GEOPHYSICAL RESEARCH LETTERS, VOL. 32, L14705, doi:10.1029/2005GL023552, 2005

Ratio of the Greenland to global temperature change: Comparison of observations and climate modeling results

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Received 18 May 2005; revised 19 June 2005; accepted 23 June 2005; published 21 July 2005.

[1] Temperature changes over Greenland are of special interest due to a possible melting of the Greenland Ice Sheet and resulting sea level rise. General Circulation Models (GCMs) predict that the temperature changes in Greenland should proceed at a faster rate than the global temperature change. Until now there has been no confirmation that Greenland's long-term temperature changes are related to the global warming and that they proceed faster than the global temperature change. Using double correlations between the Greenland temperature records, North Atlantic Oscillation (NAO) index and global temperature change we find a region of Greenland that is not affected by the NAO. Using this region as an indicator of Greenland's temperature change that is related to global warming, we find that the ratio of the Greenland to global temperature change due to global warming is 2.2 in broad agreement with GCM predictions. **Citation:** Chylek, P., and U. Lohmann (2005), Ratio of the Greenland to global temperature change: Comparison of observations and climate modeling results, *Geophys. Res. Lett.*, *32*, L14705, doi:10.1029/2005GL023552.

1. Introduction

[2] During the current global warming period climate changes in polar regions and especially in Greenland are of special interest [*Zwally et al.*, 1998; *Serreze et al.*, 2000; *Polyakov et al.*, 2002]. Melting of the ice sheet and subsequent sea level rise would spell disaster not only for Greenland but also for the whole planet. Sea levels were about 6m higher during the previous interglacial than today, possibly due to at least a partial melt of the Greenland ice sheet [*Cuffey and Marshall*, 2000].

[3] General Circulation Models (GCMs) used for climate simulations and projection of future climate changes predict that the temperature increases in polar regions should be enhanced compared to the average global temperature rise. Specifically the warming in Greenland should proceed at the rate 1.2 to 3 times faster than the global average according to transient climate model predictions summarized in the 2001 Intergovernmental Panel on Climate Change (IPCC) report [*IPCC*, 2001]. There has been no observational evidence yet to confirm that the long-term Greenland temperature changes proceed at a faster rate than the global mean change (increases in Greenland's temperature in the 1990s are generally attributed to the post Mt. Pinatubo recovery and to the changes in atmospheric circulation related to the North Atlantic Oscillation).

[4] The North Atlantic Oscillation itself can be in principle affected by the global warming due to increasing greenhouse gas concentrations. However, a recent comparison of several state-of-the-art climate models [*Rauthe et al.*, 2004] suggests a relatively low sensitivity of the NAO to greenhouse gas radiative forcing, with slightly positive and negative trends occurring in different models and no statistically significant trends.

[5] Recent analysis of Greenland's temperature time series [*Chylek et al.*, 2004] suggested that Greenland has been predominantly cooling since the peak temperatures in the 1930s. The temperature changes at most of the Greenland coastal stations are dominated by the North Atlantic Oscillation that masks any temperature changes that may be related to the current global warming epoch. To remove the effect of the NAO from the temperature records is not an easy task and it may lead to subjective results (depending on the way the NAO correction is performed).

[6] We follow a different path to recover the global warming signal in Greenland's temperature records. The west and east coasts of Greenland are not affected equally by the NAO. Our strategy is to find a region on the Greenland coast that is least affected by changes in atmospheric circulation characterized by the NAO.

2. Data

[7] For our analysis we use the Greenland coastal station temperature records as given at the GISS NASA website (http://www.giss.nasa.gov/data/update/gistemp/) and the North Atlantic Oscillation (NAO) index [*Hurrell*, 1995; *Hurrell and van Loon*, 1997] calculated from the normalized sea level pressure differences between Lisbon (Portugal) and Stykkisholmur (Iceland) and averaged for the months of December, January, February and March (http://www.cgd.ucar.edu/cas/jhurrell/nao.stat.winter.html). Missing data are not replaced by other proxies or by averages; they are simply not included in calculations. Data are not adjusted in any way except that five-year running averages are calculated and used in our analysis where indicated.

