Forty years High Arctic climatological dataset of the Polish Polar Station Hornsund (SW Spitsbergen, Svalbard)

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Abstract. The article presents the climatological dataset from the Polish Polar Station Hornsund located in the southwest part of Spitsbergen - the biggest island of the Svalbard Archipelago. Due to a general lack of long-term in situ measurements and observations, the high Arctic remains one of the largest climate-data deficient regions on the Earth. Therefore, the described time series of observations in this paper are of unique value. To draw conclusions on the climatic changes in the Arctic, it is necessary to analyse and compare the long-term series of continuous, in situ observations from different locations, rather than relying on the climatic simulations only. In recent decades, rapid environmental changes occurring in the Atlantic sector of the Arctic are reflected in the data series collected by the operational monitoring conducted at the Hornsund Station. We demonstrate the results of the 40 years-long series of observations. Climatological mean values or totals are given, and we also examined the variability of meteorological variables at monthly and annual scale using the modified Mann-Kendall test for trend and Sen's method. The relevant daily, monthly, and annual data are provided on the PANGAEA repository (https://doi.pangaea.de/10.1594/PANGAEA.909042, Wawrzyniak and Osuch, 2019).

1 Introduction

For the analysis of the Arctic climate change, the long term operational monitoring of meteorological variables including reliable observations and measurements is obligatory. Weather conditions are crucial drivers that have feedback on many environmental components, and it is important to have a relevant dataset of atmospheric observation data if analysing the variability and fluctuations of climate at any given location. Climate change in the Arctic reflects a global warming trend, but the warming here is much faster than in lower latitudes (IPCC, 2019). The characteristics of Earth's climate zones are primarily determined by astronomical factors, but there are differences in the mechanisms that cause a regional warming trend and determine their magnitude. The presence of solar radiation, modified by the degree of cloudiness and type of clouds is the main factor influencing the transfer of energy. In polar regions during the polar night, the sole source of energy is the dynamic advection of heat from the oceanic and atmospheric circulations with regional differences throughout the area. Mechanisms of

Arctic amplification are still not fully understood but include feedback of reduced summer albedo due to reduction of sea ice extent and snow cover loss, higher sea surface temperatures, an increase of atmospheric water vapour content, cloud conditions, and changes in atmospheric circulation (IPCC, 2019). The growing number of positive annual air temperature anomalies in the Arctic varies substantially within the region, with the strongest changes observed in the Atlantic sector (Przybylak, 2016). Here, the Greenland Sea to the West of Svalbard is dominated by the West Spitsbergen Current, carrying warm (3–6°C) and salty (>35‰) Atlantic waters towards the Fram Strait. In this region, this flow is over 200 km wide and strongly influences the air temperature in the SW Spitsbergen area, especially during the winter (Walczowski et al., 2017). The specific maritime and mild climatic conditions are also influenced by local and regional factors as sea ice cover and its distribution (Dahlke et al., 2020), the presence of glaciers, orography of the terrain, and location near the seashore. The climatic variables such as air temperature, humidity, and precipitation vary significantly across the archipelago (Nordli et al., 2014; Osuch and Wawrzyniak, 2017a) as well as around the Hornsund Fjord (Araźny et al., 2018). Long-term, high-quality, in-situ consistent meteorological observations have been collected at the Hornsund Station located at the northern shore of this fjord. Relatively to the other parts of the Arctic, air temperatures in Svalbard are the highest at this latitude and their observed changes are one of the largest on Earth (IPCC, 2019). There is evidence for anomalies and changes in recent years in Atlantic sector of the Arctic, along western Spitsbergen, including higher air temperature (Gjelten et al., 2016) and higher liquid precipitation (Osuch and Wawrzyniak, 2017a). These changes have many environmental implications, leading to prolongation of the ablation season (Osuch and Wawrzyniak, 2017b), the negative mass balance of glaciers (Van Pelt et al., 2019), and permafrost degradation (Wawrzyniak et al., 2016).

2 Study area

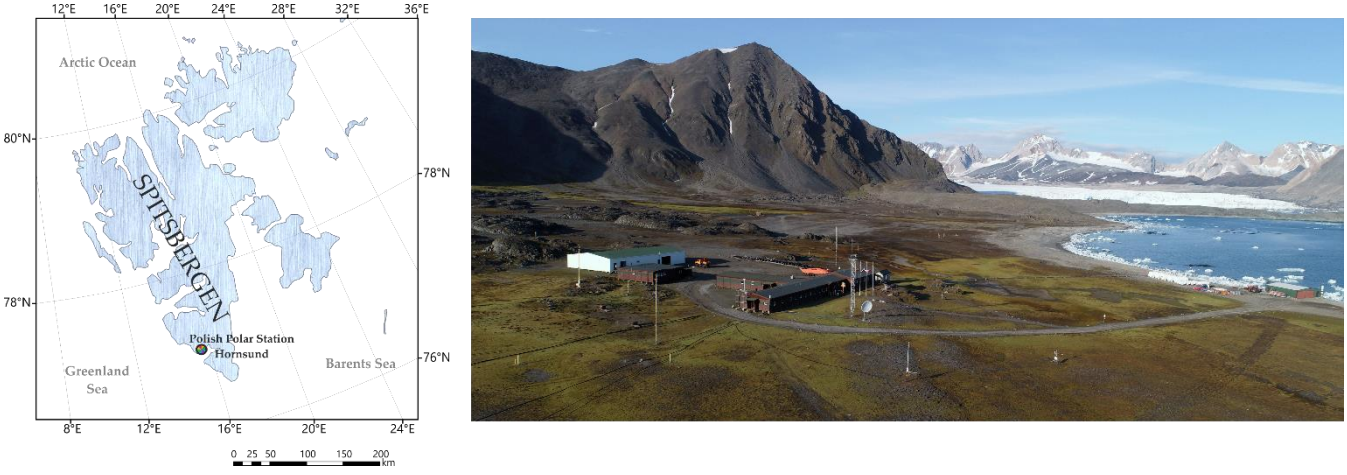

Figure 1 Polish Polar Station Hornsund on Spitsbergen in the Svalbard Archipelago

