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RESEARCH ARTICLE

Air temperature conditions in northern Nordaustlandet (NE Svalbard) at the end of World War II

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This article presents the results of an investigation into air temperature conditions in northern Nordaustlandet (NE Svalbard) based on meteorological observations made by German soldiers towards the end of World War II (1944/1945) and 4 months after its end. Traditional analysis using mean monthly data was supplemented by a detailed analysis based on daily data: maximum temperature, minimum temperature and diurnal temperature range. The latter kind of data made it possible to study such aspects of climate as the number of "characteristic days" (i.e., the number of days with temperatures exceeding specified thresholds), day-to-day temperature variability, and duration, onset and end dates of thermal seasons. The results from Nordaustlandet for the warmest period of the early 20th century warming period (ETCWP) were compared with temperature conditions both historical (the end part of the Little Ice Age) and contemporary (different sub-periods taken from the years 1981–2017) to estimate the range of warming during the ETCWP.
Analysis reveals that the expedition year 1944/1945 in Nordaustlandet was, in the majority of months, the warmest of all analysed periods, that is, both historical and contemporary periods. The study period was markedly warmer than 1981–2010 (mean annual −6.5 vs. −8.4 °C) but colder than the periods 2011–2016 (−5.7 °C) and 2014–2017 (−5.8 °C). The majority of mean monthly air temperatures in the ETCWP lies within two standard deviations of the modern 2014–2017 mean. This means that values of air temperature in the study period lie within the range of recent temperature variability. All other thermal characteristics show changes in accordance with expectations associated with general warming of the Arctic (i.e., a decrease in diurnal temperature range and number of cold days, and an increase in number of warm days). The latter days were most common in the ETCWP.

KEYWORDS
air temperature, Arctic, early instrumental data, ETCWP, Svalbard, WWII

1 | INTRODUCTION

The network of meteorological stations in the Arctic is very sparse at present and was much more sparse before the mid-20th century (Przybylak, 2000, 2002). Therefore, any new, even short, series of meteorological data for pre-1950 is very valuable for analysis of climate change and variability in the region. During World War II (WWII) some meteorological stations in the Arctic were temporarily closed. As a result, for the duration of WWII there are usually significant gaps in observation series. This is particularly true for the Norwegian Arctic (see, e.g., Hanssen-Bauer, Solas, & Steffensen, 1990; Nordli, 1990, 2010; Nordli, Hanssen-Bauer, & Førland, 1996; Nordli, Przybylak, Ogilvie, & Isaksen, 2014;

Steffensen, 1969, 1982), which was located in a place of strategic value between western Europe and northeastern Europe, that is, near the route of sea convoys organized by the Allies to transport necessary goods to Murmansk and Archangelsk to help the Soviet Union in its fight with the German army (Szupryczyński, 2011). In middle of 1941, all Norwegian meteorological stations operating in Svalbard were destroyed by the German army. Later on, however, the German army decided to set up nine stations, automatic and manned, in various places on the Svalbard coast and in the Greenland Sea (see Figure 1) because weather information for this part of the Arctic was very important to military operations. All of them worked usually for about 1 year and one third of them operated in the last year of WWII. Up till now, however, no detailed statistics, except for monthly means calculated for some stations by the Norwegian Meteorological Institute (Isfjord Radio and Longyearbyen), have been presented to the scientific community from those observations (Steffensen, 1969, 1982). The WWII sub-period is one of the warmest parts of the early 20th century warming period (ETCWP, 1921–1950), most expressed in the Arctic, and in particular in Greenland and Svalbard (Nordli, 2010; Przybylak, 2002, 2016). The ETCWP has been studied for many years, but still the mechanisms responsible for the rapid warming in this time have not been fully identified (see, e.g., Bengtsson, Semenov, & Johannessen, 2004; Serreze & Francis, 2006; Wood & Overland, 2010; Yamanouchi, 2011; Tokinagaa, Xiec, & Mukougawab, 2017; Wegmann, Brönnimann, & Compo, 2017, and many other references cited in particular in the last two listed publications). Bengtsson et al. (2004) summarized the state of knowledge saying that: "The 1920–1940 Arctic warming is one of the most puzzling climate anomalies of the 20th century." Factors limiting the achievement of a unified position on the causes of warming include the fact that the available meteorological data and information on the hydrosphere and cryosphere either contain gaps, or have insufficient temporal or spatial resolution. There is also a particular lack of information on forcing mechanisms (e.g., Sou et al. (2013) wrote: "In terms of the natural forcings, both solar and volcanic forcings are subject to considerable uncertainty"). For the abovementioned reasons, any new data describing the Arctic climate system (ACS) in the ETCWP are very important and can be helpful for better identification of its climate drivers. The quality controlled and corrected meteorological measurements taken in northern Nordaustlandet (Wordiebukta, in southeastern Rijpfjord, $\phi = 80°4'$N, $\lambda = 22°24'$E) during the Haudegen expedition of September 15, 1944 to September 5, 1945 led by Dr. Wilhelm Dege are the first step of our activity undertaken at Nicolaus Copernicus University as part of a research project aiming at collecting all available data for the ACS, in particular of those omitted usually for the shortness

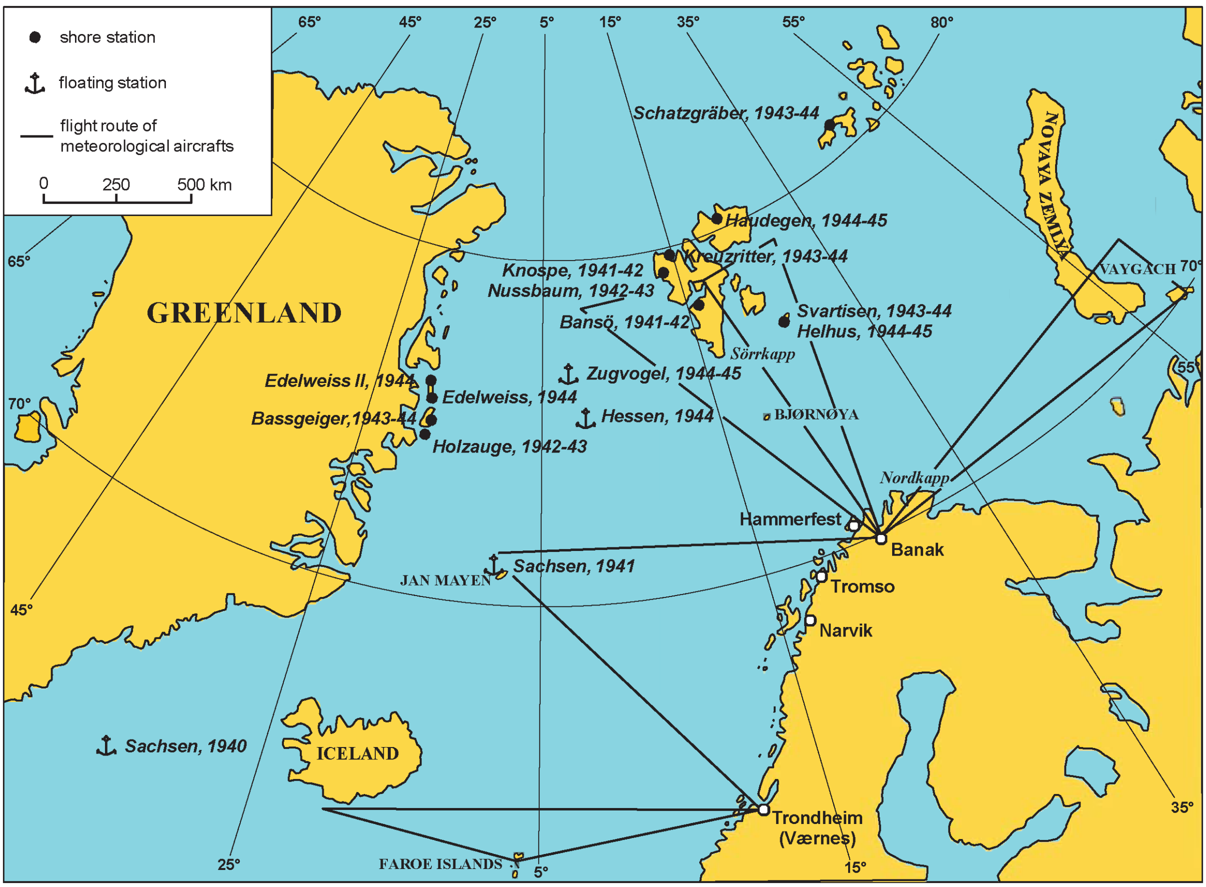

FIGURE 1 Map showing the activity of German meteorological stations, 1940–1945 (Szupryczyński, 2011) [Colour figure can be viewed at wileyonlinelibrary.com]

of their series (expedition measurements). This was the second year-round series of measurements (the first was made in Depot Point by the Oxford University Arctic Expedition 1935–1936 (see Glen, 1937a, 1937b, 1939) made for Nordaustlandet (see Table 1). What is more, eight air temperature measurements a day are usually available for this point for the entire period of observations, while for Depot Point only monthly means are available. Therefore, in our opinion, new insight into the character of weather on Svalbard at the end of the WWII, and 4 months after its end (May 8), can be gained from detailed analysis of the daily and sub-daily data from the Haudegen station. For this reason all references to "Haudegen" in this article should be understood as synonymous with "Haudegen station in the year 1944/1945". At present, there is only very a short summary of weather conditions during the expedition written by Dege (1960).

The main aims of the article are the following: (a) to give the scientific community a corrected and reliable series of daily air temperature data for this part of Nordaustlandet for the expedition year 1944/1945, for which data do not exist for Svalbard, (b) to present a detailed analysis of the different thermal characteristics using four parameters (TMEAN = daily mean, TMAX = daily highest temperature, TMIN = daily lowest temperature and DTR = diurnal temperature range), and (c) to compare the thermal conditions of the study expedition year (1944/1945), representing the warmest part of the ETCWP, to those occurring in more distant periods (end of the Little Ice Age (LIA), covering the second half of the 19th century, see Isaksson et al., 2003; Isaksson, Kohler, et al., 2005; Przybylak, 2016) and more recent periods (contemporary warming periods [CWPs]) 1981–2010 and 2011–2017.

