Geografiska Annaler: Series A, Physical Geography

ISSN: 0435-3676 (Print) 1468-0459 (Online) Journal homepage: http://www.tandfonline.com/loi/tgaa20

Spatial variations in air temperature and humidity over Hornsund fjord (Spitsbergen) from 1 July 2014 to 30 June 2015

Andrzej Araźny, Rajmund Przybylak, Przemysław Wyszyński, Tomasz Wawrzyniak, Adam Nawrot & Tomasz Budzik

To cite this article: Andrzej Araźny, Rajmund Przybylak, Przemysław Wyszyński, Tomasz Wawrzyniak, Adam Nawrot & Tomasz Budzik (2017): 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

To link to this article: http://dx.doi.org/10.1080/04353676.2017.1368832

Published online: 14 Sep 2017.

GEOGRAFISKA ANNALER: SERIES A, PHYSICAL GEOGRAPHY, 2017
https://doi.org/10.1080/04353676.2017.1368832

Spatial variations in air temperature and humidity over Hornsund fjord (Spitsbergen) from 1 July 2014 to 30 June 2015

Andrzej Araźny [a,b], Rajmund Przybylak [a], Przemysław Wyszyński [a], Tomasz Wawrzyniak [b], Adam Nawrot [b] and Tomasz Budzik [c]

[a]Department of Meteorology and Climatology, Faculty of Earth Sciences, Nicolaus Copernicus University, Toruń, Poland; [b]Polish Academy of Sciences, Institute of Geophysics, Warsaw, Poland; [c]Department of Climatology, Faculty of Earth Sciences, University of Silesia, Sosnowiec, Poland

ABSTRACT

This article presents the variations in air temperature and humidity in the region of the Hornsund fjord for the period from 1 July 2014 to 30 June 2015. Based on measurements at 11 sites, it was established that significant topoclimatic differences were dependent on height above sea level, substrate type, distance from the sea, exposition, atmospheric circulation and the ice conditions. The thermal and humidity conditions of individual sites are presented in relation to the weather conditions at the Polish Polar Station in Hornsund (HOR). In the study period, the warmest annual mean air temperature occurred at Hyttevika (HYT), and the coldest on the summit of Fugleberget (FUG), respectively, +1.1°C and −3.7°C relative to HOR. Meanwhile, relative humidity differs from HOR values most strongly on Fugleberget, where it is greater by an average of 14%. Atmospheric circulation and ice cover were shown to have a significant impact on thermal and humidity conditions. The greatest spatial variations in air temperature (3.0°C) in Hornsund region (between HOR and FUG) occurred in winter during anticyclonic advection from the northern sector. The greatest difference in relative air humidity (20%) relative to HOR occurred in FUG in autumn during cyclonic advection from the eastern sector. The east–west thermal and humidity gradients along the fjord are more pronounced when sea ice is present. Differences in air temperature and relative humidity between the sites located in the inner (TRE) and outer parts of the fjord (HG4 and HYT) rose by about 2.0–2.5°C and 7–9%, respectively.

ARTICLE HISTORY
Received 13 October 2016
Revised 19 July 2017
Accepted 19 July 2017

KEYWORDS
Arctic; Spitsbergen; Hornsund; air temperature; humidity; atmospheric circulation; ice conditions

1. Introduction

Spitsbergen (the Svalbard archipelago, the Arctic) is experiencing significant climatic changes (*inter alia*, Przybylak 2007, 2016; Araźny 2008; Nordli 2010; Marsz and Styszyńska 2013; Nordli et al. 2014; Przybylak and Araźny 2016). The average annual air temperature for the years 1898–2012 at the Svalbard Airport station in the centre of Spitsbergen rose by 2.6°C per 100 years, within which, the greatest increase (of 3.9°C per 100 years) was for spring (Nordli et al. 2014).

As a result of climate changes which are causing, among others, a recession in tidewater glaciers, the surface area of the Hornsund fjord is increasing. It is the most southerly fjord on Spitsbergen. At the beginning of the twentieth century, the fjord grew by 1 km^2 per annum, while currently, in the twenty-first century, the annual tempo is 3 km^2 (Błaszczyk et al. 2013). This process is causing a range of environmental changes in the Hornsund fjord itself and in the surrounding area (*inter*

CONTACT Andrzej Araźny andy@umk.pl

alia, Wojczulanis-Jakubas et al. 2008; Majewski et al. 2009; Zagórski et al. 2015; Pawłowska et al. 2016).

The first topoclimatic studies on Spitsbergen were conducted during the Swedish–Russian expedition to the north-eastern part of the island between July 1899 and August 1900. Meteorological measurements and observations were conducted regularly at two points: on the shore of Treurenberg Bay (22 m a.s.l.) and on the slopes of Massif Olimp (408 m a.s.l.) (Przybylak and Dzierżawski 2004).

In the Hornsund region, topoclimatic studies were first conducted on a local scale during the International Geophysical Year, when, in 1957, the Polish Polar Station in Hornsund was founded. They were conducted in the meteorological site located near the station (HOR), and at the glaciological station in the upper part of the Werenskioldbreen glacier (Kosiba 1960). The annual topoclimatic variation has previously only been elaborated for the region north of the Hornsund fjord (Sikora et al. 2010, 2011; Przybylak et al. 2014). For financial and logistical reasons, the time period and spatial coverage of topoclimatic measurements in the Hornsund area have changed constantly (*inter alia*, Baranowski and Głowicki 1975; Baranowski 1977; Pereyma 1983; Pereyma and Piasecki 1984, 1988; Migała et al. 2008; Araźny et al. 2010). The literature on the Norwegian Arctic includes articles which describe the general climatic conditions around parts of other fjords on Spitsbergen (e.g. Isfjorden, Kongsfjorden and others) based on a small number of stations (most often 1–3, e.g. Svendsen et al. 2002; Láska et al. 2012; Christiansen et al. 2013; Przybylak et al. 2014; Gjelten et al. 2016). This work, however, is based on documentary material from 11 points around the fjord and located in various geographic environments.

Air temperature and relative humidity are very important climatic elements in the Arctic, and in every part of the Earth (Przybylak 2016). This article presents, for the first time, the annual variations in thermal and humidity conditions for the entire Hornsund region. The objective of this work is to show the main features of the spatial variations in topoclimatic conditions, and to examine the role of atmospheric circulation and ice cover in this process. The detailed results presented in the article represent a valuable new addition to our understanding of the detailed meteorological conditions in effect around a fjord surrounded by glaciers in arctic conditions.

2. Location, data and methods

The research area is located around the Hornsund fjord, in the south-western part of Spitsbergen (Figure 1). The Hornsund fjord separates the south-lying Sørkappland from the main part of the

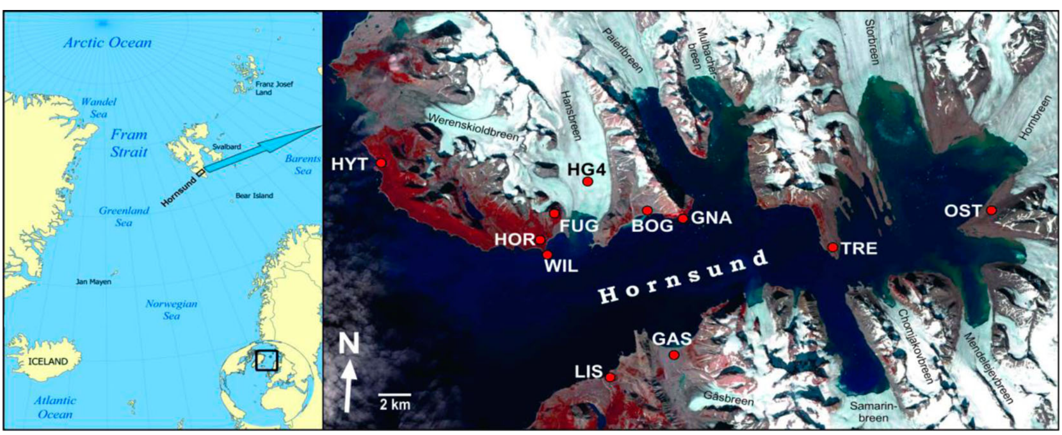

Figure 1. Location of meteorological sites used in this study (HOR, HYT, etc. – meteorological sites, see Table 1). Based on the Landsat 8 image (2 August 2016).

island, and neighbours with Wedel Jarlsberg Land to the north and Torell Land to the north-east. The fjord is approximately 35 km long and approximately 14.5 km wide at its entrance from the Greenland Sea. The fjord extends latitudinally, and is banked on both sides by predominantly longitudinally arranged groups of mountains, including Dunøysundet, Sofiekamen, Luciakamen, Hyrnefjellet-Braemfjelletz and the mountains of Sørkappland with the Hornsundtind massif (the highest peak in southern Spitsbergen, at 1431 m a.s.l.). The fjord is surrounded by narrow coastal plains formed from raised marine terraces. They are wider in the western part of the fjord, but very narrow in the central part (200–400 m) or non-existent where glaciers or steep mountain slopes directly enter the sea.