The Stanisław Siedlecki Polish Polar Station in Hornsund (77°00'N 15°33'E) located 300 m from the shore of Isbjørnhamna Bay of the Hornsund Fjord in SW Spitsbergen (Fig. 1), was established during the International Geophysical Year in 1957. Since 1978 it conducts year-round scientific research and is the northernmost permanent Polish scientific site, that throughout the years has become a modern interdisciplinary scientific platform that carries out research projects aimed at a better understanding of the functioning of the arctic nature and the changes it undergoes. The Hornsund Fjord is approximately 35 km long and approximately 14.5 km wide at its mouth to the Greenland Sea. The coastline of Hornsund is diversified, with multiple bays and glaciated valleys. A recent expansion of the ice-free areas is observed in Svalbard, with the most significant retreats of the tidewater glaciers (Błaszczyk et al., 2013), so the recognition of the changes in the functioning of the environmental system becomes more and more essential. The station is set on a marine terrace at 10 m a.s.l.. This terrace, raised during Holocene (Lindner et al., 1991), consists of sea gravel and is covered by a diversity of tundra vegetation types. The slopes of the nearest mountain ranges Fugleberget (569 m) and Ariekammen (517 m) are located 1 km north from the station. Around 800 m NE from the station lies the lateral moraine of Hansbreen glacier. Recently the distance from the station to the front of Hansbreen is around 2.5 km. The ground here has a continuous permafrost layer down to more than 100 m deep (Wawrzyniak et al., 2016).

At Hornsund meteorological site indexed by international numbering system 01003 (www.oscar.wmo.int), managed by the Institute of Geophysics Polish Academy of Sciences, since July 1978 year-round, systematic, continuous measurements and observations at WMO standards have been conducted. The results of automatic measurements and visual observations are sent as the SYNOP-code to WMO database every 60 minutes and 3 hours, respectively. Since January 2001 most of the traditional instruments were replaced by an automatic weather station with Vaisala QLC-50 logger. The sensors of the new system have been installed on meteorological mast, situated 160 m SW of the main station building. To replace Vaisala QLC-50 in September 2016 new system Vaisala MAWS 301 was set on the same meteorological mast. To determine the degree of compatibility and homogeneity of the measurements, the old and new sensors were operating simultaneously for more than one year. The results of the analysis allowed to combine time series and since January 2018 the data comes from Vaisala MAWS 301. A comprehensive description of measurements and instruments can be found in collective work edited by Marsz and Styszyńska (2013) and in Table 1. Although the time series of the data stretches up to July 1978, here we analyse the variability of climatic conditions over the period 1979–2018 and in some cases 1983-2018, based on the availability of observations without gaps. The daily, monthly, and annual averages or sums and the extreme range (min and max), computed from observations are provided in the scientific digital data repository - PANGAEA (Wawrzyniak and Osuch, 2019).

3 Meteorological variables

Inter-seasonal weather fluctuations are determined by the changing Arctic climate system and atmospheric circulation. The changing global climate also modifies regional conditions. Weather conditions are crucial factors that have local feedback on many environmental components. Meteorological variables collected at the Hornsund Station help to characterise the climate

variability in this part of the Arctic and for a long time have been the background for multiple studies conducted in the SW Spitsbergen (Osuch and Wawrzyniak, 2017b, Wawrzyniak et al., 2017). Due to the diurnal variability of all meteorological variables, in this study, we use descriptive statistic methods to present the course and variation of multiple parameters. For most meteorological parameters, monthly mean values are calculated from daily mean values which are retrieved using the 3-hourly values (eight values a day, between 00:00 and 21:00 UTC); in case of precipitation 6-hourly values (12:00, 18:00, and 00:00, 06:00 UTC of the following day); and daily sum of total solar radiation from Campbell–Stokes recorder obtained at the midnight.

Table 1 Meteorological data measured at Hornsund including variables, current sensors, the period of operation, height, units, and their annual averages or sums.

Variable	Location	Sensor	Period of operation	Height	Unit	Mean/sum
Air temperature (TA)	77°00'1.261" N 15°32'12.267" E	Traditional thermometer in Stevensons screen, Vaisala HMP 45D (since Jan 2001), HMP155 (since Jan 2018)	1979-2018	2 m agl	[°C]	TAmax=-1.3 TAmean=-3.7 TAmin=-6.0
Relative humidity (RH)	77°00'1.261" N 15°32'12.267" E	Hygrometer, HMP45D (since Jan 2001), HMP155 (since Jan 2018)	1979-2018 with gap 01.07.1982-16.08.1982	2 m agl	[%]	79.7
Precipitation	77°00'5.734" N 15°32'17.077" E	Hellmann Rain Gauge D-200	1979-2018	1 m agl	[mm]	478
Atmospheric pressure (PA)	77°00'1.261" N 15°32'12.267" E	Mercury barometer, PTB200A (since Jan 2001), Baro-1QML-AV (since Jan 2018)	1983-2018	Reduced to the sea level	[hPa]	1008.7
Wind speed (WS) and direction (WD)	77°00'1.261" N 15°32'12.267" E	Fuess 90z wind meter, Vaisala WAA151 (since Jan 2001), Vaisala WMT702 (since Jan 2018)	1983-2000 2001-2016 2017-2018	10 m agl	[m/s]	5.5
Sunshine duration (SD)	77°00'5.935" N 15°32'14.3" E	Campbell–Stokes Heliograph	1979-2018	2 m agl	[h]	1030.8

Cloudiness	On location	Visual observations	1983-2018		[octas]	5.85
Visibility	On location	Visual observations	1983-2018		[marine scale]	7.40

3.1 Air temperature

Air temperature (TA) can be presumed to be one of the most sensitive indicators of climatic changes. The time series of daily TA from the Hornsund Station covers the period 1979 to 2018. In the case of daily mean TA, there are no gaps in data while for maximum and minimum daily TA data for 01.09.1979, 29.02.1980, 15.06.2012, and 19.06.2017 are missing. Figure 2a presents the variability of the annual mean of minimum, mean, and maximum TA in 1979-2018 at the Hornsund Station. An upward trend is clearly visible for the three analysed variables. The significance of the trend was estimated by the modified Mann-Kendall test (Mann, 1945; Kendall, 1975; Hamed and Rao, 1998) taking into account autocorrelation of time series. The slope of the trend was estimated using Sen's method (Sen, 1968), where the slope is calculated as a median of the slopes of all pairs of points. The outcomes of the modified Mann-Kendall indicated that the trends are statistically significant; the estimated p-value is very small (less than 1e-07) for three presented variables.

