Variations in temperature-related extreme events (1975–2014) in Ny-Ålesund, Svalbard

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Abstract

We present a comprehensive analysis of temperature-related extreme events in Ny-Ålesund (78.9°N, 11.9°E) using data from three meteorological stations. The results show that annual mean temperatures in Ny-Ålesund increase at a rate that is four times faster than the global mean from 1975 to 2014 with no ‘hiatus’ in recent decades. The annual diurnal temperature range shows a negative trend as minimum daily temperature increases at a faster rate than maximum daily temperature. A negative trend in cold extremes and a positive trend in warm extremes are observed. This asymmetry hints at potential changes in the probability distribution of temperatures in Ny-Ålesund.

Keywords: Arctic; climate change; extremes

1. Introduction

Extreme events, such as heat waves, droughts, floods, and hurricanes, interact with exposed and vulnerable human and natural systems to produce disasters (IPCC, 2013). Overwhelming evidence indicates that climate extremes have frequently occurred on both regional and global scales in recent years (Osborn et al., 2000; Alexander et al., 2006; Donat et al., 2013; Chen and Sun, 2015). The intensification of climate extremes is causing dangerous changes in the economy and ecosystems, and to society and human health (Handmer et al., 2012). Enhanced warming is observed at high latitudes in response to increased CO₂ relative to the warming trends at mid- and low-latitudes. Polar amplification may cause an increased probability of extreme weather events in mid-latitudes (Francis and Vavrus, 2012). Therefore, the variations in mean climate and extreme events at high latitudes should be investigated.

Recent studies indicate that climate extremes have changed at mid-high latitudes. Cold/warm extreme events show a positive trend in North America since the late 1960s (CCSP, 2008a; Peterson et al., 2008; Zhang et al., 2010). In European and Mediterranean countries, a decrease in large-scale occurrences of cold extremes and an increase in warm/hot extremes are generally consistent with global trends of temperatures and their extremes (Moberg et al., 2006; Della-Marta et al., 2007). A significant positive trend in the frequency of heat waves and a negative trend in the number of cold spells have also been observed in Australia and the majority of Asia since the middle of the 20th century (Chambers and Griffiths, 2008; Choi et al., 2009; You et al., 2010; Wang et al., 2013; Chen and Sun, 2014).

However, few studies have examined extreme events in polar regions. Tuomenvirta et al. (2000) indicated that mean maximum and minimum temperatures in western coastal Greenland show a decreasing trend from 1950 to 1995 and opposite trends over the Nordic Seas and Fenno-Scandia. These results indicate considerable regional differences for extreme events over the Arctic. A high frequency in warm days is observed at Svalbard Airport from 1975 to 2010 with a negative trend in cold nights (Bednorz, 2011; Bednorz and Kolemdowicz, 2013; Tomczyk and Bednorz, 2014).

Ny-Ålesund (78.9°N, 11.9°E), which is located on the west coast of Svalbard (Spitsbergen), is one of the northernmost archipelagos in the Arctic. Although Ny-Ålesund has its own weather features, it provides valuable evidence for climate change in the general Arctic. Several studies have analysed climate change in Ny-Ålesund and identified a significant warming in recent decades (Førland and Hanssen-Bauer, 2000; Førland et al., 2011; Maturilli et al., 2013, 2015). However, extreme events and their changes have been given minimal attention. In this study, we investigate changes in temperature and its related extremes in Ny-Ålesund based on data from three meteorological stations. This investigation may advance our understanding of intensity and frequency of climate extremes in the Arctic and the influence of global warming on extreme events.

2. Methods

2.1. Data

We obtained data from three meteorological stations in Ny-Ålesund, Svalbard (Figure S1, Supporting
Table 1. List of the 14 ETCCDI temperature extreme indices (TX for maximum temperature and TN for minimum temperature).

| Index   | Index name            | Definition                                                                 | Units |
|---------|-----------------------|---------------------------------------------------------------------------|-------|
| TXx     | Max TX                | Warmest daily maximum temperature                                         | °C    |
| TXn     | Min TX                | Coldest daily maximum temperature                                         | °C    |
| TNx     | Max TN                | Warmest daily minimum temperature                                         | °C    |
| TNn     | Min TN                | Coldest daily minimum temperature                                         | °C    |
| DTR     | Diurnal temperature range | Mean difference between daily maximum and minimum temperature           | °C    |
| FD      | Frost days           | Annual number of days when TN < 0°C                                     | days  |
| ID      | Ice days             | Annual number of days when TX < 0°C                                     | days  |
| GSL     | Growing season length | Annual number of days between the first occurrence of 6 consecutive days | days  |

For the Northern Hemisphere this is calculated from 1 January to 31 December while for the Southern Hemisphere it is calculated from 1 July to 30 June.