2 | AREA, DATA AND METHODS

Nordaustlandet island, with an area of ca. 15,000 km^2, is the second largest island of Svalbard, after Spitsbergen (39,000 km^2) (Hisdal, 1985). The majority of its area (ca. 75%) is covered by ice caps, of which the greatest are Vestfonna and Austfonna. The remaining part of the island (mainly northwestern) is covered by tundra and rocks. As a result of this spatial distribution of surface types, expeditions both in historical and contemporary periods were localized in the northwestern part of Nordaustlandet (see Figure 2). This figure also shows the location of the other stations from which data were taken for analysis. Air temperature data for expedition year 1944/1945 for Haudegen station, and their measurement methods, were taken from the publication "Wissenschaftliche Beobachtungen auf dem Nordostland von Spitzbergen 1944–1945", Berichte des Deutschen Wetterdienstes, Nr.72 (Dege, 1960). Meanwhile, the personal narratives of Wilhelm Dege (leader of the expedition) were published originally in German (Dege, 1954) and were recently translated into English by William Barr (Dege, 2003). The latter publication, as well as the website http://www.dailymail.co.uk/news/article-3708492/The-Nazi-s-surrender-Incredible-untold-story-final-German-soldier-hand-pistol-spending-war-battling-polar-bears-Arctic-weather-station.html, contains a detailed description of the expedition, with illustrations, also including of thermometers, which is not contained in Dege (1960). Dege (2003, fig. 13) shows that air temperature measurements were carried out in a Stevenson screen at a height of about 160 cm using mercury-thallium thermometers. Measurements were conducted at different times of the day (usually eight measurements a day), and therefore mean daily values calculated using them (altogether 26 different formulas) were corrected using the method proposed by Przybylak and Vízi (2005). For calculation of corrections, hourly data from Hornsund station (southern Spitsbergen) from the years 1979–1983 were used. Comparison of all thus-calculated daily means to analogous means calculated from 24 hr reveals that biases were very small, that is, below ±0.1 °C. The corrected series of daily data was used in the present analysis and is also attached to this article (see Appendix S1, Supporting information). In addition to mean daily average values, extreme temperatures were also used for analysis. Both TMAX and TMIN were derived from extreme thermometers (except Mosselbukta station, where they were chosen from 24 hourly measurements), while DTR was calculated by subtracting daily TMIN from TMAX. There is

TABLE 1 Sources of air temperature series for northern Svalbard used in the present article

No.	Location	ϕ	λ	Altitude (m a.s.l.)	Period	Resolution of data	Data sources
1	Haudegen	80°04′N	22°24′E	17	Sep 15, 1944–Sep 5, 1945	f	Dege (1960)
2	Rijpfjorden	80°13′N	22°29′E	10	May 10, 2014–Apr 30, 2017	h	UNIS, The University Centre in Svalbard
3	Depot Point (Brandy Bay)	80°23′N	19°29′E	5	Aug 15, 1935–Aug 20, 1936	m	Glen (1939)
4	Crozierpynten (Treurenberg)	79°55′N	16°51′E	22	Aug 1, 1899–Aug 15, 1900	h	Westman (1904)
5	Verlegenhuken	80°04′N	16°15′E	8	Oct 1, 2010–Aprl 30, 2017	d	Norwegian Meteorological Institute, Data: eKlima.met.no
6	Mosselbukta (Mosselbai)	79°53′N	16°04′E	12	Sep 12, 1872–Jun 30, 1873	h	Wijkander (1875)
7	Ny-Ålesund	78°55′N	11°56′E	8	Jan 1, 1981–Apr 30, 2017	d	Norwegian Meteorological Institute, Data: eKlima.met.no

d = daily; f = fixed; h = hourly; m = monthly.

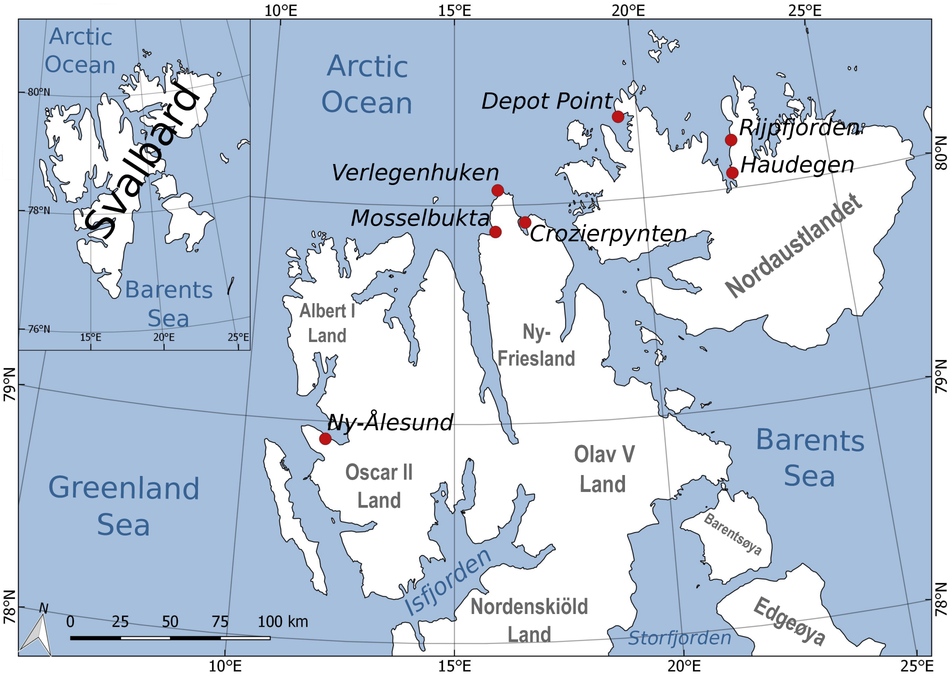

FIGURE 2 Location of land meteorological stations (dots) in northern Svalbard analysed in this study [Colour figure can be viewed at wileyonlinelibrary.com]

no information in Dege (1960) on the timings of extreme temperature measurements, but they were probably made in line with the standard rules during evening measurements (i.e., at 0800 CET (UTC +1)). We have adjusted TMAX and TMIN to days ending at midnight and such data are presented in Appendix S1.

Thermal conditions occurring during the study period were compared both with historical (end of the 19th century) and contemporary (end of the 20th century and beginning of the 21st century) values of the analysed variables. For this purpose data series from stations in northwestern Nordaustlandet and northern Spitsbergen were used (Table 1). The majority of them are short (1–5 years) which may influence the reliability of the results. The biases, however, if they do occur, are significantly reduced by the fact that all the data series come from periods of relatively stable climate conditions. In our previous articles of similar character to the present work (Przybylak & Wyszyński, 2017; Przybylak, Wyszyński, Nordli, & Strzyżewski, 2016) we present evidence that changes in temperature in the second half of the 19th century were not large and that air temperatures for quite a large number of individual stations from different areas in the Atlantic Arctic showed similar behaviour as temperature data from the two historical years used in the present article. The stability of air temperature in the second half of the 19th century is also confirmed by data from meteorological stations (e.g., Vardo, Archangelsk) in operation at that time, as well as different available sets of data for the Arctic (see Przybylak et al., 2016, fig. 11). The stability of the climate at the end of the LIA is also confirmed by proxy data (records of δ^{18}O from ice-cores from Austfonna, see Isaksson et al., 2003, fig. 3) and dendrochronological data (Weijers, Broekman, & Rozema, 2010). Atmospheric circulation described using the North Atlantic Oscillation (see Isaksson, Divine, et al., 2005, fig. 2) was also stable. Thus, we can conclude that the two historical stations, only available for the end of the 19th century in northern Svalbard, represent relatively well the temperature conditions in the study area in the mentioned period. We should also emphasize that measurement data are always better than any similar data reconstructed based on proxy data (ice-cores, lake sediments or dendrochronological widths). On the other hand, the expedition year 1944/1945 being analysed here very well represents the ETCWP (see next section for details) identified by Nordli et al. (2014) for the years 1920–1961 based on homogeneous series (1898–2012) from Svalbard Lufthavn. Series of data from the end part of the CWP consist of 3–5 years of observations, and thus it seems that they quite well represent the recent very warm thermal regime (since 1999) distinguished also by Nordli et al. (2014) based on regime shift analysis using the Radionov test.

Przybylak et al. (2014) show that spatial diversity of air temperature in Svalbard is quite large, and therefore to reliably compare the air temperature from the ETCWP with other periods, all monthly data taken from Spitsbergen stations were spatially adjusted to the Haudegen location, using the following formula:

$$T_H = T_C + c,$$

where T_H is the monthly data adjusted to the Haudegen location, T_C is the monthly data from the comparative station and c is the spatial correction (difference).

Parallel measurements from May 2014 to April 2017 exist for Rijpfjorden, located very near to Haudegen, as well as for Verlegenhuken and Ny-Ålesund. Thanks to these series of data, it was possible to calculate monthly corrections (differences) for TMEAN, TMAX and TMIN between the latter two stations and Rijpfjorden using the following formula:

$$c = T_R - T_{V(NA)},$$

where c is the spatial correction (difference), T_R is the monthly TMEAN, TMAX or TMIN at the location of Rijpfjorden and $T_{V(NA)}$ is the monthly TMEAN, TMAX or TMIN at the location of Verlegenhuken or Ny-Ålesund for the common period from May 2014 to April 2017 for all of these three sites.

As can be seen in Figure S1, Rijpfjorden was colder than Verlegenhuken in all months (by 1 °C from June to February and by 2 °C in the spring months) and colder than Ny-Ålesund from September to February by 1–2 °C, and in the rest of the year by more than 2 °C, with the maximum difference reaching 5 °C in the spring months. Temperature differences calculated between Rijpfjorden and Verlegenhuken were also used for Mosselbukta and Crozierpynten, which lie very near to Verlegenhuken (see Figure 2). However, we should expect potential biases as a result of the calculations of spatial gradients being based on only a 3-year-long data series. To roughly estimate the magnitudes of these biases, anomalies of 3-year average temperature gradients between reconstructed series for Pyramiden (central part of Spitsbergen, Gjelten et al., 2016) and observational data for Ny-Ålesund have been calculated with reference to long-term 1969–2014 temperature gradients. We have assumed that the above mentioned gradients (see also Przybylak et al., 2014) are the closest ones to the gradients between Rijpfjorden and Ny-Ålesund/Verlegenhuken which are unavailable for long-term period. Analysis of the frequency of biases (not shown) has revealed that they are not so large, usually varying between −0.3 and 0.4 °C for autumn (SON), winter (DJF) and year with frequencies of 95.5, 77.3 and 88.6%, respectively. For summer (JJA) biases are even smaller and range from −0.1 to 0.4 °C (84.1%). Larger biases, from −0.1 to 0.6 °C, occur only in spring (MAM) with a frequency of 68.2%.

Daily data have not been spatially adjusted to the location of Haudegen, which should be taken into account when considering the comparisons of different temperature characteristics using this kind of data to be presented. However, series of both monthly and daily air temperature data in the area of northern Svalbard are strongly correlated (Pearson's coefficient of correlation (r) being always greater than .95 and .91 for monthly and daily values, respectively) (Table S1) and therefore data from present-day stations located near the historical sites can reliably be used for comparison purposes.

Standard methods commonly used in climatology were used in the work. Basic statistical characteristics (coefficient of correlation [r], standard deviation [SD], skewness [$\gamma 1$] and kurtosis [$\gamma 2$]) of analysed series of air temperature data were calculated according to formulas recommended by Von Storch and Zwiers (1999).