The estimated slope of trend equal to 1.34, 1.14, and 1.00°C/decade for minimum, mean, and maximum TA respectively. These are one of the highest increases of mean TA on the planet, more than six times larger than the global average of +0.17°C per decade (NOAA, 2020). The rest of the world is not expected to experience such changes until the end of this century (Hanssen-Bauer et al., 2019). The results of trend analyses for mean monthly TA (min, mean, and max) are presented in Table 2. In almost all months there are statistically significant trends except March. In all analysed cases the estimated slope of trend has positive values and indicated the increase in TA. A comparison of the results between variables shows that the largest changes were found for minimum daily TA (1.34°C/decade) while the lowest for the maximum daily TA (1.0°C/decade). Taking into account changes between months, the largest changes were estimated for January, February, and December (larger than 2.0°C/decade for minimum and mean daily TA). The smallest statistically significant are trends in July and August with slopes of the trend around 0.3°C/decade.

Figure 2b shows the boxplots of monthly averages of minimum, mean and maximum daily TA from the period 1979-2018. The variability of TA depends on the season, with the highest amplitudes during winter months. Summer TA is rather constant, with monthly means reaching usually slightly below 5.0°C. Average monthly TA during winter and early spring usually drop below -10.0°C. The results are in general accordance with observations made at other arctic stations and reveal that winter is characterised by the highest variability of TA (Gjelten et al., 2016; Osuch and Wawrzyniak, 2017a). The amplitude between the extreme high and low in this season may be several times higher than in summer. These fluctuations are determined by the relatively stable anticyclonic subsidence with extreme cold and the turbulent cyclonic disturbances that bring higher temperatures, greater cloudiness, and heavy precipitation. The lowest recorded TA measured at a 2 m height above solid ground at Hornsund Station was -35.9°C on 16.01.1981, while the absolute maximum 15.6°C on 31.07.2015. Mean annual air temperature (MAAT) in long-term 1979-2018 is -3.7°C. The average coldest month is March with mean TA -10.2°C, and on

the average warmest month is July with the mean TA of 4.6°C. The coldest month on record with mean -17.9°C was January 1981, and the warmest July 2016 with mean 6.3°C. Additionally, in the data set we also provided monthly and annual positive (PDD) and negative degree days (NDD), calculated as the sum total of daily mean temperatures above or below the 0°C respectively.

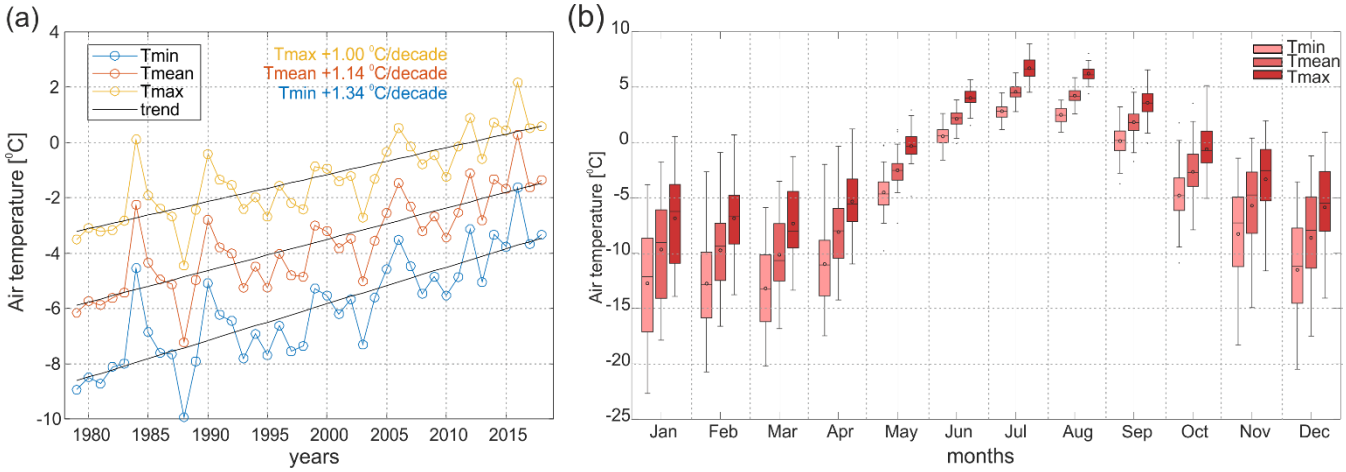

Figure 2 (a) Variability of an *annual* mean of min, mean, and max air temperatures in 1979-2018. (b) Variability of the *monthly* mean of min, mean, and max air temperatures in 1979-2018. On each box, the central line indicates the median, the circle represents the mean, and the bottom and top edges of the box indicate the 25th and 75th percentiles, respectively. The whiskers extend to the most extreme data points are not considered as outliers, and the outliers are plotted individually as dots.

Table 2 The slope of the trend in monthly and annual data (air temperature TA, relative humidity RH, precipitation Precip, atmospheric pressure at sea level PA, wind speed WS, wind direction WD, estimated by Sen's method in the period 1979-2018 for air temperature and sunshine duration and in 1983-2018 for other variables. The results of trend analysis by modified Mann-Kendall method to account for autocorrelation in the time series. Bold numbers denote statistically significant trend at the 0.05 level.

month	TAmin [°C/dec]	TAmean [°C/dec]	TAmax [°C/dec]	RH [%/dec]	Precip [mm/dec]	PA [hPa/dec]	WS [m/decs]	SD [h/dec]	Cloudiness [octas/dec]	VV [-/dec]
JAN	**2.70**	**2.29**	**1.86**	-0.33	**3.51**	**1.54**	-0.14	0.00	0.12	-0.03
FEB	**2.46**	**2.14**	**1.74**	-0.41	1.48	**0.50**	0.06	**1.38**	-0.01	-0.06
MAR	0.74	0.57	**0.34**	**-1.13**	-1.61	**-0.27**	-0.13	5.52	0.04	**0.15**
APR	**1.37**	**1.00**	**0.79**	-0.64	-0.41	**-0.66**	-0.12	2.36	0.16	0.11
MAY	**0.97**	**0.70**	**0.49**	-0.27	1.92	**-0.10**	**0.40**	-10.07	0.00	-0.06
JUN	**0.61**	**0.52**	**0.54**	**-0.65**	-3.23	**0.27**	0.23	-1.80	0.11	0.13
JUL	**0.36**	**0.27**	**0.31**	0.26	1.11	**0.67**	0.12	-5.92	0.12	-0.07
AUG	**0.37**	**0.33**	**0.33**	0.00	7.49	**0.30**	0.09	5.18	0.02	-0.02
SEP	**0.73**	**0.67**	**0.62**	0.62	**19.67**	**0.18**	**0.50**	-1.33	0.16	-0.10

