Greenland warming of 1920–1930 and 1995–2005

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[1] We provide an analysis of Greenland temperature records to compare the current (1995–2005) warming period with the previous (1920–1930) Greenland warming. We find that the current Greenland warming is not unprecedented in recent Greenland history. Temperature increases in the two warming periods are of a similar magnitude, however, the rate of warming in 1920–1930 was about 50% higher than that in 1995–2005. **Citation:** Chylek, P., M. K. Dubey, and G. Lesins (2006), Greenland warming of 1920–1930 and 1995–2005, *Geophys. Res. Lett.*, *33*, L11707, doi:10.1029/2006GL026510.

1. Introduction

[2] The changing climate of Greenland is an important factor in the interpretation of the current state and prediction of the future behavior of the Greenland ice sheet. Melting of the Greenland ice sheet has become a common concern in future climate projections with sea level increases of six to seven meters and coastal flooding all over the world. The response of the Greenland ice sheet to changing environmental conditions is a result of a complicated nonlinear interaction between variable solar radiation, atmospheric composition, atmospheric and ocean circulation, state of ice sheet dynamics, cloudiness, precipitation, near surface air temperature and amount of aerosols suspended in the atmosphere as well as deposited on the surface of the ice sheet. Although the research articles reporting the mass balance of the Greenland ice sheet range between a decreasing [*Krabill et al.*, 2000; *Thomas et al.*, 2000] and an increasing total mass [*Zwally and Giovinetto*, 2000; *Johannessen et al.*, 2005; *Zwally et al.*, 2005], there is a general agreement that the ice sheet is thinning close to its margins and thickening in the ice sheet interior. There is also a well-documented increase in the ice sheet melt area during recent years [*Abdalati et al.*, 2001; *Steffen et al.*, 2004] as well as an evidence of glacier acceleration at least in some parts of Greenland [*Rignot and Kanagaratnam*, 2006]. Reports of Greenland temperature changes are equally diverse suggesting a long term cooling and shorter warming periods [*Box*, 2002; *Polyakov et al.*, 2002; *Hanna and Cappelen*, 2003; *Chylek et al.*, 2004].

[3] It has been found that the temperature records at most Greenland coastal stations are highly correlated [*Hanna and Cappelen*, 2003; *Chylek et al.*, 2004; *Chylek and Lohmann*, 2005] with the North Atlantic Oscillation (NAO) index [*Hurrell*, 1995], while the summer temperature at the Summit of the Greenland ice sheet shows a decreasing tendency since the beginning of the measurements in 1986 [*Chylek et al.*, 2004]. A temperature increase observed at Greenland coastal stations within the last decade is suspected to play a part in melting ice sheet at lower elevations, to contribute to global sea level rise and to be at least partially responsible for an accelerated outflow of ice to the sea. In this paper we investigate how the current rising air temperatures compare to the historical temperature record and whether the 1995–2005 Greenland warming is unprecedented in Greenland's recent history. We provide a statistical analysis of Greenland temperature records, comparison of Greenland and global temperature trends and a comparison of the current (1995 to 2005) Greenland warming with

