Answer to reviewer 1

Interactive comment on “40 years High Arctic climatological dataset of the Polish Polar Station Hornsund (SW Spitsbergen, Svalbard)” by Tomasz Wawrzyniak and Marzena Osuch Anonymous Referee #1 Received and published: 14 January 2020

R: In this paper, authors presented a unique meteorological dataset from an Arctic weather station in the Svalbard Archipelago for the period of 1979-2018. The paper is very well-organized and the dataset presented is a very useful contribution to the monitoring of remote northern regions that can be used for testing and evaluating hydrology, weather, and climate models and to validate remote sensing products. I recommend publishing the paper after a minor revision and addressing the following comments.

A: We appreciate the reviewer comments as they provide valuable feedback to increase the quality of this paper. We revised our manuscript and corrected the text and figures and included additional descriptions according to the suggestions. Detailed answers are included below. Referee text (R) and author responses (A) are indicated.

R: General comments: 1. I am wondering if the authors can provide information about snow depth and snow water equivalent, which are key elements for the Arctic environment. How about soil temperature and moisture and permafrost information?

A: The time series of snow depth was presented in Osuch, M., & Wawrzyniak, T. (2017). Variations and changes in snow depth at meteorological stations Barentsburg and Hornsund (Spitsbergen). Annals of Glaciology, 58(75pt1), 11-20. doi:10.1017/aog.2017.20

So far the work on historical ground temperature data (from the borehole 1 m deep) is in progress and as new (10, 12 and 20 m deep) boreholes were established two years ago in Hornsund we are preparing an article on modelling of the ground thermal regime in deeper layers. There are plans to measure soil moisture but so far there is none.

Specific comments:

R: 1. Title: Replace "40" with "Forty"

A: Corrected

R: 2. Line 7: Replace "SW part" with "southwest".

A: Corrected

R: 3. Line 9-10: Start as a new sentence and rephrase it as "Therefore, the described time series of observations in this paper are of unique value."

A: Corrected.

R: 4. Line 11 (also line 58): I would remove ", systematic," as we use "systematic" for errors and not observations. Also, add "and compare" after "analyse" in the line above and remove "and comparing the corresponding data". Change "rely" to "relying".

A: Corrected.

R: 5. Line 16: Spell out "PANGAEA" or introduce it.

A: PANGAEA is a Data Publisher for Earth & Environmental Science, that in our opinion is a recognizable repository of scientific data.

R: 6. Line 19-20: Rephrase the sentence and remove the "if condition".

A: Rewritten "For the analysis of the Arctic climate change, the long term operational monitoring of meteorological variables including reliable observations and measurements is obligatory."

R: 7. Line 23-24: Add references for this claims: "The climatic characteristics are primarily determined by astronomical factors, but there are differences in the mechanisms that cause a regional warming trend and determine their magnitude."

A: We corrected the text and added missing reference: 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).

R: 8. Line 26: Replace "ocean and atmospheric" with "oceanic and atmospheric" to be consistent.

A: Corrected.

R: 9. Line 37: Change to read as "There are evidences for anomalies and changes in the recent years in western Spitsbergen, including higher are temperature ...".

A: Corrected.

R: 10. Fig 1 caption: Add "in the Svalbard Archipelago" to the end of the caption.

A: Corrected.

R: 11. Line 46: Replace "became" with "has become".

A: Corrected.

R: 12. Line 51: Use lower case for "Station" here and anywhere else (e.g., in line 53) that does not follow a name. Use short sentences with clear "subject" and "verb" in each sentence. Verbs like "covered, raised, and covered" need a subject. For instance, it can be used as "it is covered/raised". –
A: Corrected.

R: 13. Figure 2 and other figures if relevant: I am wondering if you can add the significant trend values on the figures.

A: Added.

R: 14. Line 121: Check the grammar here and throughout the manuscript. Here, add "are" before "not considered".

A: Corrected.

R: 15. Table 2: Are the numbers with a star sign statistically significant? The caption is confusing. You should assign the symbols for those that are statistically significant not the opposite. Define variable indices in the caption, e.g., What is VV?

A: Changed, we added the description of abbreviations.

R: I suggest removing RH and maybe WS columns as they seem not statistically significant.

A: We would like to show the trends of every analyzed variable in this table, as in our opinion the table serves as a summary of the estimated trends.

R: 16. I suggest removing Figure 3 for relative humidity, because it is somehow presented later in Figure 5 in the form of atmospheric vapour pressure and it does not show any significant trends, not monthly nor annually.

A: Thank you for this comment. The structure of this article is organized with variables and relative humidity and atmospheric pressure and we really want to keep all variables in the presented order.

R: 17. Line 141 and throughout the paper: Replace "a lack of a statistically significant trend" with "a statistically insignificant trend".

A: Corrected.

R: 18. Line 156: Rewrite as: "...creates a relatively moist climate in SW Spitsbergen region, which ...

A: Corrected.

R: 19. Figure 7: Remove the trend line if it is insignificant (e.g., line 197). Same goes to Figure 8.

A: Changed.

R: 20. Figure 9 can be easily merged to Figures 8 and 10.

A: We would like to keep the order and the structure of the paper – to present each variable in the same manner.

Answer to reviewer 2

Interactive comment on “40 years High Arctic climatological dataset of the Polish Polar Station Hornsund (SW Spitsbergen, Svalbard)” by Tomasz Wawrzyniak and Marzena Osuch Anonymous Referee #2 Received and published: 28 January 2020 The arcticle "40 years High Arctic climatological dataset of the Polish Polar Station Hornsund (SW Spitsbergen, Svalbard)“ by Wawrzyniak and Osuch describes meteorological observation data from Hornsund Station on Svalbard.

In the manuscript, the authors present both the climatological appearance of the meteorological variables and their change over time. The according data set is available with different temporal averaging resolution at the PANGAEA repository. The 40 year data record provides a valuable contribution to the monitoring of climate change in this Arctic region. The manuscript is well structured and needs only minor revision as listed below.

We appreciate the reviewer comments as they provide valuable feedback to increase the quality of this paper. We revised our manuscript and corrected the text and figures and included additional descriptions according to the suggestions. Detailed answers are included below. Referee text (R) and author responses (A) are indicated.

— General Comments —

R: In addition to a climatological analysis, the authors present trends of various meteorological parameters. As trend analysis builds on homogeneous data series, the change of instrumentation during the observation period needs to be considered. For some parameters, the different instrumentation may have had different precision and uncertainties, while for others the time resolution of the measurements may have impacted the homogeneity (e.g. when switching from 3-hourly observations with a mercury barometer to 60-second observations with a Vaisala PTB200A sensor). While the general quality control of the time series is described, please add a statement on the data homogeneity of each individual parameter and its suitability to derive trends.

A: We described the changes in instrumentation and added the information that the old and new sensors were operating simultaneously for more than one year to compare the results and determine the degree of compatibility and homogeneity of the measurements.

— Specific Comments —

R: lines 22-27: climate change in the Arctic is not just reflecting the global warming trend, but is known to be amplified by various processes that go beyond astronomical factors. Please provide according references here Lines 26-27: what about latent heat release from open water where there used to be sea ice cover?

A: We extended the text: 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 vapor content, cloud conditions, and changes in atmospheric circulation (IPCC, 2019).

R: Line 36-37: air temperature changes in Hornsund are the largest on Earth ? What about other stations on Svalbard ? Please put into context of Svalbard region (see e.g. Gjelten et al., Pol.Res.2016) and North Atlantic Arctic in general.

A: We corrected the text: 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. 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).

We compared the results of trend analysis for different meteorological stations in the period 1979-2018, including those located in Svalbard (Hornsund, Barentsburg, Bjornoya, Hopen, Lufthavn, NyAlesund, Sveagruva) and you are right. The results are as listed in the table below – trends [°C/decade].