OCT	**1.16**	**1.07**	**1.01**	**1.50**	**13.53**	**1.15**	0.05	0.79	0.28	-0.08
NOV	**1.73**	**1.46**	**1.37**	0.30	5.43	**-0.60**	0.24	0.00	**0.26**	**-0.17**
DEC	**2.56**	**2.39**	**2.18**	0.18	5.24	**-0.95**	-0.06	0.00	**0.13**	-0.10
annual	**1.34**	**1.14**	**1.00**	0.10	**61.60**	**0.25**	0.08	-8.39	**0.12**	-0.02

3.2 Air humidity

The water vapour drives multiple atmospheric processes and has a significant influence on the global climate. It is the main greenhouse gas, affecting surface by feedback cycle through changing energy balance through radiative fluxes and cloud formation. According to general concepts, the Arctic warming of recent decades is accompanied by the hydrological cycle intensification (Vihma et al., 2015). To understand the variability of water vapour concentration and its causes is highly important, especially for climate studies as well as in water balance calculations. At the Hornsund Station, the air humidity is measured recently by sensor HMP155 that replaced the previously used HMP45D sensor. The observations cover period 1979-2018, but measurements were performed four times a day (0, 6, 12, 18 UTC) within the periods: 1.07.1978-26.07.1981 and 16.08.1982-31.07.1986, two times a day (6 and 18 UTC) from 27.07.1981 to 30.06.1982, eight times a day (0, 3, 6, 9, 12, 15, 18, 21 UTC) since 1.08.1986. Daily time series of the relative humidity (RH) was calculated as a mean of all available measurements within a particular day. There is a gap in the measurements from 01.07.1982 to 15.08.1982. Therefore the trend analyses were performed for the period 1983-2018.

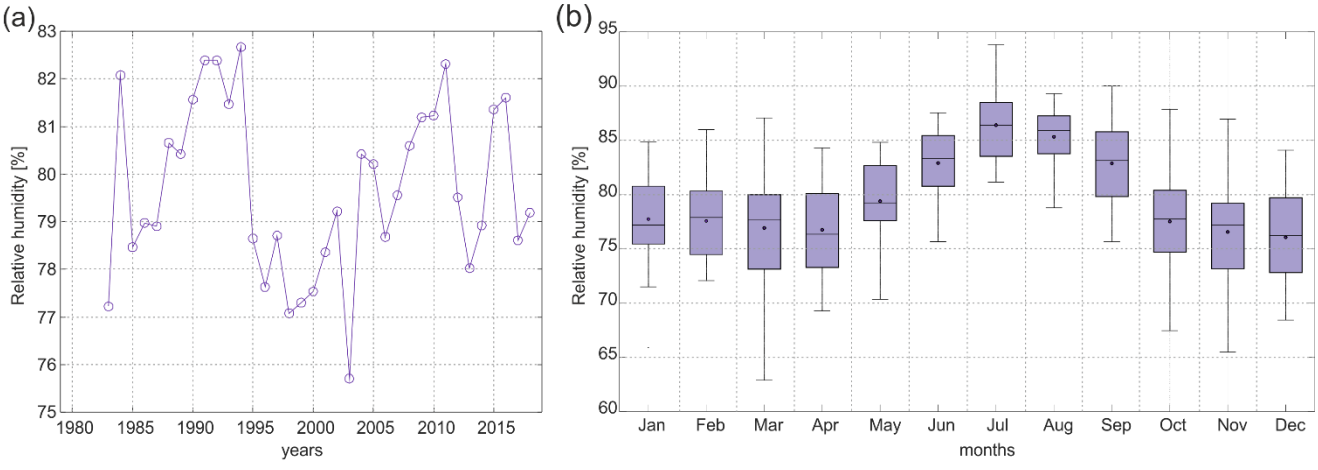

Figure 3 (a) Variability of an annual mean of relative humidity in 1983-2018 at Hornsund. (b) Variability of mean monthly relative humidity in 1983-2018 at Hornsund.

The variability of the annual mean RH in the period 1983-2019 is presented in Figure 3a. The average over the period 1983-2018 is 79.7%. The range of variability is from 75.7% (2003) to 82.7% in 1994. The trend analyses indicated a a statistically insignificant trend.

The course of the monthly mean RH in the period 1983-2018 is presented in Figure 3b. Higher values of mean RH are observed in warmer months of the year and lower during winter. Such high values are attributed to continual dominance of marine air masses. The annual course of the RH is strongly connected with the air temperature and shows typical variability. It generally increases with warmer air temperatures. However, most of the trends are not statistically significant at the 0.05 level except March, June, and October.

The analyses at daily time scale indicated that drops of RH below 50% are recorded rather sporadically, although these can occur throughout the year. Such situations are connected with advection of strongly cooled air masses, foehn effects, or katabatic winds from Hansbreen (Marsz and Styszyńska, 2013). The minimum observed quantity reached 24% on 15.01.1981. The maximum of the observed RH is equal to 100%. Such conditions occurred 27 times in the period 1979-2018.

3.3 Precipitation

In the case of precipitation, the daily sum at the Hornsund Station is calculated from four measurements obtained from unfenced Hellmann Rain Gauge at 12:00, 18:00, and 00:00, 06:00 of the following day, with the orifice 200 cm², placed 1 m above the ground level. The time series of the daily sum of precipitation cover period 1979-2018 with the gap in July 1982.

The influence of the West Spitsbergen Current creates a relatively moist climate in SW Spitsbergen region, which is clearly reflected in the amount of precipitation. In comparison to the other meteorological stations in Spitsbergen (Osuch and Wawrzyniak, 2017a; Hanssen-Bauer et al., 2019), the annual amount reaching 477 mm is the highest. The variability of the annual sums of precipitation in the period 1983-2018 is shown in Figure 4a. The amount of precipitation varies from 230 mm in 1987 to 805.5 mm in 2016. The trend analyses indicated large changes, an increase of 61.6 mm/decade for the annual sums of precipitation.