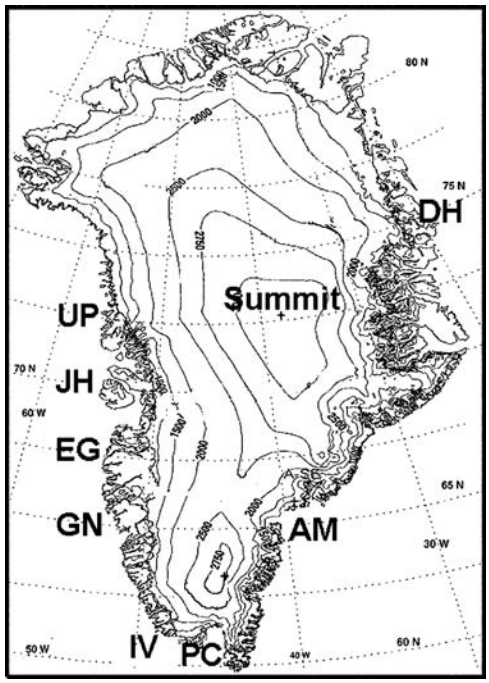

Figure 1. The two Greenland stations, Gothab Nuuk (GN) and Ammassalik (AM) have temperature records for more than 100 years that includes the 1995–2005 warming period. Temperature records at Upernavik (UP), Jakobshavn (JH), and Ivigtut (IV) cover the 1920–1930 warming span, while records at Egedesminde (EG), Prins Christi (PC) and Dansmarkhavn (DH) cover the 1995–2005 warming period.

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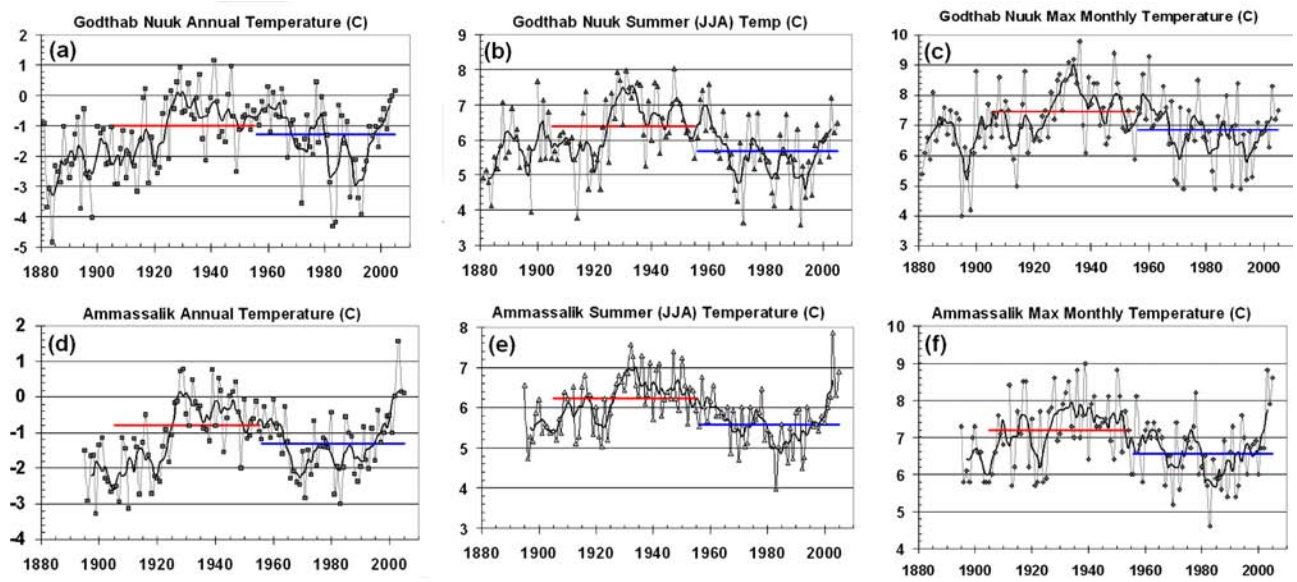

Figure 2. (a and d) Records of an annual average, (b and e) summer months (June, July and August) average, and (c and f) the warmest month of a year temperature at Godthab Nuuk and Ammassalik. Solid black curve is a five-year running average, red horizontal line is a 1905–1955 average and horizontal blue line is a 1955–2005 average temperature. All temperature data used are from the NASA GISS website.

the warming that occurred in Greenland during the first half of the 20th century.

