Cloudiness and weather variation in central Svalbard in July 2013 as related to atmospheric circulation

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Abstract
The paper describes synoptic situations and associated weather conditions in the central part of the Svalbard Arctic archipelago (Petuniabukta, Billefjorden) during two weeks of the summer 2013. The circulation types in July 2013 were compared with the long-term average circulation pattern in the period 1961–2010. Cloudiness and weather conditions in different atmospheric circulation types were described. Atmospheric pressure, 2-m air temperature, precipitation, 6-m wind speed and wind direction data from an automatic weather station located on the coastal glacier-free zone of Petuniabukta were used for further analysis. From July 5 to 19, 2013, radiation and advection weather types, heavy precipitation, rapid change of wind speed, 2-m air temperature and high cloudiness variation were described in detail within of the five most frequent synoptic situations. Foehn and halo phenomena were also reported in the study period.

Key words: *atmospheric circulation, climate, cloudiness, weather, Svalbard, Arctic*

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Introduction

Atmospheric and oceanic circulations significantly influence the specific climate of the Arctic region. However, the Arctic is sensitive to climate change due to recently identified numerous interactions and feedback mechanisms (Curry et al. 1996). The bounded or otherwise limited atmospheric forcing pronounced in the re-

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cent climate variability can influence other processes and phenomena, which determine the specific polar ecosystem and cold environment of our planet. Amplification of greenhouse-induced warming in the polar regions can be seen in changes of large-scale atmospheric circulation, strengthening of the westerly flow components and cyclonal activity on the polar fronts (ACIA 2005). The increase of air temperature in the Arctic region over the last few decades is at least two times more than the global mean (Miller et. al 2010, IPCC 2013).

The observed warming is connected with a large reduction of sea ice. Sea ice loss can also have an impact on atmospheric circulation. Two effects contributing to a slower eastward progression of Rossby waves in the upper-level flow have been identified: (1) weakened zonal winds and (2) increased of wave amplitude (Francis et al. 2012). Slower progression of upper-level waves may cause the associated surface weather variation in the mid-latitudes to be more persistent. Arctic sea ice loss induces a southward shift of the summer jet stream over Europe, causes more cyclonal activity in the Arctic zone (Brümmer et al. 2000, Graversen et al. 2008), and increased precipitation in northern Europe (Screen, 2013). The decline of autumn sea ice may contribute to the cold and snowy winters in the northern countries of Europe and North America (Tang et al. 2013).

The significant warming trend of air temperatures since 1960 in the Arctic has often been connected to changes in circulation patterns (*e.g.* Przybylak 2000, Tuomenvirta et al. 2000, Førland and Hanssen-Bauer 2003). Sea ice cover in the Arctic Ocean determines complex thermodynamical processes, due to high surface albedo and stable stratification, which leads to the formation of specific atmospheric boundary layer conditions (Mäkiranta et al. 2011). The seasonal aspect of sea ice changes can be seen in *e.g.* transformation of air masses, near-surface temperature and weather pattern variations (Witoszová et Láska 2012). Spatiotemporal variation of cloudiness and near-surface weather conditions in Arctic fjords can significantly differ compared to the marginal parts of fjords facing the open sea. Numerous studies have been concerned with the atmospheric boundary layer on Svalbard, focusing mainly on stable stratification in spring (*e.g.* Lampert et al. 2010, Kilpeläinen et al. 2011, Mayer et al. 2012). However, only a few studies have addressed cloudiness and cloud development over Svalbard during summer (Shiobara et al. 2003, Kejna et al. 2012, Láska et al. 2012).

In this study, we present near-surface meteorological measurements and cloud observations in the central part of the Svalbard archipelago. The purpose of this paper is to (i) describe the types of large-scale atmospheric circulation that lead to significant variation of individual meteorological parameters and (ii) assess local circulation phenomena, precipitation and cloud development over a narrow Arctic bay with steep topography.