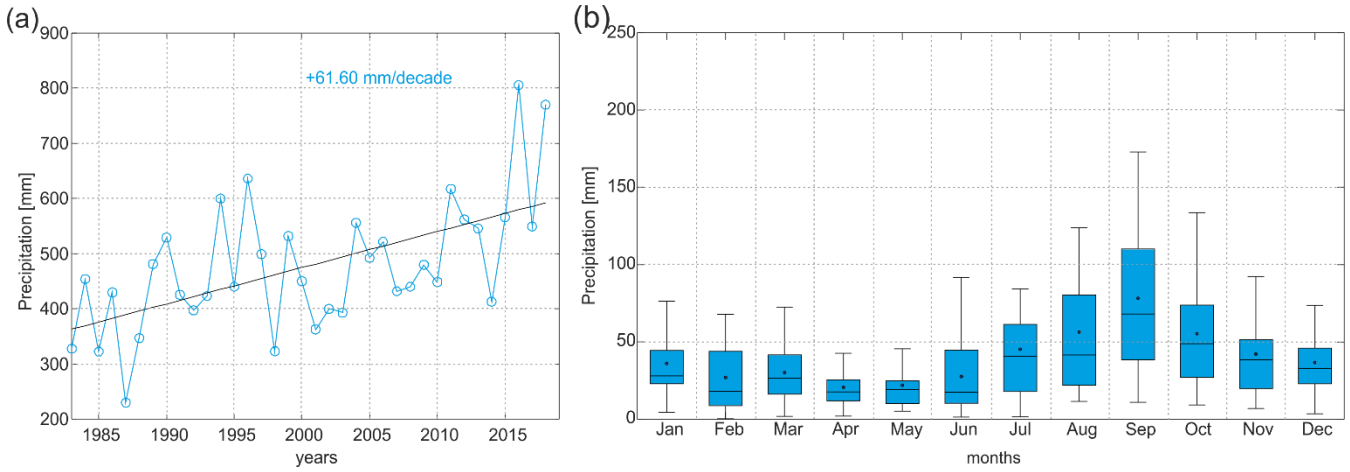

Figure 4 (a) Variability of annual sums of precipitation in 1983-2018 at Hornsund. (b) Variability of mean monthly sums of precipitation in 1983-2018 at Hornsund.

The annual course of monthly sums of precipitation from the period 1983-2018 is presented in Figure 4b. The driest months are April and May with the average 23 and 24 mm respectively. The highest precipitation is recorded in September reaching on average 75 mm. Trend analyses presented in Table 2 indicated statistically significant changes in January (3.51 mm/decade), September (19.67 mm/decade), and October (13.53 mm/decade).

3.4 The atmospheric pressure

The measurements of the atmospheric pressure (PA) at Hornsund started in July 1978. In the beginning, PA was measured with a mercury barometer every 3 hours. Since 2001 measurements have been conducted every 60 seconds with a Vaisala PTB200A sensor, replaced by BARO-1QML_AV in 2018. The lowest recorded PA reduced to sea level at Hornsund Station was 982.2 hPa on 30.08.1994, while the absolute maximum 1028.5 hPa on 07.08.1987. Mean annual PA in long-term 1983-2018 is 1008.7 hPa and its variability is presented in Figure 5a. It is visible an increasing trend (0.25 hPa /decade) but statistically insignificant (pval>0.05).

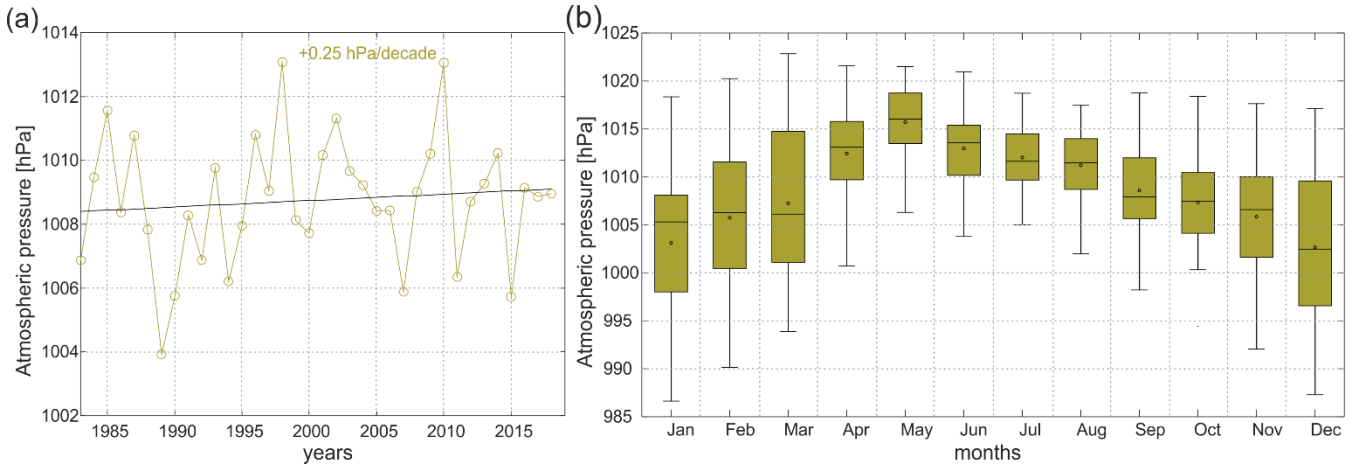

Figure 5 (a) Variability of mean annual air pressure reduced to sea level in 1983-2018 at Hornsund. (b) Variability of mean annual air pressure reduced to sea level in 1983-2018 at Hornsund.

Figure 5b shows the variability of the mean monthly PA over period 1983-2018. Well pronounced seasonality is visible, with mean monthly pressure higher than 1010 hPa from April to August. The month with the lowest mean PA is December with mean 1002.7 hPa, and the month with the largest PA is May with the mean of 1015.7 hPa. The variability of mean monthly PA within the observation period also is visible with the largest variability in January and February (larger than 30 hPa) and the smallest in July (13.7 hPa). The trend analyses of mean monthly PA resulted in statistically insignificant trend for all months.