2. Long Term Greenland Temperature Records

[4] There are only two stations in Greenland with century-long temperature measurement records that contain the 1995–2005 warming period. Both are in the southern part of Greenland (close to latitude of 64°N) with Godthab Nuuk on the west and Ammassalik on the east coast (Figure 1). The time series of the average temperature, average temperature during the summer months of June to August (JJA), and the average temperature of the warmest month of the year are shown in Figure 2. The points represent individual values, while solid curves show the five years running averages. A horizontal line on the left hand side of each figure shows the average temperature from 1905 to 1955, and a horizontal line in the right hand side of each figure shows the average temperature from 1955 to 2005.

[5] The year 2003 was an exceptionally warm on the southeastern part of Greenland coast represented by the temperature records at Ammassalik (Figure 1). A record high temperature was reached in 2003 for the month of August, for the summer (JJA) average, as well as for an annual average temperature. In the following year, 2004, the temperature was closer to a normal with the summer and the annual average temperature being the 33rd and 9th highest, respectively. It is not clear if 2003 was a year with an atmospheric circulation anomaly or a result of an unusually strong penetration of the north Atlantic current bringing warm waters further north than usual along the Greenland east coast.

[6] Although the whole decade of 1995–2005 was relatively warm, the temperatures at Godthab Nuuk and Ammassalik were not exceptionally high. Almost all decades between 1915 and 1965 were warmer than or at least as warm as the 1995 to 2005 decade (Figure 3) suggesting that the current warm Greenland climate is not unprecedented and that similar temperature were a norm in the first half of the 20th century.

[7] There is no statistically significant difference between the average temperature from the 1905 to 1955 period and 1955 to 2005 period (red and blue lines in Figure 2a) at Godthaab Nook station. The temperature difference (Table 1) between the two 50 years intervals (0.29 K) is within the sum of the standard deviations of the two means (0.33K). However, the 1955–2005 averages of the Summer (JJA) temperature and the temperature of the warmest month of a year at Godthaab Nuuk are significantly lower (temperature differences are two to three times the sum of standard deviations) than the corresponding average during the 1905–1955 years, suggesting colder summers within 1955–2005 years compared to pre-1955 years (Figure 2). Similarly, at the Ammassalik station, the annual, summer and the warmest month averages are significantly higher during the 1905 to 1955 period compared to the 1955 to 2005 time span (Table 1).

3. Statistical z-Score Test

[8] The temperature time series are often treated subjectively by visualizing the shape of the graphs like those shown in Figure 2. However, a subjective analysis may lead to contradicting interpretations. Therefore, it is useful to use some objective tool to interpret observations. For this purpose we have used the z-score statistical test of a mean [*Kachigan*, 1986].

[9] We wish to determine whether the mean temperature of a given post-1955 decade may be produced by chance by

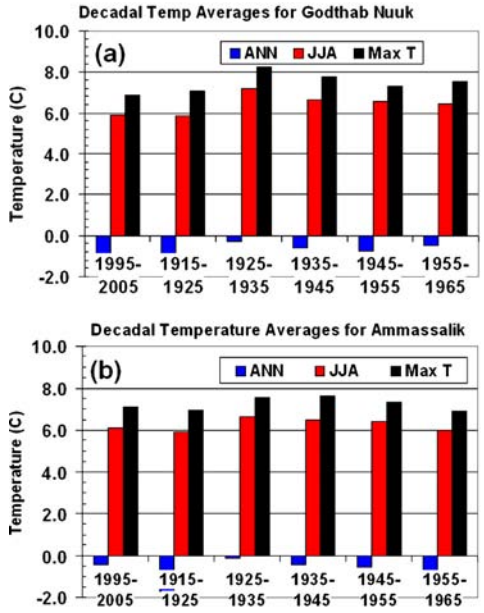

Figure 3. Almost all of the 1915 to 1965 decades at both Godthab Nuuk and Ammassalik were at least as warm as the 1995–2005 average (blue – annual, red – summer, black – warmest month temperature).

a series of the pre-1955 temperatures. The answer is given by the z-score calculated as:

$$z = \frac{\langle y \rangle - \langle X \rangle}{\sqrt{\frac{\sigma_y^2}{n_y} + \frac{\sigma_X^2}{n_X}}} \quad (1)$$

where $\langle y \rangle$, σ_y and n_y are the temperature average, standard deviation and a number of years within the chosen decade and $\langle X \rangle$, σ_X and n_X are the temperature average, standard deviation and number of years of the pre-1955 time series. An absolute value of z above the critical value of z = 2.58, means that the hypothesis of two means being equal has to be rejected at the 0.01 significance level (less then 1% probability that the two means that are really equal will be classified as being not equal) [*Kachigan*, 1986].