Hornsund	Barentsburg	Bjornoya	Hopen	Lufthavn	NyAlesund	Sveagruva
1.14	0.97	0.71	1.15	1.13	0.96	1.06

Gjelten et al. in Pol.Res. 2016 presented trends for the period 1979-2015 – different than in our study (1979-2018), so the results are slightly different.

R: Line 54-55: the maximum holocene extent of Hansbreen glacier does not add any useful information here; suggest to skip this sentence

A: Removed.

R: Line 57: 01003 seems to be the official WMO station number, so I suggest to provide the link to the OSCAR database (https://oscar.wmo.int/surface/#/) instead of ogimet.

A: Changed.

R: Lines 94-95: does this citation of Hanssen-Bauer et al. (2019) really refer to the minimum, mean, and maximum TA increase found in the Hornsund station data ? Please set the context correctly.

A: We corrected the text: 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).

R: Line 130-131: when was the humidity sensor replaced ? This should also be mentioned in Table 1. - Table 1: change in instrumentation needs to be documented more precisely, e.g. the change in pressure sensor is missing completely. Also the other instruments have likely not been changed at the turn of the year, so please provide at least the month of change. Annual mean values containing data from different instruments should be analyzed with care in regard of data homogeneity.

A: We added the information on the changes of instruments in Table 1 and added to the text: 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**.

R: Line 158: Given uncertainty issues with solid precipitation measurements (e.g. blowing snow, undercatch; see Forland & Hanssen-Bauer, Pol.Res.2013), please provide more details on the precipitation measurement set-up. Are there one or two fences installed around the Hellmann gauge?
A: We added the information that Hellman gauge at Hornsund station is unfenced. We are recently working on the article that compares data from three different precipitation gauges installed in Hornsund in last years (one fence Geonor and Parsivel), though for long period only the Hellman gauge has been used in the same, unchanged spot. We present raw data of measured precipitation, that can be recalculated to take into account eg wind-induced undercatch with wind speed data that is also provided.

R: Have any infrastructural changes occurred to the measurement site that may affect the blowing snow?

A: Redevelopment of the station's main building in 2004, when a northern wing was added, is a potential factor that could influence measurements. However, we did not find significant step change in snow depth nor in precipitation amount after 2004, suggesting that this event had a minimal effect on the measurements. The rain gauge is placed some 60 m from the station's buildings. We analyzed the impact of changes in infrastructure on the snow depth here: - Osuch, M., & Wawrzyniak, T. (2017). Variations and changes in snow depth at meteorological stations Barentsburg and Hornsund (Spitsbergen). Annals of Glaciology, 58(75pt1), 11-20. doi:10.1017/aog.2017.20

R: Table 2 : For some of the parameters, the given numbers pretend a precision that is not given by the measurements (e.g. relative humidity, precipitation).

A: It is not the precision of the instruments but the slope of trend rounded to two decimal places.

R: For the sunshine duration, the total possible duration for each month would be of interest, in particular for the month of February which is partly in the dark season but sees a considerable siginificant trend.

A: That is true and it was studied by Wojkowski et al. 2015, that may be found in the reference list.

R: Lines 171-172: Since 2001, the pressure measurements are taken every 60 seconds. Please describe how you retrieve the 3-hourly value (is it a mean of +/- 1.5 hours around the time step ?).

A: These are the instantaneous data from given time.

R: Lines 205-206: The analysis of the atmospheric energy balance requires up- and downward components of the radiative flux, sensible heat flux, latent heat flux and momentum flux . . . Please correct your statement here.

A: That is true, we changed the text: 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.

R: Lines 286-288: please add a reference.

A: We added the reference: NOAA National Centers for Environmental information, Climate at a Glance: Global Time Series, published February 2020, retrieved on February 27, 2020 from https://www.ncdc.noaa.gov/cag/, 2020.

— Technical Corrections —

R: Line 7: Southwest instead of SW.

A: Corrected.

R: Line 150: The minimum observed quantity . .

A: Corrected.

R: Line 232: The minimum value of annual mean was observed. . .

A: Corrected.

R: Line 237: The annual cycle. . .

A: Corrected.

R: Line 243: . . . with a marine scale that ranges. . .

A: Corrected.

R: Line 252: add ". . . on the local scale." (consider possible advection of pollution).

A: Corrected.

~~40~~ 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~~SW~~ 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.~~, so described series is of unique value.~~ 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, ~~systematic,~~ in situ observations from different locations~~ and comparing the corresponding data~~, 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 ~~If~~ of the Arctic climate change~~s,~~ ~~are considered, then~~ 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 ~~crucial~~ 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 ~~re are regional differences throughout the area~~(IPCC, 2019). The ~~climatic~~ 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 ~~D~~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 ~~Hornsund~~ Svalbard are the highest at this latitude and their observed changes are one of the largest on Earth (IPCC, 2019). ~~are the largest on Earth.~~ 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) ~~Recently observed along the western Spitsbergen: higher air temperatures~~ 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 beco~~a~~me 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~~ station is set on a marine terrace at 10 m a.s.l..~~,~~ This terrace, raised during Holocene (Lindner et al., 1991), consists of ~~covered with~~ sea gravel and is~~,~~ ~~raised during Holocene (Lindner et al., 1991),~~ 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 s~~S~~tation. Around 800 m NE from the ~~Station~~ station lies the lateral moraine of Hansbreen glacier~~, which was at its maximum Holocene extent in Little Ice Age (Błaszczyk et al., 2009)~~. Recently the distance from the ~~Station~~ 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~~ogimet.com~~), 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~~ station building. To replace Vaisala QLC-50 ~~In July 2009 Norwegian Meteorological Institute installed an automatic Vaisala weather station that is operating simultaneously at the same mast. I~~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. ~~Vaisala QLC-50 was replaced by 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 ~~repository~~ (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.

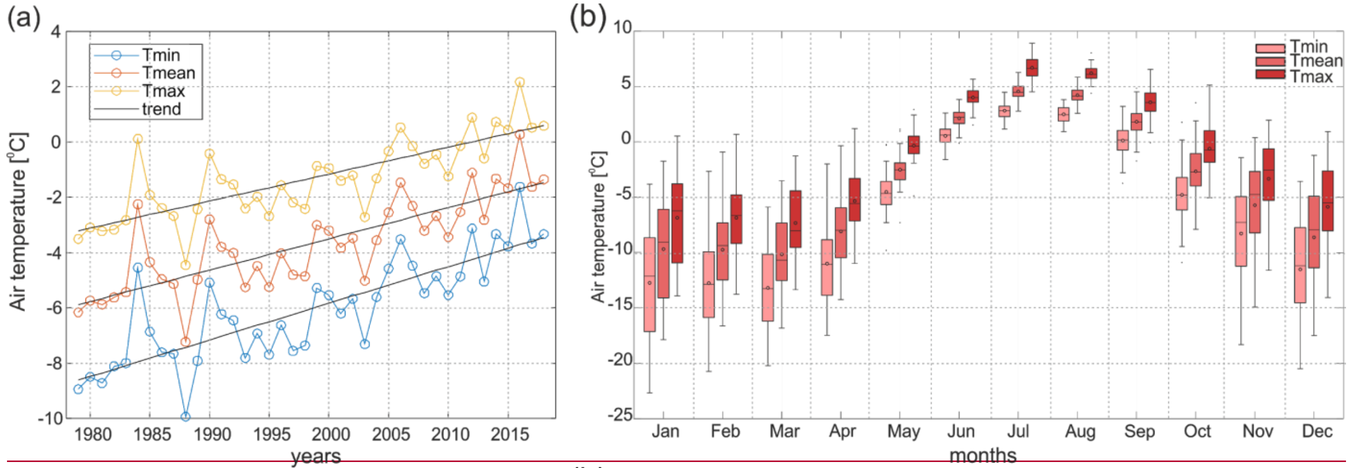
Variable	Location	Sensor	Period of operation	Height	Unit	Mean/sum
Air temperature (TA)	77°00'1.261" N 15°32'12.267" E	~~A t~~Traditional thermometer in Stevensons screen, Vaisala HMP 45D (since Jan 2001), HMP155 (since Jan 2018)	1979-2018	2 m agl	[°C]	TAmax=-1.3 TAmean=-3.7 TAmin=-6.0
Relative humidity (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~~ mm~~
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~~ hPa~~

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 the highest increases of TA on the planet, and 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~~ 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.



