1.12 REGIONAL, SEASONAL, AND HISTORIC ARCTIC TEMPERATURE CHANGE

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1. INTRODUCTION

Recent studies show considerable change in the Arctic over the previous three decades in both physical and biological indicators (Serreze et al. 2001; Overland et al. 2003). These indicators suggest a shift in atmospheric parameters such as the Arctic Oscillation and related stratospheric cooling around 1989, while sub-Arctic records such as permafrost records show more gradual trends. It is obviously important to put these recent changes into historical context.

Two recent studies call into question major changes in the recent period based on longitudinally and annually averaged temperature data. Przybylak (2000) states "contemporary global warming in the Arctic is either very weakly marked or even not seen at all." Polyakov et al. (2002) concludes that Arctic air-temperature trends during the 20th century do not support the predicted polar amplification of global warming. Both papers, as well as Kelley et al. (1982), note the important warm event in the 1920–1940 period in relation to current conditions. Although both analyses appear technically correct, they both are subject to the difficulty of preselecting specific periods to calculate trends, which they caution against. It is important to put Arctic change at least in the context of the period from the end of the little ice age (early 1800s) to present, noting the major warm event in the first half of the 20th century as the end of a long period of rising temperatures that were documented by contemporaries in the 1920s and 1940s. This mid-century warm period does not appear to clearly be a part of a low frequency oscillation (LFO) when the 19th century data are investigated. It is also important to parse change by season.

Comparison and modeling of several proxy records with solar variations, aerosols from volcanoes, and carbon dioxide increases make an important case for the relation of historical temperatures and volcanoes (Briffa et al. 2002). In particular, the cool period in the first half of the 1800s can in part be associated with major aerosol production, while the warm period in the first half of the 20th century had almost no production. That atmospheric circulation anomalies were present during these times is not inconsistent with this external forcing impacting latitudinal temperature gradients. The only exception to their model was the last half of the 20th century, which had warm temperatures and increased volcano influence. These authors use this result as an argument for the importance of the uniqueness of CO_2 increases in overcoming the volcanic deficit in the recent period.

Thus we have two competing visions of the current situation at high northern latitudes. In this paper we reexamine the historical climate observational record. We focus on changes in each season and in different regions of the Arctic, rather than developing an additional contribution to annual zonal averages. Although data coverage is far from complete, we consider it important to make the best use of existing information. With recent understanding of the North Atlantic Oscillation (NAO) and Arctic Oscillation (AO) dynamics and their relation to stratospheric cooling in winter and spring, we can develop a more regionally and seasonally dependent conceptual model of Arctic temperature change.

The fourth International Polar Year is scheduled for 2007 and is focused on unresolved issues of polar influence on climate variability. It is fitting to review the data that began with the first polar year (1882–1883), which marked a transition from exploration to scientific study. It is also fitting to update the analyses of those authors in the 1920s–1940s who noted major Arctic changes and pioneered the concept of climate variability in contrast to the prevailing uniformitarianism.

2. ACQUISITION AND PREPARATION OF MONTHLY SURFACE AIR TEMPERATURE DATA

The long term records of monthly mean surface air temperature are based primarily on the GHCN (Global Historical Climatology Network) dataset, available online at http://www.ncdc.noaa.gov/cgi-bin/res40.pl?page=ghcn.html. The data are organized by WMO location index, with records from adjacent locations supplementing that from the primary site.

Another source of monthly mean data is contained in the WMSC (World Monthly Surface Climatology) dataset ds570.0 compiled at NCDC (National Climatic Data Center) and which can be accessed online through NCAR (National Center for Atmospheric Research) http://dss.ucar.edu/catalogs/ranges/range560.html with monthly updates at http://dss.ucar.edu/datasets/ds570.0/data/recent_files/.

