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Variability of observed temperature-derived climate indices in the Arctic

Heidrun Matthes *, Annette Rinke, Klaus Dethloff

Alfred Wegener Institute for Polar and Marine Research, Potsdam, Germany

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ABSTRACT

Arctic temperature is analyzed in view of its extremes based on climate indices derived from daily mean, maximum, and minimum temperature. This analysis is done for the pan Arctic domain and region-specific for the eastern and western Russian Arctic. The variability of temperature-related indices over the last four decades is presented, in which the spatial distribution and regional differences as well as its temporal trends are discussed. The analysis is based on ERA40 data and station data in the Russian Arctic. Station-based results for 1958–2008 show a significant decrease of frost days (−0.8 days/decade) over the eastern Russian Arctic in spring. The trends in warm (cold) spell days are not statistically significant; except in western Russian Arctic in summer for cold spell days (−2 days/decade). The inter-annual variability of the indices is large and shows pronounced decadal variations. ERA40 data generally reproduce well the inter-annual variability in the climate indices as seen in observations, but they show some deficiencies in the magnitudes and trends of the indices.

1. Introduction

The Arctic is under rapid transition and observations show a consistent picture of surface warming and reduction in all components of the cryosphere (IPCC, 2007). Studies on trends of seasonal mean temperature indicate warming trends over most of the Arctic, especially pronounced in winter and spring, but depending on the period analyzed (Serreze and Francis, 2006). The ACIA (2005) report presents the Arctic warming for annual trends as well. It is also suggested that the expected future warming may be associated with a greater frequency of extremely warm temperatures (recently, e.g., Rinke and Dethloff, 2008). The understanding of the climate variability of extremes on a regional level is of increasing importance as it directly impacts the residents and is needed for investigations of ecological and societal changes. In recent years, specific months (e.g., record warm March 1996 in Northern Alaska, record warm spring and summer 2007 in the Arctic) were characterized by record temperatures, and attracted great attention in the public. However, it is apparent that the patterns and variability of extreme events have received little attention in the Arctic assessments. Thus, the question has arisen whether significant changes of extreme temperature are already present in the Arctic. Global analyses of temperature and precipitation extremes have been conducted by various authors using land-based gridded daily data sets. For example, Kiktev et al. (2003) show trends in the annual number of frost days for the northern hemisphere, indicating a significant decrease in frost days of up to 4 days/decade for almost all mid-latitudes. For high latitudes, trends are mainly insignificant or could not be calculated due to a lack of data. The authors calculate a warming over Scandinavia and Alaska associated with a decreasing trend in frost days of up to 2 days/decade; a cooling is calculated over Eurasia south of Novaya Zemlya. Alexander et al. (2006) provide more complete information for the Arctic. They calculate that the number of frost days and the cold spell days decreased over most parts of the Arctic. However, most trends over the high latitudes are not significant.

Our analysis aims at providing more regional results for temperature-based climate indices over the Arctic and is based on the European Centre for Medium-Range Weather Forecasts reanalysis (ERA40) and on Russian station data, covering 1958–2008. The detailed regional analysis for the Russian Arctic has its background in the EU project CARBO—North (http://www.carbonorth.net/) which aims at quantifying the carbon budget in Northern Russia. For this purpose, past, recent and future climate changes are investigated in the Russian Arctic.

The paper continues in Section 2 with a description of the applied data sets and the performed data analysis. In Section 3, the spatial and temporal variability of selected temperature-related climate indices and their trends are presented. The results are summarized in Section 4.

2. Data and analysis

2.1. Daily temperature data sets

The data set for the pan Arctic analysis is the ERA40 reanalysis data set which covers the 44-year-long period from 1958 to 2001

* Corresponding author. Alfred Wegener Institute for Polar and Marine Research Telegrafenberg A43, D-14473 Potsdam, Germany. Tel.: +49 331 2882101; fax: +49 331 2882178.
E-mail address: Heidrun.Matthes@awi.de (H. Matthes).

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(Uppala et al., 2005). For the comparison with the station data, the ERA40 data have been interpolated on the station locations. The indices have then been calculated from the interpolated time series after removing those days which had missing values in the station data.

The station data set used for the analysis over the Russian Arctic is called "Global Summary of the Day" (GSOD; www.ncdc.noaa.gov/oa/mpp/freedata.html). From this, a total of 644 stations (all located in the Russian Arctic and north of 60 N) have been used, covering 1958–2008. Compared to ERA40, here the last recent 7 years 2002–2008 are included. It is the case that almost no station has full data coverage over the whole 51-year-long period. The data set has been split for the analysis into two separate parts, GSOD east (324 stations) and GSOD west (320 stations), indicating that they include all stations located east and west of Ural mountains, respectively (Fig. 1). Therewith, the analysis has been done regionally for the two different climate regions of east and west part of Russian Arctic.

From both data sets, daily minimum, maximum and mean temperatures have been analyzed.

2.2. Climate indices and trend analysis

The classification of extreme temperature is based on climate indices (Peterson et al., 2001) and shown in Table 1. Here in the paper, selected temperature-related indices are discussed which are important for the living conditions in the Arctic. In addition to temperature indices (warm and cold spell days), indices illustrating vegetation conditions (growing season length, growing degree days) and frost conditions (frost days) are studied.