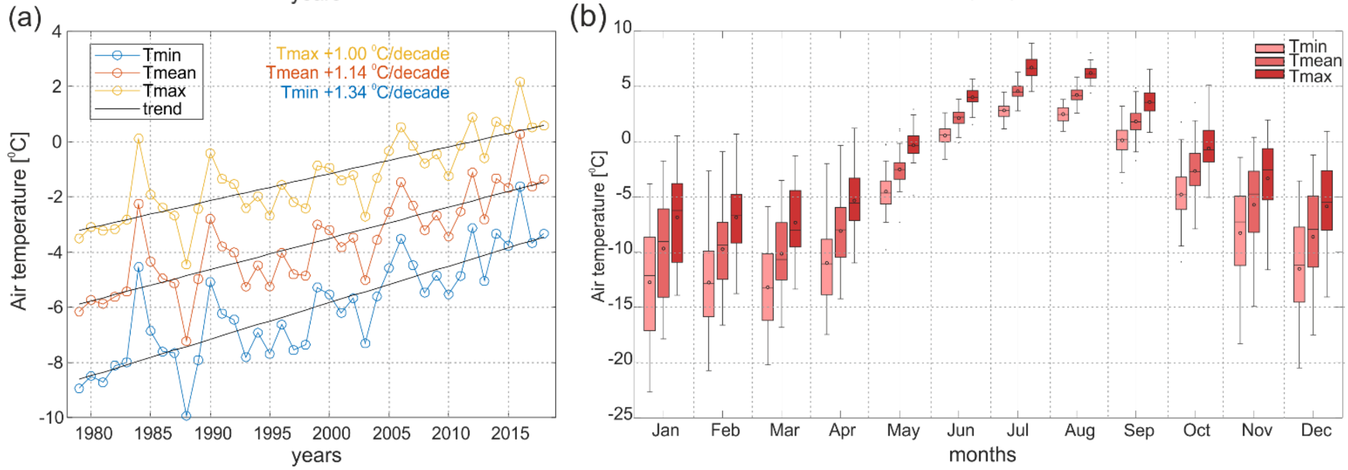


Figure 2 (a) Variability of an *annual* mean of min, mean, and max air temperatures in 1979-2018. (b) Variability of the *monthly* mean of min, mean, and max air temperatures in 1979-2018. On each box, the central line indicates the median, the circle represents the mean, and the bottom and top edges 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.

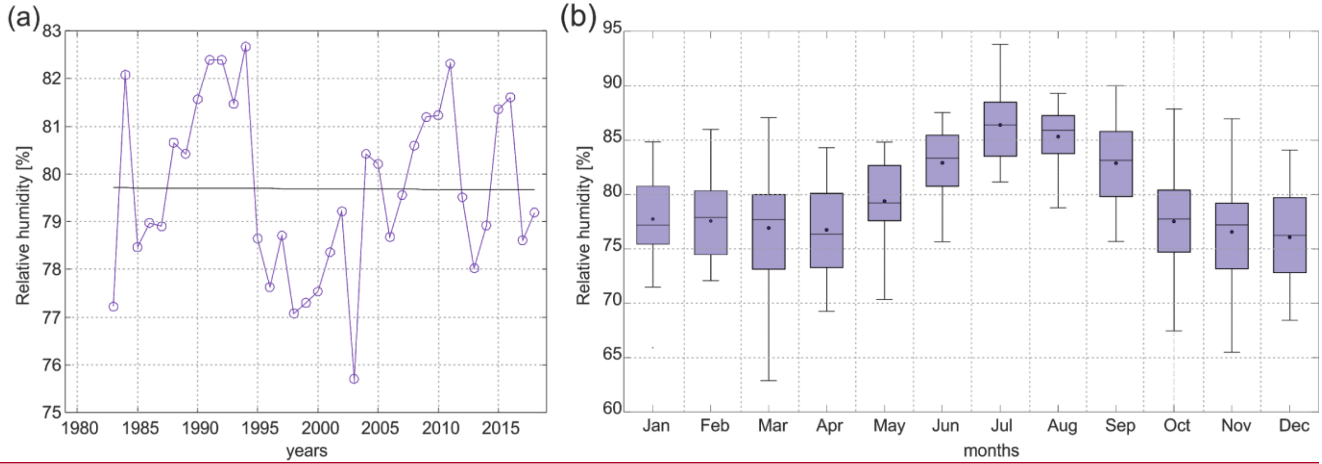
Table 2 The slope of the trend in monthly and annual data (air temperature TA, relative humidity RH, precipitation Precip, atmospheric pressure at sea level PA, wind speed WS, wind direction WD, estimated by Sen's method in the period 1979-2018 for air temperature and sunshine duration and in 1983-2018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



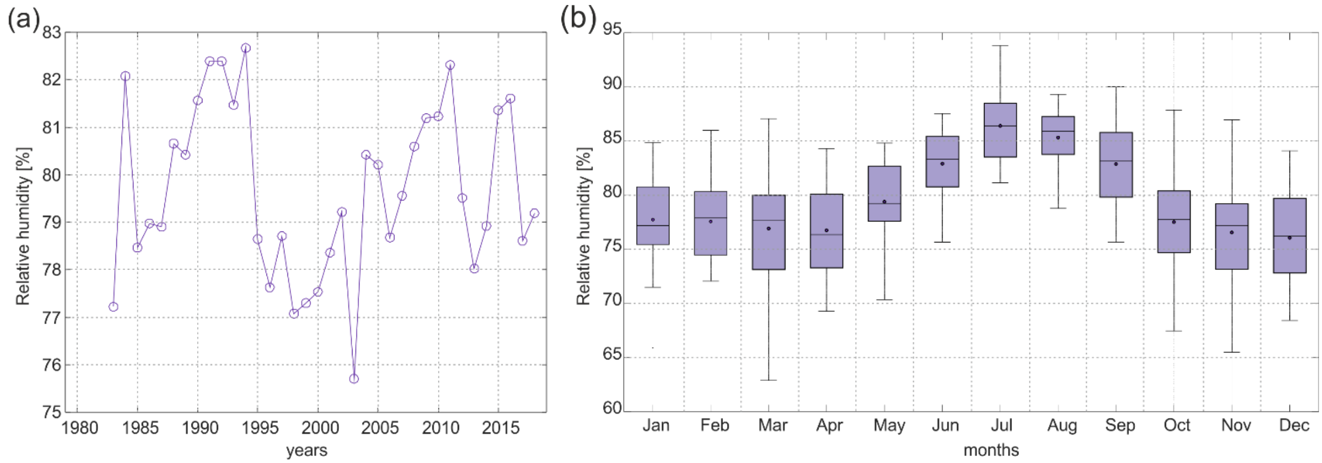


Figure 3 (a) Variability of an annual mean of relative humidity in 1983-2018 at Hornsund. (b) Variability of mean monthly relative humidity in 1983-2018 at Hornsund.