The meteorological station at the Polish Polar Station in Hornsund has conducted continuous meteorological observations since 1978, as part of the network of Norwegian stations, and is registered with the World Meteorological Organisation. In addition, in spring and summer of 2014, 10 measurement sites for air temperature were set up, 7 of which also measured relative humidity (Table 1 and Figure 1). Three sites (BOG, GAS and OST) were destroyed by polar bears, and consequently cover a shorter time series. The measurement sites represented the varied conditions of the geographic environment around the Hornsund. At the HOR and HG4 sites, measurements were made using Vaisala sensors, while, at the remaining sites, HOBO® automatic loggers (Onset Corp., USA) were used for the same purpose. The accuracy of measurement was ±0.2°C and ±2.5% for temperature and humidity, respectively. All air temperature and air humidity recording sensors were installed in radiation shields at 2 m above ground level. Measurements were conducted at hourly intervals for the period from 1 July 2014 to 30 June 2015 at all sites. As previous studies have shown, such intervals are fully sufficient for the calculation of diurnal averages (Przybylak and Vizi 2005). From the set of 24 hourly data values, a diurnal average was calculated and maximum and minimum values were identified. The diurnal temperature range was calculated as the difference between the maximum and minimum values. For the analysis of meteorological data, standard methods employed universally in climatology were used.

This study employed the seasonal divisions proposed by Gavrilova and Sokolov (1969): autumn (September–October), winter (November–March), spring (April–May) and summer (June–August).

Table 1. Characteristics of meteorological sites operating in the Hornsund region in the period from July 2014 to June 2015.

No.	Site	GPS coordinates	Altitude (m a.s.l.)	Parameter	Location of measurement point
1	HOR	77°00′03″N 15°32′25″E	10	*T*, RH	Polish Polar Station in Hornsund, meteorological garden, marine terrace, 300 m from the fjord
2	HYT	77°03′02″N 15°08′35″E	8	*T*, RH	near the 'Hyttevika' *trapper hus*, coastal terrace with rocks
3	HG4	77°02′27″N 15°38′48″E	180	*T*, RH	central section of the Hans Glacier, near equilibrium line, 3 km from the fjord
4	FUG	77°01′11″N 15°33′56″E	568	*T*, RH	summit of the Fugleberget, 1.5 km from the fjord
5	BOG	77°00′56″N 15°45′14″E	18	*T*	Bogstranda, marine terrace
6	GNA	77°00′55″N 15°52′43″E	5	*T*, RH	Gnålodden, near the *trapper hus*, at the foot of Sofiekammen, coastal terrace
7	OST	77°00′53″N 16°35′54″E	14	*T*	Ostrogradskijfjella, outwash fan on dead ice
8	WIL	76°59′44″N 15°33′06″E	7	*T*, RH	Wilczekodden, marine terrace with rocks
9	TRE	76°59′35″N 16°14′56″E	31	*T*, RH	Treskelodden, at the end of the Treskelen peninsula, outwash plain on dead ice
10	GAS	76°56′11″N 15°51′58″E	2	*T*, RH	Gåshamnøyra, outwash plain on bedrock
111	LIS	76°55′12″N 15°41′12″E	14	*T*	Lisbetdalen, marine terrace

Note: *T* – air temperature, RH – relative humidity.

For the analysis of the influence of atmospheric circulation on the studied meteorological elements, the calendar of circulation types after T. Niedźwiedź (2016) was used. The author of the catalogue distinguishes 21 types, for which the basic classification is by direction of advection (or lack of clear inflow), and type of baric regime (Niedźwiedź 2013a). If a given day had advection, it was marked with a capital letter indicating the direction from which air inflow was coming (N, S, E and W). The type of baric regime was indicated using the index ‘a’ for anticyclonic situations, or ‘c’ for cyclonic situations. The one-year study period did not allow reliable results to be gathered for the 21 types proposed in the calendar, so they were grouped after the method proposed by Przybylak (1992): NWa + Na + NEa, NWc + Nc + NEc – air-mass advection from the north, north-west and north-east; Ea + SEa, Ec + SEc – air-mass advection from the east and south-east; Sa + SWa + Wa, Sc + SWc + Wc – air-mass advection from the south, south-west and west; Ka + Ca – anticyclonic wedge and central anticyclonic situation; Bc + Cc – cyclonic trough and central cyclonic situation. Thermal characteristics were calculated for those circulation types whose frequency of occurrence was ≥5.

For analysis of the influence of sea ice on air temperature and humidity, maps of icings published by the Norwegian Meteorological Institute were used (http:/polarview.met.no/).

3. Results and discussion

3.1. Spatial variations in air temperature

The study period (July 2014–June 2015) was warmer (by 1.0°C) at HOR than the long-term average for the years 1978–2012 (Styszyńska 2013). In the annual course, the greatest positive anomalies were noted in March and January (5.2°C and 4.6°C), while the greatest negative anomalies occurred in February and May (0.8°C and 0.1°C, respectively) when compared to the long-term (1978–2012) monthly average.

During the study year, the warmest areas were HYT (–1.1°C) and WIL (–1.9°C). Both these sites are located on the western shore of the Hornsund. The HYT site stands out for having the mildest conditions because it is protected orographically to the east, the direction from which predominantly cold, dry air masses flow in. The coolest sites were the mountain peak FUG (–5.9°C) and the Hans Glacier HG4 (–4.3°C) (Table 2). The low temperature at FUG is influenced by the altitude of the site (568 m a.s.l.), while in the case of HG4, apart from its altitude (180 m a.s.l.), it is also related to being located on a glacial substrate (Figure 1).

The annual course of air temperature in the Hornsund region between July 2014 and June 2015 reached its minimum in February (Figure 2), when the lowest monthly average values ranged from –15.1°C at the FUG mountain peak to –9.4°C at HYT on the western coast. The highest average monthly temperature for all sites was in July. The highest monthly average temperatures were observed at the GAS and HYT sites (6.1°C and 6.0°C, respectively) while the lowest (resulting

Table 2. Mean monthly and annual air temperature (°C) in Hornsund (HOR) and comparison with other meteorological sites (HYT–HOR, etc.) used in this study in the period of July 2014–June 2015.

Site	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Year
HOR	5.6	5.0	2.3	−0.3	−4.4	−7.6	−5.8	−11.3	−5.3	−4.2	−2.8	2.9	−2.2
HYT–HOR	0.4	0.5	0.4	1.1	1.0	1.2	1.4	1.8	1.9	1.5	1.2	0.3	1.1
HG4–HOR	−3.2	−2.7	−2.1	−2.1	−2.6	−2.6	−1.9	−2.1	−1.8	−2.3	−1.0	−1.3	−2.1
FUG–HOR	−2.5	−2.9	−4.4	−4.1	−3.9	−4.1	−4.2	−3.8	−3.4	−3.9	−3.4	−3.7	−3.7
BOG–HOR	0.3	0.1	−0.1	−0.1	−0.3	−0.1	0.0						
GNA–HOR	−0.1	−0.1	0.2	0.0	0.3	0.1	0.0	−0.4	−0.1	−0.2	−0.1	−0.2	0.0
OST–HOR		−0.7	−0.6	−0.9									
WIL–HOR	−0.3	−0.4	0.2	0.4	0.6	0.9	0.5	0.6	0.3	0.3	0.2	−0.2	0.3
TRE–HOR	−0.8	−1.0	−0.7	−0.8	−0.4	−0.7	−1.1	−2.5	−2.1	−2.4	−1.3	−1.5	−1.3
GAS–HOR	0.6	0.4	0.3										
LIS–HOR	0.3	0.3	0.0	−0.1	0.2	−0.3	−0.3	0.0	0.2	0.2	0.6	0.0	0.1

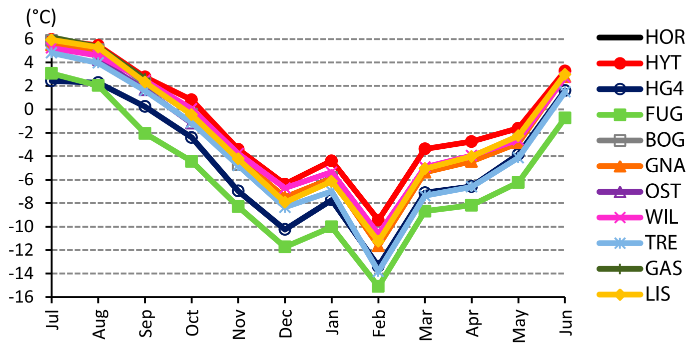

Figure 2. Annual courses of air temperature in the Hornsund fjord area in the period from July 2014 to June 2015.

from the hypsometry of the higher altitude sites) were on the Hans Glacier at HG4 (2.4°C) and in the mountains at FUG (3.1°C) (Figure 2). The annual course of air temperature in the study period was similar to that of the long-term average, with the coldest and warmest months being February and July, respectively (e.g. Przybylak 1992; Araźny 2008; Nordli et al. 2014).