[10] To demonstrate how the z-score test works, we have applied it first to the 1880–2005 series of the global temperature, temperature over the land, and over the ocean as shown in Figure 4a. The z-score test results (Figure 4b) clearly indicate that the average global temperature in each of the post 1955 decade is not equal to the pre-1955 average temperature and that the mean temperature of each decade is higher (z > 2.58) that the pre-1955 average. The probability that we are wrong in this conclusion is less than 1% (the significance level 0.01 of the z-score). The same conclusion is obtained for the atmospheric temperature over the ocean and, for the decades after 1975, also for temperature over the land. Thus the z-score test (Figure 4d) clearly interprets temperature series (Figure 4a) as a global warming within each decade compared to the pre-1955 average.

[11] Next we apply the z-score test to the temperature series at Godthab Nuuk and Ammassalik. The results are strikingly different (Figure 5) from the global temperature test. Only the mean temperature within the 1955 to 1965 decade at Godthab Nuuk and within the 1995 to 2005 decade at Ammassalik is warmer than the pre-1955 average at the 0.01 significance level. There is no indication that the mean summer temperature or the temperature of the warmest month of a year in any of the post-1955 decade is higher than their pre-1955 average.

[12] An additional z-score test has been applied to a set of successive decadal means from 1885 to 2005 for Godthab Nuuk and from 1895 to 2005 for Ammassalik time series. Two neighboring decadal means were compared to determine if the means could be produced by the same series. The results indicate two warming periods (z > 2.58) within the span of the years of available temperature records. The first warming occurred during the time period of 1915 to 1935 and the second warming from 1995 to 2005. These periods are treated in more details in the following section.

4. Comparison of Greenland Warming of 1995–2005 and 1920–1930

[13] The two periods of intense warming (1995 to 2005 and 1920 to 1930) are clearly visible in the Godthab Nuuk and Ammassalik temperature records (Figure 2). Unfortunately Godthab Nuuk and Ammassalik are the only stations that have a time record spanning both warming periods. The

Table 1. Means (Column 3) of the Annual, Summer (JJA) and the Warmest Month of a Year Temperatures Within the Two 50 Years Intervals (1905 to 1955 and 1955 to 2005), Standard Deviations of the Means (Column 4), a Difference of Mean Temperatures (Column 5), and the Sum of Standard Deviations (Column 6)

		Mean T, °C	Standard Deviation of Mean T, °C	1905 to 1955 Mean T Minus 1955 to 2005 Mean T, °C	Sum of Standard Deviations, °C
Godthaab	1905–1955	−1.01	0.16	–	–
Annual T	1955–2005	−1.30	0.17	+0.29	0.33
Godthaab	1905–1955	6.39	0.14	–	–
Summer T	1955–2005	5.68	0.13	+0.71	0.27
Godthaab	1905–1955	7.47	0.15	–	–
Warmest T	1955–2005	6.85	0.15	+0.62	0.30
Ammassalik	1905–1955	−0.80	0.12	–	–
Annual T	1955–2005	−0.30	0.13	+0.50	0.25
Ammassalik	1905–1955	6.23	0.09	–	–
Summer T	1955–2005	5.57	0.19	+0.66	0.18
Ammassalik	1905–1955	7.20	0.12	–	–
Warmest T	1955–2005	6.56	0.13	+0.64	0.25