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. ~~lack of a statistically significant trend.~~

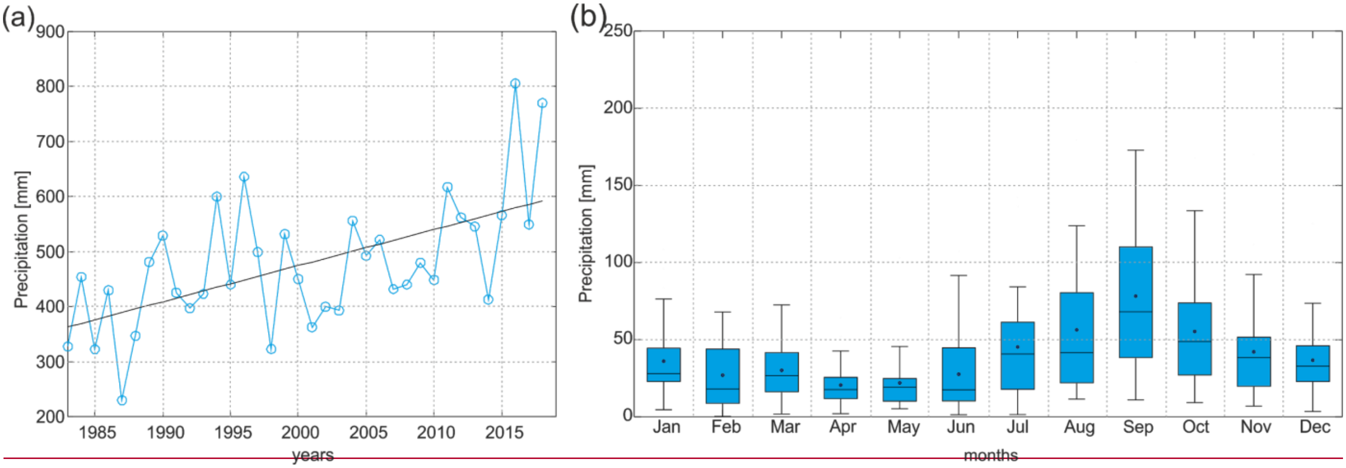
The course of the monthly mean RH in the period 1983-2018 is presented in Figure 3b. Higher values of mean RH are observed in warmer months of the year and lower during winter. Such high values are attributed to continual dominance of marine air masses. The annual course of the RH is strongly connected 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 ~~of observation~~ 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 ~~creates in SW Spitsbergen region a relatively moist climate 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.



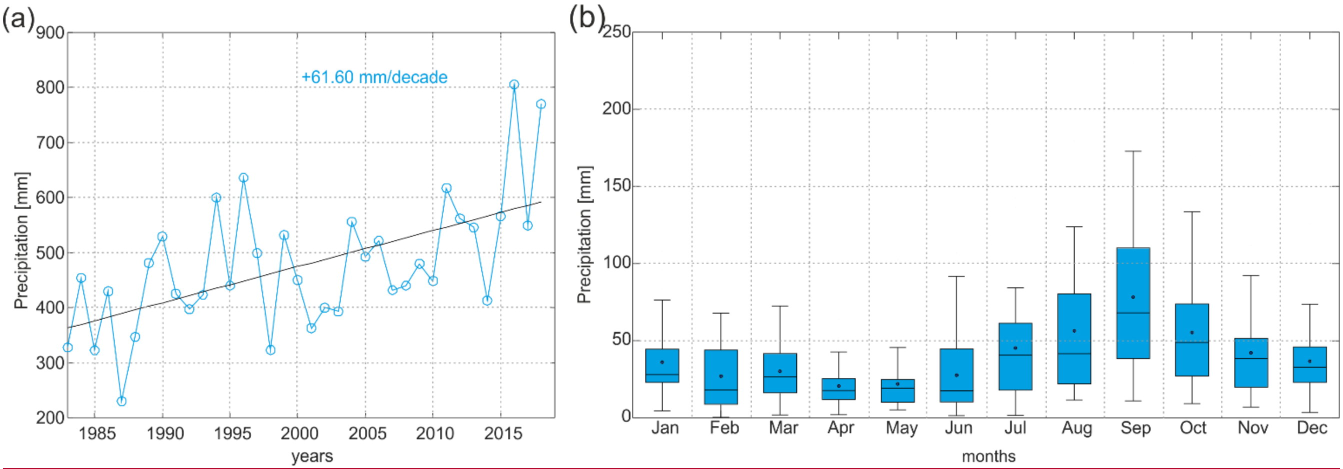


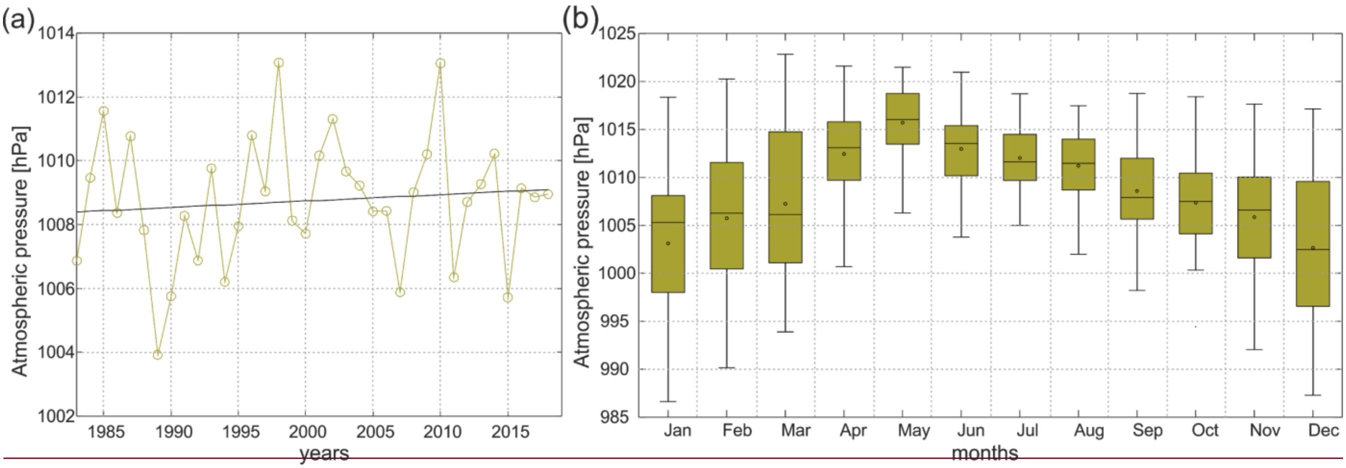
Figure 4 (a) Variability of annual sums of precipitation in 1983-2018 at Hornsund. (b) Variability of mean monthly sums of precipitation in 1983-2018 at Hornsund.

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 ~~not~~ statistically insignificant (pval>0.05).