3.5 Wind speed and direction

The wind is a result of atmospheric circulation and is highly correlated with the intensity of cyclonic activity (Przybylak 2016). The wind regime results from the latitudinal shape of the Hornsund fjord, location near the seashore and local topography. The measurements of wind speed (WS) and wind direction (WD) were performed at Hornsund with different sensors: 1978-2000 with the Fuess 90z wind meter, 2001-2017 with Vaisala WAA151 for direction and wind speed, since 2018 with Ultrasonic Wind Sensor WMT702. At Hornsund Station the height of the anemometer is 10 m above the ground, around 20 m above sea level. WS is measured with an accuracy of 0.1 m/s and WD with 5°. The wind rose for the Hornsund station is presented in Figure 6. Winds blowing from the East, along the fjord, are prevailing.

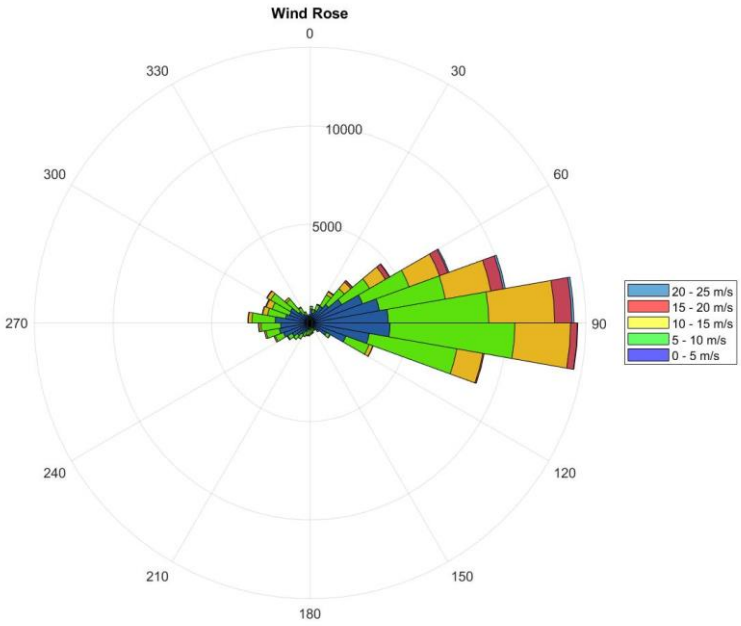

Figure 6 The wind rose for the Hornsund station for the period 1983-2018.

The variability of the mean annual WS at Hornsund in the period 1983-2018 is shown in Figure 7a. The average over the period 1983-2018 is equal to 5.5 m/s. The lowest values of WS was observed in 1985 (4.8 m/s) while the largest in 1998 (6.3 m/s). There is a statistically insignificant trend in mean annual WS.

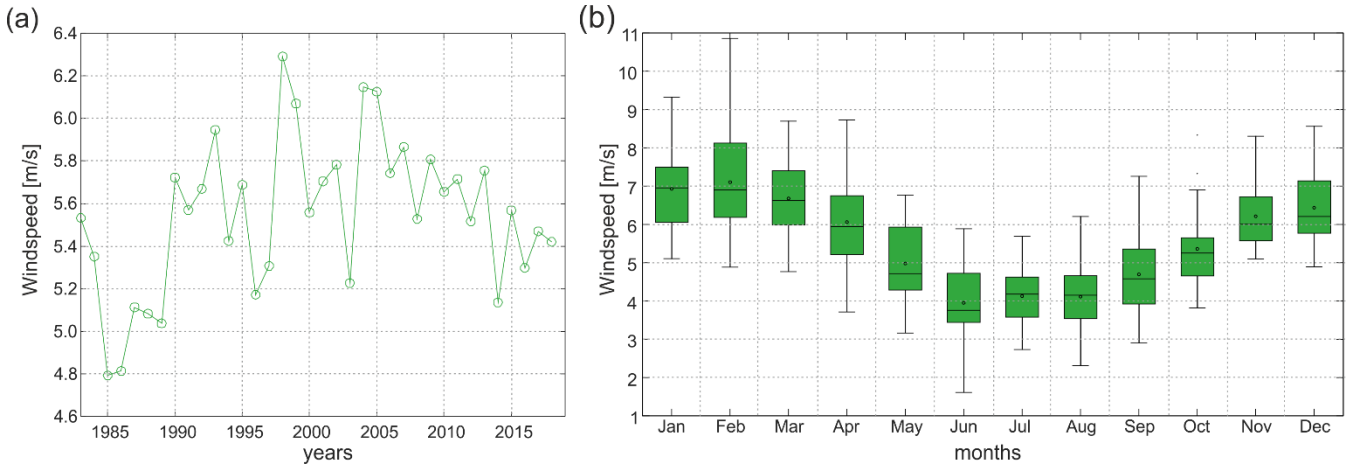

Figure 7 (a) Variability of mean annual wind speed in 1983-2018 at Hornsund. (b) Variability of the mean monthly wind speed at Hornsund in the period 1983-2018.

The variability of mean monthly WS in the period 1983-2018 is presented in Figure 7b. WS regime is well visible with smaller average values during summer months (minimum 4.0 m/s in June) and larger average values during winter (maximum 7.1 m/s in February). Such variability is a result of the extreme cyclone events that often occur during arctic winters (Rinke et al., 2017).

3.6 Sunshine duration

Sunshine duration (SD) is one of the important meteorological variables that provides data on the time period during which direct solar radiation reaches the Earth's surface and partly on the quantity of total solar energy. Daily SD is measured at Hornsund using a Campbell-Stokes sunshine recorder (CS). It uses a direct optical method with the heat energy of the Sun's direct radiation burning the card. Such traditional sunshine recorder has been in service worldwide since the nineteenth century and although there are multiple automatic radiometers used simultaneously at the Hornsund Station, the longest data is recorded by CS. The time series of sunshine duration cover period 1983-2018. At the Hornsund Station, the polar night lasts 104 days (October 31 – February 11), while the polar day lasts 117 days (April 24 – August 18).

Figure 8a shows the variability of the annual sums of SD at Hornsund in the period 1979-2018. The mean value is 1030.8 h that is about 28% of the potential SD calculated for the station (Wojkowski et al., 2015). The large span in the annual SD is visible. The minimum value (755.4 h) was observed in 1994 and maximum (1325.6 h) in 1985. The slightly decreasing trend in SD is visible but statistically insignificant at the 0.05 level.