Number of characteristics days, as well as onset, end and duration of thermal seasons were calculated according to the threshold values proposed by Przybylak and Vízi (2005) and Baranowski (1968), respectively. Details of this methodology were described recently by Przybylak and Wyszyński (2017), and therefore are not repeated here. In the case of thermal seasons, mean monthly air temperature data from all stations were used. However, data from distant stations, that is, those in Spitsbergen, have been adjusted to the Haudegen location. The following formulas constructed by Gumiński (1948) were used to calculate the onset and end of the particular thermal season based on thresholds proposed by Baranowski (1968), that is, −2.5 and 2.5 °C:

$$\text{(a) } x = \frac{t_p - t_1}{t_2 - t_1} 30, \quad \text{(b) } x = \frac{t_1 - t_p}{t_1 - t_2} 30,$$

where (a) is the formula for rising air temperature in the annual cycle and (b) is the formula for falling air temperature in the annual cycle. t_1 is the mean air temperature in the month preceding the occurrence of the threshold temperature. t_2 is the mean air temperature in the month following the occurrence of the threshold temperature. t_p is the threshold air temperature. x is the number of days between day of threshold air temperature and 15th day of preceding month.

Method assumptions:

- Monthly mean air temperature falls on the 15th day of the month.
- Every month has 30 days.
- Air temperature changes steadily (rise, fall) from month to month.

The number of days (x) calculated from both formulas is added to the 15th day of preceding month. If the value is greater than 15, the real number of days in this month (28, 30 or 31) is taken into account in the process of adding. In this way the sought date is obtained. It will be the date of the end of a given season or the date of onset of the next season, depending on which seasonal threshold the air temperature is being counted for.

For Haudegen station, which is our main subject of interest in this article, thermal seasons have been also delimited using daily data with a supplementary methodology proposed by Kosiba (1958) to precisely distinguish dates of onset and end of seasons (for details see Przybylak & Wyszyński, 2017).

Due to the lack of daily data for Depot Point, the number of characteristic days could not be calculated. Similarly, a gap in data for summer for Mosselbukta did not allow thermal seasons to be determined, because all characteristics could be calculated for winter only.

3 | RESULTS AND DISCUSSION

3.1 | Monthly resolution

Analysis of thermal conditions in the central part of the Svalbard archipelago using homogenized series from Svalbard

Airport (see Nordli et al., 2014, figs. 5 and 6) reveals that the meteorological observations conducted in Haudegen during the expedition year 1944/1945 reliably represent the ETCWP in the region, which was identified by Nordli et al. (2014) for the period 1920–1961 and referred to by them as the "long-lasting warm regime." In this period, the mean annual air temperature in Svalbard Airport reached −5.6 °C, while in the year 1944/1945 it was −5.5 °C, and thus very similar. Mean annual air temperature in Haudegen (excluding September) reached −6.5 °C (Table 2). Dege (1960) estimated mean September air temperature as 1.0 °C and the annual mean as −5.8 °C (see his table 3). The method of this estimation is not given in his publication and we therefore decided not to include this September value in our calculations in the article. It seems to us that this estimation is not fully reliable (too high) because even in the CWP (year 2010) mean air temperature in September was less than −0.5 °C (see Przybylak et al., 2014, fig. A1) or September 1944 (probably estimated by Dege) was exceptionally warm. In Haudegen, the warmest and coldest months occurred in July and January, respectively, as is also noted most often at present times (see, e.g., Przybylak, 1992). Mean air temperature in July was 4.8 °C, while in January it was −16.1 °C (Figure 3a). Excluding January, the course of air temperature in wintertime was untypical, April was colder than February and March, and November colder than December. As a result, spring was slightly colder than winter in terms of TMEAN and TMAX, but not of TMIN (Table 2). The highest air temperature ($TMAX_{abs}$ = 13.7 °C) was recorded in July, while the lowest ($TMIN_{abs}$) was in January (−35.5 °C). Clearly greater changes in the annual cycle are seen in $TMIN_{abs}$ than in $TMAX_{abs}$, while monthly means of TMAX and TMIN have a very similar course throughout the year (Figure 3a).

For comparison purposes, all available air temperature data have been collected for the northern part of Svalbard from late in the LIA period to recent times in order to roughly describe its changes in this time (see Figure 3b–d). The expedition year 1944/1945 in Nordaustlandet was in the majority of months the warmest of all analysed periods. The thermal privilege of this year is particularly large in comparison to years from the late LIA period (first two bars from the left in Figure 3b–d). In the winter half of year, that is, from October to March (except January), air temperature differences usually vary between 5 and 10 °C, and even exceed 10 °C in February and March. On the other hand, in the warm half-year the differences are significantly smaller, varying most often between 0 and 5 °C. The same tendencies are also observed in Svalbard Airport temperature series which were recently homogenized and prolonged to the end of the 19th century (Nordli et al., 2014). Larger differences in the winter half-year than the warm half-year are the result of greater temperature variability in the former

TABLE 2 Seasonal means of air temperature in northern Svalbard in stations analysed in this study, with differences between Haudegen and reference stations. Negative values are shown in italic, positive in bold font. Common comparative periods ON and Oct–Aug were used due to the particularity of the expedition year 1944/1945

Station	Parameter	Air temperature means (°C)					Air temperature differences (°C), Haudegen minus reference stations				
		ON	DJF	MAM	JJA	Oct–Aug	ON	DJF	MAM	JJA	Oct–Aug
Haudegen 1944–1945	TMAX	*−3.1*	*−7.8*	*−7.9*	**5.1**	*−3.5*					
	TMEAN	*−5.8*	*−11.3*	*−11.4*	**2.5**	*−6.5*					
	TMIN	*−8.5*	*−15.1*	*−14.7*	**0.3**	*−9.6*					
Mosselbukta adj. 1872–1873	TMAX	*−7.7*	*−13.0*	*−12.6*			**4.6**	**5.2**	**4.7**		
	TMEAN	*−11.3*	*−16.8*	*−16.3*			**5.5**	**5.5**	**4.9**		
	TMIN	*−15.3*	*−21.3*	*−20.8*			**6.7**	**6.2**	**6.1**		
Crozierpynten adj. 1899–1900	TMAX	*−10.8*	*−11.4*	*−14.8*	**2.2**	*−8.5*	**7.7**	**3.6**	**6.9**	**2.9**	**5.0**
	TMEAN	*−13.1*	*−15.5*	*−19.3*	**0.4**	*−11.7*	**7.2**	**4.2**	**7.9**	**2.2**	**5.2**
	TMIN	*−15.7*	*−19.7*	*−23.9*	−1.5	*−15.2*	**7.2**	**4.7**	**9.1**	**1.8**	**5.6**
Depot Point 1935–1936	TMAX	*−1.2*	*−9.8*	*−10.7*	**4.3**	*−4.6*	*−1.9*	**2.0**	**2.8**	**0.8**	**1.2**
	TMEAN	*−3.5*	*−12.7*	*−14.1*	**2.2**	*−7.3*	*−2.4*	**1.4**	**2.7**	**0.3**	**0.8**
	TMIN	*−5.9*	*−15.4*	*−17.4*	**0.3**	*−9.9*	*−2.6*	**0.3**	**2.7**	**0.0**	**0.3**
Ny-Ålesund adj. 1981–2010	TMAX	−6.1	−10.3	−9.8	**2.4**	*−5.9*	**3.0**	**2.5**	**1.9**	**2.7**	**2.5**
	TMEAN	−8.5	−13.4	−12.8	**1.1**	*−8.4*	**2.7**	**2.2**	**1.4**	**1.5**	**1.9**
	TMIN	*−11.4*	*−16.9*	*−16.2*	*−0.2*	*−11.1*	**2.9**	**1.8**	**1.4**	**0.5**	**1.5**
Verlegenhuken adj. 2011–2016	TMAX	*−3.4*	*−7.0*	*−7.4*	**3.5**	*−3.6*	**0.4**	*−0.8*	*−0.5*	**1.6**	0.2
	TMEAN	*−5.6*	*−9.6*	*−9.6*	**2.0**	*−5.7*	*−0.2*	*−1.6*	*−1.7*	**0.5**	−0.8
	TMIN	*−8.1*	*−12.6*	*−12.3*	**0.4**	*−8.2*	*−0.4*	*−2.4*	*−2.5*	*−0.1*	*−1.4*
Rijpfjorden 2014–2017	TMAX	*−2.4*	*−7.3*	*−7.9*	**3.4**	*−3.7*	*−0.7*	*−0.5*	*0.0*	**1.7**	**0.2**
	TMEAN	*−4.5*	*−9.8*	*−10.3*	**1.9**	*−5.8*	−1.3	−1.5	−1.1	**0.6**	−0.8
	TMIN	*−6.9*	*−12.5*	*−13.1*	**0.3**	*−8.1*	−1.6	−2.5	−1.7	**0.0**	−1.5

adj. = data spatially adjusted to Haudegen location; for details see section 2.

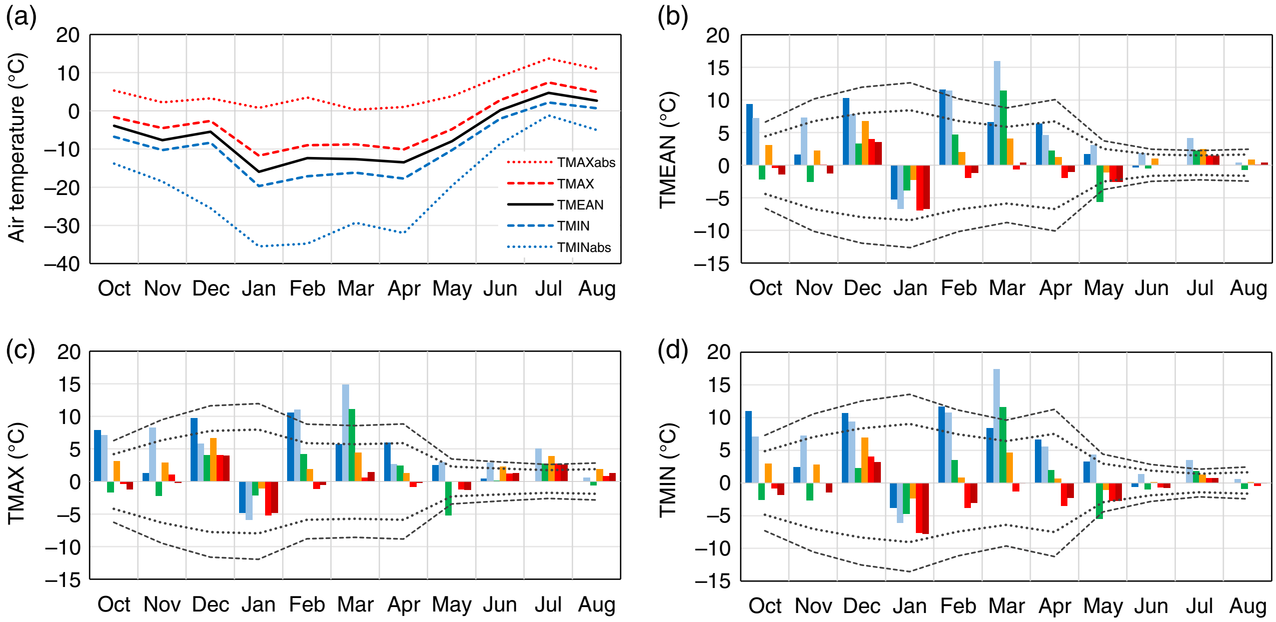

FIGURE 3 (a) Annual courses of monthly air temperature (TMAXabs, TMAX, TMEAN, TMIN and TMINabs) in Haudegen 1944–1945. Monthly differences of TMAX (b), TMEAN (c) and TMIN (d) between Haudegen 1944–1945 and (from left to right) Mossebukta 1872–1873 (dark blue), Crozierpynten 1899–1900 (light blue), Depot Point 1935–1936 (green), Ny-Ålesund 1981–2010 (orange), Verlegenhuken 2011–2016 (light red), Rijpfjorden 2014–2017 (dark red). Data from mentioned stations were subtracted from Haudegen. Dotted and dashed lines indicate ±1 *SD* and ±2 *SD*, respectively. *SDs* have been calculated on the basis of present data (1981–2010) taken from Ny-Ålesund [Colour figure can be viewed at wileyonlinelibrary.com]