Our focus is on long-term time series from northerly latitudes with comprehensive zonal coverage. To minimize data gaps and to extend the series as far as possible, data from these sources were combined as follows:

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- all stations north of 64N in the GHCN database were selected; this avoided biasing the collection with the large number of stations from 60–64°N,
- each record was initially populated with data from the primary WMO location,
- data gaps were successively filled using information from the supplementary adjacent location in the order they appear in the GHCN Version-2 file,
- updates, and some insertions in earlier gaps, were made based on the WMSC (ds570.0) dataset,
- time series, for each station and month, were quality-checked and a few spurious values were eliminated,
- stations with no data prior to 1931 were discarded with a few exceptions where zonal coverage is sparse.

The result is a set of 59 stations. Although data in the Arctic is often considered sparse, 59 stations is in fact major historical coverage compared to lower latitudes with more ocean areas.

3. VISUAL INSPECTION OF HISTORICAL TEMPERATURE TIME SERIES

We provide time/longitude plots of temperature anomalies (based on 1961–1990 means) of the station data for January (Fig. 1), April (Fig. 2), August (Fig. 3), and October (Fig. 4). A 5-year running mean was applied for each station as well as local smoothing. Visual inspection suggested much spatial correlation within different segments of the Arctic. These are roughly Scandinavia/NE Atlantic, N. Siberia, Beringia, NW Canada, greater Baffin Bay, and E. Greenland/Iceland. The Scandinavian sector extends eastward roughly to Archangelsk. Beringia represents the region on both sides of Bering Strait. The inland location of Fairbanks groups more strongly with NW Canada than with Beringia. The Baffin Bay region consists of land stations from both western Greenland and northeastern Canada. The longest records are from Scandinavia, eastern Greenland and Iceland, but there are several regionally representative sites which begin before 1900.

We justify the 5-year smoothing as an approach for subjectively investigating century-long decadal change. Climate records often indicate change through a shift in the frequency of extreme events. For example, the number of winters with cold stratospheric temperature anomalies increased in the 1990s relative to the 1980s. Changes in the frequency of volcanic events on decadal scales which affect the hemisphere have been noted. There are natural changes in storminess from year-to-year. There is also the potential for a high-latitude influence from the quasi-biennial-oscillation (QBO). Thus decadal scales appear to be an appropriate scale to address climate variability over the instrumental record, suppressing the interannual scale.

3.1 *Winter (Figure 1)*

The Scandinavian sector shows a strong interdecadal NAO signature throughout the instrumental record with particularly warm temperatures in the mid 1930s and 1990s. Western Siberia and the Kara Sea had warm anomalies from the late 1930s through the early 1950s, generally in phase but somewhat later than Scandinavia. A major event was the warm anomalies across Siberia and north America in the 1980s when Scandinavia was cool; this event has reversed to cool for all regions except NE Canada. Our decadal analysis reinforces the point made by other authors on the care which must be taken in selecting intervals for calculating trends. For example, Siberia and Alaska would show a positive trend over the previous 50 years even though the main feature was a decadal warming in the 1980s followed by cool anomalies.

3.2 *Spring (Figure 2)*

Spring as represented by April surface temperatures is the time when sunlight returns to the Arctic and the winter low-stratospheric polar vortex weakens and breaks down. The most striking feature is the longitudinal bandedness of the anomalies. This is shown most strongly in the large warm anomalies since the late 1980s with particularly strong anomalies in the Kara Sea/western Siberia, Beringia, and NW Canada. Except for a short period in the mid 1970s, the Arctic was cool in spring from the 1960s to the 1990s. Of particular interest are the previous warm anomalies for the Arctic as a whole in the late 1940s/early 1950s, especially for the Kara Sea and Beringia which correspond to the locations of warmest anomalies in the recent decade.

3.3 *Summer (Figure 3)*

Note that the temperature scale on Fig. 3 is about one-third of the winter (Fig. 1) and one-half of spring (Fig. 2). One would expect smaller anomalies in part because of the impact of sea ice melt on coastal stations as a buffer for temperature extremes. At first inspection there is more local variation than in other seasons. There are generally cool periods before 1910 in Scandinavia, 1920 in Greenland, and 1970 in much of central Siberia eastward to central north America. The strength of the warm anomalies in the 1930/1950s from Baffin through western Siberia and cool anomalies for the rest of the Arctic is similar to the winter data (Fig. 1) and unlike spring. However in recent decades summer temperature anomalies mirror spring warm anomalies from central Siberia eastward to central Canada.