Study area

The study area is located in the central part of Spitsbergen, the Svalbard Arctic archipelago. Petuniabukta is a northward oriented bay, which is connected with Billefjorden and Isfjorden, the second longest fjord in the Svalbard archipelago (Fig. 1). The coastal zone of Petuniabukta is predominantly glacier-free, formed by tundra vegetation (numerous vascular plants, mosses, and lichens), shallow pools, seepages, bare soils (cryosols/gelisols type) and sedimentary rocks (Prach et al. 2012). The vicinity of Petuniabukta is enclosed on the west, north and east by the steep slopes of the Pyramiden (935 m a.s.l.), Mumien (770 m a.s.l.), Sfinksen (905 m a.s.l.) and Lovehøvden (610 m a.s.l.) mountain ridges. Numerous valley glaciers (Ferdinandbreen, Svenbreen, Hørbyebreen, Ragnarbreen, and Ebbabreen) and their glacial forelands close the coastline of Petuniabukta (Fig. 2). The study site is in the maritime high Arctic climate region. Daily mean air temperature varied between -32.6 °C and 12.2°C (2008-2010). Daily mean global solar radiation ranged from 0 to 380 Wm^{-2} over the entire period. An overview of the weather conditions and climate features of Petuniabukta is given by Láska et al. (2012).

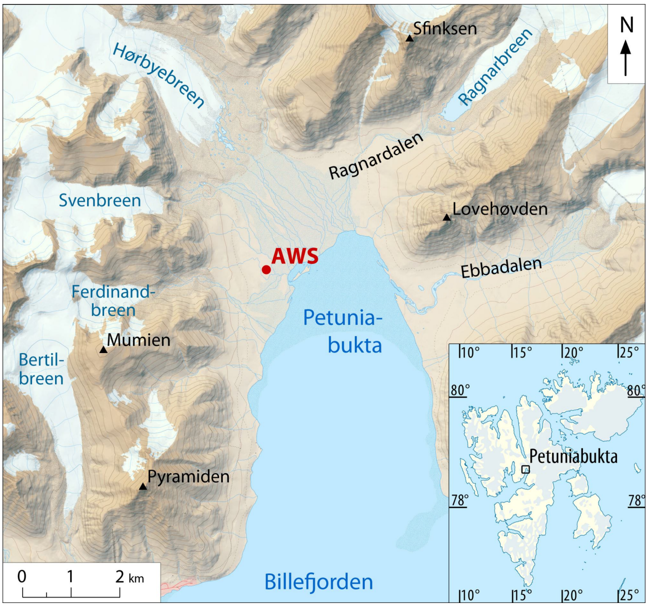

Fig. 1. Location of the study site and automatic weather station (AWS) in the final part of Petuniabukta (Billefjorden), central Spitsbergen.

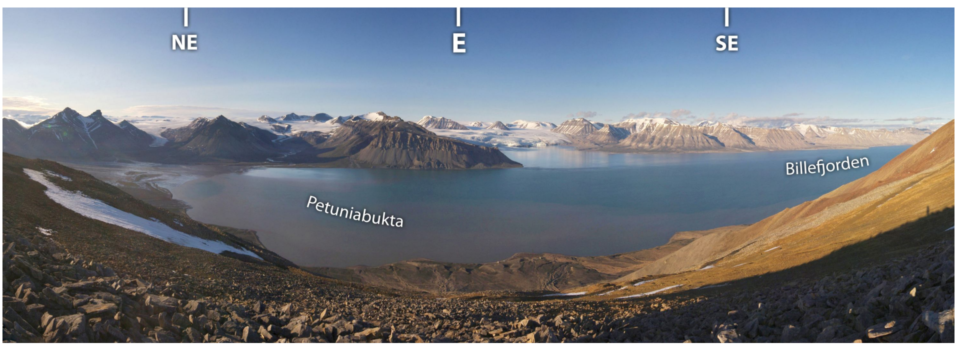

Fig. 2. Coastal zone of Petuniabukta with Ragnarbreen, Ebbabreen and Nordenskjöld glaciers in the background. The photo was taken from the eastern slope of Pyramiden Peak at an altitude of 550 m a.s.l.