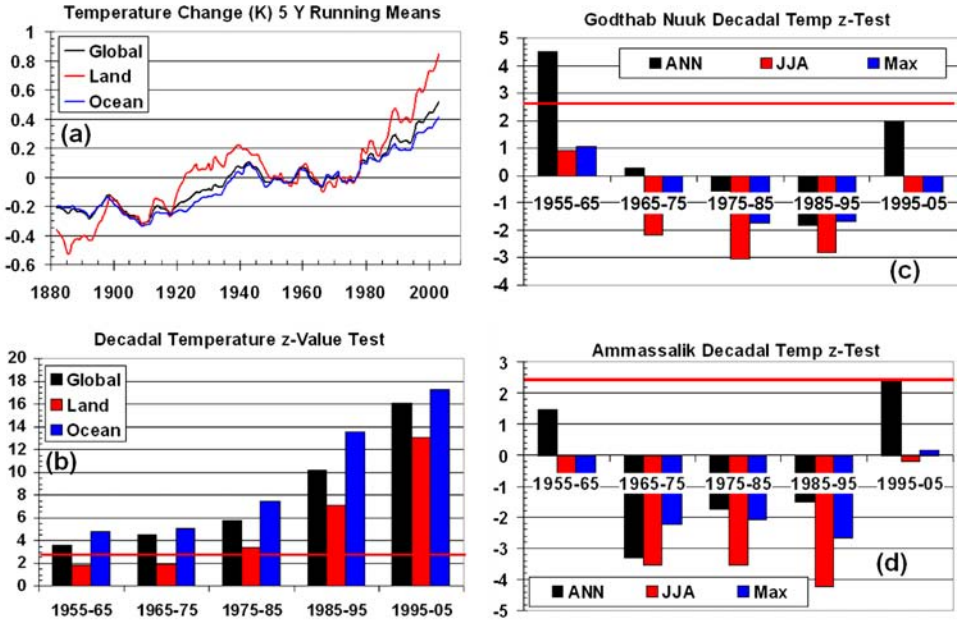

Figure 4. (a) Global earth surface temperature, an average temperature over the land, and over the ocean (data from the NASA GISS website). The curves are 5-year running averages. (b) The results of the z-score test indicate (z-values above the 2.58 red line) that temperatures within each decade were warmer than pre-1955 average. (c and d) The z-score test suggests predominantly cooling with respect to the pre-1955 average at Godthab Nuuk and Ammassalik (black – annual, red – summer, blue – warmest month).

current warming is also recorded in three additional temperature time series (Figure 5) from Egedesminde, Prins Christi and Dansmarkhavn (Figure 1) stations, while the 1920 to 1930 warming record is available at Ivigtut, Jakobshavn and Upernavik (Figure 5). Thus we have records from five coastal stations (including Godthab Nuuk and Ammassalik) for each warming period. A visual comparison (Figure 5) suggests that the both warming periods were of a similar character with a few degree temperature increase within a decade at all available Greenland locations. Table 2 summarizes basic characteristics of temperature records during the two warming periods. It is apparent that the average rate of warming was considerably higher within the 1920–1930 decade than within the 1995 to 2005 decade.

5. Discussion and Conclusion

[14] We have analyzed temperature time series from available Greenland locations and we have found that:

[15] i) The years 1995 to 2005 have been characterized by generally increasing temperatures at the Greenland coastal stations. The year 2003 was extremely warm on the southeastern coast of Greenland. The average annual temperature and the average summer temperature for 2003 at Ammassalik was a record high since 1895. The years 2004 and 2005 were closer to normal being well below temperatures reached in 1930s and 1940s (Figure 2). Although the annual average temperatures and the average summer temperatures at Godthab Nuuk, representing the southwestern coast, were also increasing during the 1995–2005 period, they stayed generally below the values typical for the 1920–1940 period.

[16] ii) The 1955 to 2005 averages of the summer temperatures and the temperatures of the warmest month at both Godthaab Nuuk and Ammassalik are significantly lower than the corresponding averages for the previous 50 years (1905–1955). The summers at both the southwestern and the southeastern coast of Greenland were significantly colder within the 1955–2005 period compared to the 1905–1955 years.