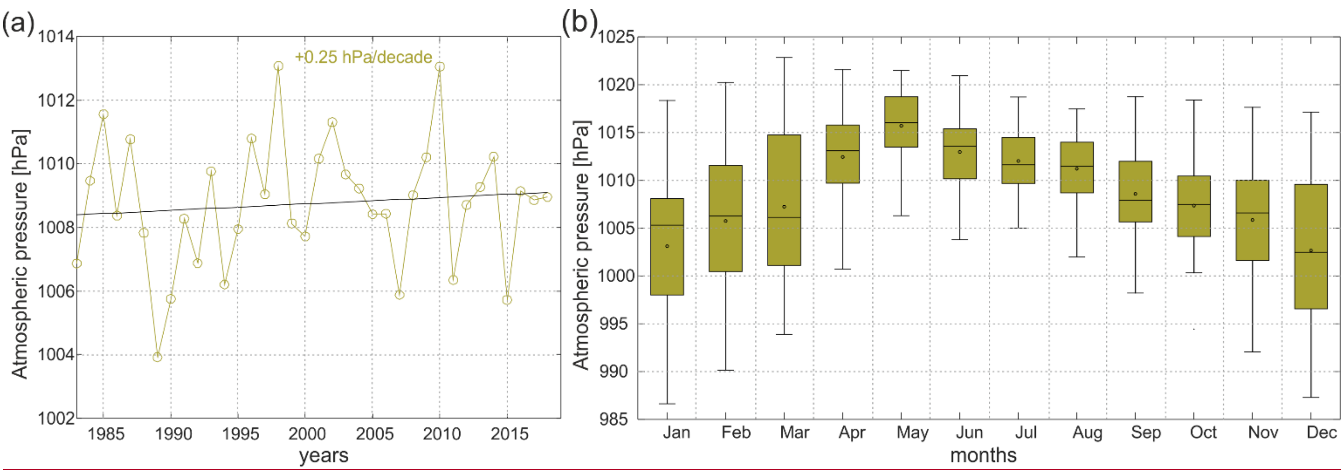


Figure 5 (a) Variability of mean annual air pressure reduced to sea level in 1983-2018 at Hornsund. (b) Variability of mean annual air pressure reduced to sea level in 1983-2018 at Hornsund.

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 ~~a lack of~~ 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.

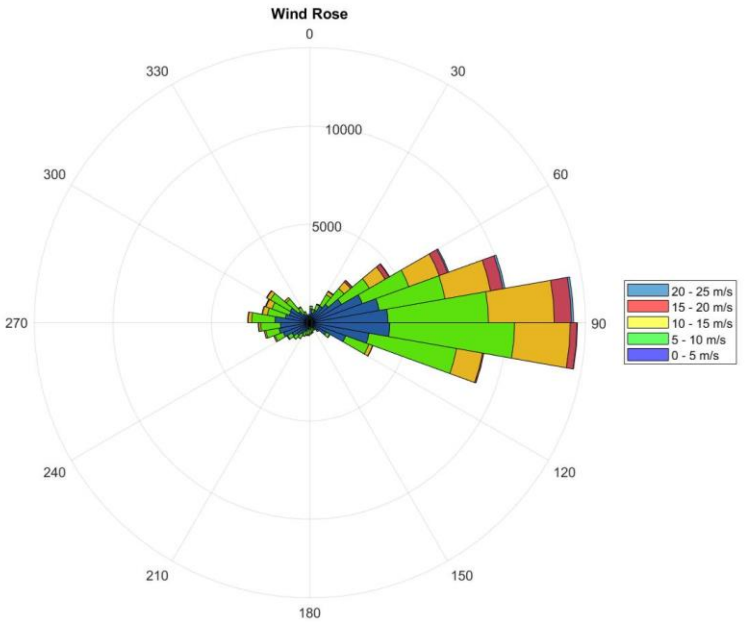
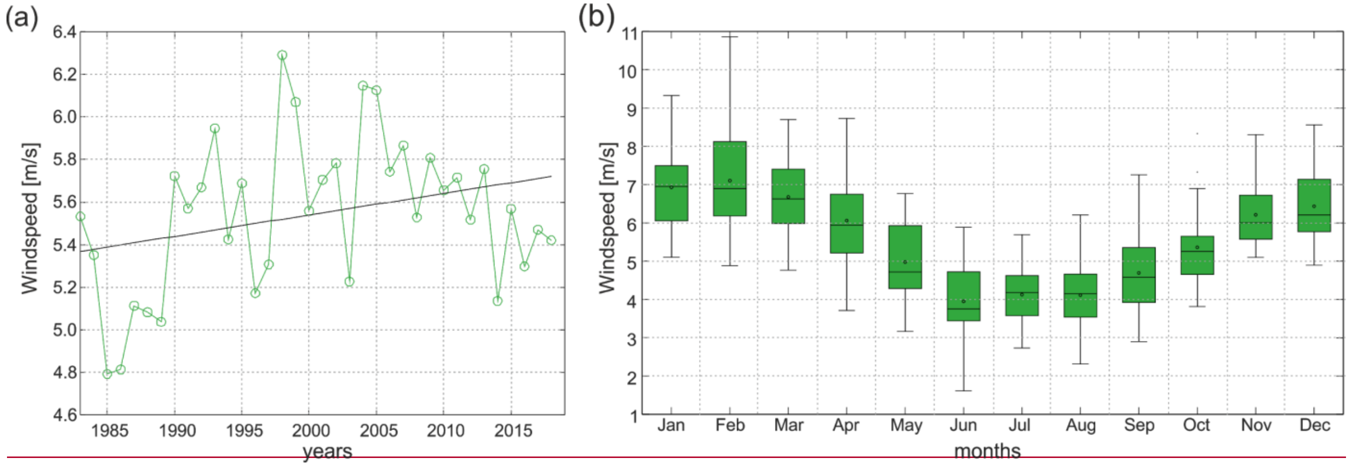


Figure 6 The wind rose for the Hornsund station for the period 1983-2018.

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 ~~lack of a~~ statistically insignificant trend in mean annual WS.