period connected with stronger and more vigorous cyclonic activity (Isaksen et al., 2016) and weaker solar radiation (and lack thereof during the polar night) than in the latter period. An important role in these seasonal differences in variability can also be played by the sea ice extent around the Svalbard archipelago. Isaksen et al. (2016) found, for example, that sea ice extent in the Barents Sea and the region north of Spitsbergen played a major part in the recent atmospheric warming in Spitsbergen and that it has a greater influence on winter than summer air temperature. The study period was colder than the late 19th century only in January, by about 5 °C (Figure 3b–d). The final year of WWII was still markedly warmer than 1981–2010 (mean annual −6.5 vs. −8.4 °C), but colder than periods taken from the second decade of the 21st century, when average temperature varies from −5.7 °C (2011–2016) to −5.8 °C (2014–2017) (see Table 2 and Figure 3b–d). This result is in line with findings presented for the entire Arctic which document that the end of the ETCWP was the warmest period in the entire 20th century in the Arctic, but in comparison with the period since 1995 has lost this thermal privilege (Przybylak, 2007, 2016). It is worth noting, however, that in Nordaustlandet, the summer of 1945 was the warmest of all analysed periods. Changes in summer air temperature in this part of Svalbard and in its central area (Nordli et al., 2014) from the 19th century to present times, and from the mid-20th century onwards on western coasts (Gjelten et al., 2016), are significantly smaller than in other seasons, which also is in good agreement with findings presented for other parts of the Arctic, for example, the resolute region in the Canadian Arctic (Przybylak & Vízi, 2005), the entire Svalbard including surrounding seas (Przybylak et al., 2016), Novaya Zemlya (Przybylak & Wyszyński, 2017). Analysis of mean values of TMAX and TMIN differences between the end of WWII and other periods reveals that their behaviour is very similar to that of TMEAN. However, the greatest monthly and seasonal mean differences of all analysed air temperature parameters, are usually seen in TMIN, except for the long-term period 1981–2010 (see Table 2 and Figure 3b–d). All differences between mean monthly air temperature values calculated between the reference period (1944/1945) and other analysed periods usually lie within two SDs from the modern 1981–2010 mean. Similar results were obtained for older historical periods, for example, for the Canadian Arctic (Przybylak & Vízi, 2005; Wood & Overland, 2003), the entire Svalbard archipelago and surrounding seas (Przybylak et al., 2016), Novaya Zemlya (Przybylak & Wyszyński, 2017) and the entire Arctic (Przybylak, Vízi, & Wyszyński, 2010).

3.2 | Daily and sub-daily resolution

Przybylak and Vízi (2005) stated that: "In the process of averaging, important climatic information may very often be lost." For this reason, similarly as we did recently in our article analysing climate changes in Novaya Zemlya (Przybylak & Wyszyński, 2017), we have decided in this article to analyse again the air temperature regime for Nordaustlandet in a more precise way, using different parameters of daily data (TMEAN, TMAX, TMIN and DTR).

Annual course of TMEAN in the expedition year 1944/1945, when superimposed on their present-day (2014–2017) mean annual course derived from the nearby Rijpfjorden station, show that in the Haudegen there occurred spells both warmer and colder than today. As expected, the colder ones were more common than the warmer, in particular in the period from October to May (Figure 4). On the other hand, warm spells were more frequent in summer. As a result, average seasonal values in Haudegen were lower in autumn, winter and spring by 1.1–1.5 °C, while in summer they were higher by 0.6 °C. Both the positive and negative differences in TMEAN very seldom exceed 10 °C. In a few cases, the cold spells had a lower temperature than today by as much as 20 °C (see the turn of January–February, Figure 4). Almost all positive differences vary within two SDs of the present mean. Negative differences cross this boundary markedly more often than positive ones, but their frequency in comparison to the rest was also small. The greatest differences occur in the cold half-year as a result of the greatest variability of TMEAN during this period. Roughly speaking, the results presented here for the northern part of Nordaustlandet are similar to those shown for the Canadian Arctic and Novaya Zemlya. However, due to the smaller degree of continentality of climate both in northern Svalbard and Novaya Zemlya (greater cyclonic activity) compared to the Canadian Arctic (see Przybylak, 2016, fig. 4.2), negative temperature differences in the first two mentioned regions were markedly greater than in the Canadian Arctic. The magnitude of warm spells is more or less the same in all compared regions, while they were noted more frequently in the Canadian Arctic. This may partly be because different years were analysed for each of the three regions.

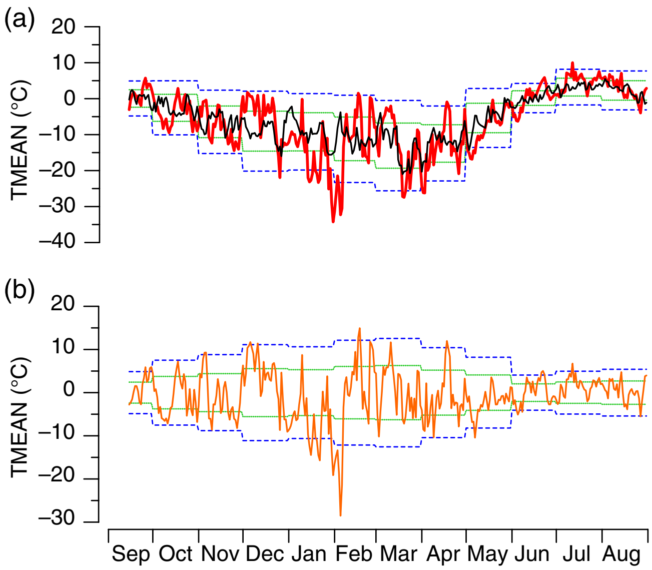

FIGURE 4 (a) Annual courses of daily TMEAN in Haudegen (September 15, 1944–August 31, 1945, thick solid red) and Rijpfjorden (2014–2017, thin solid black) and (b) their differences (solid orange). Data from Rijpfjorden were subtracted from Haudegen. Dotted green and dashed blue lines indicate mean daily for each month ±1*SD* and ±2*SD*, respectively. *SDs* have been calculated on the basis of present data (May 2014–April 2017) taken from Rijpfjorden [Colour figure can be viewed at wileyonlinelibrary.com]

More precise information about the character of air temperature changes between the expedition year 1944/1945 and the other analysed historical and contemporary periods is presented in Figure 5, where relative frequencies of occurrence of TMEAN are stratified into one-degree intervals. As results from Figure 5, TMEANs in the four analysed seasons in the northern part of Svalbard usually have multi-modal distributions both in historical and contemporary periods. TMEAN distributions in all analysed periods are skewed to the left, with the exception only of summer 2014–2017 in Rijpfjorden. They also have platykurtic distributions in all sites and seasons (except summers 1900 in Crozierpynten and 1945 in Haudegen). Comparison of TMEAN distribution in Haudegen and analogous distributions in different contemporary periods reveals that the range of TMEAN is more or less similar. On the other hand, in Haudegen frequencies of low autumn and spring TMEAN values are evidently greater than present values, while for winter values they are smaller, except for Verlegenhuken (Figure 5a–c). In summer, the shapes of TMEAN distributions are most similar between compared periods, although there is a greater frequency of low negative TMEAN in Haudegen (1945) than in contemporary periods (1981–2010, 2014–2017 and 2012–2016). Comparison of TMEAN distributions in Haudegen in 1944/1945 and in two historical periods—1899/1900 (Crozierpynten) and 1872/1873 (Mosselbukta) representing the late LIA period—shows an evident shift of frequency of TMEAN to the right in all seasons, that is, to greater values (Figure 5d, e). It is worth adding, however, that the range of occurrence of highest TMEAN intervals did not change, except for autumn in Mosselbukta. On the other hand, in historical times a lot of intervals with very low TMEAN occurred, which were not observed in the year 1944/1945 representing ETCWP, except for summer when no change in this characteristic between compared periods is noted.

Day-to-day variability of TMEAN (i.e., magnitude of change from 1 day to the next) in Haudegen in 1944/1945 was greatest in winter, and lowest in summer (Figure 6), similarly to the present climate (Przybylak, 2002). A secondary maximum can be also distinguished at the turn of March and April (Figure 6a). In winter, 11-day moving averages of this characteristic usually vary between 2.5 and 5 °C with a maximum near 7 °C in the turn of February–March. In summer, day-to-day variability of TMEAN is usually less than 2.5 °C. The annual cycle of monthly means shows that the greatest day-to-day variability of TMEAN in Haudegen occurred in January and February (about 4.5 °C), and the lowest in June (1.3 °C) and July (1.4 °C) (Figure 6b). The TMEAN variability was also estimated using *SD*. According to this measure of variability, it is evidently highest in Haudegen in February (9.8 °C) and lowest in July (2.3 °C) (Figure 6c). Day-to-day variability

