Recent cooling in coastal southern Greenland and relation with the North Atlantic Oscillation

Edward Hanna[1] and John Cappelen[2]

Received 3 July 2002; revised 11 September 2002; accepted 11 September 2002; published 12 February 2003.

[1] Analysis of new data for eight stations in coastal southern Greenland, 1958–2001, shows a significant cooling (trend-line change −1.29°C for the 44 years), as do sea-surface temperatures in the adjacent part of the Labrador Sea, in contrast to global warming (+0.53°C over the same period). The land and sea temperature series follow similar patterns and are strongly correlated but with no obvious lead/lag either way. This cooling is significantly inversely correlated with an increased phase of the North Atlantic Oscillation (NAO) over the past few decades (r = −0.76), and will probably have significantly affected the mass balance of the Greenland Ice Sheet. *INDEX TERMS:* 3309 Meteorology and Atmospheric Dynamics: Climatology (1620); 3319 Meteorology and Atmospheric Dynamics: General circulation; 3349 Meteorology and Atmospheric Dynamics: Polar meteorology; 1610 Global Change: Atmosphere (0315, 0325); 1827 Hydrology: Glaciology (1863). **Citation:** Hanna, E., and J. Cappelen, Recent cooling in coastal southern Greenland and relation with the North Atlantic Oscillation, *Geophys. Res. Lett.*, *30*(3), 1132, doi:10.1029/2002GL015797, 2003.

[2] Greenland, the world's largest island, is important climatically and glaciologically. The Greenland Ice Sheet, if it were to melt in its entirety, could contribute 6–7 m to global sea-level rise [*Hvidberg*, 2000]. The Ice Sheet is either approximately currently in balance or losing mass [*Abdalati*, 2001] but with a large uncertainty. It experiences large interannual variations in snow accumulation and ablation [*Braithwaite*, 1994; *McConnell et al.*, 2001; *Hanna et al.*, 2002]. Mean annual temperatures around the southern edge of the Ice Sheet are only a few degrees below freezing, −5°C being typical [*Ohmura*, 1987], and summer temperatures rise a few degrees above freezing. The marginal zones of the Ice Sheet, from which most of the surface meltwater runoff occurs, are therefore critically sensitive to climatic change (especially to a summer warming). Here we explore recent climatic change in southern Greenland, its relation to the North Atlantic Oscillation (NAO) and possible effects on the Ice Sheet mass balance.

[3] Annual temperature series from eight Danish Meteorological Institute stations in coastal and near-coastal southern Greenland (Figure 1), were averaged to produce a "Composite Greenland Temperature" (CGT) (Figure 2). Most of the stations are in south-west Greenland. CGT is based on recently published data [*Cappelen et al.*, 2001], with an update to 2001, and the presence of data from at least seven out of the eight stations in any year. The Greenland station temperature records were closely examined and compared with records for related climatic elements from the same stations. Station data were also inter-compared to search for systematic offsets which (where they could not be accounted for by local conditions) were also corrected. A new series was calculated using a Gaussian filter with a standard deviation of three years [G3, equivalent to a 10-year running mean (RM)]. This series shows a least-squares linear regression trend-line decrease of 1.29°C (σ = 0.63°C) from 1961–2001, compared with a simultaneous trend-line increase of 0.53°C (σ = 0.16°C) for similarly filtered global mean temperature (GMT). GMT is from the Hadley Centre and Climatic Research Unit [*Jones et al.*, 1999; *Parker et al.*, 1995]. In other words while conditions warmed significantly globally, they cooled significantly in coastal southern Greenland.