3.4 *Fall (Figure 4)*

Like spring, the fall shows strong longitudinal Arctic-wide covariability in monthly temperature anomaly

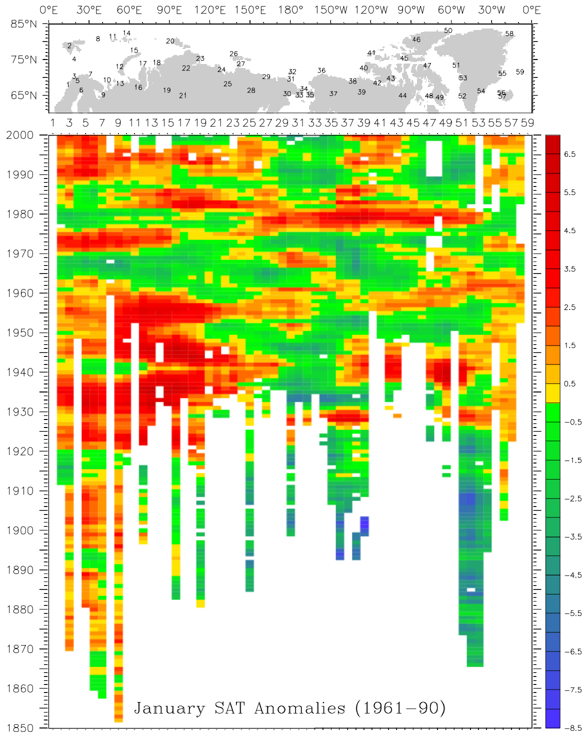

Figure 1. Time/longitude plots of winter surface temperature anomalies for 59 Arctic stations, located across the top of the figure. Anomalies are based on 1961–1990 normals.

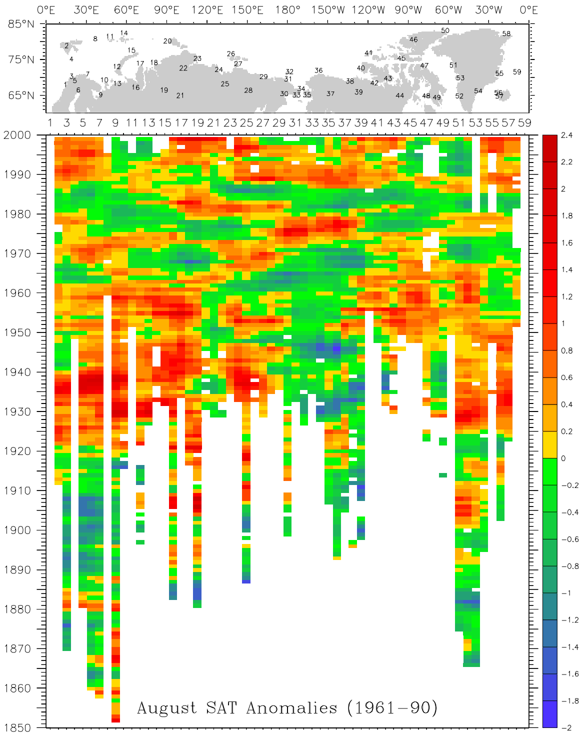

Figure 3. Same as Fig. 1 for August.