The highest and lowest air temperature values and average diurnal ranges are presented in Figure 3. The highest absolute air temperature (12.3°C) occurred on 25 July at 15 UTC at HOR, during cyclonic circulation from NW. In the summer highest maximum temperature values range from the aforementioned 12.3°C at HOR on a marine terrace to 7.4°C on the glacier at HG4. In summer, the lowest minimum temperatures were observed in the mountains at FUG (–4.7°C). In the same period, only on the south coast at LIS did the temperature not fall below 0°C. In the autumn months, the highest temperature value (11.2°C) occurred at HYT on the western coast, while the lowest (–16.4°C) was on the Hans Glacier at HG4. The autumn range of the mean diurnal temperature was similar to that of summer. In winter, the absolute maximum temperature ranged from 5.4°C at TRE to 0.0°C in the mountains at FUG. In winter, the lowest minimum temperatures (below –25°C) are observed in the glacier (HG4), in the inner central part of the fjord (TRE, GNA) and in the mountains (FUG).

Winter saw the year's greatest average diurnal temperature, which ranged from 3.9°C at WIL to 6.4°C at HG4 (Figure 3). In spring, the range of maximum temperatures was similar to that of winter. They ranged from 5.2°C at GNA to 0.1°C at FUG. In the same period, minimum temperatures

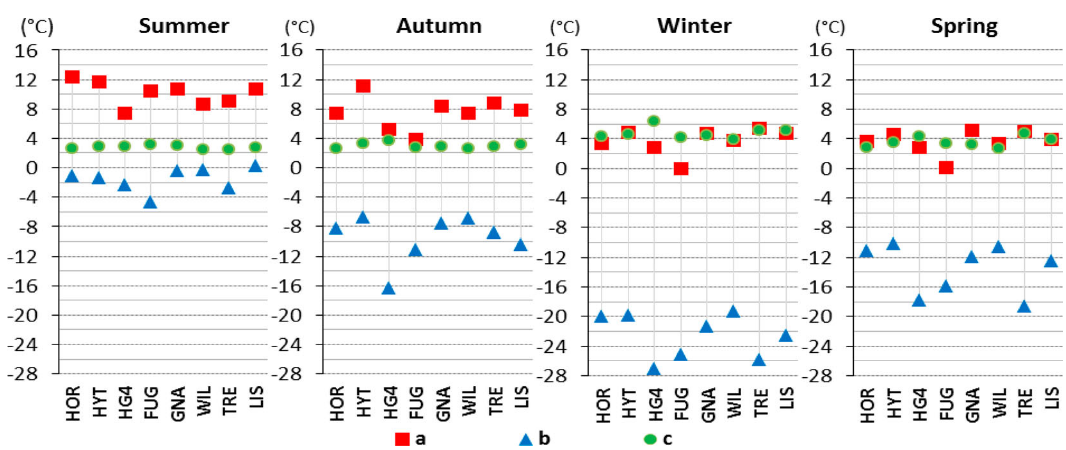

Figure 3. Values of absolute maximum (a), absolute minimum (b) and mean diurnal range (c) of air temperature in the area of the Hornsund fjord in particular seasons in the period from July 2014 to June 2015.

ranged from −10.1°C at HYT to −18.6°C at TRE deep in the fjord. During the year-long study period, the area of most extremely varied thermal conditions, with the highest absolute range, was the area deep inside the fjord at TRE (34.8°C) and on the mountain peak of FUG (35.5°C).

The air temperature in summer is not highly varied. This is confirmed by the low values of the standard deviation of average diurnal air temperature values. Summer is the period of lowest thermal variations between individual sites in the Hornsund region (e.g. Migała et al. 2008, Araźny et al. 2010). The standard deviation in summer ranged from 0.9°C (at WIL and TRE) to 2.0°C (at FUG and HG4). The fact that the lowest variability of average diurnal air temperature occurs in summer is associated with the low air temperature gradient between the Norwegian Arctic and lower latitudes. This results from the low influence of atmospheric circulation on day-to-day temperature changes, as shown by Niedźwiedź (2013b), who calculated that, for example in June, for certain circulation types the average air temperature in Hornsund ranges only from 0.9°C (under anticyclonic conditions coming from the north) to 3.0°C (under anticyclonic conditions coming from the south). Meanwhile, winter is the period with the greatest variability in average diurnal air temperature values, whose standard deviation varied from 4.7°C (WIL) to 6.0°C (TRE). Meanwhile, according to Niedźwiedź (2013b), the fact that winter has the largest variability of day-to-day air temperature changes in Hornsund results from strong winter warmings (with advection of air from the south-west) and large coolings (under anticyclonic conditions coming from the north and north-east). This is the result of winter having a many times greater latitudinal air temperature gradient than summer. The average standard deviation values calculated from all sites are approximately 0.5°C higher in spring than in autumn.

In order to remove the impact of height a.s.l. on the spatial variations in air temperature in the study area, the values were reduced to sea level using a gradient of 0.66°C per 100 m. This value was used because that is the average annual vertical air temperature gradient between the HOR Base Station and the highest point in the mountains at FUG. Throughout the year, the reduced-to-sea-level temperature values at HG4 and TRE were lower than at HOR (Figure 4). The cause of their lower temperatures is the cooling influence of the glacier surface and of sea ice. In the study area, the greatest negative average seasonal difference was found in spring between the stations of TRE and HOR (−1.7°C) (Figure 4). Meanwhile, according to both actual and reduced values, the HYT site, with its thermal advantage of being on the western coast, is decidedly the warmest in Hornsund across all seasons (Figure 4). Particularly large anomalous values (1.3–1.5°C) were seen in winter and spring. During the astronomical polar night (31 October 2003–11 February 2004), Migała et al. (2004) found that the HYT was also identified as being warmer than HOR (by 0.8°C).

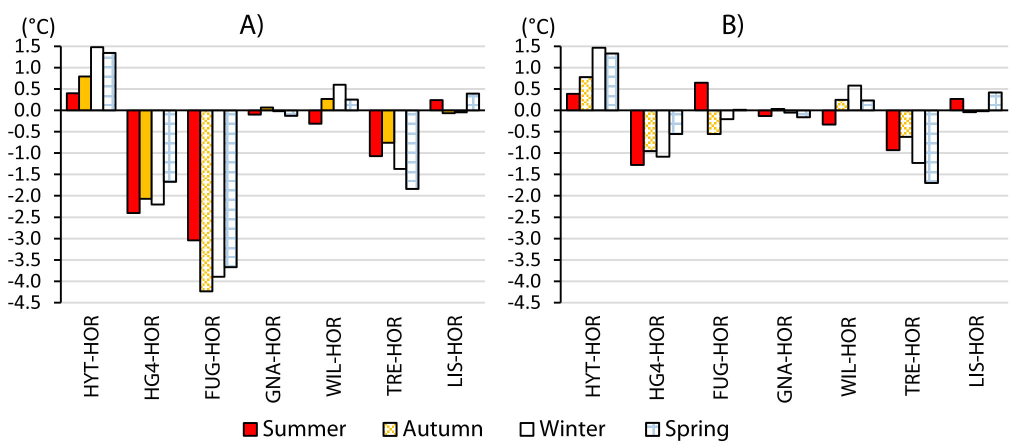

Figure 4. Mean differences in air temperature (°C) at station level (A) and reduced to sea level (B) between Hornsund and other measurement sites in the area of the Hornsund fjord, in particular seasons in the period from July 2014 to June 2015.

3.2. Spatial variations in relative humidity

The second studied meteorological element was relative humidity, which in all sites, except two located in the top of Fugleberget mountain (FUG) and in Treskelen Peninsula (TRE, with the most maritime climate) have an annual cycle similar to that observed for air temperature. Hornsund fjord is, for most of the year, influenced by humid maritime air masses carried from over the Atlantic by cyclonic action (Araźny 2008). In the study period, the relative humidity at the HOR Base Station was 1% higher than for the long-term period (Styszyńska 2013). The highest differences occurred in March and April (greater by 6–7%) and in August (less by 5%).

During the study period, the highest annual means of relative humidity values among the observation sites (94 and 91%) were at FUG and TRE (Table 3). At FUG, the lack of changes in relative air humidity over the annual cycle is caused by the frequent occurrence of low and orographic clouds. Meanwhile, the second location (in the eastern part of the Hornsund fjord, TRE) has the most maritime climate. The station is located in the middle of the fjord at the end of a peninsula (Figure 1), and there is usually substantial stratocumulus cloud cover causing frequent rainfall. On the other hand, the lowest annual means for relative humidity were measured at the HOR and HYT sites (at 80%) (Table 3). The greatest difference in relative humidity compared to that of HOR (of 14%) was recorded at FUG (Table 3). In the study period (July 2014–June 2015), the minimum relative humidity at most sites (apart from HYT) occurred in February 2015. This situation is associated with the advection of dry Arctic air masses. In that month, the highest average relative humidity (88%) occurred on the FUG mountain peak, and the lowest (74%) on the coastal terraces at HOR and HYT (Table 3 and Figure 5). The highest values of relative humidity, as with air temperatures, were recorded in July for most of the area. This is connected to the inflow of warm, humid maritime air masses over the cool land from a south-westerly direction (Niedźwiedź 2013b). In July, the highest average relative humidity (96%) was noted at the mountain site of FUG, and the lowest (87%) was at HOR. The analysed annual course of relative humidity in the area around Hornsund, with its lowest values in winter and highest during the short summer, was in accordance with Hornsund's long-term climatic situation (e.g. Przybylak 1992; Araźny 2008; Marsz and Styszyńska 2013).