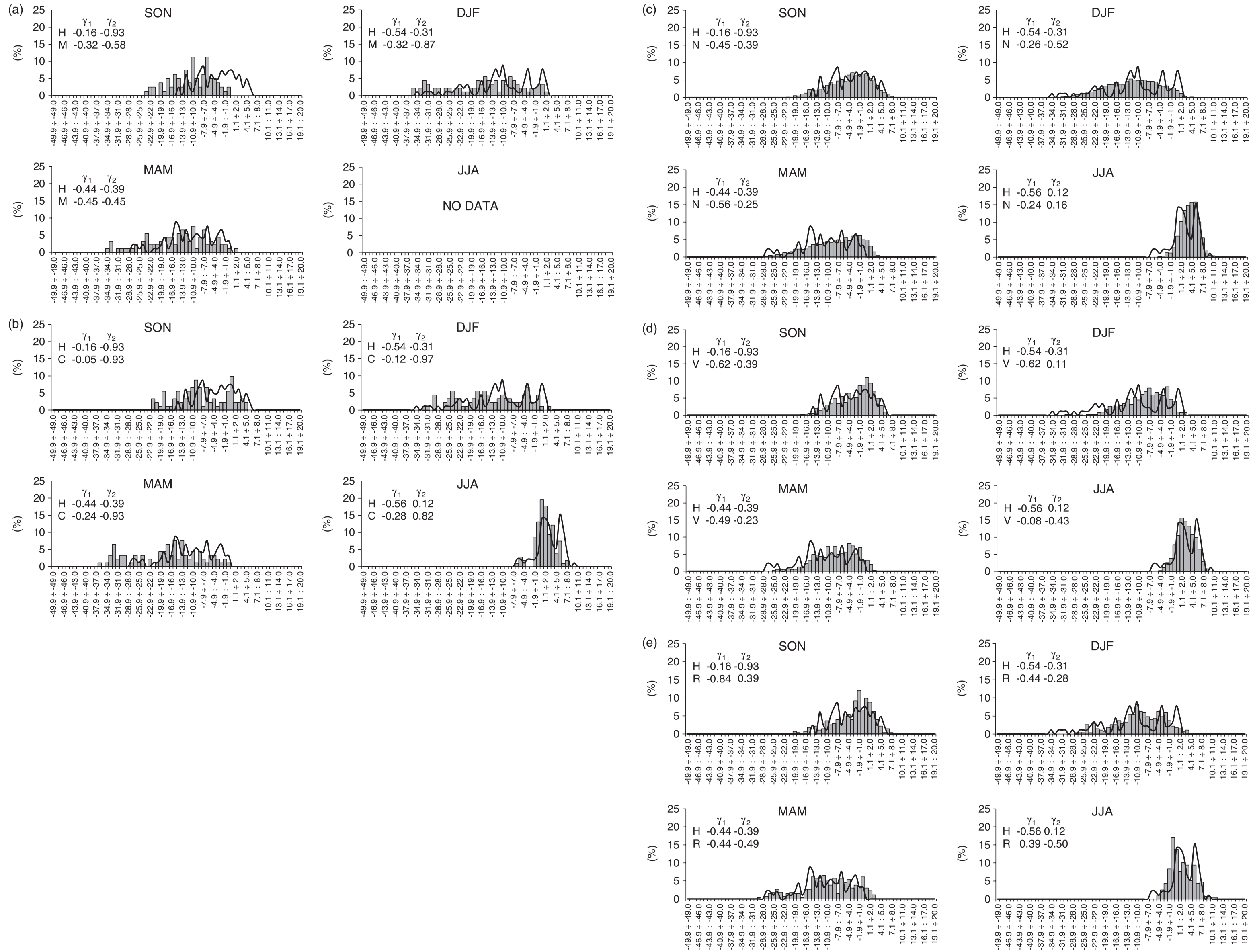

FIGURE 5 Seasonal (September–November, December–February, etc.) relative frequencies of occurrence (in %) of TMEAN in Haudegen 1944–1945 (lines in all charts) and other sites (bars) in northern Svalbard: (a) Mosselbukta 1872–1873, (b) Crozierpynten 1899–1900, (c) Ny-Ålesund 1981–2010, (d) Verlegenhuken 2011–2016 and (e) Rijpfjorden 2014–2017. Values of skewness (γ1) and kurtosis (γ2) are also shown. Explanation of abbreviations: H = Haudegen, M = Mosselbukta, C = Crozierpynten, N = Ny-Ålesund, V = Verlegenhuken and R = Rijpfjorden. Note that TMEAN for Haudegen for September has been taken from periods September 15–30, 1944 and September 1–5, 1945

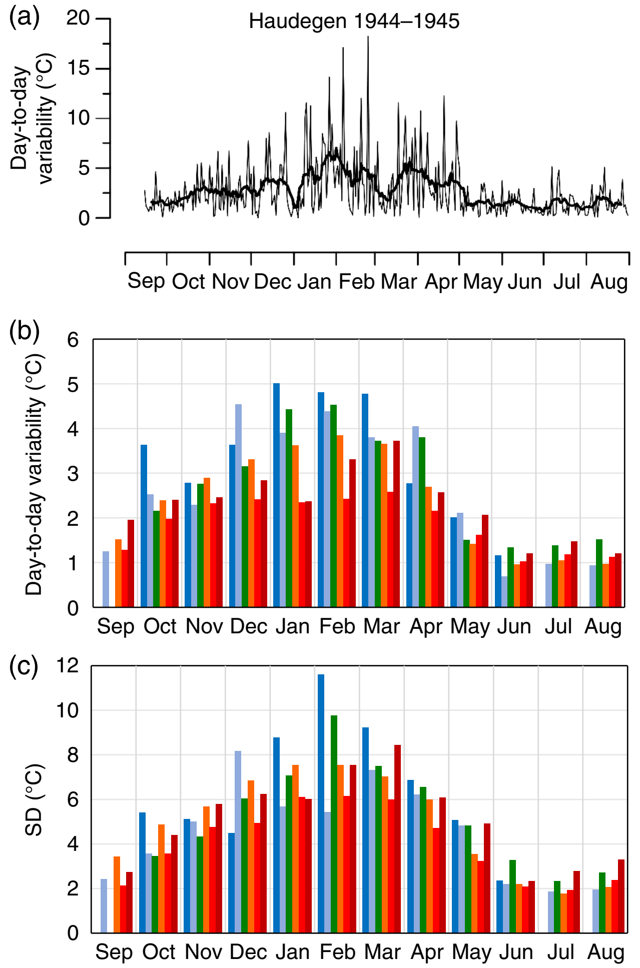

FIGURE 6 (a) Annual courses of day-to-day variability of MDAT in Haudegen 1944–1945. Thick black line indicates 11-day moving average. (b) Monthly means of day-to-day variability of MDAT in (from left to right) Mosselbukta 1872–1873 (dark blue), Crozierpynten 1899–1900 (light blue), Haudegen 1944–1945 (green), Ny-Ålesund 1981–2010 (orange), Verlegenhuken 2011–2016 (light red) and Rijpfjorden 2014–2017 (dark red). (c) The same as in (b) but shown in *SD* [Colour figure can be viewed at wileyonlinelibrary.com]

of TMEAN in northern Nordaustlandet in 1944/1945 was usually smaller than in Mosselbukta (1872/1873) and similar to that observed in Crozierpynten in 1899/1900 in the entire year, except summer (Figure 6b). On the other hand, there is a clear decrease in day-to-day variability of TMEAN from the end of WWII to recent times, particularly in winter and in spring. In summer months, variability in the ETCWP was usually greater than in either historical or contemporary periods (Figure 6b). Roughly similar patterns to those described above are seen in TMEAN variability estimated using *SD* (c.f., Figure 6c,b). As expected, day-to-day variability of TMEAN in Nordaustlandet in 1944/1945 was higher than in the mid-19th century in the northern Canadian Arctic (see Przybylak & Vízi, 2005, fig. 5c), in particular in the cold half-year (domination of cyclones/anticyclones, respectively). On the other hand, compared to historical periods for Novaya Zemlya (see Przybylak & Wyszyński, 2017, fig. 6), no significant change of TMEAN variability was noted. There was a decrease in day-to-day variability of TMEAN observed throughout most of the year from historical to present times in northern Svalbard and an increase in TMEAN day-to-day variability for the Canadian Arctic.

Annual courses of DTR in Haudegen (Figure 7) differ markedly from those observed in historical times in the Canadian Arctic (Przybylak & Vízi, 2005, fig. 6) and differ less from those observed in Novaya Zemlya (Przybylak & Wyszyński, 2017). In the Canadian Arctic, the highest values of DTR occurred from April to June and from October to March in Novaya Zemlya. On the other hand, in Haudegen, the markedly highest DTR occurred from January to April with mean monthly values varying slightly between 7.4 and 8.1 °C (Figure 7). The lowest values of the DTR in both Novaya Zemlya and Svalbard are noted in summer (<5 °C), while in the Canadian Arctic besides summer also in winter (<5 °C). In northern Svalbard, a clear decrease in the DTR between historical and present-time values is noted, which is particularly large in comparison to the values of DTR for the most recent periods (2011–2016 and 2014–2017; data taken from Verlegenhuken and Rijpfjorden, respectively) (see Figure 7b). On the other hand, DTRs in Haudegen (1944/1945) and Ny-Ålesund (1981–2010) are very similar from October to May, while in summer they are clearly greater in Haudegen. It is also worth noting that, of all analysed periods, the DTRs in Haudegen are the highest in summer (Figure 7b). The same tendency, that is, a decreasing DTR from historical to present times was also found for Novaya Zemlya by Przybylak and Wyszyński (2017), who, in addition, indicated a possible mechanism responsible for this long-term change in DTR.

To estimate more in-depth the character of air temperature changes throughout the whole study period, the frequency of occurrence of days which cross certain thresholds has been calculated (for details see section 2 and Przybylak & Wyszyński, 2017). The relative frequencies of occurrence of different kinds of such "characteristic days" in northern Svalbard are shown in Figure 8. Exceptionally warm days (TMAX > 15 °C) occurred only in summer in Ny-Ålesund and only on a few days (Table 3 and Figure 8). Very warm days (TMAX > 10 °C) were also quite rare, but occurred in all places and only in summer. The greatest frequency of these days occurred in Haudegen (7.6%) and in Ny-Ålesund (5.7%), while significantly fewer of them (frequencies of 2–3%) were observed at the rest of the stations. Even in recent years (2014–2017) in Rijpfjorden, lying only 19 km to the north of the Haudegen station, the number of very warm days was less than half of those in expedition year 1944/1945. Warm days (TMAX > 5 °C) are the first category of days which is noted also outside summer. At no station (except Ny-Ålesund) did they occur in spring (Table 3 and Figure 8). Of course, warm days are most common in summer, ranging 30.8% in Crozierpynten (1899/1900) to 63.9% in Ny-Ålesund (1981–2010), a large number of such days (50.0%) also occurred in Haudegen

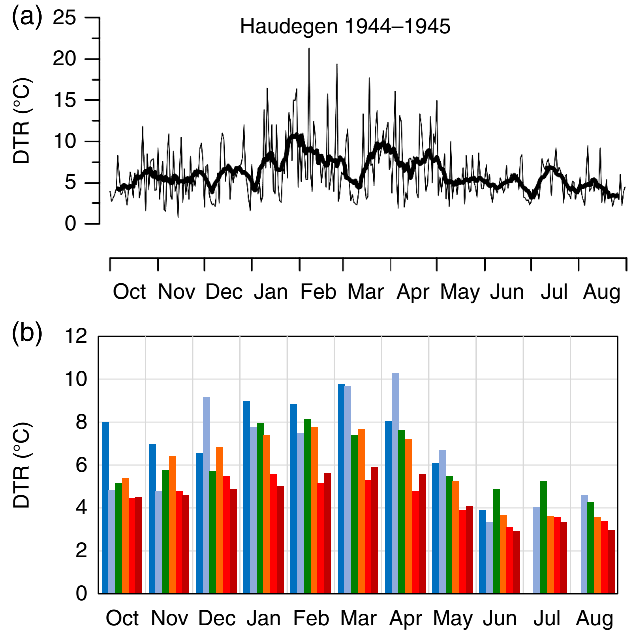

FIGURE 7 (a) Annual courses of diurnal temperature range (DTR) in Haudegen 1944–1945. Thick black line indicates 11-day moving average. (b) Monthly means of DTR in (from left to right) Mosselbukta 1872–1873 (dark blue), Crozierpynten 1899–1900 (light blue), Haudegen 1944–1945 (green), Ny-Ålesund 1981–2010 (orange), Verlegenhuken 2011–2016 (light red) and Rijpfjorden 2014–2017 (dark red) [Colour figure can be viewed at wileyonlinelibrary.com]

(1944/1945). Ny-Ålesund is in part of northern Svalbard which is significantly warmer than the area where the rest of the analysed stations is located (see Przybylak et al., 2014, fig. 3) and therefore without correction should not be taken into account in studies determining changes in time of all the characteristic days presented here. Statistics however are shown because this is the most northerly station with regular meteorological observations in Svalbard, which in addition is climatically closest to the conditions occurring in northern parts of the Ny Friesland peninsula and Nordaustlandet island.