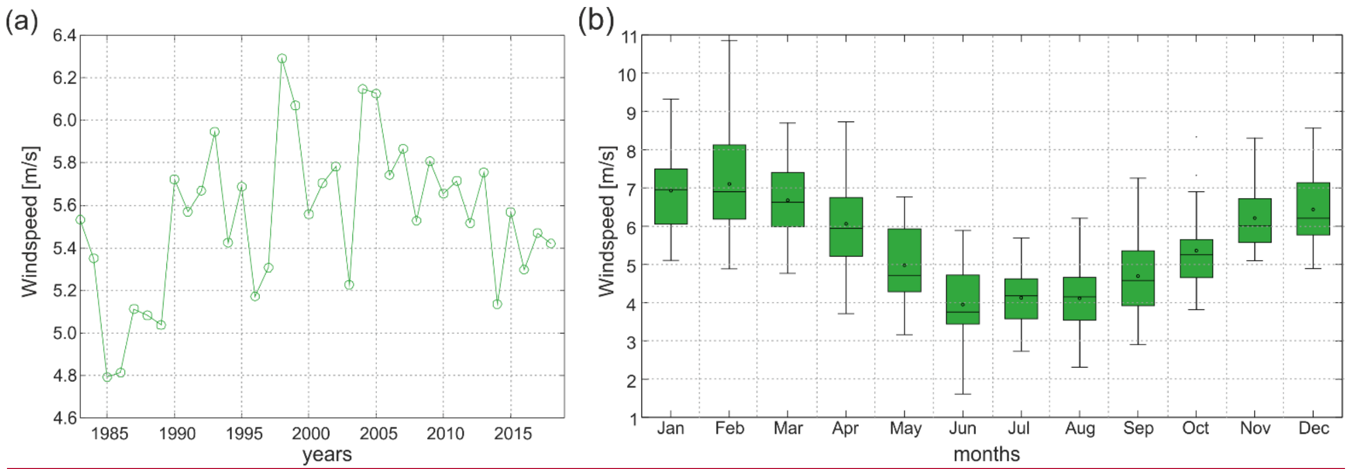


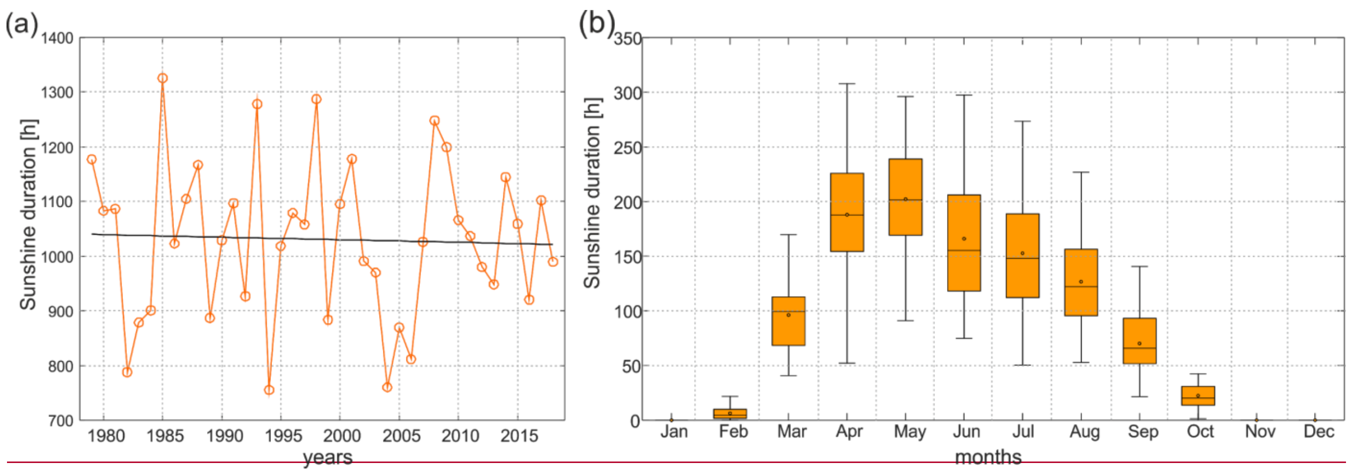
Figure 7 (a) Variability of mean annual wind speed in 1983-2018 at Hornsund. (b) Variability of the mean monthly wind speed at Hornsund in the period 1983-2018.

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 ~~an~~ 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. ~~allows the analysis of the atmospheric energy balance widely used in climate research.~~ 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~~ 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 ~~not~~ statistically insignificant at the 0.05 level.



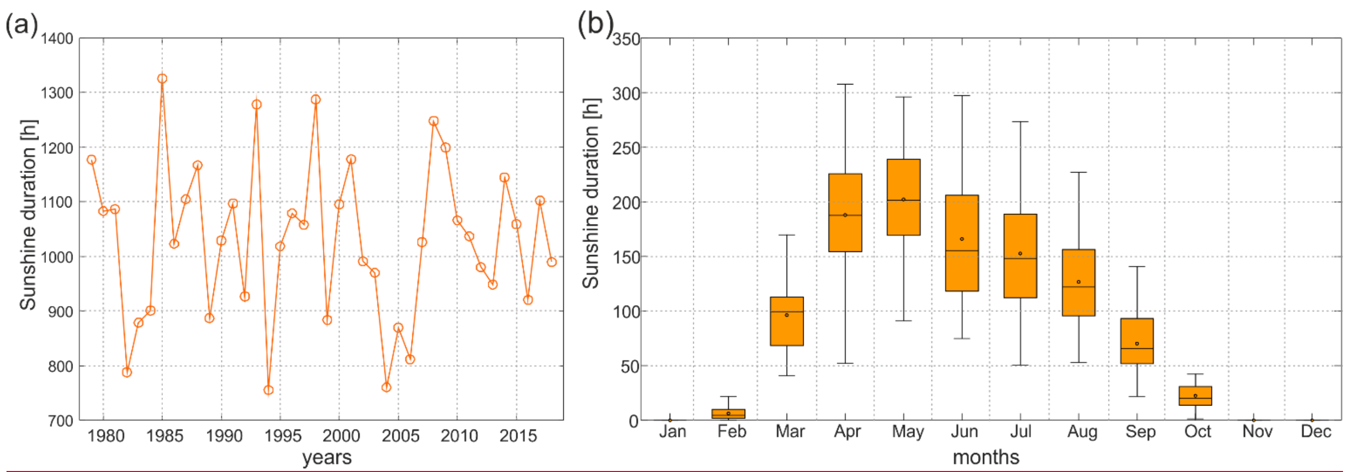


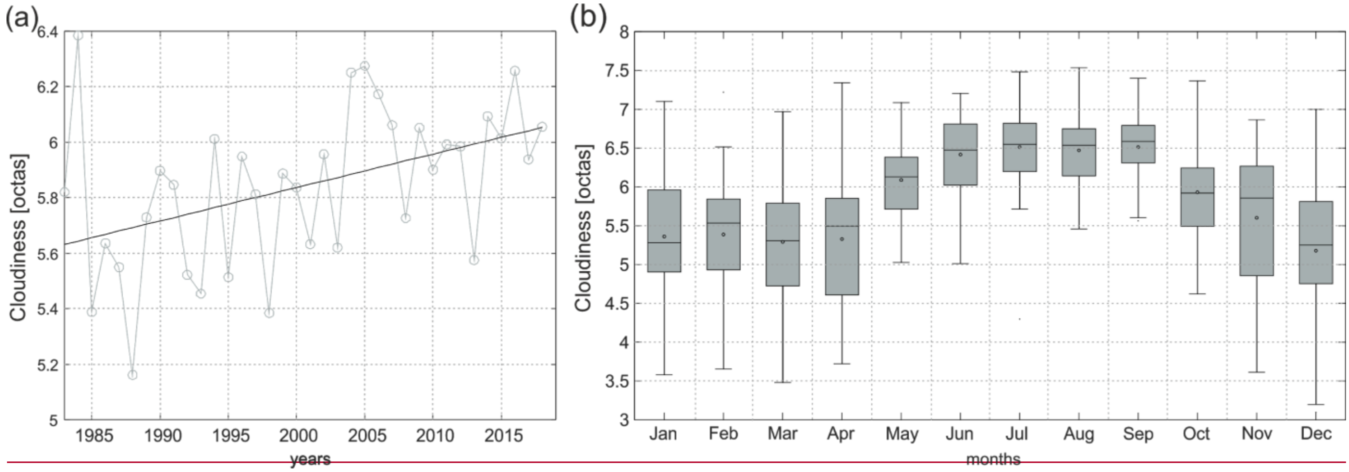
Figure 8 (a) Variability of mean annual sunshine duration in 1979-2018 at Hornsund. (b) Variability of the monthly sums of sunshine duration at Hornsund in the period 1979-2018.

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 ~~The minimum value of annual 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.