In the Hornsund region, the diurnal averages and individual hourly values of relative humidity reach 100% throughout the year at all sites (Figure 6). On the other hand, absolute drops in individual hourly values (to 19%) are observed at FUG and HYT (Figures 6 and 7). The first of the aforementioned drops in humidity happened on 1 February 2015 at 22 UTC at HYT during a change in atmospheric circulation from type SEa to type Ea. This drop in humidity, and accompanying rise in temperature, extended only to the western part of the study area. The second incident, however, occurred at 5 UTC on 27 February 2015 during a transition of air mass from type Nc to type SEc. On that day, the mountain (FUG) and glacier (HG4) sites on the northern side of the fjord were the first to experience the influence of the Nc atmospheric circulation. In both cases described above, cold air flowing downwards probably warmed adiabatically, leading to a fall in the air's relative humidity.

Table 3. Mean monthly and annual relative humidity (%) in Hornsund (HOR) and comparison with other meteorological sites (HYT–HOR, etc.) used in this study in the period of July 2014–June 2015.

Site	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Year
HOR	87	80	79	81	80	75	78	74	84	78	83	83	80
HYT–HOR	5	5	3	−2	0	−2	−7	0	−5	−3	−2	3	0
HG4–HOR	5	7	6	4	5	3	1	2	1	1	0	10	4
FUG–HOR	9	10	17	16	17	18	16	14	13	14	13	14	14
GNA–HOR	2	4	1	3	1	3	4	3	2	3	2	4	3
WIL–HOR	4	7	4	4	4	5	6	7	4	6	4	5	5
TRE–HOR	7	12	9	10	8	14	13	13	9	14	10	12	11
GAS–HOR	2	4	5										

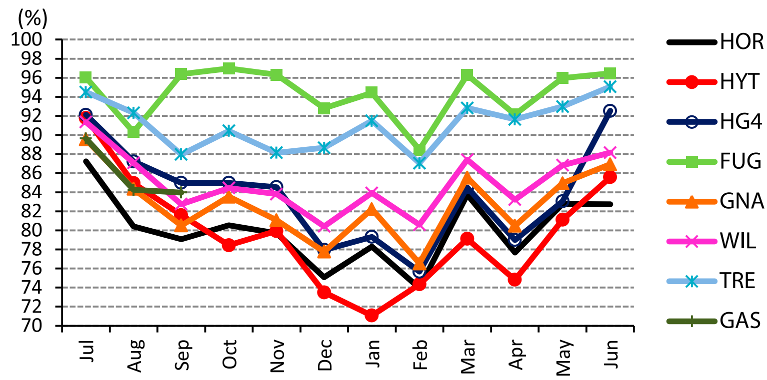

Figure 5. Annual courses of relative humidity in the Hornsund fjord area in the period from July 2014 to June 2015.

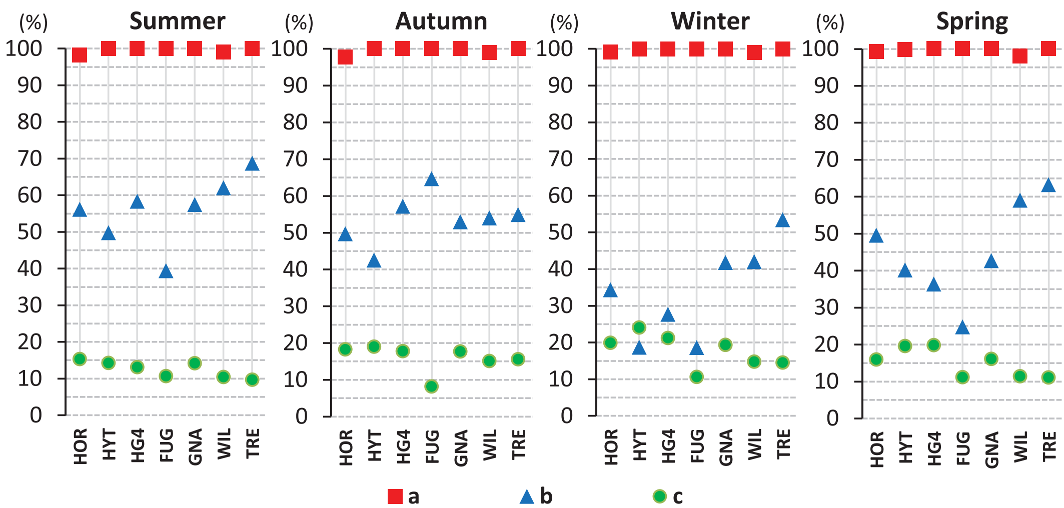

Figure 6. Values of relative humidity: absolute maximum (a), absolute minimum (b) and mean diurnal range (c) in the area of the Hornsund fjord in particular seasons in the period from July 2014 to June 2015.

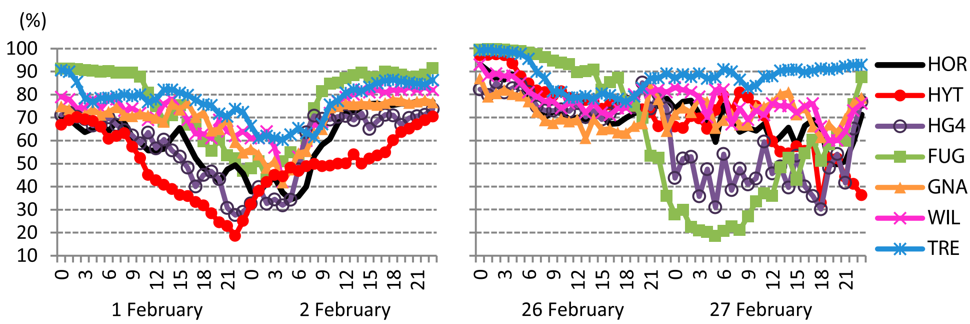

Figure 7. Course of relative humidity in the area of the Hornsund fjord on selected days: 1–2 February and 26–27 February 2015.

3.3. Thermo-humidity variability in the diurnal cycle

The diurnal course of air temperature during the year in the Hornsund region was markedly varied (Figure 8). In summer and spring, the diurnal courses of air temperature had the greatest ranges. In

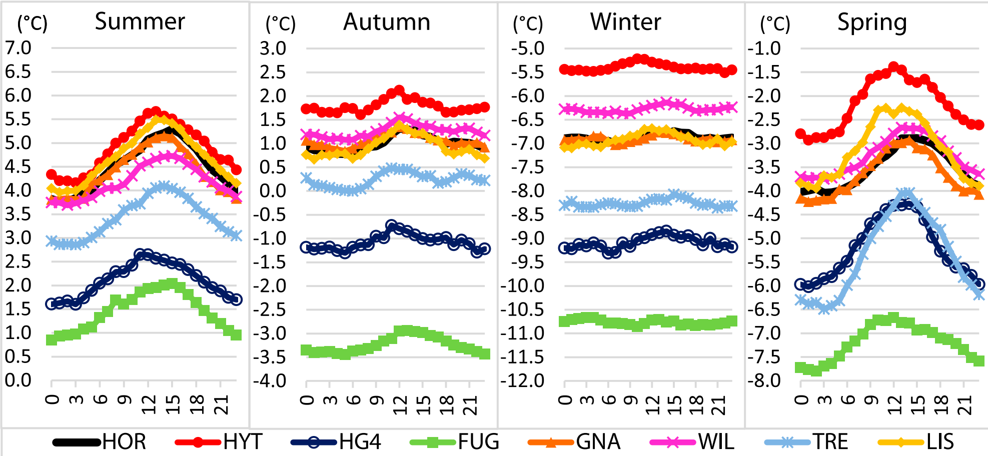

Figure 8. Mean diurnal courses of air temperature in particular seasons in the area of the Hornsund fjord in the period from July 2014 to June 2015.

these two seasons, the average courses at the majority of sites have their highest values during the afternoon hours of 13–15 UTC, and lows values in the 'night-time' hours of 0–4 UTC. The TRE site saw the highest average seasonal range – of 2.4°C – in spring. In autumn, average diurnal temperature ranges are for all sites, at 0.5–0.6°C (about 3 times narrower than in summer and spring). In winter, diurnal courses are flat, and diurnal air temperature ranges are low, at 0.2–0.4°C, except at the HG4 site (0.5°C).