[8] From the Greenland coastal temperature records we have selected all stations that have at least 25 years of uninterrupted temperature records up to the year of 2005 (Figure 1). Two of the stations are located on Greenland's west coast (Egedesminde and Godthab Nuuk), two are on the east coast (Ammassalik and Danmarkshavn) and one is located on the south shore (Prins Christi). Detailed coor-

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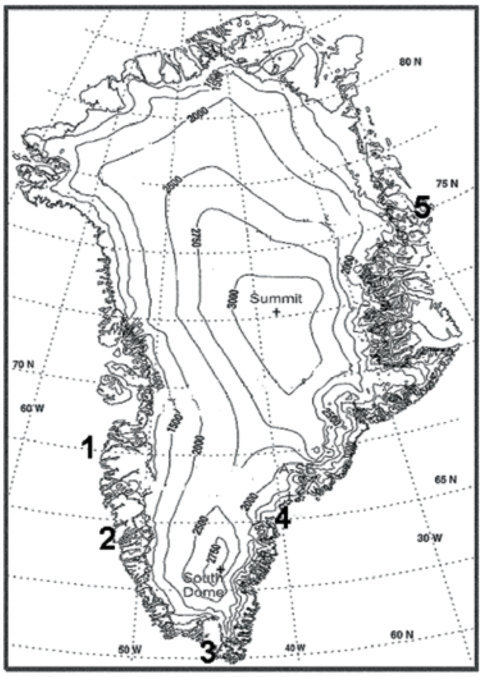

Figure 1. Selected Greenland coastal stations: Egedesminde (1), Godthaab Nuuk (2), Prins Christy (3), Ammassalik (4) and Danmarkshaven (5).

dinates and elevations of individual stations are listed in Table 1.

3. Analysis

[9] We assume that temperature records at Greenland's coastal stations are affected primarily by changes in atmospheric circulation (characterized by the NAO index) and by global change causes (e.g., changes in greenhouse gases concentration [*IPCC*, 2001], changes in atmospheric loading and physical and chemical characteristics of atmospheric aerosols [*Lohmann and Feichter*, 2005], changes in land use and surface albedo [*Myhre and Myhre*, 2003], and cosmic ray variability and its effect on clouds [*Marsh and Svensmark*, 2000; *Kristjánsson et al.*, 2002; *Carslaw et al.*, 2002]). To assess if the NAO or global change factors are dominant at a given station we calculate the correlation coefficients of the station's five years running average temperature record with the five year average of the winter (DJFM) NAO index (Table 2, column 2) and with the five year running average of the global temperature anomaly (Table 2, column 3) for the time period from 1975 to 2004 that characterizes the current phase of global warming.

[10] We classify the results into three groups: (a) stations with a significant correlation with the NAO index (correlation coefficient $r > 0.6$) and low correlation with global temperature change ($r < 0.4$), (b) stations with moderate correlations with both the NAO index and global temperature change (correlation coefficients between $0.4 < r < 0.6$), and (c) stations with a low correlation with the NAO index ($r < 0.4$) and high correlation with the global temperature change ($r > 0.6$). All stations on the west and south coast (Egedesminde, Godthaab Nuuk and Prins Christy) belong to the group (a), being strongly affected by the NAO. Ammassalik with a moderate correlation to both the NAO and global temperature change is a sole member of the group (b). Finally, Danmarkshavn is the only station belonging to the group (c) with a strong correlation to the global temperature change ($r = 0.91$) and almost no correlation to the NAO index ($r = 0.09$). We conclude that Danmarkshavn (and the adjacent region of the northeastern Greenland) is a site where temperature changes are related to global temperature trends and not influenced by the NAO. This is the only suitable station with a sufficient length of the temperature record to investigate a possible relation between the local (or regional) and global temperature changes. All other considered temperature records are significantly influenced by the NAO and any possible global warming signal will be masked by changes related to changes in atmospheric circulation.

[11] Although we are using the five years averages of temperature records and NAO index in calculating the correlation coefficients, similar results are obtained with annual (Table 2, column 4) or seasonal (Table 2, columns 5 and 6) data. The correlation coefficients between stations' temperature and the NAO index are generally lower for the annual and seasonal values, however the basic conclusion (Danmarkshavn is the only station that is not affected by the NAO) remains unchanged.