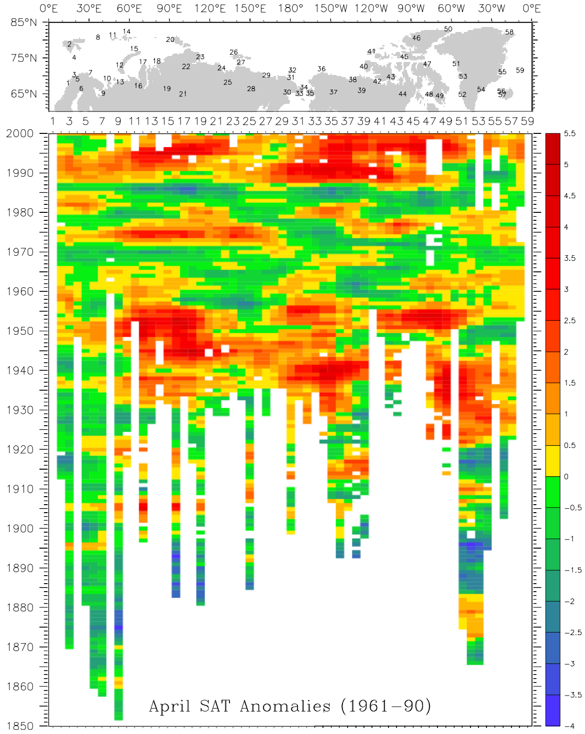

Figure 2. Same as Fig. 1 for April.

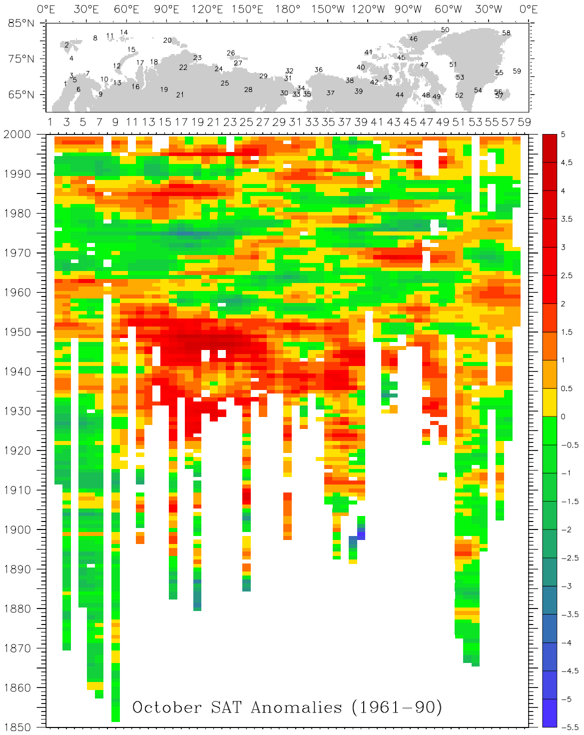

Figure 4. Same as Fig. 1 for October.

patterns. Particularly strong are the warm anomalies from the late 1930s to the early 1950s. This pattern is repeated in the 1980/1990s but with more temporal variability at individual stations. Greenland eastward through Scandinavia was generally cool before 1930.

4. DISCUSSION

We note considerable differences in interdecadal temperature variability based on season and region. Of particular interest is the warm period in the 1920–1930s annual-average-pan-Arctic temperature. Inspection of Fig. 1 suggests that this increase is dominated by the European sector. Except for the late 1920s, the Baffin Bay region is cold during this period and there are increased westerlies across the North Atlantic suggesting an NAO connection noted by many authors (Fu et al. 1999). Several authors attribute the warm annual northern hemisphere temperatures to the lack of vulcanism compared with the 1800s (Crowley 2000). This may be true for the non-winter months but several authors make a case for winter warming in Eurasia from large volcanic eruptions. Robock and Mao (1992) note high latitude winter warming from the 12 largest volcanoes since 1883, which is also evident in our Fig. 1. The physical argument is that the radiational effects are larger at low latitude, thus producing primarily a dynamical response in midlatitude due to increased latitudinal temperature gradients. The sub-Arctic response is the plus NAO pattern of warm air advection. Thus the winter warming of the European sector in the 1930s, which influences the pan-Arctic annual average temperature anomalies, cannot be clearly attributed to the lack of vulcanism. Its cause remains uncertain with natural variability due to decadal changes in atmospheric circulation dynamics as a major candidate.