Similar studies of diurnal courses for HOR, but over longer time periods, have been presented by Baranowski (1968) for the years 1957/1958, Przybylak (1992) for the period 1978–1983 and Araźny (2008) for the years 1991–2000. According to the aforementioned authors, the majority of ranges for individual months are close to those presented in Figure 8, but there has been a clear increase in the air temperature of the cooler half of the year, and of the winter months in particular.

The average diurnal course of relative humidity in the Hornsund region is the opposite of the average course of air temperature. In the study area, this diurnal course is significantly varied

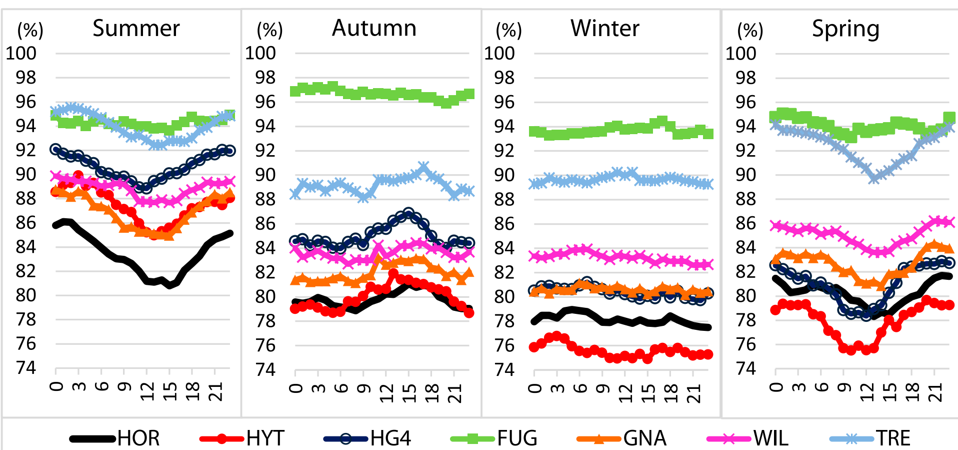

Figure 9. Mean diurnal courses of relative humidity in particular seasons in the area of the Hornsund fjord in the period from July 2014 to June 2015.

(Figure 9). In spring and summer, diurnal courses of humidity have a very pronounced shape. The exception is FUG, which had frequent low cloud cover and had very uniform humidity conditions throughout the diurnal cycle. Summer and spring diurnal relative humidity ranges are about 3–4% at all sites. The HOR site in summer saw the highest average diurnal relative humidity range, at 5.3%. In autumn and spring, under conditions of reduced or zero solar radiation, the average courses at all stations showed a lack of variability in relative humidity over the diurnal cycle. Average relative humidity ranges at those times were 1–2% at all sites.

3.4. The influence of atmospheric circulation on thermo-humidity conditions

Atmospheric circulation is one of the main factors responsible for recent changes in Arctic climate (Serreze and Francis 2006). It plays a significantly greater role in the Norwegian Arctic than it does in other parts of the Arctic. Its greatest influence is felt during the polar night, when no solar radiation reaches the surface of the region (*inter alia*, Araźny 2008; Niedźwiedź 2013b).

Atmospheric circulation in the Hornsund region was analysed based on comparisons of the frequencies of occurrence of circulation types over the long-term period of 1951–2013 and the study period of 2014–2015 (Figure 10). Over the course of the year from July 2014 to June 2015, lows predominated (65.8%), with a frequency double that of highs (31.0%). There were 12.9% more cyclonic situations than in the long-year period of 1951–2013. In the study period, increased cyclonic activity brought more warm air masses to Hornsund than usual, which caused an increase in temperature of 1.0°C above the long-term average.

Over the study period (July 2014–June 2015), cyclonic circulation occurred most frequently: NWc + Nc + NEc (25.2%), Ec + SEc (15.9%) and Sc + SWc + Wc (14.5%). The most rarely observed circulation type was anticyclonic: Sa + SWa + Wa (3.6%) and Ea + SEa (6.8%). The greatest differences between the study period and the long-term period were seen in the summer (Figure 10). In summer, the frequency of occurrence of types NWc + Nc + NEc increased (5.4%), while indeterminate situations fell (–4.1%). More situations of type Sc + SWc + Wc were observed (4.1%) in winter, and fewer of type Sa + SWa + Wa (–3.1%) in spring.

Average differences in air temperature and humidity values for combined atmospheric circulation types between the HOR Base Station and other study areas are presented in Figures 11 and 12.

The warmest summer weather on Spitsbergen comes with highs from the directions E–SE–S, while it is coldest comes predominantly during Nc lows (Niedźwiedź 2013b). In the summer of 2014–2015, average air temperature differences were greatest (2.0°C) for FUG–HOR and were associated with type Sa + SWa + Wa. This can be explained by a strong inversion in the temperature profile and/or the strong heating of FUG's rocky summit by sunny weather, which was greater than the heating of the marine terrace at HOR (Araźny et al. 2010). Conversely, the largest negative

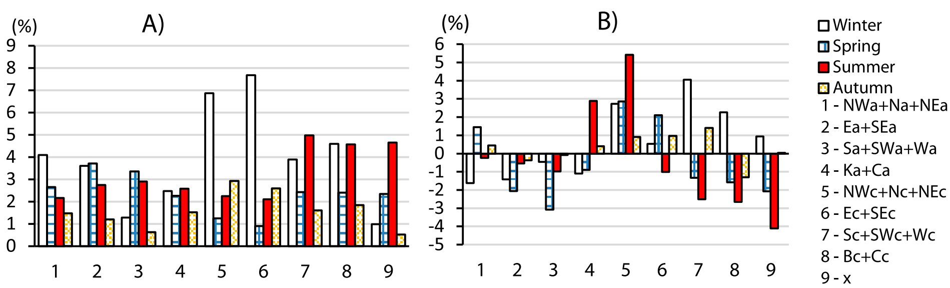

Figure 10. Frequency of occurrence of combined types of atmospheric circulation over Spitsbergen in the period 1951–2013 (A) and mean differences between frequency types of circulation in particular seasons in the period 1951–2013 and July 2014–June 2015 (B).

Note: Frequency values from July 2014 to June 2015 were subtracted from those in 1951–2013.

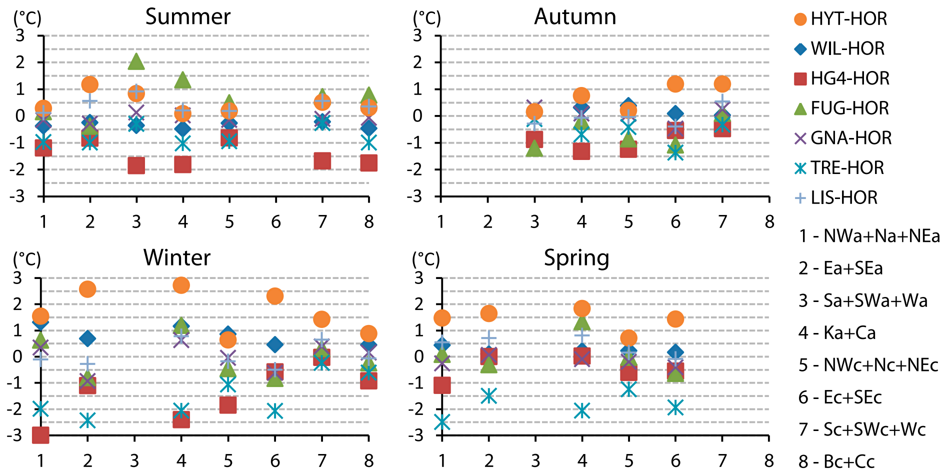

Figure 11. Mean differences of air temperature (°C) between Polish Polar Station in Hornsund (HOR) and other measurement sites in the area of the Hornsund fjord for combined types of atmospheric circulation in particular seasons in the period July 2014–June 2015.

Note: values shown for number of instances ≥5.

differences in temperature were observed between HG4 and HOR for most synoptic situations (Figure 11). This was influenced by the cold, glacier environment of the Hans.

The smallest differences between individual sites and HOR occurred in autumn. In this period, values ranged from –1.3°C between HG4 and HOR for type Ka + Ca, to 1.2°C between HYT and HOR for types Ec + SEc and Sc + SWc + Wc. The area around HYT has particularly favourable thermal conditions. Air advection in cyclonic conditions from southern and western sectors brings warmer air over the area.