A basis for calculating the indices has been defined to take the occurrence of missing data values into account. The data of a station were included in the analysis of a season if the station had 10 or less missing values in the input data within that season, except for indices that count consecutive days (like cold spells). For those indices, only seasons with full data coverage were included. The presented times series show a station mean for a specific season, if at least 10% of the stations deliver data for that season. Counters (like frost days) were normalized on the maximum number of days in the season, accounting for the existence of missing values. To show the variability of the inter-annual variability within the calculated time series, the standard deviation development relative to an 11-year gliding mean (and assigned to the center of the 11-year window) is included in the figures. The standard deviation is calculated if at least 6 years within the 11-year window have data.

Furthermore, trends in the climate indices have been analyzed. They were calculated using a linear regression with the least squares method. To gain information on the significance of the obtained trends, a bootstrapping approach was used as described in Kiktev et al. (2003), except for the moving block re-sampling. To account for spatial correlation in the gridded ERA40 data, the same re-sampling sequence was used for each grid point (see again Kiktev et al., 2003). All trends marked significant are significant at the 95%-level. Significance was assigned to a "zero trend", if the sum of squares of deviations from the mean were less than 5% of the mean. As the time series in the station data contain missing values, it is necessary to make sure that a shown trend is evenly based on values from the entire period. Therefore, the whole 51-year period has been divided in four 11-year-long intervals and a 7-year-long interval for the rest (1958–1968, 1969–1979, 1980–1990, 1991–2001, and 2002–2008). And thus, a trend for a certain period is only shown, if at least five years (respectively three years in the last period) of data are contained for each of these intervals within the trend's period. Additionally, the spatial distribution of stations delivering values to a certain index could have changed throughout the analyzed period and thereby influenced the calculated trends. To asses this problem, the spatial distribution of missing values over time was analyzed for each index. The missing values were found to be rather evenly distributed over the whole area taken into account.

Table 1
Classification of extreme temperature based on climate indices. TX90 is the 90th percentile calculated from a five-day gliding mean of the daily maximum temperature of the reference period 1961–1990 and TN10 is the 10th percentile calculated from a five-day gliding mean of the daily minimum temperature of the reference period. *t*_mean is used as denotation for the daily mean temperature, *t*_min and *t*_max for daily minimum and maximum temperature respectively.

Frost days	FD	# of days per season with $t\_min < 0$ °C
Cold spell days	CSDI	# of at least 6 consecutive days with $t\_min < TN10$
Cold nights	TN10p	# of days per season with $t\_min < TN10$
Warm spell days	WSDI	# of at least 6 consecutive days with $t\_max > TX90$
Warm day-times	TX90p	# of days per season with $t\_max > TX90$
Growing degree days	GD4	Sum of daily temperature means per season for days with $t\_mean > 4$ °C
Growing season length	GSL	# of days between the first occurrence of 6 consecutive days with $t\_mean > 5$ °C and the first occurrence after the 1st July of at least six consecutive days with $t\_mean < 5$ °C

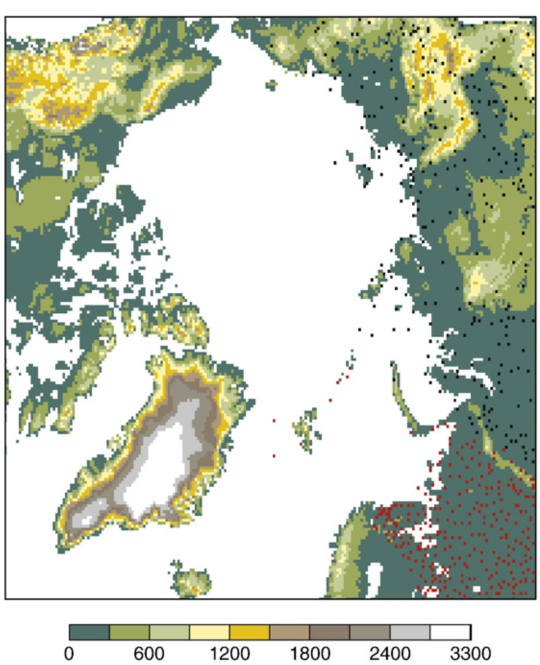

Fig. 1. Map of station distribution of the GSOD data set. In total, daily data from these 644 stations have been analyzed (324 stations in eastern part plotted black, 320 stations in western part plotted blue). Colors refer to the orographic height [m].

3. Results

3.1. Frost days

Fig. 2 shows the 44-year seasonal mean frost day patterns for the transition seasons spring (March–May) and autumn (September–November), based on ERA40. As expected, the maximum numbers of frost days occur over the central Arctic and Greenland. In autumn the numbers of frost days are still moderate over Siberia (~60–80 days) and Alaska/Canadian Archipelago (50–70 days) due to the transition from summer. But then in spring, the large amount of frost days over most parts of the Arctic continues from winter. It is of interest to investigate if the number of frost days changed within the period