4. Ratio of Global Warming Related Temperature Change in Greenland to Mean Global Temperature Change

[12] Since the northeastern part of Greenland's shore is not affected by the NAO, we use the Danmarkshavn station to represent the global warming component of the current temperature change. To determine the rate of temperature change at the Danmarkshavn station and the global temperature change (during the 1975–2004 time span) we use the least square constrained linear fit to the data shown in Figure 2. The results is: ΔTGLOBAL = 0.019K/year for global temperature change and ΔT = 0.041K/year for Danmarkshavn, Greenland. This suggests that the ratio of the temperature change at Danmarkshavn, Greenland (the region of Greenland that is not affected by the NAO) to the global temperature change is $\Delta T/\Delta T$ GLOBAL = 2.2.

5. ECHAM Model Results

[13] In recent equilibrium studies the ECHAM4 GCM was coupled to a mixed-layer ocean and the difference between present-day (represented by the mid-1980s) and pre-industrial conditions was obtained (Figure 3). If the effects of increasing anthropogenic sulfate and carbonaceous aerosols (simulation AP), or increasing well-mixed greenhouse gases (simulation GHG) are considered separately in model runs, the net effect of the two runs would be

Table 1. List of Stations With Geographical Locations and Temperature Records Available

	Latitude, N	Longitude, W	Elevation, m
Egedesminde	68°42′	52°45′	43
Godthaab Nuuk	64°10′	51°45′	80
Prins Christy	60°3′	43°10′	88
Ammassalik	65°36′	37°38′	50
Danmarkshavn	76°46′	18°10′	11

Table 2. Correlation Coefficients Between Temperature Records (1975–2004) of Individual Stations and North Atlantic Oscillation Index or Global Temperature Change[a]

	5 Year NAO	5 Year Global T	1 Year NAO	Winter (DJF) NAO	Summer (JJA) NAO
Egedesminde	−0.78	0.22	−0.58	−0.60	−0.50
Godthaab Nuuk	−0.83	0.05	−0.67	−0.67	−0.59
Prins Christy	−0.63	0.33	−0.58	−0.72	−0.23
Ammassalik	−0.43	0.59	−0.45	−0.44	−0.13
Danmarkshavn	0.09	0.91	−0.15	−0.01	−0.07

[a]Five year running (columns 2 and 3) averages are used for the winter (DJFM) NAO and annual temperature (global and at individual stations). For comparison we show also the annual (column 4) and seasonal (columns 5 and 6) correlations.

that the Greenland surface temperature changes would exceed the global mean near-surface temperature by a factor of 1.4 to 1.6. This factor increases to 2.2 if both anthropogenic aerosols and well-mixed greenhouse gases are increased together in the same model run (simulation GHG + AP), because of non-linear interactions [*Feichter et al.*, 2004]. While the temperature change is rather uniform in the AP and GHG experiments (Figure 3), in the combined GHG + AP experiment, aerosol cooling dominates near the biomass burning emission areas in Africa and South America and downwind of the fossil fuel source regions in Europe and South-East Asia. The greenhouse gas warming is still amplified over land at high latitudes. Because these experiments are equilibrium simulations, no comparison with the actual temperature time series can be made at this point. However, the ratio of the predicted Greenland warming to the global mean warming of 2.2 with both aerosols and greenhouse gases included happened to be equal to what is observed at the Danmarkshavn on the Greenland northeastern coast, in an area that is shielded from the influence of the NAO. Although the exact agreement has to be considered fortuitous due to uncertainties in parameterization of various processes, it suggests a broad general agreement between model results and observations (when the influence of the NAO is eliminated).