| Index   | Name         | Definition                                                                 | Units |
|---------|--------------|---------------------------------------------------------------------------|-------|
| CSDI    | Cold spell duration | Annual number of days with at least 6 consecutive days when TN < 10th percentile | days  |
| WSDI    | Warm spell duration | Annual number of days with at least 6 consecutive days when TX > 90th percentile | days  |
| TX90p   | Warn days    | Share of days when TX > 90th percentile                                   | %     |
| TX10p   | Cold days    | Share of days when TX < 10th percentile                                   | %     |
| TN90p   | Warn nights  | Share of days when TN > 90th percentile                                   | %     |
| TN10p   | Cold nights  | Share of days when TN < 10th percentile                                   | %     |

Information. Sverdrup Research station, which was established by the Norwegian Polar Institute (NPI), provides the greatest amount of daily meteorological observation data (1975 to present) for the vicinity of Ny-Ålesund. The joint French-German Arctic Research Base by Alfred Wegener Institute for Polar and Marine Research and Polar Institute Paul Emile Victor (AWIPEV) operates a 10 m meteorological tower, which is mounted on a measurement field with soft tundra ground. It provides data with 5-min intervals from 1994 to 1998 and data with 1-min intervals from 1998 to 2011. China established the Yellow River (YR) station in 2003. This station operates a meteorological tower on the eastside of the township near the Bird Sanctuary. The height of the tower was changed from 6 to 10 m in August 2007. Continuous observation data from 2005 are available with a 1-h resolution at a level of 2 m. The observations of the three stations are obtained from the World Meteorological Organization (WMO) standard; the data are extensively applied (Førland and Hanssen-Bauer, 2000; Førland et al., 2011; Maturilli et al., 2013, 2015). In the following sections, the three stations are denoted by NPI, AWI, and YR.

### 2.2. Climate extreme indices

The 14 temperature-related extreme indices proposed by the Expert Team on Climate Change Detection and Indices (ETCCDI) are analysed in this study (Table 1). The ETCCDI climate indices are very popular and extensively utilized in climate research and related fields (e.g. Zhang et al., 2011; Sillmann et al., 2013) due to their robustness and fairly straightforward calculation and interpretation. The indices are primarily selected for the assessment of changing climates, including changes in intensity, frequency and duration of temperature-related events. The indices are calculated using a FORTRAN package, as documented at the ETCCDI climate change indices website (http://etccdi.pacificclimate.org/software.shtml). All raw data from the three stations are resampled to a common daily resolution using an arithmetic mean. Note that we use the Sen’s slope method (Sen, 1968) to compute the linear trend of the considered variables and the non-parametric Mann–Kendall approach for the significance test. Regarding probability density distribution (PDF), we employ the Kolmogorov–Smirnov two-sample test to determine if two samples are from the same distribution.

### 3. Results

The annual mean air temperature in Ny-Ålesund shows a significant warming trend from 1975 to 2014 (~0.79 °C decade⁻¹; Table S1), which is four times larger than the trend for global mean temperature (~0.17 °C decade⁻¹) (Figure 1(a)). Temperatures during the winter season exhibit an enhanced warming (1.75 °C decade⁻¹) with greater inter-annual variability (3.34 °C year⁻¹). The observations from the three stations show reasonable consistency (Figure 1). Based on an 11-year sliding linear trend, the magnitude of the warming trend in Ny-Ålesund is gradually decreased (Figure 1(b)), which is consistent with the global mean. The results show a continuous warming trend in the winter temperatures in Ny-Ålesund since the mid-1990s, whereas the trend of global mean temperature is weakened and turns to a negative phase in recent years (Figure 1(d)). The global mean summer temperatures exhibit a ‘hiatus’ since the late 1990s, whereas summer temperatures in Ny-Ålesund exhibit a negative trend in recent years (Figure 1(f)). These results
Figure 1. Left: the time series of air temperature for the global mean and the three stations in Ny-Ålesund for the annual mean (a), the winter season (c) and the summer season (e). Right: the 11-yr sliding linear trends of air temperature for the global mean and the NPI station in Ny-Ålesund for the annual mean (b), the winter season (d) and the summer season (f). The global averaged data are obtained from HadCRUT4.

Figure 2. Time series of minimum daily temperature (a–c), maximum daily temperature (d–f) and diurnal temperature range (g–i) from the three stations in Ny-Ålesund for the annual mean (a, d, g), winter season (b, e, h), and summer season (c, f, i).
Temperature-related extreme events in Ny-Ålesund

Figure 3. Time series of the annual mean maximum of TX (TXx), minimum of TX (TXn), maximum of TN (TNx), minimum of TN (TNn), frost days (FD), ice days (ID), warm spell duration (WSDI), cold spell duration (CSDI), warm days (TX90p), cold days (TX10p), warm nights (TN90p), cold nights (TN10p), and growing season length. Please refer to Table 1 for detailed definitions.

indicate different temperature behaviours between the Ny-Ålesund and the globe. Thus, the variations in temperature-related extremes in Ny-Ålesund should be examined.