Winter is a period of high thermal contrasts on Spitsbergen, with the season seeing the most extreme influences on air temperature. The greatest negative anomalies occurred during the

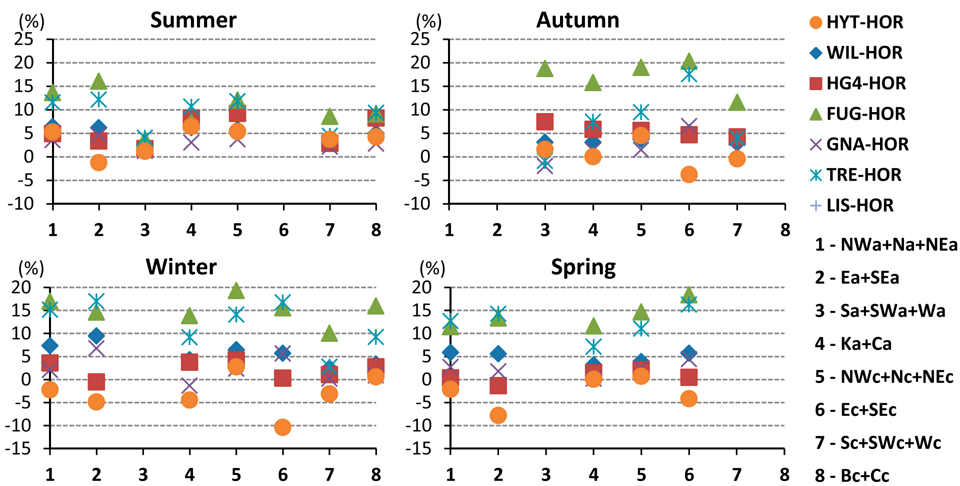

Figure 12. Mean differences of relative humidity (%) between Polish Polar Station in Hornsund (HOR) and other measurement sites in the area of the Hornsund fjord for combined types of atmospheric circulation in particular seasons in the period July 2014–June 2015.

Note: values shown for number of instances ≥5.

anticyclonic situations Na and NEa, which cause significant cooling. However, the strongest winter warmings were observed for the two types SWa and SWc, which brought warm maritime air masses (Niedźwiedź 2013b). The greatest spatial variation in air temperatures between HOR and other sites occurred in winter. The smallest negative average temperature difference (–3.0°C) was identified between HG4 and HOR for anticyclonic air circulation from directions NW + N + NE. In the winter of the study period, the warmest point relative to the Polish Polar Station at HOR for all types (except NWc + Nc + NEc) was HYT. The warmest conditions (2.7–2.6°C) are noted when air-mass inflow is of types and directions Ea + SEa and Ka + Ca.

In spring, the warmest point compared to HOR for all types is HYT. Meanwhile, the greatest negative differences in spring were between HOR and TRE. They were particularly the greatest for type NWa + Na + NEa. This was caused by a high from the north causing a significant cooling and a change in the ground cover around the TRE site. In the spring season deep inside the fjord a dense ice cover formed (Figure 13).

In the summer months, the highest average differences in relative air humidity (16–14%) were between the FUG and HOR sites, and occurred during types Ea + SEa and NWa + NWa + NEa, respectively (Figure 11). In summer across the whole study area, for type Sa + SWa + Wa, homogenous humidity conditions and the lowest variations (1–4%) relative to HOR occur. In summer, a negative difference (–1%) was only observed for type Ea + SEa between HYT and HOR. In the transitional seasons (autumn and spring) and winter, the highest positive values for differences in relative air humidity (10–20%) were for FUG–HOR. Such high values were noted for all synoptic types, and the greatest difference (20%) was observed in autumn for type Ec + SEc. In the aforementioned three seasons, large positive differences in humidity were also noted between TRE and HOR for most types. Meanwhile, the greatest negative differences in values (10% and 8%, respectively) were noted between HYT and HOR in spring (for type Ec + SEc) and in winter (for types Ea + SEa). In the whole area of Hornsund, the lowest spatial variations in humidity are brought by cyclonic air advection from S + SW + W in winter and autumn, and air inflow in an anticyclonic wedge or centre in spring (Figure 12).

3.5. The influence of sea ice on thermo-humidity conditions

The spatial variability of the thermal and humidity conditions in the Hornsund region is shaped by the actions of multiple simultaneous factors. According to Marsz et al. (2013), an increase in the temperature of the waters of the Atlantic and the intensity of atmospheric circulations from the southern sector should be accompanied by a rise in air temperature in Hornsund. The same authors list sea-ice cover as playing the next most important role. By cutting off the flow of heat and moisture from the ocean surface to the atmosphere, sea-ice cover had an impact on air humidity and temperature.

The western part of the Hornsund fjord remains under the strong influence of the Greenland Sea and, flowing along the western coast to the north, the warm West-Spitsbergen Current (Marsz, Styszyńska 2013). Hornsund's location in the south of the island of Spitsbergen means that the area's climate is heavily dependent on maritime influences. One of the regulators of the size and nature of this influence is the temporally and spatially changeable sea-ice cover (Muckenhuber et al. 2016). Radiation budget and large-scale atmospheric circulation in the Arctic are the main drivers of the surface temperature, together with the areal extent and concentration of sea-ice cover and the associated sea-surface temperature, especially in winter (Benestad et al. 2002; Screen et al. 2012). Local climate conditions in the Hornsund fjord are also significantly influenced by the temperature of Atlantic water, the extent of whose inflow into the fjord fluctuates greatly from year to year (e.g. Walczowski and Piechura 2011; Walczowski 2013).

In the study period, there was only zero ice cover in the Hornsund fjord in July to September and in January (Figure 13). The waters of Hornsund were most covered with ice in December (ice density 1–4/10) and from February to May (ice density 1–4 to 10/10). The influence of ice cover is clearly

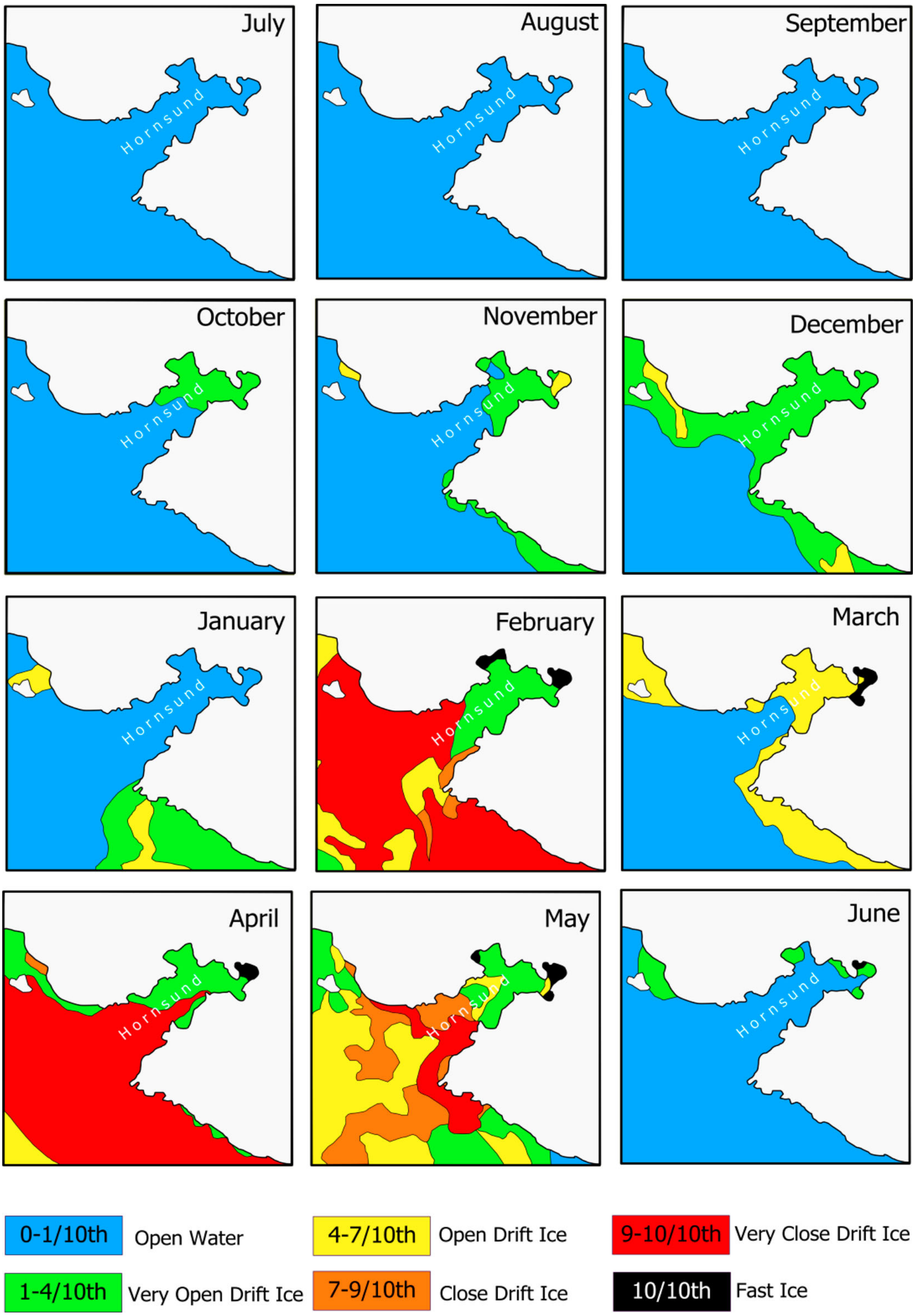

Figure 13. Distribution of ice in the Hornsund fjord in the period July 2014–June 2015.