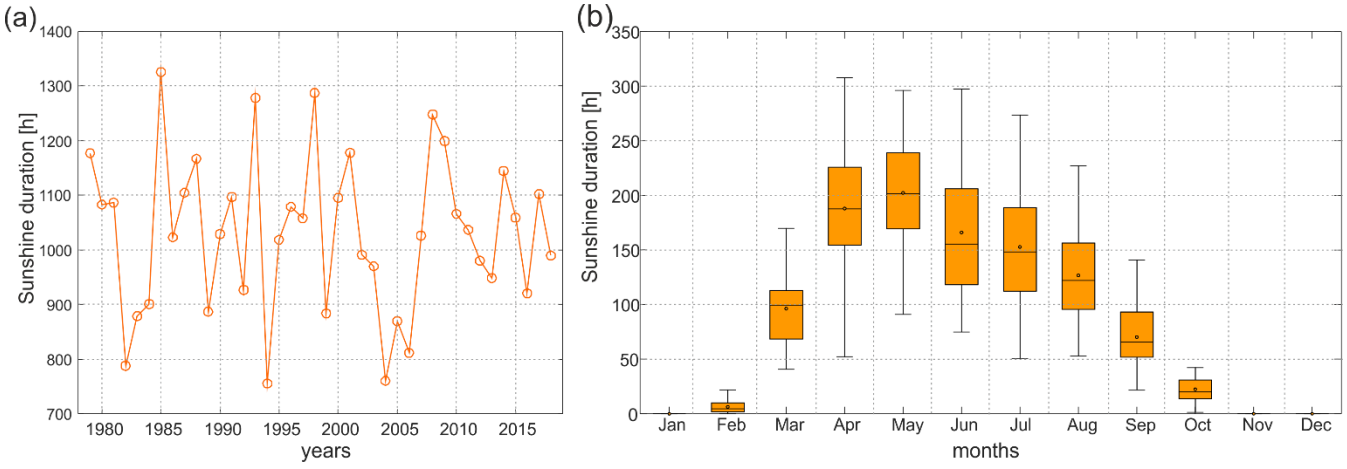

Figure 8 (a) Variability of mean annual sunshine duration in 1979-2018 at Hornsund. (b) Variability of the monthly sums of sunshine duration at Hornsund in the period 1979-2018.

Monthly total SD is presented in Figure 8b. Its variability results from the different duration of the day at the location (latitude 77N) with zero SD during the polar night.

3.7 Cloudiness

Arctic clouds have a warming effect on the surface during most of the year because their effect of increasing the downward longwave radiation dominates their effect of reducing the net solar radiation over high-albedo snow and ice surfaces. In summer, however, clouds typically have a cooling effect on surface types with a lower albedo, such as the open sea, melting sea ice, and ground (Intrieri et al., 2002; Shupe and Intrieri, 2004). Observations of cloudiness at the Polish Polar Station in Hornsund are conducted by meteorologists and describe the predominant sky condition based upon octas (eighths) of the sky covered by opaque (not transparent) clouds. There are many factors that may hinder the heterogeneity and evaluation of cloudiness, due to the annual change in the meteorological observers and a fact that observers might be subjective, although are provided with clear observable criteria.

Annual averages of cloudiness in the period 1983-2018 is presented in Figure 9a. The mean over this period equals 5.85 octas. The minimum value of annual mean was observed in 1988 (5.16 octas) and maximum in 1984 (6.39 octas). An increasing tendency of mean annual cloudiness is visible. The estimated trend (slope 0.13 octas/decade) is statistically significant at the 0.05 level.

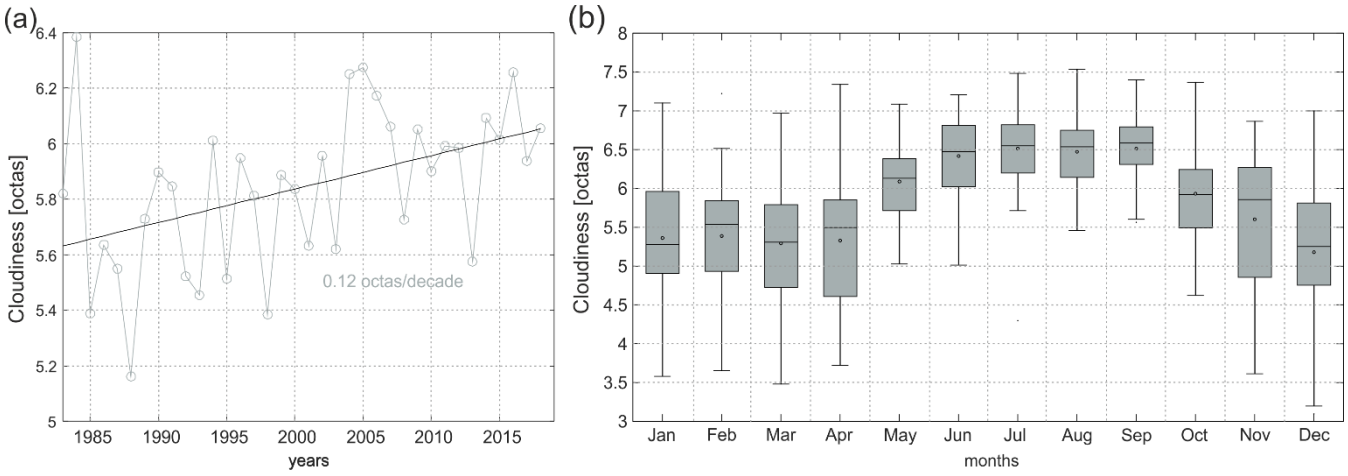

Figure 9 (a) Variability of mean annual cloudiness in 1983-2018 at Hornsund. (b) Variability of the monthly sums of cloudiness at Hornsund in the period 1983-2018.

The variability of the monthly cloudiness in the period 1983-2018 is presented in Figure 9b. The annual cycle is characterised by lower mean cloudiness during the cold period from October till April (5.5-6.0 octas), and this period is also characterised by large inter-annual variability. The period from May till September is on the average more cloudy (6.0-6.7 octas) and inter-annual variability is lower.