[4] Sea-surface temperatures off SW Greenland for an area centred on 62.5°N, 52.5°W (Labrador Sea), also seem to have cooled over a similar time period (Figure 3). G3 series of HadSST1 [*Parker et al.*, 1995; *Rayner et al.*, 1996] decreased 0.44°C (σ = 0.20°C) and NOAA (National Oceanographic and Atmospheric Administation) SST blended to the National Centers for Environmental Prediction (NCEP) Reanalysis skin temperature [*Kalnay et al.*, 1996] decreased 0.80°C (σ = 0.29°C) during 1961–99 and 1961–2001 respectively (data from HadSST1 were available only to 1999). There are common patterns to the observed land and sea coolings and no obvious lag: perhaps changes in air temperature/atmospheric circulation in southern Greenland predominantly influence SST in the Labrador Sea rather than vice versa, although establishing the exact cause and effect is challenging. Correlation coefficients between 5-year RMs of the series are: 0.69 between the two SST series, 0.71 between CGT and HadSST1, and 0.92 between CGT and NCEP SST. These 'r' values are all statistically significant at the 5% level, and the latter at the 1% level (see Dr. David Stephenson's Web site at http://www.met.rdg.ac.uk/cag/), even allowing for autocorrelation in the time series.

[5] The stronger/increasing phase of the NAO during the last ~35 years (see Dr. James Hurrell's Web site "North Atlantic Oscillation (NAO) Indices Information" at www.cgd.ucar.edu/~jhurrell/nao.html links in with the observed cooling (Figure 4). The 5-yr. RM of NAO was significantly negatively correlated with 5-yr. RM CGT (r = −0.76) during 1961–2000. This is to be expected as southern Greenland is near Iceland, one of the 'ends of the seasaw' of the NAO [*van Loon and Rodgers*, 1978]. Recent milder conditions over north-west Europe were accompanied by stronger cold northerly winds over Greenland. It is unknown whether this is a long-term trend, possibly forced by anthropogenic greenhouse warming, or

[1]Institute of Marine Studies, University of Plymouth, UK.
[2]Danish Meteorological Institute, Copenhagen, Denmark.

0094-8276/03/2002GL015797

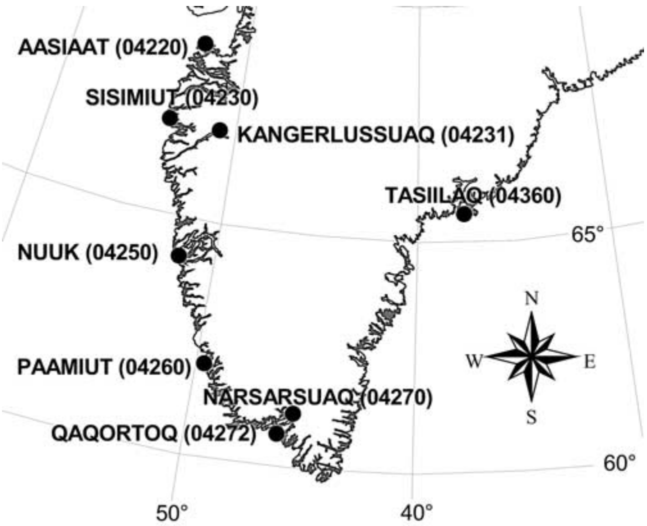

Figure 1. Map showing eight Danish Meteorological Institute stations in coastal southern Greenland, data from which were used in this study.

simply natural/random climatic variation. The NAO-temperature link doesn't explain what caused the observed cooling in coastal southern Greenland (what 'drives' the NAO?) but it does lend it credibility.