Note: The situation of ice in the middle of the month (based on http:/polarview.met.no/).

marked on local topoclimatic conditions from February to May. Its greatest influence is observed at TRE, which is the most easterly site in Hornsund. In July and August, it was warmer (by 2.0°C) than the HG4 glacier station. Meanwhile, from February to May, when TRE was surrounded by ice cover, colder conditions (by −0.3°C) were observed for this region than even those seen on the Hans Glacier at HG4 (Figures 2 and 4(b)). A similarly large influence of sea ice on air temperature was found by comparing the warmest part of the study area (HYT) and the previously analysed TRE. In conditions free of sea ice (in July and August) the temperature at TRE was 1.3°C lower than at HYT, while with sea ice present (February–May) this difference increased to 3.7°C. The research results given above for Hornsund are in accordance with the results of other researchers working in other areas of the Arctic (e.g. Screen and Simmonds 2010; Boisvert and Stroeve 2015).

The occurrence of sea-ice cover had an influence on the increases (7% and 9%) of differences in relative humidity values between the two aforementioned periods (between TRE and HG4 and between TRE and HYT, respectively) (Figure 5). It was caused mainly by the decrease of humidity in sites HG4 and HYT during the occurrence of sea-ice cover in Hornsund Fjord, while in TRE changes in humidity were small. This is surprising result, because TRE is, out of all sites, most surrounded by the sea ice. It seems that sea ice has a less significant impact on humidity here than in the outer parts of the fjord (HG4 and HYT) due to differences in local conditions. To inner part of the fjord, less transformed humid air masses are coming from the Greenland Sea leading to greater frequency of occurrence of clouds and precipitation. In addition, circulation of air masses is here more vigorous than in the outer parts of the fjord.

4. Summary and conclusions

A significant spatial variations in air temperature and relative humidity were observed in the Hornsund region. The main influences on variations were height above sea level, substrate type, atmospheric circulation, ice cover and remoteness from the open waters of the Greenland Sea.

The hypsometry and varied land relief around Hornsund increase thermal and humidity contrasts, especially during sunny weather. However, areas located directly next to the fjord have reduced contrasts, with, for example, lower diurnal temperature ranges of air temperature and humidity.

The warmest annual mean air temperature in the study period occurred on the western coast at Hyttevika, and the coldest on the mountain peak of Fugleberget (+1.1°C and −3.7°C, respectively, relative to Hornsund). Relative humidity differs most from values in Hornsund on Fugleberget, where it is greater by an annual average of 14%. Relative humidity in the Hornsund region has an annual cycle similar to that observed for air temperature, except at two sites – those located at the top of Fugleberget mountain and on the Treskelen Peninsula (with the most maritime climate).

Air temperature and humidity are to a large extent shaped by regional atmospheric circulation. This is most marked in winter. In the vicinity of the Hornsund fjord, for example, the greatest winter warmings are associated with air advection from SW, S and W, regardless of baric regime. On the other hand, the greatest negative anomalies occurred during anticyclonic advection from N and NE. The lowest range of temperature fluctuations occurred in summer, during advection from the S–E sector, regardless of type of baric regime.

The greatest spatial variations in air temperature (−3.0°C) in the Hornsund region, relative to the Hornsund Base Station (which was for the mountain site of Fugleberget), occurred in winter during circulation types NWa + Na + NEa. Meanwhile, the greatest difference in relative air humidity (20%) relative to Hornsund (also for Fugleberget) was in autumn, for type Ec + SEc.

The east–west thermal and humidity gradients along the fjord are more pronounced when sea ice is present. Differences in air temperature and relative humidity between the sites located in the inner (TRE) and outer parts of the fjord (HG4 and HYT) rose by about 2.0–2.5°C and 7–9%, respectively.

Acknowledgements

The authors wish to give sincere thanks to the XXXVII Polish Polar Expedition the Polish Academy of Sciences on Spitsbergen for their help in conducting measurements.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This research was conducted under the Polish-Norwegian project entitled 'Arctic climate system study of ocean, sea ice and glaciers interactions in Svalbard area (AWAKE-2)', Polish-Norwegian Research Programme (Pol-Nor/198675/17/2013 (AWAKE-2)).

Notes on contributors

Andrzej Araźny is an Assistant Professor at the Department of Meteorology and Climatology at Nicolaus Copernicus University in Toruń (Poland). The author is a Ph.D. in Natural Sciences (2005), geography, specialised in climatology, with the degree awarded following the dissertation – 'Bioclimate of the Norwegian Arctic and its variability in the years of 1971–2000'. He spent 50 months during the Polar expeditions to the Arctic and Antarctic, among others; he participated in three annual expeditions to Hornsund (Spitsbergen, Arctic). He has been author and co-author of 150 scientific and popular science publications and reports on the climatology of Polar areas and Poland, human biometeorology, changes and fluctuations of the bioclimate and monitoring of the natural environment. More details are available at https://www.researchgate.net/profile/Andrzej_Arazny.

Rajmund Przybylak is a full professor of climatology (2006) and head of the Department of Meteorology and Climatology at Nicolaus Copernicus University in Toruń (Poland) since 2000. He is a President of the Polish Geophysical Society. Rajmund Przybylak received a Ph.D. in Natural Sciences in 1988 (Nicolaus Copernicus University) and the second scientific degree (habilitation) in 1997 (Adam Mickiewicz University). His research interests are: climate of the Polar regions (in particular the Arctic) and Poland; historical climatology; climate variability and climate change and their causes. He is author of more than 300 published original scientific papers (including 6 scientific monographs). More details are available at https://www.researchgate.net/profile/Rajmund_Przybylak.

Przemysław Wyszyński is a Ph.D. in Earth Sciences and works as a research fellow (post-doc) in the Department of Meteorology and Climatology, Nicolaus Copernicus University (Poland). His main field of interest is the historical climatology of the Arctic and recovery of early instrumental data in order to improve existing reanalysis systems. He has been the principal investigator and collaborator in many research projects (e.g. ArcRu https://arcru.wordpress.com/, CEArc http://cearc.umk.pl/. Przemek attended four polar expeditions to the Svalbard region. He has been author and co-author of 8 papers concerning the history of the Arctic climate and its present changes and processes published in international peer-reviewed journals.

Tomasz Wawrzyniak is a Ph.D. student at the Department of Polar and Marine Research Institute of Geophysics, Polish Academy of Sciences. He graduated (M.Sc.) in geography and spatial management from Adam Mickiewicz University in Poznań. He has been leader of grants for young scientists, leader of an abiotic team in the EduScience project, and participant in international projects.

Adam Nawrot is an Assistant Professor at the Department of Polar and Marine Research Institute of Geophysics, Polish Academy of Sciences. His main research focuses on water balances and matter flux in arctic catchments. His Ph.D. thesis (2011) was on 'Operation of the small glaciated catchment geosystem (Arie, Spitsbergen)'. He took part in several national and international research projects. He has been involved in several summer and spring fieldwork campaigns around Spitsbergen, focused on snowpack chemical and physical properties, pollutants deposited in the snowpack, glaciers' mass balance as well as water hydrochemistry and water balance of the Polar catchments. He co-authors scientific and popular science publications and reports as well as a number of conference presentations and posters.

Tomasz Budzik is the specialist at Department of Climatology at the University of Silesia in Katowice (Poland). He is a geographer, climatologist, and specialist of automatic weather stations in Polar Regions. He participated in several expeditions to the Arctic and Antarctic regions. He is author and co-author of several dozen scientific articles and reports.