3.7 Visibility

The horizontal visibility is quantified using observations made by meteorologists in the surroundings of the Hornsund Station with a marine scale that ranges from 1 to 9. The visual observations are performed using known distances to the surrounding mountains and other objects. Values 1 and 2 correspond to very bad visibility, 0-50 m and 50-200 m, respectively. Bad visibility (200 m – 1 km) is represented by value 3. Weak horizontal visibility represents conditions with 1-2 km and 2-4 km that are quantified as 4 and 5 in the applied scale. Moderate horizontal visibility, described as 6 in the scale, represent conditions when an object or light can be clearly discerned from 4-10 km. Good horizontal visibility (7 in the scale) is 10-20 km, very good (8) 20-50 km and extremely good (9) is for horizontal visibility larger than 50 km. Noted visibility might be reduced by multiple factors, including all products of the condensation of water vapour such as fog, precipitation, as well as darkness during cloudy conditions throughout the polar night, as there are no artificial lights in the area. There are no anthropogenic factors that would reduce visibility in the vicinity of the Hornsund Station as it is located in the middle of the strictly protected South Spitsbergen National Park. Due to that reduced visibility cannot be an indicator of poor air quality on the local scale.

Figure 10a shows the variability of mean annual visibility in the period 1983-2018. On average in this period is good horizontal visibility that amounts 7.40; minimum mean annual visibility was observed in 2016 (7.08) while maximum in 1987 (7.70). A decreasing tendency is visible (slope of trend -0.02 per decade) however the trend is statistically insignificant at the 0.05 level. Variability of the mean monthly visibility at Hornsund in the period 1983-2018 is presented in Figure 10b. It is characterised by both low inter-annual and interseasonal variability and on average reaches values between 7 and 8.

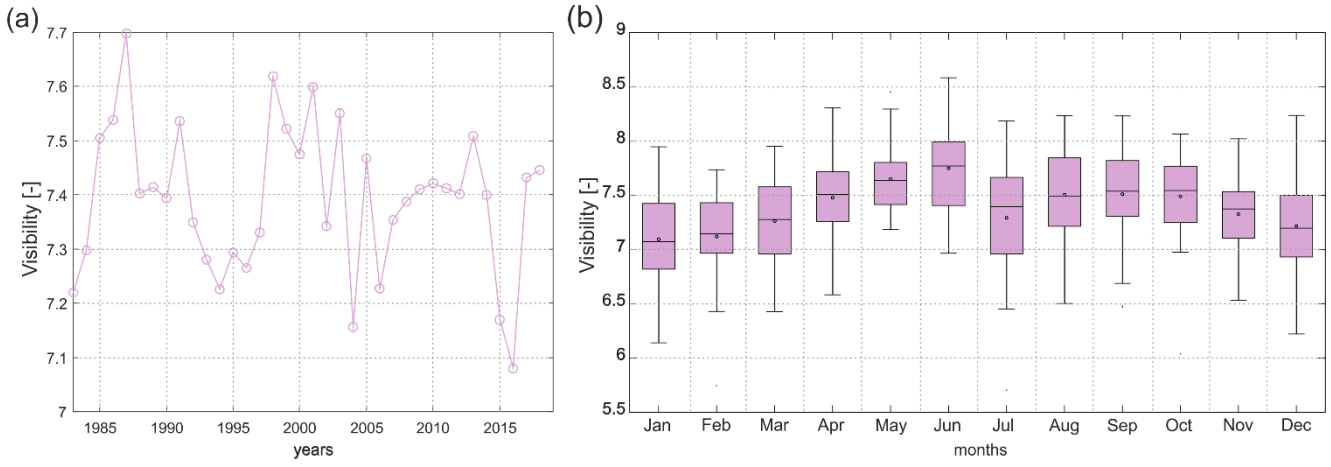

Figure 10 (a) Variability of mean annual visibility in 1983-2018 at Hornsund. (b) Variability of the mean monthly visibility at Hornsund in the period 1983-2018.

4 Quality control of the time series

All presented datasets have undergone a thorough quality control process. Such process consisted of multiple steps as the measurements may not be homogenous due to the varying number of observations during the day, changes of sensors, and other factors (Estévez et al., 2011). In the first step, the data were visualised as a time series that allowed verification if all data have been collected and that the record structure is correct, complete, and without any gaps. In this way also the presence of outliers and step change in the data was tested. To determine the degree of compatibility and homogeneity of the measurements from different sensors, changed over years, the old and new sensors were operated simultaneously for more than one year. The results allowed to combine time series. In the following step, different variables were compared to test the internal consistency between variables. Such analyses include a comparison of minimum, mean, and maximum daily TA that follow the rule TAmax>TAmean>TAmin. In the case of WS and WD following conditions were tested WS=0 and WD=0, WS≠0 and WD≠0. In the third step temporal consistency of time series was analysed with the help of statistical tests of homogeneity (Pettit and Standard Normal Homogeneity Test). In the last step, the same variables but from different meteorological stations in Svalbard were compared. The air temperature time series were tested against observations in Barentsburg, Bjørnøya, Hopen, Longyearbyen (Svalbard Lufthavn), Ny Ålesund, and Sveagruva. For that purpose, the data were visualised and checked with the Standard Normal Homogeneity Test (Alexandersson, 1986; Nordli et al., 1996). The applied algorithm showed good performance in both detecting breakpoints and identifying homogeneous time series. By application of the relative method, with comparison to the other available datasets from Svalbard, the gradual and step changes due to climate change were not found as a source of inhomogeneity.

5 Data availability

The dataset described in this article is available on the PANGAEA repository (Wawrzyniak and Osuch, 2019: https://doi.pangaea.de/10.1594/PANGAEA.909042).

6 Summary

This paper has presented details of a long-term (1979–2018) dataset from the meteorological site at the Polish Polar Station Hornsund located in the SW part of Spitsbergen. The data series includes daily, monthly and annual air temperature, PDD, NDD, the sum of precipitation, air humidity, atmospheric pressure, wind speed and direction, sunshine duration, cloudiness, and visibility. This rich dataset, now available online, is a valuable source for documenting the state of the climate in SW Spitsbergen that represents the Atlantic sector of the Arctic. With the positive trend of mean annual temperature +1.14°C/decade in the last four decades (1979-2018), the climate in Hornsund is warming in this period more than six times larger than the global average that amounts +0.17°C per decade (NOAA, 2020). All climatological variables presented in this

study have many environmental implications and there are both broad scientific interest and societal need to understand climate variability and its influence on geoecosystems.

7 Author Contributions

TW and MO wrote the paper and carried out the data processing and analysis.

8 Competing Interests

The authors declare that they have no conflict of interest.

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