Days with severe frost (TMAX < −30 °C) were noted very rarely in northern Svalbard, mainly occurring in winter, but also in spring at sites in the LIA period. In the most recent years they have not occurred at all, even in winter (Table 3 and Figure 8). Very cold days (TMAX < −20 °C) occurred with significantly greater frequency in the 19th century (15–25%) than in the late period of the ETCW and in the CWPs (less than 10%). At the majority of stations they were noted only in winter and spring (Table 3 and Figure 8). Cold days (TMAX < −10 °C) were most frequent again in Mosselbukta and Crozierpynten (about 50–60% in winter and spring) and least frequent in Verlegenhuken (22–24%). Only in summer did this category of days not occur (Table 3 and Figure 8). Frost days (TMAX < 0 °C) in the northern Svalbard are very common in all seasons except summer (usually above 80% in winter and spring, and above 60% in autumn, but <20% in summer). Similarly as in the Canadian Arctic (Przybylak & Vízi, 2005, fig. 7), in northern Svalbard (Figure 8) these days were observed also in July and August, which was not the case in the Novaya Zemlya (Przybylak & Wyszyński, 2017, fig. 8).

Slight frost days (TMAX > 0 °C and TMIN ≤ 0 °C) occurred most often from May to September/October, similarly as in Novaya Zemlya and the Canadian Arctic, with the maximum at all sites being in June, when at least 40% of such days were observed (Figure 8). They were particularly common in Crozierpynten (1899/1900), where in this month the frequency reached 60.0%. It is worth adding that the frequency of those days at this site in July was only slightly lower than in June (Figure 8). The number of slight frost days in northern Svalbard and in Novaya Zemlya is more or less similar, while in the Canadian Arctic it is clearly greater.

Comparison of the number of characteristic days in Haudegen to their number at other analysed stations is shown in Figure 9. In the expedition year 1944/1945 all categories of cold days were more common in Haudegen than in Ny-Ålesund (1981–2010) and Verlegenhuken (2011–2016), but in these latter two stations there is an important geographical bias. The most reliable results are from comparison with data from Rijpfjorden (2014–2017) near the Haudegen station. Analysing Figure 9 we must state that generally no change is observed in cold days. A slightly smaller number of cold summer days occurred in the ETCWP than at present. On the other hand, in both 19th century periods a markedly greater number of cold days was noted in all months except January. Warm days were up to almost 20% more frequent in Haudegen than other stations both in historical and in more recent periods (Figure 9). Only in Ny-Ålesund did more such days occur, which, as mentioned earlier, was the result of this station being located in the warm part of Svalbard. The number of slight frost days (TMAX > 0 °C and TMIN ≤ 0 °C), similarly as in Novaya Zemlya, does not show clear changes throughout the time analysed in the article. It should be noted, however, that there was a significantly greater number of slight frost days in Haudegen (1944/1945) in December than in the rest of the analysed stations (Figure 9).

Przybylak and Wyszyński (2017) present a review of the existing propositions for the division of the year into seasons in the Arctic. As a result of this review, they suggest using the four-thermal-season delimitation proposed by Baranowski (1968), who used for this purpose two threshold values (−2.5 and 2.5 °C) (for more details see also section 2). According to Przybylak and Wyszyński (2017), "one advantage of this division is the fact that it is possible to study (besides mean values of air temperature in the given season) changes in onset, end and duration of each thermal season." For these reasons, in the present article we have used Baranowski's criteria for studies of changes in thermal season characteristics between the ETCWP and other historical and present-day periods.

Table 4 presents dates of the onset and end of each thermal season in the ETCWP and other historical and modern periods. Except for two stations (Depot Point and Rijpfjorden) located very near Haudegen station, data from stations listed in Table 4 were spatially corrected to the Haudegen location using the method described in section 2.

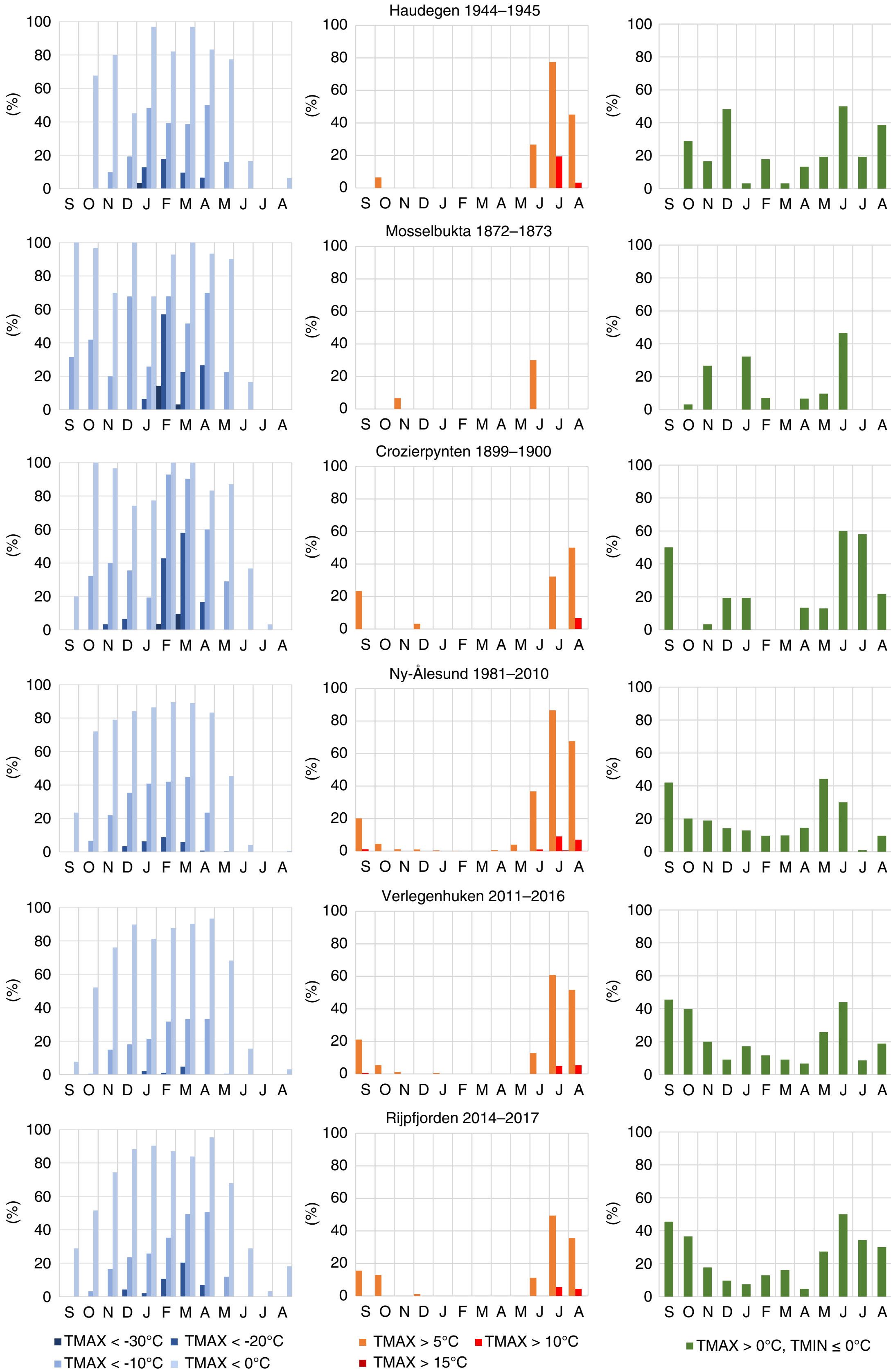

FIGURE 8 Annual courses of relative frequency of occurrence (in %) of characteristic days in northern Svalbard in stations analysed in the study. Order of characteristic days from coldest to warmest ones is shown from left to right [Colour figure can be viewed at wileyonlinelibrary.com]

TABLE 3 Relative frequency of occurrence (in %) of characteristic days in northern Svalbard in stations analysed in the study

	Haudegen 1944–1945					Mosselbukta 1872–1873					Crozierpynten 1899–1900				
Characteristic days	ON	DJF	MAM	JJA	Oct–Aug	ON	DJF	MAM	JJA	Oct–Aug	ON	DJF	MAM	JJA	Oct–Aug
Tmax > 0 °C, Tmin ≤ 0 °C	23.0	23.3	12.0	35.9	23.6	14.8	13.3	5.4			1.6	13.3	8.7	43.0	19.1
Tmax < 0 °C	73.8	74.4	85.9	7.6	59.1	83.6	86.7	94.6			98.4	83.3	90.2	11.2	65.7
Tmax < −10 °C	4.9	35.6	34.8	0.0	20.0	31.1	53.3	47.8			36.1	47.8	59.8	0.0	34.3
Tmax < −20 °C	0.0	10.0	5.4	0.0	4.2	0.0	20.0	16.3			1.6	15.6	25.0	0.0	10.9
Tmax < −30 °C	0.0	1.1	0.0	0.0	0.3	0.0	4.4	1.1			0.0	1.1	3.3	0.0	1.1
Tmax > 5 °C	3.3	0.0	0.0	50.0	14.3	3.3	0.0	0.0			0.0	1.1	0.0	30.8	9.7
Tmax > 10 °C	0.0	0.0	0.0	7.6	2.1	0.0	0.0	0.0			0.0	0.0	0.0	2.8	0.9
Tmax > 15 °C	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			0.0	0.0	0.0	0.0	0.0
	Ny-Ålesund 1981–2010					Verlegenhuken 2011–2016					Rijpfjorden 2014–2017				
Characteristic days	ON	DJF	MAM	JJA	Oct–Aug	ON	DJF	MAM	JJA	Oct–Aug	ON	DJF	MAM	JJA	Oct–Aug
Tmax > 0 °C, Tmin ≤ 0 °C	19.5	12.4	23.0	13.4	16.9	30.1	12.7	13.9	23.6	19.2	27.3	10.0	16.0	38.0	22.6
Tmax < 0 °C	75.5	86.6	72.5	1.5	57.4	63.9	86.2	83.9	6.2	59.5	62.8	88.6	82.4	16.7	62.2
Tmax < −10 °C	14.1	39.3	22.9	0.0	19.4	7.7	23.6	22.3	0.0	13.9	9.8	28.0	37.8	0.0	19.5
Tmax < −20 °C	0.1	6.1	2.2	0.0	2.3	0.0	1.1	1.6	0.0	0.7	0.0	5.5	9.5	0.0	4.0
Tmax < −30 °C	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Tmax > 5 °C	2.8	0.5	1.5	63.9	18.6	3.3	0.2	0.0	42.0	12.2	6.6	0.4	0.0	32.2	10.3
Tmax > 10 °C	0.0	0.0	0.0	5.7	1.6	0.0	0.0	0.0	3.4	0.9	0.0	0.0	0.0	3.3	0.9
Tmax > 15 °C	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Thanks to that effort, it was possible to study the changes in thermal season characteristics over time.