ORCID

Andrzej Araźny http://orcid.org/0000-0002-4277-9599

References

Araźny A. 2008. Bioklimat Arktyki Norweskiej i jego zmienność w okresie 1971–2000. Toruń: Wydawnictwo UMK; p. 215.
Araźny A, Migała K, Sikora S, Budzik T. 2010. Meteorological and biometeorological conditions in the Hornsund area (Spitsbergen) during the warm season. Pol Polar Res. 31(3):217–238.
Baranowski S. 1968. Termika tundry peryglacjalnej SW Spitsbergen. 68. Wrocław: Acta Universitatis Wratislaviensis; p. 77.
Baranowski S. 1977. The subpolar glaciers of Spitsbergen seen against the climate of this region. 410. Wrocław: Acta Universitatis Wratislaviensis; p. 94.
Baranowski S, Głowicki B. 1975. Meteorological and hydrological investigations in the Hornsund region made in 1970. In: Results of investigations of the Polish scientific expeditions 1970–1974. Wrocław: Acta Universitatis Wratislaviensis; vol. I, 251; p. 35–39.
Benestad RE, Hanssen-Bauer I, Skaugen TE, Førland EJ. 2002. Associations between sea-ice and the local climate on Svalbard. In: Dnmi Klima. 07/02. Oslo: Norwegian Meteorological Institute; p. 1–13.
Błaszczyk M, Jania JA, Kolondra L. 2013. Fluctuations of tidewater glaciers in Hornsund Fiord (Southern Svalbard) since the beginning of the 20th century. Pol Polar Res. 34(4):327–352.
Boisvert LN, Stroeve JC. 2015. The Arctic is becoming warmer and wetter as revealed by the atmospheric infrared sounder. Geophys Res Lett. 42:4439–4446.
Christiansen HH, Humlum O, Eckerstorfer M. 2013. Central Svalbard 2000–2011 meteorological dynamics and periglacial landscape response. Arctic Antarct Alp Res. 45(1):6–18.
Gavrilova LA, Sokolov SI. 1969. Vremennaya izmentchivost temperatury vozdukha v Arktikie. In: Trudy Arkticheskogo i Antarkticheskogo Nauchno-Issledovatel'skogo Instituta. 287. Leningrad: Gidrometeoizdat; 59–68.
Gjelten HM, Nordli Ø, Isaksen K, Førland EJ, Sviashchennikov PN, Wyszyński P, Prokhorova UV, Przybylak R, Ivanov BV, Urazgildeeva AV. 2016. Air temperature variations and gradients along the coast and fjords of western Spitsbergen. Polar Res. 35:29878.
Kosiba A. 1960. Some of results of glaciological investigations in SW Spitsbergen carried out during the Polish I.G.Y. Spitsbergen expeditions in 1957, 1958 and 1959. Zeszyty Naukowe Uniwersytetu Wrocławskiego, Nauki Przyrodnicze. Ser. B., 4, Wrocław.
Láska K, Witoszová D, Prošek P. 2012. Weather patterns of the coastal zone of Petuniabukta, central Spitsbergen in the period 2008–2010. Pol Polar Res. 33:297–318.
Majewski W, Szczuciński W, Zajączkowski M. 2009. Interactions of Arctic and Atlantic water-masses and associated environmental changes during the last millennium, Hornsund (SW Svalbard). Boreas. 38:529–544.
Marsz AA, Styszyńska A. 2013. Climate and climate change at Hornsund, Svalbard. Gdynia: Gdynia Maritime University; p. 402.
Marsz AA, Styszyńska A, Niedźwiedź T. 2013. Comprehensive effects of changes of sea ice extent, sea surface temperature and atmospheric circulation on the air temperature at Hornsund. In: AA Marsz, A Styszyńska, editors. Climate and climate change at Hornsund, Svalbard. Gdynia: Gdynia Maritime University; p. 182–188.
Migała K, Buchert L, Pereyma J. 2004. Termika powietrza w rejonie fiordu Hornsund (SW Spitsbergen) w warunkach nocy polarnej. In: Xxx Międzynarodowe Sympozjum Polarne. Gdynia: Streszczenia; p. 118–119.
Migała K, Nasiółkowski T, Pereyma J. 2008. Topoclimatic conditions in the Hornsund area (SW Spitsbergen) during the ablation season 2005. Pol Polar Res. 29:73–91.
Muckenhuber S, Nilsen F, Korosov A, Sandven S. 2016. Sea ice cover in Isfjorden and Hornsund, Svalbard (2000–2014) from remote sensing data. Cryosphere. 10:149–158.
Niedźwiedź T. 2013a. The atmospheric circulation. In: AA Marsz, A Styszyńska, editor. Climate and climate change at Hornsund, Svalbard. Gdynia: Gdynia Maritime University; p. 57–74.
Niedźwiedź T. 2013b. Influence of atmospheric circulation on the air temperature at Hornsund. In: AA Marsz, A Styszyńska, editors. Climate and climate change at Hornsund, Svalbard. Gdynia: Gdynia Maritime University; p. 165–172.
Niedźwiedź T. 2016. Calendar of atmospheric circulation types for Spitsbergen – a digital dataset. Sosnowiec: Katedra Klimatologii Uniwersytetu Śląskiego.
Nordli Ø. 2010. The Svalbard airport temperature series. Bull Geogr Phys Geogr Ser. 3:5–25.
Nordli Ø, Przybylak R, Ogilvie AEJ, Isaksen K. 2014. Long-term temperature trends and variability on Spitsbergen: the extended Svalbard Airport temperature series 1898–2012. Polar Res. 33:21349.

Pawłowska J, Zajączkowski M, Łącka M, Lejzerowicz F, Esling P, Pawlowski J. 2016. Palaeoceanographic changes in Hornsund Fjord (Spitsbergen, Svalbard) over the last millennium: new insights from ancient DNA. Clim Past. 12:1459–1472.

Pereyma J. 1983. Climatological problems of the Hornsund area, Spitsbergen. 714. Wrocław: Acta Universitatis Wratislaviensis; p. 134.

Pereyma J, Piasecki J. 1984. Meteorological conditions in the Werenskiold basin. In: Field investigation performer during the glaciological Spitsbergen expeditions in 1983. Katowice: Uniwersytet Śląski; p. 12–14.

Pereyma J, Piasecki J. 1988. Warunki topoklimatyczne i hydrologiczne w rejonie Lodowca Werenskiölda na Spitsbergenie w sezonie letnio-jesiennym 1983 roku. In: Wyprawy Polarne Uniwersytetu Śląskiego 1980–1984. Katowice: Uniwersytet Śląski; p. 107–122.

Przybylak R. 1992. Stosunki termiczno-wilgotnościowe na tle warunków cyrkulacyjnych w Hornsundzie /Spitsbergen/ w okresie 1978–1983. Warszawa: Dokumentacja Geograficzna. 2; p. 105.

Przybylak R. 2007. Recent air-temperature changes in the Arctic. Ann Glaciol. 46:316–324.

Przybylak R. 2016. The climate of the Arctic. 2nd ed. Atmospheric and Oceanographic Sciences Library 52, Heidelberg: Springer; p. 287.

Przybylak R, Araźny A. 2016. Warming and drying of tundra and glacier summer climate in NW Spitsbergen from 1975 to 2014. Pol Polar Res. 37(2):173–192.

Przybylak R, Araźny A, Nordli Ø, Finkelnburg R, Kejna M, Budzik T, Migała K, Sikora S, Puczko D, Rymer K, Rachlewicz G. 2014. Spatial distribution of air temperature on Svalbard during 1 year with campaign measurements. Int J Climatol. 34:3702–3719.

Przybylak R, Dzierżawski J. 2004. Stosunki termiczno-wilgotnościowe w Zatoce Treurenberg i na Masywie Olimp (NE Spitsbergen) w okresie 1.08.1899–15.08.1900. Probl Klimatologii Polarnej. 14:133–147.

Przybylak R, Vizi Z. 2005. Ocena dokładności stosowanych metod obliczania średnich i ekstremalnych dobowych wartości temperatury powietrza w Arktyce Amerykańskiej w XIX wieku. Probl Klimatologii Polarnej. 15:27–39.

Screen JA, Deser C, Simmonds I. 2012. Local and remote controls on observed Arctic warming. Geophys Res Lett. 39: L10709.

Screen JA, Simmonds I. 2010. The central role of diminishing sea ice in recent Arctic temperature amplification. Nature. 464.

Serreze MC, Francis JA. 2006. The Arctic on the fast track of change. Weather. 61(3):65–69.

Sikora S, Araźny A, Budzik T, Migała K, Puczko D. 2010. Warunki meteorologiczne i biometeorologiczne okolic Hornsundu (Spitsbergen Zachodni) w roku 2009. Probl Klimatologii Polarnej. 20:83–101.

Sikora S, Budzik T, Migała K, Puczko D. 2011. Warunki meteorologiczne i biometeorologiczne południowo-zachodniego Svalbardu w 2010 roku. Probl Klimatologii Polarnej. 21:213–228.

Styszyńska A. 2013. Results of observations. In: AA Marsz, A Styszyńska, editors. Climate and climate change at Hornsund, Svalbard. Gdynia: Gdynia Maritime University; p. 321–365.

Svendsen H, Beszczynska-Møller A, Hagen JO, Lefauconnier B, Tverberg V, Gerland S, Ørbæk JB, Bischof K, Papucci C, Zajaczkowski M, et al. 2002. The physical environment of Kongsfjorden-Krossfjorden, an Arctic fjord system in Svalbard. Polar Res. 21:133–166.

Walczowski W. 2013. Frontal structures in the West Spitsbergen current margins. Ocean Sci. 9:957–975.

Walczowski W, Piechura J. 2011. Influence of the West Spitsbergen current on the local climate. Int J Climatol. 31:1088–1093.

Wojczulanis-Jakubas K, Jakubas D, Stempniewicz L. 2008. Avifauna of Hornsund area, SW Spitsbergen: present state and recent changes. Pol Polar Res. 29:187–197.

Zagórski P, Rodzik J, Moskalik M, Strzelecki MC, Lim M, Błaszczyk M, Promińska A, Kruszewski G, Styszyńska A, Malczewski A. 2015. Multidecadal (1960–2011) shoreline changes in Isbjørnhamna (Hornsund, Svalbard). Pol Polar Res. 36(4):369–390.