Figure 2 illustrates the time series of mean maximum and minimum daily temperatures in Ny-Ålesund. Both time series show a significant positive trend in the past 40 years (Figure 2(a)–(c)), especially for the winter season since mid-1990s (Table S1). The annual diurnal temperature range (DTR) exhibits a decreasing trend (0.012 °C year\(^{-1}\)) during 1975–2014 (Figure 1(g)) as the minimum daily temperature increases at a faster rate than the maximum daily temperature (Table S1). The negative trend in annual DTR since the mid-1980s is contradictory to the DTR behaviour over global land surfaces (Rohde et al., 2013). Note that the summer DTR shows a positive trend (0.02 °C year\(^{-1}\)) due to the rapid increase in the maximum daily temperature.

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In response to the increased temperatures, a significant negative trend in the annual occurrence of cold days (~2.7% decade^{-1}) and nights (~3.5% decade^{-1}) is observed from 1975 to 2014 (Figure 3(b) and (d); Table S2). Although the annual occurrence of warm days and nights shows a long-term upward trend in the past 40 years (Figure 3(a) and (c)), their magnitudes (1.3–1.8% decade^{-1}) are relatively small. The annual occurrence of warm nights does not exhibit a significant trend from 1975 to 2000 and shows a negative trend in recent years (Figure 3(c)). The temperatures on the coldest days (nights) significantly increase during 1975–2014 (Figure 3(f) and (g)) with a significant positive trend of 2.3 (2.5) °C decade^{-1} (Table S2). However, the temperatures on the hottest days and nights reveal a large magnitude of inter-annual variations with an insignificant long-term upward trend (Figure 3(e) and (h)). This result may be attributed to a small warming trend in summer temperatures. In addition, the local SST and large-scale circulation patterns are likely to influence the absolute temperature indices (e.g., temperatures on the hottest days) based on previous studies (Scaife et al., 2008; Alexander et al., 2009).

The cold spell duration exhibits a significant negative trend of ~8 days decade^{-1} from 1975 to 2014 with a larger decreasing trend from 1994 to 2010 (Figure 3(j); Table S2). The significant decline since the early 1990s is similar to the trend in cold spells at middle and high latitudes (Alexander et al., 2006; Chen and Sun, 2015). Although the warm spell duration increased over the past 40 years, minimal change and a downward trend since the early 2000s is observed (Figure 3(i)). The annual occurrence of frost days and ice days in Ny-Ålesund shows a significant negative trend (3–9 days decade^{-1}) during the study period, especially since the early 1990s (Figure 3(k) and (l)).

The growing season length, which affects hydrologic factors and biologic territories (Logan et al., 2003; CCSP, 2008b), increases in Ny-Ålesund from 1975 to 2014 (Figure 3(m)) with a long-term trend of ~4 days decade^{-1}. This result is similar to the change...
Temperature-related extreme events in Ny-Ålesund show a negative trend in cold extremes and a positive trend in warm extremes. The negative trend in extreme minimum temperatures is larger than the positive trend in extreme maximum temperatures. This asymmetry hints at potential changes in the shape and/or scale of the distribution of temperatures in Ny-Ålesund. According to the probability distribution function, it is likely (at 99% confidence level) that there is a decreased frequency in the cold tails of temperatures after mid-1990s and a decreased frequency of temperature above freezing point (Figure 4). The maximum and minimum temperatures indicate a similar shift. However, additional observations are required to accurately assess potential changes in the shape of the distribution of temperature.

4. Summary

In this study, we present a comprehensive picture of changes in temperature-related extremes from 1975 to 2014 based on the station data in Ny-Ålesund. The annual warming trend in Ny-Ålesund during the past 40 years is four times larger than the global mean. The continuous warming since the mid-1990s is inconsistent with the ‘hiatus’ in global warming trend in terms of annual mean temperature. The annual DTR exhibits a negative trend from 1975 to 2014, whereas the summer DTR shows a positive trend. In response to the increased temperature, the temperature-related extremes in Ny-Ålesund show a negative (positive) trend in cold (warm) extremes. Specifically, Ny-Ålesund experiences a significant increase (decrease) in the annual occurrence of warm days (cold nights). The temperatures on the coldest days (nights) exhibit a significant positive trend of 2.3 (2.5) °C decade⁻¹, whereas the trend of the temperatures on the hottest days (nights) is moderate. The annual occurrence of cold spells, frost days, and ice days shows a long-term negative trend from 1975 to 2014, whereas the annual occurrence of warm spells shows a positive trend. In addition, the growing season length is prolonged in Ny-Ålesund with a trend of ~4 days decade⁻¹.

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Supporting information

The following supporting information is available:

Figure S1. (a) Map of Svalbard in the Arctic region showing the location of Ny-Ålesund. (b) The location of three meteorological stations (NPI, AWI, YR).
Table S1. Linear trends (°C year⁻¹) of the maximum temperature, minimum temperature, diurnal temperature range and mean temperature at the three stations.
Table S2. Linear trends of temperature-related extremes (Table 1) at the three stations. Units are % year⁻¹ for TX90p, TX10p, TN90p, and TN10p, °C year⁻¹ for TXx, TXn, TNx, and TNn, and days year⁻¹ for the remaining indices.

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