Dates of winter (TMEAN ≤ −2.5 °C) onset in northern Nordaustlandet varied from mid-September to mid-October (see Table 4). In line with expectations, earlier onset was noted in times older than the ETCWP, and later onset in more recent times (2011–2016 and 2014–2017). The end of winter usually occurs at the turn of May–June, and only in the expedition year 1935/1936 did it finish half a month earlier. The length of winter in more recent years is 10–20 days shorter than in the ETCWP, and 30–35 days shorter than winter 1899/1900. Large-scale winter warming in more recent times (after 2010) is clearly seen even in comparison to the 1981–2010 period (Table 4). Differences in winter duration reach 20–30 days. The second-longest season (50–70 days) is usually autumn (−2.5 °C < TMEAN < 2.5 °C), which starts in August, in particular the second half, and finishes between mid-September and mid-October. In the ETCWP, autumn was 5–15 days shorter than in recent years. Duration of spring (−2.5 °C < TMEAN < 2.5 °C) and summer (TMEAN ≥ 2.5 °C) was comparable and varied most often from 30 to 40 days (Table 4). Thus, non-significant changes occurred between the ETCWP and more recent warming period (after 2010). In colder periods, both in historical (summer 1900) and contemporary (1981–2010) times, summers did not occur at all (Table 4). Analysis of thermal season characteristics (dates of onset, end and duration) reveals good agreement with the changes which are expected to occur due to general warming of Nordaustlandet in the 20th and 21st centuries. Similar conclusions have also been presented for Novaya Zemlya by Przybylak and Wyszyński (2017).

4 | CONCLUSIONS AND FINAL REMARKS

The main results obtained from our investigations can be summarized as follows.

1. Meteorological data gathered for northern Nordaustlandet during the expedition year 1944/1945 considerably fill the existing gaps of data for the study time and area.
2. In most months, the study period in Nordaustlandet was the warmest of all analysed periods, that is, both historical and contemporary. The thermal privilege of this expedition year is particularly large compared to years of the LIA. The study period was also markedly warmer than 1981–2010 (mean annual −6.5 vs. −8.4 °C), but colder than periods from the second decade of the 21st century, when average temperatures vary from −5.7 °C (2011–2016, Verlegenhuken) to −5.8 °C (2014–2017, Rijpfjorden).
3. The majority of mean monthly air temperatures in the ETCWP is within two *SDs* of the modern 1981–2010 mean. This means that values of air temperature in the study period lie within the range of recent temperature variability. Similar results were obtained for older historical periods, for example, for the Canadian Arctic, the entire Svalbard archipelago and surrounding seas, Novaya Zemlya as well as for the entire Arctic.

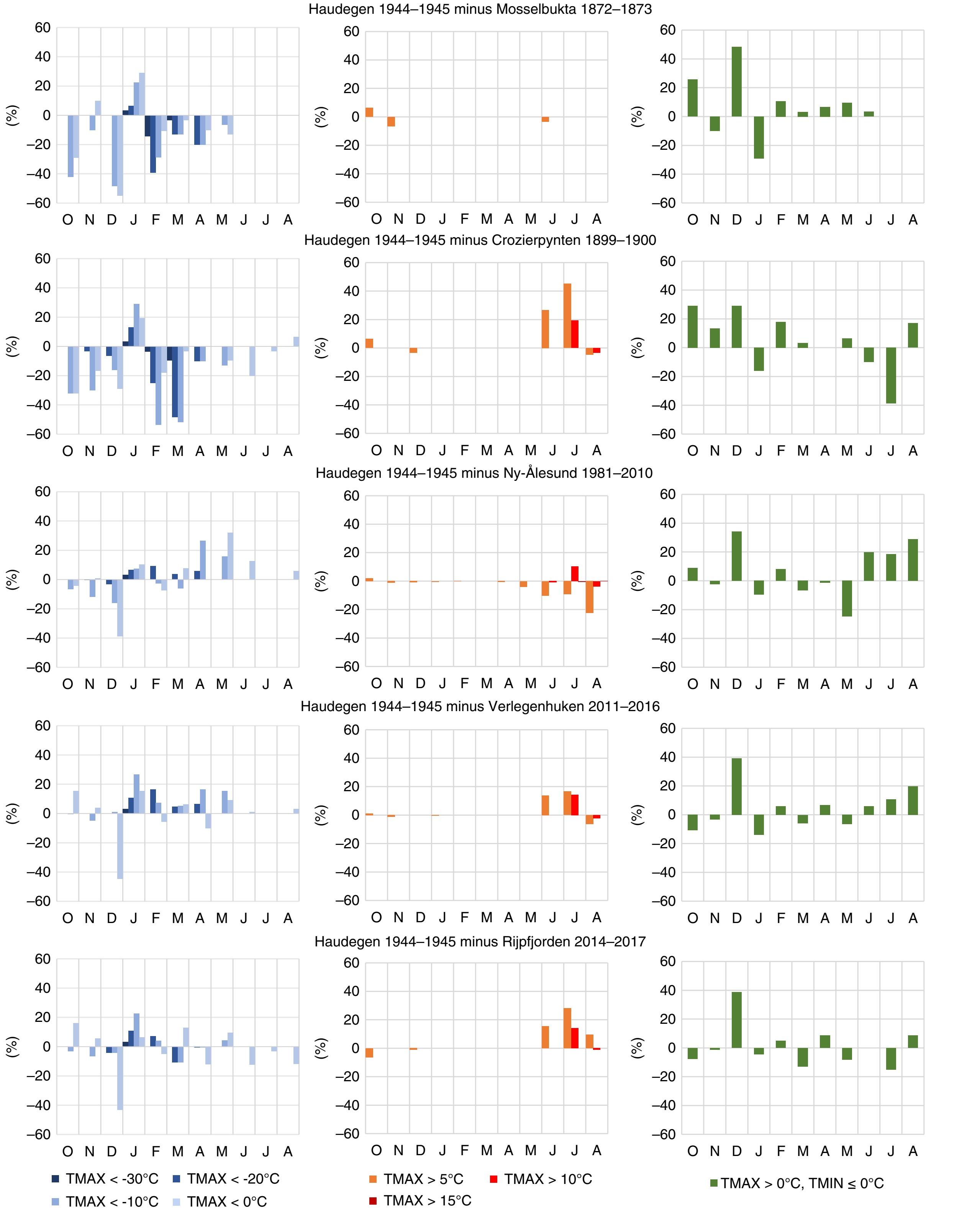

FIGURE 9 Annual courses of differences between the number of characteristic days (in %) in northern Svalbard in stations analysed in the study. Data from reference stations were subtracted from Haudegen. Order of characteristic days from coldest to warmest ones is shown from left to right [Colour figure can be viewed at wileyonlinelibrary.com]

4. Day-to-day variability of TMEAN in northern Nordaustlandet in 1944/1945 was usually smaller than in Mosselbukta (1872/1873) and similar to that observed in Crozierpynten in 1899/1900 in the entire year, except summer (Figure 6b). On the other hand, there is a clear decrease in day-to-day variability of TMEAN from the end of the WWII to recent times, particularly in winter and in spring. In summer months, variability in the

TABLE 4 Dates of the onset and end of each thermal season in northern Svalbard in stations analysed in the study

Thermal seasons	Winter				Spring				Summer				Autumn			
	Date		Duration		Date		Duration		Date		Duration		Date		Duration	
	Onset	End	Days	%	Onset	End	Days	%	Onset	End	Days	%	Onset	End	Days	%
Haudegen 1944–1945[a]	Oct 3	Jun 8	249	68.2	Jun 9	Jul 7	29	7.9	Jul 8	Aug 14	38	10.4	Aug 15	Oct 2	49	13.5
Haudegen 1944–1945[b]	Oct 8	May 4	240	65.8	Jun 5	Jul 29	55	15.1	Jul 30	Aug 25	27	7.4	Aug 26	Oct 7	43	11.7
Crozierpynten adj. 1899–1900	Sep 21	Jun 12	265	72.6	Jun 13	Spring/autumn								Sep 20	100	27.4
Depot Point 1935–1936	Sep 14	May 15	245	67.1	May 16	Jul 14	60	16.4	Jul 15	Aug 20	36	9.9	Aug 21	Sep 13	24	6.6
Ny-Ålesund adj. 1981–2010	Sep 22	Jun 6	258	70.7	Jun 7	Spring/Autumn								Sep 21	107	29.3
Verlegenhuken adj. 2011–2016	Oct 8	May 31	236	64.7	Jun 1	Jul 7	37	10.1	Jul 8	Aug 17	41	11.2	Aug 18	Oct 7	51	14.0
Rijpfjorden 2014–2017	Oct 15	May 31	229	62.7	Jun 1	Jul 7	37	10.1	Jul 8	Aug 7	31	8.6	Aug 8	Oct 14	68	18.6

adj. = data spatially adjusted to Haudegen location; for details see section 2.

[a] Based on daily data.

[b] Based on monthly data.

ETCWP was usually greater than in either historical or contemporary periods.

5. Annual courses of the DTR in Haudegen (Figure 7) differ markedly from those observed in historical times in the Canadian Arctic, and differ less from those observed in Novaya Zemlya. In the Canadian Arctic, the highest values of DTR occurred from April to June, but from October to March in Novaya Zemlya. On the other hand, in Haudegen, the markedly highest DTR occurred from January to April with mean monthly values varying slightly between 7.4 and 8.1 °C. In northern Svalbard, a clear decrease in DTR between historical and present-time values is noted, and is particularly large compared to values of DTR calculated for the most recent periods (2011–2016 and 2014–2017; data taken from Verlegenhuken and Rijpfjorden, respectively).
6. Generally, no change is observed in frequency of occurrence of cold days between the ETCWP and CWPs. A slightly smaller number of cold summer days occurred in the ETCWP than occur at present. On the other hand, in both 19th-century periods, a markedly greater number of cold days was noted in all months except January. Warm days were up to 20% more frequent in Haudegen than in historical and more recent periods.
7. Changes in duration (and of onset and end) of thermal seasons are in line with the observed general warming throughout the 20th and 21st centuries. The main features of observed changes are (a) shortening of winter in years after 2010 by 10–20/30–35 days in comparison to the ETCWP and winter of 1899/1900, respectively, (b) non-significant changes in duration of summer between the ETCWP and more recent warming period (2011–2017), (c) lack of summer in historical times and in the period 1981–2010, (d) lengthening of both spring and autumn from the ETCWP to the period 2011–2017, but by less than 10 days.

This article is the fourth written by us to give a deeper regional insight (northern Svalbard) into climate changes in historical times in the Arctic (the previous ones were Przybylak & Vízi (2005), Przybylak et al. (2016) and Przybylak & Wyszyński (2017)). These have improved the quality and reliability of our knowledge about different aspects of air temperature conditions (not only monthly, seasonal and yearly means) in the Arctic in historical times for which only very limited data exist. The occurrence of climate warming/cooling epochs over the last 120 years is also confirmed by the different air temperature characteristics calculated for northern Svalbard and other Arctic areas mentioned in the article for historical/contemporary periods. However, still more such works are urgently needed to improve our knowledge, in particular for the Russian Arctic. Therefore, data rescue activity for Arctic areas and greater climate reconstruction efforts to improve of our knowledge about climate changes on the regional scale is more and more urgently needed.