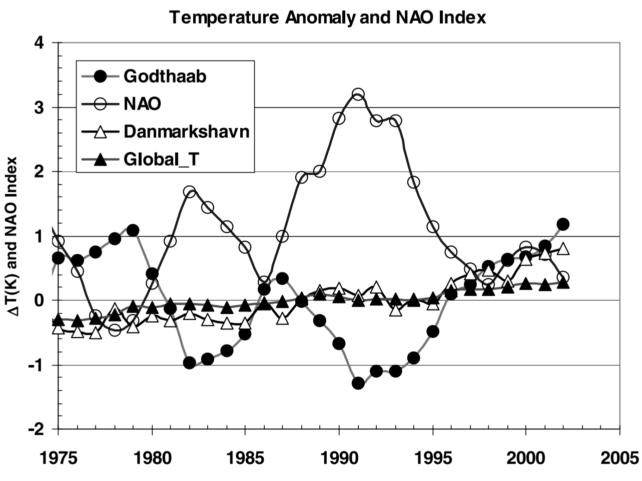

Figure 2. Temperature anomaly (with respect to the 1975–2004 average) of the global temperature and temperature records at Godthaab Nuuk and Danmarkshavn. Temperature changes at Godthaab Nuuk on the west coast of Greenland are highly anti-correlated with the NAO index ($r = -0.83$) with almost no correlation to the global temperature changes ($r = 0.05$). On the other hand temperature records at Danmarkshavn, on the northern part of the east coast, are highly correlated with global temperature changes ($r = 0.91$) with almost no correlation to the NAO index ($r = 0.09$).

6. Discussion and Conclusion

[14] We have found that the NAO and global warming affect different parts of Greenland's coast in a highly non-uniform manner. While the temperature changes along the

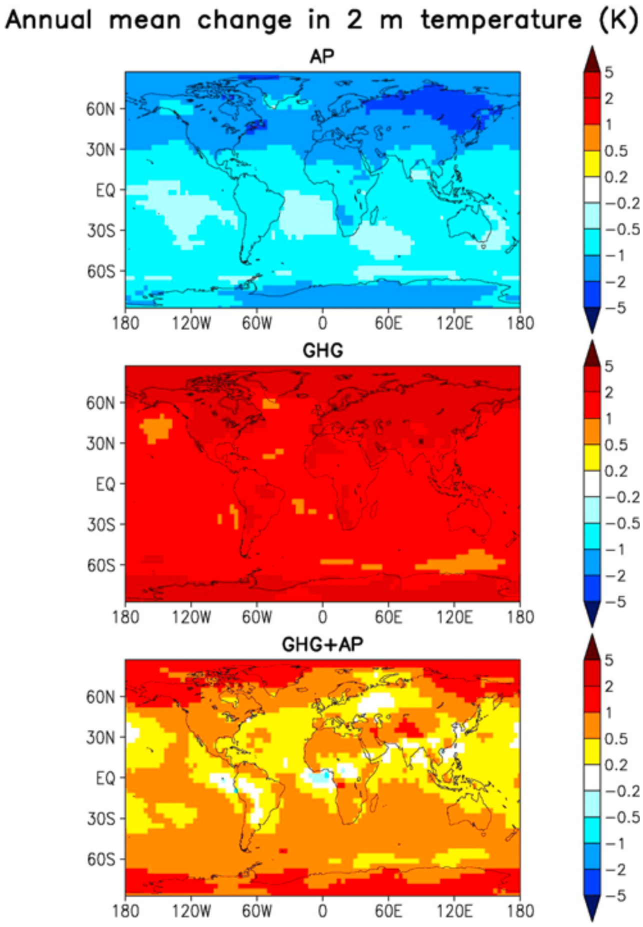

Figure 3. Near surface temperature change from the pre-industrial to the current (1985) state of atmospheric greenhouse gases and aerosols. Three coupled atmosphere-mixed layer ocean equilibrium simulations with ECHAM4 (adapted from *Feichter et al.* [2004]) are for a scenario in which only anthropogenic aerosols are considered (AP), only well-mixed greenhouse gases (GHG) and both gases and aerosols (GHG + AP).

southwestern coast are dominated by the NAO, the changes along the northeastern coast are essentially not affected by the NAO and they are instead dominated by global warming. The rate of the temperature change along Greenland's northeastern shore is found to be 2.2 times larger that the change of the global mean temperature. This falls within the range of 1.2 to 3.1 predicted by various climate models [*IPCC*, 2001]. Our analysis suggests an agreement between observation and climate model predictions of the rate of temperature change due to global warming in Greenland and its ratio to the rate of global temperature change.

[15] **Acknowledgment.** The reported research was partially supported by Los Alamos National Laboratory's Directed Research and Development Project entitled ''Resolving the Aerosol-Climate-Water Puzzle (20050014DR)''.

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