[17] iii) Although the last decade of 1995–2005 was relatively warm, almost all decades within 1915 to 1965 were even warmer at both the southwestern (Godthab Nuuk) and the southeastern (Ammassalik) coasts of Greenland.

[18] iv) The Greenland warming of the 1995–2005 period is similar to the warming of 1920–1930, although the rate of temperature increase was by about 50% higher during the 1920–1930 warming period.

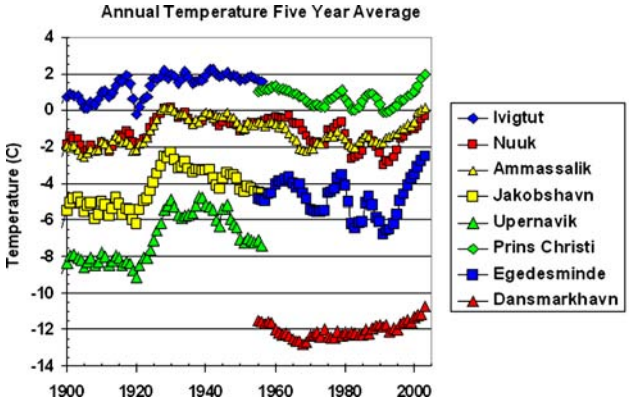

Figure 5. The 1995–2005 and 1920–1930 warming periods at Greenland stations show a similar behavior.

Table 2. The Rate of Temperature Change (K/year) for Two Greenland Warming Periods

	1995–2005	1920–1930
Ivigtut	–	0.25
Prins Christi	0.22	–
Godthab Nuuk	0.18	0.29
Ammassalik	0.2	0.28
Jakobshavn	–	0.41
Egedesminde	0.34	–
Upernavik	–	0.45
Dansmarkhavn	0.16	–
Average Rate	0.22	0.34

[19] v) There are significant differences between the global temperature and the Greenland temperature records within the 1881–2005 period. While all the decadal averages of the post-1955 global temperature are higher (warmer climate) than the pre-1955 average, almost all post-1955 temperature averages at Greenland stations are lower (colder climate) than the pre-1955 temperature average.

[20] An important question is to what extent can the current (1995–2005) temperature increase in Greenland coastal regions be interpreted as evidence of man-induced global warming? Although there has been a considerable temperature increase during the last decade (1995 to 2005) a similar increase and at a faster rate occurred during the early part of the 20th century (1920 to 1930) when carbon dioxide or other greenhouse gases could not be a cause. The Greenland warming of 1920 to 1930 demonstrates that a high concentration of carbon dioxide and other greenhouse gases is not a necessary condition for period of warming to arise. The observed 1995–2005 temperature increase seems to be within a natural variability of Greenland climate. A general increase in solar activity [*Scafetta and West*, 2006] since 1990s can be a contributing factor as well as the sea surface temperature changes of tropical ocean [*Hoerling et al.*, 2001].

[21] The glacier acceleration observed during the 1996–2005 period [*Rignot and Kanagaratnam*, 2006] has probably occurred previously. There should have been the same or more extensive acceleration during the 1920–1930 warming as well as during the Medieval Warm period in Greenland [*Dahl-Jensen et al.*, 1998; *DeMenocal et al.*, 2000] when Greenland temperatures were generally higher than today. The total Greenland mass seems to be stable or slightly growing [*Zwally et al.*, 2005].

[22] To summarize, we find no direct evidence to support the claims that the Greenland ice sheet is melting due to increased temperature caused by increased atmospheric concentration of carbon dioxide. The rate of warming from 1995 to 2005 was in fact lower than the warming that occurred from 1920 to 1930. The temperature trend during the next ten years may be a decisive factor in a possible detection of an anthropogenic part of climate signal over area of the Greenland ice sheet.

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