfortunately, at this time, many studies are focused on climate change after 1975, because satellite data have become readily available. A study of climate change based on satellite data is a sort of "instant" climatology.

6. References

ACIA (Arctic Climate Impact Assessment), Cambridge Universisty Press, 2005.

Burroughs, W.J., *Climate Change*, Cambridge Univ. Press, 2001.

Crowley, T.J. and G.R. North, *Paleoclimatology*, Oxford Univ. Press, 1991.

Cruikshank, J., *Do Glaciers Listen?*, University of Washington Press, 2005.

Fagan, B., *The Little Ice Age: How climate made history*, 1300-1850, Persus Books Group, 2000.

Fritzsche, D., R. Schutte, H. Meyer, H. Miller, F. Wilhelms, T. Opel, L.M. Savatyugin, Late Holocene ice core record from Akasemii Nauk Ice Cap, Severnaya Zemlya, J.W. Dowdeswell and I.C. Willis, eds., *Annals of Glaciology*, No. 42, A150, accepted, 2006.

Gribbin, J. (ed.), *Climate Change*, Cambridge Univ. Press, 1978.

Grove, J.M., *Little Ice Age, in Encyclopedia of the Arctic* (p. 477), Routledge, 2005.

Grove, J.M., *The Little Ice Ages*, Methuen, 1982.

Hansen, J., L. Nazarenko, Reto Ruedy, Makiko Sato, Josh Willis, Anthony Del Genio, Dorothy Koch, Andrew Lacis, Ken Lo, Surabi Menon, Tica Novakov, Judith Perlwitz, Gary Russell, Gavin A. Schmidt, and Nicholas Tausnev, Earth's energy imbalance: Confirmation and implications, *Science*, **308**, no. 5727, pp 1431-1435, 2005.

Hansen, J., Private communication, 2006.

Hartmann, B. and G. Wendler, The significance of the 1976 Pacific climate shift in the climatology of Alaska, *J. Climate*, **18**, 4824, 2005.

Holgate, S.J. On the decadal rates of sea level change during the twentieth century, *Geophys. Res. Lett.*, **34**, L01602, 2007.

IPCC (Intergovernmental Panel on Climate Change), http://www.ipcc.ch.

Jones, P.D., A.E.J. Ogilvie, T.D. Davies, and K.R. Britta, *History and Climate: Memories of the Future?*, Kluwer Academic/Plenum Pub., 2001.

Jones, P.D., Early European instrumental records, *History and Climate; Memories of the Future?*, Kluwer Academic Plenum Pub., pg. 55, 2001

Jones, P.D., Hemisphere surface air temperature variations: a reanalysis and an update to 1993, *J. Climate*, **1**, 1794, 1994.

Jones, P.D., Hemispheric surface air temperature variations: recent trends and update to 1987, J. *Climate*, **1**, 654, 1987.

Lamb, H.H., *Climate, history and the modern world*, Methuen, 1982.

Ogilvie, A.E. and T. Jònsson, *The Iceberg in the Mist: Northern Research in Pursuit of a "Little Ice Age*, Kluwer Academic, 2001.

Polyakov, I.V., Genrikh V. Alekseev, Roman V. Bekryaev, Uma Bhatt, Roger L. Colony, Mark A. Johnson, Varerii P. Karklin, Alexander P. Makshtas, David Walsh, and Alexander V. Yulin, Observationally based assessment of polar amplification of global warming, *Geophys. Res. Lett.*, **29**, No. 18, 1878, 2002.

Richter-Menge, J., J. Overland, A. Proshutinsky, V. Romanovsky, J.C. Gascard, M. Karcher, J. Maslanik, D. Perovich, A. Shiklomanov, and D. Walker, Arctic Report, pp. S46-S52, K.A. Shein (ed), in *State of the Climate in 2005*, NOAA/NESDIS/NCDC and American Meteorological Society Report, BAMS, 2006.

Ruddiman, W.F., *Earth's Climate: Past and Future*, W.H. Freeman and Company, New York, 2001.

Scafetta, N. and B.J. West, Phenomenological solar signature in 400 years of reconstructed Northern Hemisphere temperature record, *Geophys. Res. Lett.*, **33**, L1778, 2006.

Serreze, M. and J.A. Francis, The arctic amplification debate, *Climate Change*, **76**, 241, 2006.

Serreze, M.C. and R.G. Barry, *The Arctic Climate System*, Cambridge Univ. Press, 2005.

Simpson, I.J., F.S. Rowland, S. Meinard, and D.R. Blake, Influence of biomass burning during recent fluctuations in the slow growth of global tropospheric methane, *Geophys. Res. Lett.*, **33**, L22808, 2006.

Trand, A. and P.O. Nordli, The Tallinn temperature series reconstructed back half a millennium by use of proxy data, *Climate Change*, **48**, 189, 2001.

van Engelen, A.F.V., J. Buisman, and F. Ijnsen, *History and Climate - Memories of the Future, A millennium of weather, winds, and water in the lower countries*, Kluwer Academic Press, New York, Boston, London, 2001.

Vinje, T., Anomalies and Trends of Sea-Ice Extent and Atmospheric Circulation in the Nordic Seas during the Period 1864-1998, *J. Climate*, 14, 255-267, 2001.

Wilson, R.C.L., S.A. Drury, and J.L. Chapman, *The Great Ice Age*, Routledge, 2000.