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REFERENCES

Baranowski, S. (1968). Termika tundry peryglacjalnej SW Spitsbergen. In *Acta universitatis wratislaviensis* (Vol. *68*). Wrocław, Poland: Państwowe Wydawn.

Bengtsson, L., Semenov, V. A., & Johannessen, O. M. (2004). The early twentieth-century warming in the Arctic—A possible mechanism. *Journal of Climate*, *17*, 4045–4057. https://doi.org/10.1175/1520-0442(2004)017<4045:TETWIT>2.0.CO;2

Dege, W. (1954). *Wettertrupp Haudegen. Eine deutsche Arktisexpedition 1944/45*. Wiesbaden, Germany: F.A. Brockhaus.

Dege, W. (1960). Wissenschaftliche Beobachtungen auf dem Nordostland von Spitzbergen 1944–1945. *Berichte des Deutschen Wetterdienstes*, *72*, 19–23.

Dege, W. (2003). In W. Barr (Ed.), *War north of 80: the last German Arctic weather station of World War II (translated from German)* (p. 361). Calgary, AB: University of Calgary Press.

Gjelten, H., Nordli, O., Isaksen, K., Forland, E., Sviashchennikov, P., Wyszyński, P., … Urazgildeeva, A. (2016). Air temperature variations and gradients along the coast and fjords of western Spitsbergen. *Polar Research*, *35*, 29878. https://doi.org/10.3402/polar.v35.29878

Glen, A. R. (1937a). The Oxford University Arctic expedition, north-east land, 1935–36. *The Geographical Journal*, *90*(3), 193–222.

Glen, A. R. (1937b). The Oxford University Arctic expedition, north-east land, 1935–36 (continued). *The Geographical Journal*, *90*(4), 289–310.

Glen, A. R. (1939). The glaciology of north-east land. *Geografiska Annaler*, *21*, 1–38.

Gumiński, R. (1948). Concerning the establishment of agricultural climatic regions in Poland (Próba wydzielenia dzielnic rolniczo-klimatycznych w Polsce). *Przegląd Meteorologiczny i Hydrologiczny*, *1*(1), 7–20.

Hanssen-Bauer, I., Solas, M. K., & Steffensen, E. L. (1990). *The climate of Spitsbergen* (DNMI Rapport No. 39/90, p. 40). Oslo, Norway: Klima.

Hisdal, V. (1985). *Geography of Svalbard* (p. 75). Oslo, Germany: Norsk Polarinstitutt.

Isaksen, K., Nordli, Ø., Førland, E. J., Łupikasza, E., Eastwood, S., & Niedźwiedź, T. (2016). Recent warming on Spitsbergen—Influence of atmospheric circulation and sea ice cover. *Journal of Geophysical Research: Atmospheres*, *121*, 11913–11931. https://doi.org/10.1002/2016JD025606

Isaksson, E., Divine, D., Kohler, J., Martma, T., Pohjola, V., Motoyama, H., & Watanabe, O. (2005). Climate oscillations as recorded in Svalbard ice core σ^{18}O records between AD 1200 and 1997. *Geografiska Annaler*, *87A*(1), 203–214. https://doi.org/10.1111/j.0435-3676.2005.00253.x

Isaksson, E., Hermanson, M., Hicks, S., Igarashi, M., Kamiyama, K., Moore, M., … Watanabe, O. (2003). Ice cores from Svalbard—Useful archives of past climate and pollution history. *Physics and Chemistry of the Earth*, *28*, 1217–1228. https://doi.org/10.1016/j.pce.2003.08.053

Isaksson, E., Kohler, J., Pohjola, V., Moore, J., Igarashi, M., Karlof, L., … van de Wal, R. S. W. (2005). Two ice-core σ^{18}O records from Svalbard illustrating climate and sea-ice variability over the last 400 years. *The Holocene*, *15*(4), 501–509. https://doi.org/10.1191/0959683605hl820rp

Kosiba, A. (1958). O konieczności ujednolicenia skali międzynarodowej podstawowych kryteriów termicznych w klimatologii. *Przegląd Geofizyczny*, *3*(11), 1.

Nordli, Ø., Przybylak, R., Ogilvie, A. E. J., & Isaksen, K. (2014). Long-term temperature trends and variability on Spitsbergen: The extended Svalbard airport temperature series, 1898–2012. *Polar Research*, *33*, 21349. https://doi.org/10.3402/polar.v33.21349

Nordli, P. Ø. (1990). *Temperature and precipitation series at Norwegian Arctic meteorological stations* (DNMI Rapport No. 40/90, pp. 1–13). Oslo, Norway: Klima.

Nordli, P. Ø. (2010). The Svalbard airport temperature series. *Bulletin of Geography. Physical Geography Series*, *3*, 5–25.

Nordli, P. Ø., Hanssen-Bauer, I., & Førland, E. J. (1996). *Homogeneity analyses of temperature and precipitation series from Svalbard and Jan Mayen* (DNMI Rapport No. 16, p. 41). Oslo, Norway: Klima.

Przybylak, R. (1992). The thermic and humidity relations against a background of the circulations conditions in Hornsund (Spitsbergen) in the period 1978–1983. *Dokumentacja Geograficzna*, *2*, 1–105 (in Polish).

Przybylak, R. (2000). Temporal and spatial variation of surface air temperature over the period of instrumental observations in the Arctic. *International Journal of Climatology*, *20*, 587–614.

Przybylak, R. (2002). *Variability of air temperature and atmospheric precipitation in the Arctic (atmospheric and oceanographic sciences library)* (Vol. *25*, p. 330). Dordrecht, The Netherlands; Boston, MA; London, UK: Kluwer Academic.

Przybylak, R. (2007). Recent air-temperature changes in the Arctic. *Annals of Glaciology*, *46*, 316–324. https://doi.org/10.3189/172756407782871666

Przybylak, R. (2016). *The climate of the Arctic (atmospheric and oceanographic sciences library)* (Vol. *52*, 2nd ed., p. 279). Cham, Heidelberg, Germany; New York, NY; Dordrecht, The Netherlands; London, UK: Springer.

Przybylak, R., Araźny, A., Nordli, Ø., Finkelnburg, R., Kejna, M., Budzik, T., … Rachlewicz, G. (2014). Spatial distribution of air temperature on Svalbard during 1 year with campaign measurements. *International Journal of Climatology*, *34*, 3702–3719. https://doi.org/10.1002/joc.3937

Przybylak, R., & Vízi, Z. (2005). Air temperature changes in the Canadian Arctic from the early instrumental period to modern times. *International Journal of Climatology*, *25*, 1507–1522. https://doi.org/10.1002/joc.1213

Przybylak, R., Vízi, Z., & Wyszyński, P. (2010). Air temperature changes in the Arctic from 1801 to 1920. *International Journal of Climatology*, *30*, 791–812. https://doi.org/10.1002/joc.1918

Przybylak, R., & Wyszyński, P. (2017). Air temperature in Novaya Zemlya Archipelago and Vaygach Island from 1832 to 1920 in the light of early instrumental data. *International Journal of Climatology*, *37*, 3491–3508. https://doi.org/10.1002/joc.4934

Przybylak, R., Wyszyński, P., Nordli, Ø., & Strzyżewski, T. (2016). Air temperature changes in Svalbard and the surrounding seas from 1865 to 1920. *International Journal of Climatology*, *36*, 2899–2916. https://doi.org/10.1002/joc4527

Serreze, M. C., & Francis, J. A. (2006). The Arctic amplification debate. *Climate Change*, *76*, 241–264. https://doi.org/10.1007/s10584-005-9017-y

Suo, L., Ottera, O. H., Bentsen, M., Gao, Y., & Johannessen, O. M. (2013). External forcing of the early 20th century Arctic warming. *Tellus A*, *65*, 20578. https://doi.org/10.3402/tellusa.v65i0.20578

Steffensen, E. (1969). The climate and its recent variations at the Norwegian Arctic stations. *Meteorologiske Annaler*, *5*, 215–349.

Steffensen, E. (1982). *The climate at Norwegian Arctic stations* (DNMI Rapport No. 5, p. 44). Oslo, Norway: Klima.

Szupryczyński, J. (2011). The second world war on Svalbard (Druga wojna światowa na Svalbardzie). *Przegląd Geograficzny*, *83*, 483–506.

Tokinagaa, H., Xiec, S.-P., & Mukougawab, H. (2017). Early 20th-century Arctic warming intensified by Pacific and Atlantic multidecadal variability. *Proceedings of the National Academy of Sciences of the United States of America*, *114*(24), 6227–6232. https://doi.org/10.1073/pnas.1615880114

Von Storch, H., & Zwiers, F. W. (1999). *Statistical analysis in climate research* (p. 484). Cambridge, UK: Cambridge University Press. https://doi.org/10.1017/CBO9780511612336

Wegmann, M., Brönnimann, S., & Compo, G. (2017). Tropospheric circulation during the early twentieth century Arctic warming. *Climate Dynamics*, *48*, 2405–2418. https://doi.org/10.1007/s00382-016-3212-6

Weijers, S., Broekman, R., & Rozema, J. (2010). Dendrochronology in the High Arctic: July air temperatures reconstructed from annual shoot length growth of the circumarctic dwarf shrub *Cassiope tetragona*. *Quaternary Science Reviews*, *29*, 3831–3842. https://doi.org/10.1016/j.quascirev.2010.09.003

Westman, J. (1904). *Physique terrestre. Meteorologie. Histoire naturelle. VIII section. Meterologie. A. Observations a la station d'hivernage. Observations meterologiques faites en 1889–1901 a la Baie de Treurenberg, Spitzberg*. Jaderin, Edvard, leader. Missions scientifiques pour la mesure d'un arc de meridien au Spitzberg enterprises en 1889–1900 sous les auspices des gouvernements russe et suedois: Mission suedoise. T.2. Physique terrestre, meterologie, historie naturelle. Sect.7–8. Stockholm: Aktiebolaget Centraltryckeriet, 2 (8A): p. 218.

Wijkander, A. (1875). Observations meteorologiques de l'expedition Arctique siedoise 1872–1873. *Kungl. Svenska vetenskapsakademiens handlingar NY följd*, *12*(7), 120.

Wood, K. R., & Overland, J. E. (2003). Accounts from 19th-century Canadian Arctic explorers' logs reflect present climate conditions. *Eos, Transactions American Geophysical Union*, *84*, 410–412.

Wood, K. R., & Overland, J. E. (2010). Early 20th century Arctic warming in retrospect. *International Journal of Climatology*, *30*, 1269–1279. https://doi.org/10.1002/joc.1973

Yamanouchi, T. (2011). Early 20th century warming in the Arctic: A review. *Polar Science*, *5*, 53–71. https://doi.org/10.1016/j.polar.2010.10.002

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