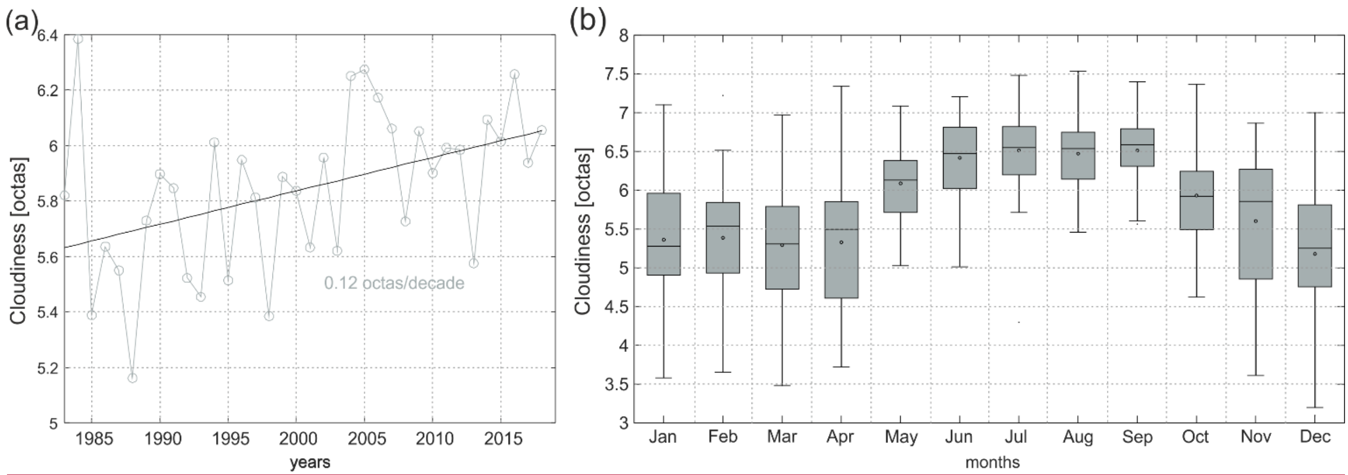


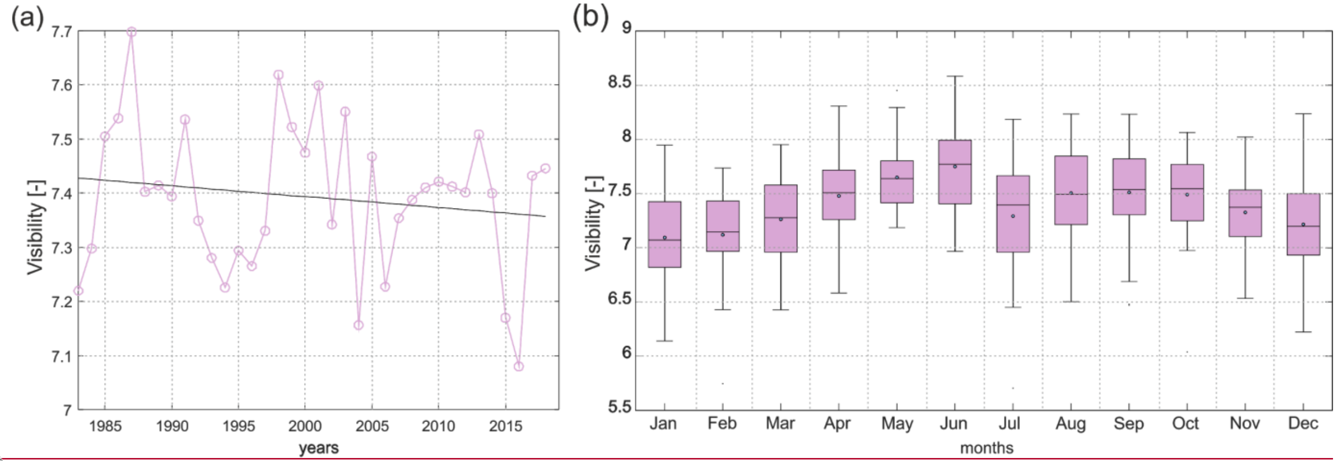
Figure 9 (a) Variability of mean annual cloudiness in 1983-2018 at Hornsund. (b) Variability of the monthly sums of cloudiness at Hornsund in the period 1983-2018.

The variability of the monthly cloudiness in the period 1983-2018 is presented in Figure 9b. The annual ~~run~~ cycle is characterised by lower mean cloudiness during the cold period from October till April (5.5-6.0 octas), and ~~it~~ this period is also characterised by large~~r~~ 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 ~~not~~ 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.



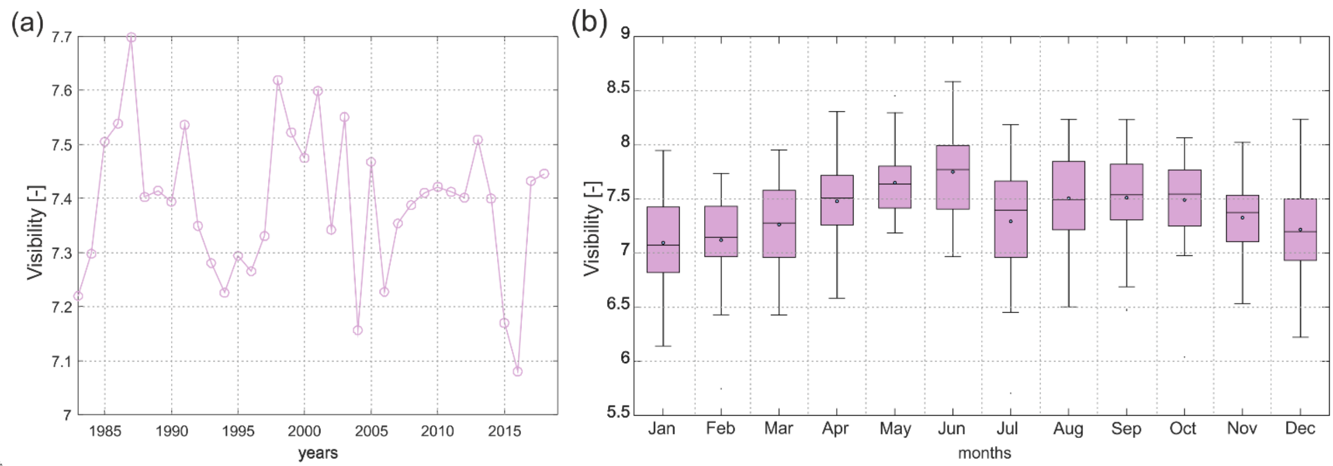


Figure 10 (a) Variability of mean annual visibility in 1983-2018 at Hornsund. (b) Variability of the mean monthly visibility at Hornsund in the period 1983-2018.

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. ~~Nowhere on the planet is climate warming faster than here.~~ 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 ~~five~~ more than six times larger ~~faster than~~ 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 ~~is~~ are both~~a~~ 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.

Acknowledgements

The authors would like to kindly thank the meteorological staff from the Polish Polar Station Hornsund listed here: https://hornsund.igf.edu.pl/about-the-station/expeditions/ for collecting the data and maintaining the meteorological monitoring. The authors also thank the two anonymous reviewers for valuable comments and suggestions. Financial support for this work was provided by the Polish National Science Centre through grant No. 2017/27/B/ST10/01269. This work was also partially supported by the Institute of Geophysics, Polish Academy of Sciences within statutory activities No 3841/E-41/S/~~2019~~ 2020 of the Ministry of Science and Higher Education of Poland.

References

Araźny, A., Przybylak, R., Wyszyński, P., Wawrzyniak, T., Nawrot, A., and Budzik, T.: Spatial variations in air temperature and humidity over Hornsund fjord (Spitsbergen) from 1 July 2014 to 30 June 2015, Geografiska Annaler: Series A, Physical Geography, 100(1), 27-43, doi: 10.1080/04353676.2017.1368832, 2018.

~~Błaszczyk, M., Jania, J. A., and Hagen, J.O.: Tidewater glaciers of Svalbard: Recent changes and estimates of calving fluxes, Polish Polar Research, 30(2), 85–142, 2009.~~

Błaszczyk, M., Jania, J. ~~-~~A., and Kolondra, L.: Fluctuations of tidewater glaciers in Hornsund Fjord (Southern Svalbard) since the beginning of the 20th century, Polish Polar Research, 34(4), 327–352, doi:10.2478/popore−2013−0024, 2013.

Dahlke, S., Hughes, N.E., Wagner, P.M., Gerland, S., Wawrzyniak, T., Ivanov, B., and Maturilli, M.: The observed recent surface air temperature development across Svalbard and concurring footprints in local sea ice cover. Int J Climatol.; 1– 20. https://doi.org/10.1002/joc.6517, 2020.

Estévez, J., Gavilán, P., and Giráldez, J. V.: Guidelines on validation procedures for meteorological data from automatic weather stations. Journal of Hydrology, 402(1-2), 144–154, doi:10.1016/j.jhydrol.2011.02.031, 2011.