With regard to spring there are major increases in temperature anomalies since the 1920s in all areas but particularly central Siberia east through North America. The warming in Alaska relates to changes in the frequency of southerly warm air advection events during the breakdown of the polar vortex (Overland et al. 2002). Figure 5 shows a composite of the surface temperature and 925 geopotential height anomalies for April for the four warmest years 1990, 1993, 1995, and 1997. On a monthly basis there are lower heights over the western Arctic with south-westerly winds in opposition to the climatological winter pattern of strong cold easterlies from eastern Siberia east to northeastern Canada. There are also southerly wind anomalies feeding warm air over the Kara Sea region. The previous warm period in the Beringia region from 1953–55 also shows lower heights in the central Arctic again with warm anomalies in Siberia, Beringia, and eastern Canada (Fig. 5). Such surface temperature patterns by analog may also have a stratospheric-AO type connection. This pattern resembles the continuation of the Arctic Oscillation (AO) positive regime into spring, although the main center of action is shifted to the central Arctic and away from the NAO area, which is strong in the classical AO definition (Thompson and Wallace 1998). However, the pattern in the 1950s is more of a wave number 1 pattern and probably relates to natural variability rather than an externally forced AO pattern.

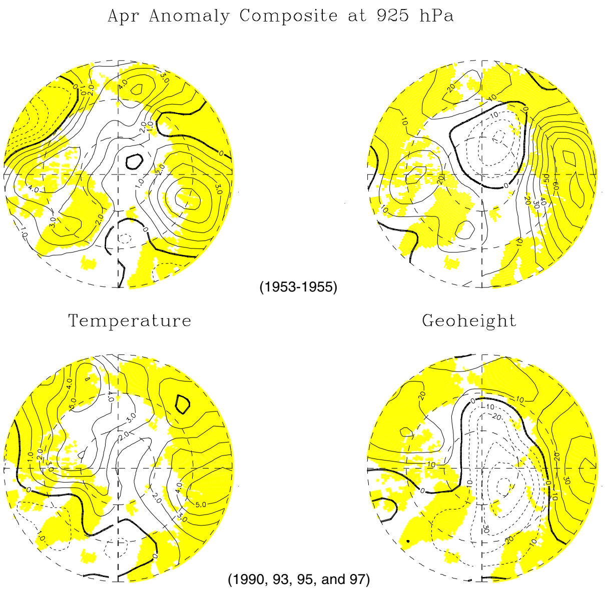

Figure 5. Top: Temperature anomalies (left) and height anomalies (right) for three warm Aprils from the 1950s. Bottom: Same as top but for warm years in the 1990s.

Except for winter in northern Europe, and fall in central Siberia, all records show a general warming over the period of record. That these trends are in non-winter months is consistent with the many papers suggesting a reduction in volcanic influences from the early 1800s through the 1950s and then an anthropogenic forcing since then, which compensates for the recent increase in frequency of volcanic forcing. While there is a general minimum in temperature anomalies in the Arctic during the 1960–1970s, we see no clear evidence of a “Low Frequency Oscillation” in the data before 1920. The only clear cycle is the presence of the well-known interdecadal wintertime NAO in the Atlantic sector. In the Arctic we have had a rise in temperatures since the mid-1800s with a maximum in the 1930–1950s, depending on region, followed by a decrease and then a recent increase. There is no clear justification for extrapolating this cycle forward as there was no clear extrapolation backward to the 1800s.

Temperature anomalies, at least in fall through spring in the Arctic, have a strong dynamic component which produce anomalous temperature advection. This is documented for both the Atlantic sector in winter and the remaining Arctic in spring. It is also possible that sea ice processes and change in land cover such as the increase in shrubs can help promote the persistence of anomalies on decadal scales. Relating temperature and local advection patterns is insufficient, however; future work needs to look at larger scale forcing of the long wave patterns through changes in latitudinal temperature gradients. The strong dynamic control in the Arctic cool season suggests care should be taken in interpreting proxy data from summer which is primarily controlled by radiational processes, as representative of annual conditions.

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