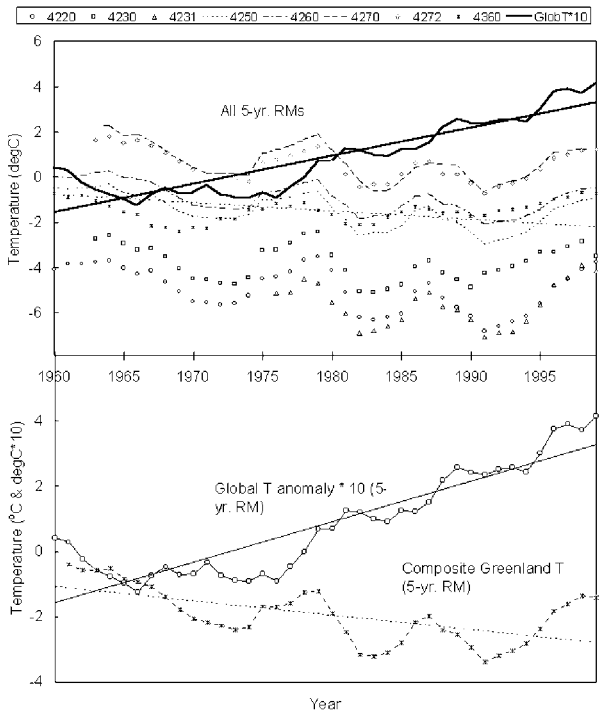

Figure 2. (a): Temperatures at the southern Greenland weather stations and factored (x10) global temperature, all 5-year running means. Greenland stations are shown by their World Meteorological Organization codes. Trend lines are shown for the 4250 (Nuuk, SW Greenland) and global temperature series. (b): Composite Greenland temperature and factored global temperature, 5-yr. running means with trend lines.

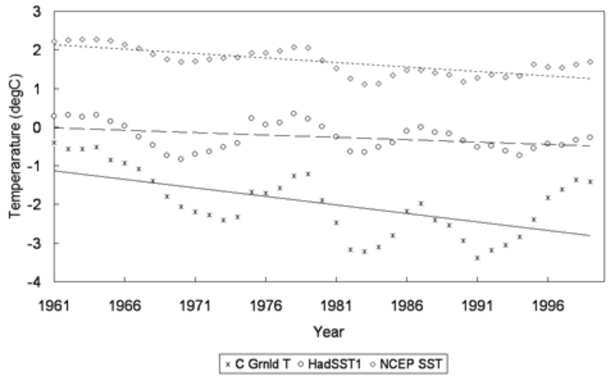

Figure 3. Composite Greenland temperature (CGT) and sea-surface temperatures [Hadley Centre (HadSST1) & US National Centers for Environmental Prediction (NCEP)] off SW Greenland, all 5-yr. running means, with trend lines.

[6] The observed cooling in coastal southern Greenland means that the southern part of the Ice Sheet most likely also cooled overall over the past few decades. Although interior (ice sheet) and coastal climates are different, the most relevant part of the Ice Sheet is that around the edges (i.e. nearest the coast) where summer melt rates and variability are highest. Ablation-temperature modelling indicates that an annual or summer temperature rise of 1°C increases ablation by ~20–50% [*Oerlemans*, 1991; *Braithwaite and Olesen*, 1993; *Ohmura et al.*, 1996; *Janssens and Huybrechts*, 2000]. So recent cooling may have significantly added to the mass balance of at least the southern half of the Ice Sheet. However, a small temperature rise during the mid-late 1990s is in agreement with observed thinning of the marginal ice/glaciers during that period [*Krabill et al.*, 2000]. So in an extension of this study, we will be very interested to compare temperature with laser/radar altimetry data of Ice Sheet surface-elevation change.

[7] Continued systematic observations from Greenland met. stations are of greatest importance for studies of polar and global climate change. We leave it to future investigators to explore the reasons behind this important regional exception to recent 'global warming'.

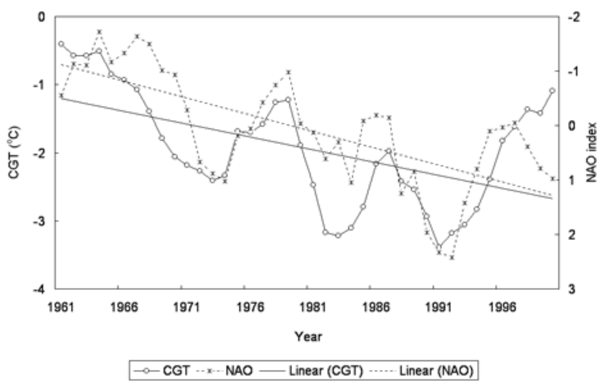

Figure 4. Comparison of Composite Greenland Temperature (CGT) and North Atlantic Oscillation (NAO) index (5-yr. running means with trend lines).