Gjelten, H.M., Nordli, Øyvind, Isaksen, K., Førland, E.J., Sviashchennikov, P. N., Wyszynski, P., Prokhorova, U. V., Przybylak, R., Ivanov, B.V., and Urazgildeeva, A. V.: Air temperature variations and gradients along the coast and fjords of western Spitsbergen. Polar Research, 35. https://doi.org/10.3402/polar.v35.29878, 2016.

Hamed, K. H., and Rao, R.: A modified Mann-Kendall trend test for autocorrelated data, J. Hydrol., 204, 182–196, 1998.

Hanssen-Bauer, I., Førland, E.J., Hisdal, H., Mayer, S., Sandø, A.B., Sorteberg, A., Adakudlu, M., Andresen, J., Beldring, S., Benestad, R., Bilt, W., Bogen, J., Borstad, C., Breili, K., Breivik, Ø., Børsheim, K.Y., Christiansen, H.H., Dobler, A., Engeset, R., Frauenfelder, R., Gerland, S., Gjelten, H.M., Gundersen, J., Isaksen, K., Jaedicke, C., Kierulf, H., Kohler, J., Li, H., Lutz, J., Melvold, K., Mezghani, A., Nilsen, F., Nilsen, I.B., Nilsen, J.E.Ø., Pavlova, O., Ravndal, O., Risebrobakken, B., Saloranta, T., Sandven, S., Schuler, T.V., Simpson, M.J.R., Skogen, M., Smedsrud, L.H., Sund, M., Vikhamar-Schuler, D., Westermann, S., Wong, W.K.: Climate in Svalbard 2100 – a knowledge base for climate adaptation. Norwegian Centre for Climate Services, Report no. 1/2019, ISSN 2387-3027, 205 pp., 2019.

Intrieri, J. -M., ~~C. W.~~ Fairall, C. W., ~~M. D.~~ Shupe, M. D., ~~P. O. G.~~ Persson, P. O.- G., ~~E. L.~~ Andreas, E. L., ~~P.~~ Guest, P., and Moritz, R. M.: An annual cycle of Arctic surface cloud forcing at SHEBA. J. Geophys. Res., 107, 8039, doi:10.1029/2000JC000439, 2002.

IPCC: The Ocean and Cryosphere in a Changing Climate. https://www.ipcc.ch/srocc/home/, 2019.

Kendall, M. G.: Rank Correlation Methods. Charles Griffin: London, 1975.

Lindner, L., Marks, L., Roszczynko, W. and Semil, J.: Age of raised marine beaches of northern Hornsund Region, South Spitsbergen, Pol. Polar Res., 12(2), 161-182, 1991.

Mann, H.: Nonparametric tests against trend, Econometrica, 13(3), 245–259, doi:10.2307/1907187, 1945.

Marsz, A. A., and Styszyńska, A.: Climate and Climate change at Hornsund, Svalbard. Gdynia Maritime University: Gdynia, Poland, ISBN: 978-83-7421-191-8, 2013.

NOAA National Centers for Environmental information, Climate at a Glance: Global Time Series, published February 2020, retrieved on February 27, 2020 from https://www.ncdc.noaa.gov/cag/, 2020.

Nordli, P. Ø., Hanssen-Bauer, I., and Førland, E. J.: Homogeneity Analyses of Temperature and Precipitation Series from Svalbard and Jan Mayen, Norwegian Meteorol. Inst. Report 16/96 KLIMA, 41, 1996.

Nordli, Ø., Przybylak, R., Ogilvie, A. E. J., and Isaksen, K.: Long‒term temperature trends and variability on Spitsbergen: the extended Svalbard Airport temperature series, 1898–2012, Polar Res., 33, 21349, doi: 10.3402/polar.v33.21349, 2014.

Osuch, M. and Wawrzyniak, T.: Climate projections in the Hornsund area, Southern Spitsbergen, Pol. Polar Res., 37(3), 379–402, doi:10.1515/popore-2016-0020, 2016.

Osuch, M. and Wawrzyniak, T.: Inter- and intra-annual changes of air temperature and precipitation in western Spitsbergen, Int. J. Climatol., 37, 3082–3097, doi:10.1002/joc.4901, 2017a.

Osuch, M. and Wawrzyniak, T.: Variations and changes in snow depth at meteorological stations Barentsburg and Hornsund (Spitsbergen), Ann. Glaciol., 58 (75), 11–20, doi:10.1017/aog.2017.20, 2017b.

Osuch, M., Wawrzyniak, T., and Nawrot, A.: Diagnosis of the hydrology of a small Arctic permafrost catchment using HBV conceptual rainfall-runoff model, Hydrology Research, 50(2), 459-478, doi:10.2166/nh.2019.031, 2019.

Przybylak, R.: The climate of the Arctic. 2nd ed. Atmospheric and Oceanographic Sciences Library 52, Heidelberg: Springer; pp. 287, doi:10.1007/978-3-319-21696-6, 2016.

Rinke, A., M. Maturilli, R.M. Graham, H. Matthes, D. Handorf, L. Cohen, S.R. Hudson, and Moore, J.C.: Extreme cyclone events in the Arctic: Wintertime variability and trends, Envir. Res. Lett., 12, 094006, doi:10.1088/1748-9326/aa7def, 2017.

Sen, P. K.: Estimates of the regression coefficient based on Kendall's tau, Journal of the American Statistical Association, 63, 1379–1389, doi: 10.2307/2285891, 1968.

Shupe, M. D., and Intrieri, J. M.: Cloud radiative forcing of the Arctic surface: The influence of cloud properties, surface albedo, and solar zenith angle. J. Climate, 17, 616–628, doi:10.1175/1520-044, 2004.

van Pelt, W., Pohjola, V., Pettersson, R., Marchenko, S., Kohler, J., Luks, B., Hagen, J. O., Schuler, T. V., Dunse, T., Noël, B., and Reijmer, C.: A long-term dataset of climatic mass balance, snow conditions, and runoff in Svalbard (1957–2018), The Cryosphere, 13, 9, 2259-2280, doi: 10.5194/tc-13-2259-2019, 2019.

Vihma, T., Screen, J., Tjernström, M., Newton, B., Zhang, X., Popova, V., Deser, C., Holland, M., and Prowse, T.: The atmospheric role in the Arctic water cycle: A review on processes, past and future changes, and their impacts, J. Geophys. Res. Biogeosci., 121, 586– 620, doi:10.1002/2015JG003132, 2016.

Walczowski, W., Beszczynska-Möller, A., Wieczorek, P., Merchel, M., and Grynczel, A.: Oceanographic observations in the Nordic Sea and Fram Strait in 2016 under the IO PAN long-term monitoring program AREX, Oceanologia, 59(2), 187-194, doi:10.1016/j.oceano.2016.12.003, 2017.

Wawrzyniak, T., Osuch M., Napiórkowski, J.J., and Westerman, S.: Modelling of the thermal regime of permafrost during 1990–2014 in Hornsund, Svalbard. Polish Polar Research 37(2): 219–242, doi: 10.1515/popore-2016-0013, 2016.

Wawrzyniak, T., Osuch, M., Nawrot, A., and Napiórkowski, J.J.: Run-off modelling in an Arctic unglaciated catchment (Fuglebekken, Spitsbergen). Ann. Glaciol. 58 (75), 36–46, doi:10.1017/aog.2017.8, 2017.

Wawrzyniak, T., Osuch, M.: A consistent High Arctic climatological dataset (1979-2018) of the Polish Polar Station Hornsund (SW Spitsbergen, Svalbard). PANGAEA, https://doi.pangaea.de/10.1594/PANGAEA.909042, 2019.

Wojkowski, J., Caputa, Z., and Leszkiewicz, J.: The impact of relief on the diversity of possible sunshine duration at Hornsund region (SW Spitsbergen), Problemy Klimatologii Polarnej 25, 179-190, 2015.