[8] **Acknowledgments.** We thank Sirpa Hakkinen at NASA/Goddard for the NOAA/NCEP SSTs, and Roger Braithwaite, Philippe Huybrechts and Atsumu Ohmura for useful advice.

References

Abdalati, W., Preface, *J. Geophys. Res*, *106*, 33,689, 2001.

Braithwaite, R. J., Thoughts on monitoring the effects of climate change on the surface elevation of the Greenland Ice Sheet, *Global Planet. Change*, *9*, 251, 1994.

Braithwaite, R. J., and O. B. Olesen, Seasonal variation of ice ablation at the margin of the Greenland ice sheet and its sensitivity to climate change, Qamanârssûp sermia, West Greenland, *J. Glaciol.*, *39*, 267, 1993.

Cappelen, J., B. V. Jørgensen, E. V. Laursen, L. S. Stannius, and R. S. Thomsen, The observed climate of Greenland, 1958–99-With climatological standard normals, 1961–90, *Tech. Rep. 00-18*, Dan. Meteorol. Inst. Minist. of Transp., Copenhagen, Denmark, 2001.

Hanna, E., P. Huybrechts, and T. Mote, Surface mass balance of the Greenland Ice Sheet from climate analysis data and accumulation/runoff models, *Ann. Glaciol.*, *35*, 67–72, 2002.

Hvidberg, C. S., When Greenland ice melts, *Nature*, *404*, 551, 2000.

Janssens, I., and P. Huybrechts, The treatment of meltwater retention in mass-balance parameterizations of the Greenland ice sheet, *Ann. Glaciol.*, *31*, 133, 2000.

Jones, P. D., M. New, D. E. Parker, S. Martin, and I. G. Rigor, Surface air temperature and its changes over the past 150 years, *Rev. Geophys.*, *37*, 173, 1999.

Kalnay, E., et al., The NCEP/NCAR 40-year reanalysis project, *Bull. Am. Meteorol. Soc.*, *77*, 437, 1996.

Krabill, W., W. Abdalati, E. Frederick, S. Manizade, C. Martin, J. Sonntag, R. Swift, R. Thomas, W. Wright, and J. Yungel, Greenland ice sheet: High-elevation balance and peripheral thinning, *Science*, *289*, 428, 2000.

McConnell, J. R., G. Lamorey, E. Hanna, E. Mosley-Thompson, R. C. Bales, D. Belle-Oudry, and J. D. Kyne, Annual net snow accumulation over southern Greenland from 1975 to 1998, *J. Geophys. Res.*, *106*, 33,827, 2001.

Oerlemans, J., The mass balance of the Greenland ice sheet: Sensitivity to climate change as revealed by energy-balance modelling, *The Holocene*, *1*, 40, 1991.

Ohmura, A., New temperature distribution maps for Greenland, *Z. Gletscherkd. Glazialgeol.*, *23*, 1, 1987.

Ohmura, A., M. Wild, and L. Bengtsson, A possible change in mass balance of Greenland and Antarctic ice sheets in the coming century, *J. Clim.*, *9*, 2124, 1996.

Parker, D. E., C. K. Folland, and M. Jackson, Marine surface temperature: Observed variations and data requirements, *Clim. Change*, *31*, 559, 1995.

Rayner, N. A., E. B. Horton, D. E. Parker, C. K. Folland, and R. B. Hackett, Version 2.2 of the global sea-ice and sea surface temperature data set, 1903–1994, *Clim. Res. Tech. Note 74*, Hadley Cent., U.K. Meteorol. Off., Bracknell, Berkshire, U.K., 1996.

Van Loon, H., and J. C. Rodgers, The seesaw in winter temperatures between Greenland and northern Europe, Part I: General description, *Mon. Weather Rev.*, *106*, 295, 1978.

J. Cappelen and E. Hanna, Institute of Marine Studies, University of Plymouth, Drake Circus, Plymouth, Devon, PL4 8AA, UK. (e.hanna@plymouth.ac.uk)