Data and Methods

Meteorological measurements and observations were performed at the coastline of Petuniabukta in the period from July 5 to 19, 2013. An automatic weather station (hereafter AWS) was used to measure atmospheric pressure, temperature, precipitation, surface wind speed and direction. The AWS was situated on the flat marine terrace (78°42.11' N, 16°27.64' E) at a height of 15 m a.s.l. (Fig. 1). Atmospheric pressure was recorded by a TMAG 518 N4H probe (CRESSTO, CZ) placed inside the data logger box. The air temperature sensor (EMS33, CZ) was mounted on the mast 2.0 m above the ground. Measurements of surface wind speed and direction were carried out using a 034B anemometer (Met One, USA) at a height of 6 m above ground. Wind speed readings were recorded as 30-min averages, while the other sensor data were stored as individual 30-min values on a data logger (EdgeBox, CZ). Precipitation was monitored with a tipping bucket rain-gauge (386 Met One, USA) with a catchment funnel area of 730 cm^2 and resolution of 0.2 mm per pulse. The gauge frame was placed at the height of 1.0 m above the ground. The 386 Met One rain-gauge is frequently used in the long-term field studies performed in harsh environments, because it has a heating unit and teflon-coated bucket.

Visual observations of cloudiness, cloud-base height and cloud genera were carried out during the study period. The cloudiness (total cloud amount between 0 and 8 oktas) was determined every two hours. Moreover, low-, middle- and high-cloud types were determined together with the height of low-level clouds according to the *Guide to Meteorological Instruments and Methods of Observation* (WMO, 2010). The characteristic forms of clouds were classified to genera to 10 basic categories, with further subdivision into cloud species (cloud shape and structure) and cloud varieties (cloud arrangement and transparency). The height of the low-cloud base was estimated by comparison with the heights of marked topographical points (peaks, mountain ridges) as given in a contour map of Petuniabukta. Perspective and distance from the clouds/hills were considered before final estimation of the cloud-base height. Therefore, the range of cloud-base height observation was limited by the topography of Petuniabukta up to 900 m above ground level. The heights of middle- and high-level clouds were not estimated.

Atmospheric circulation and synoptic situations were identified using sea level pressure (SLP) and 850 hPa geopotential height. The 6-hour pressure data were obtained from the National Centres for Environmental Prediction (NCEP) – National Centre for Atmospheric Research (NCAR) reanalysis project (Kalnay et al. 1996). Evaluation of the atmospheric circulation patterns was based on the calendar list of circulation types for the Spitsbergen area, provided by Niedźwiedź (2013). Classification is based on surface synoptic maps from which the direction of airflow and the kind of pressure pattern (cyclonic or anticyclonic) is determined (*see* e.g. Niedźwiedź 2007). The author of the classification method distinguished 21 circulation types according to the common directions of advection, adding the symbol 'a' for anticyclonic (high pressure) and 'c' for cyclonic (low pressure) systems. Other types noted were the anticyclonic centre over Spitsbergen (Ca), anticyclonic wedge (Ka), cyclonic centre over Spitsbergen (Cc), cyclonic trough (Bc), and baric col or synoptic situations which were impossible to classify (X).

Results and Discussion

Large-scale atmospheric circulation

To provide an overview of the atmospheric conditions over Svalbard, the occurrence of circulation types in July 2013 and their comparison with the long-term average pattern is presented in Fig. 3. For the month of July during the period of 1961–2010, anticyclonic wedges (Ka – 15.2%), troughs of low pressure (Bc – 9.7%), and the southwestern cyclonic type (SWc – 6.5%) were the most common large-scale flows. Over the long-term, cyclonic situations in July prevailed (53.7%) over anticyclonic ones (43.0%). The remaining circulation types (X – baric col or unclassified situations) occurred at frequencies of 3.3%. In July 2013, the prevailing cyclonic activity was, however, found on 58.1% of all days, while anticyclonic types occurred only in 35.5% of the days. As seen in Fig. 3, Ka (19.4%), SWc (16.1%), SWa (9.7%), and Nc type (9.7%) had the highest frequency in July 2013. As a consequence, the summer pressure pattern and circulation conditions, controlled by an Icelandic Low, caused the absence of several anticyclonic types, *e.g.* Na, Ea, Sa, Wa or NWa type. Similar features of the summer circulation pattern over Svalbard were also reported by Przybylak and Araźny (2006), Bednorz and Kolendowicz (2012), and Láska et al. (2012).

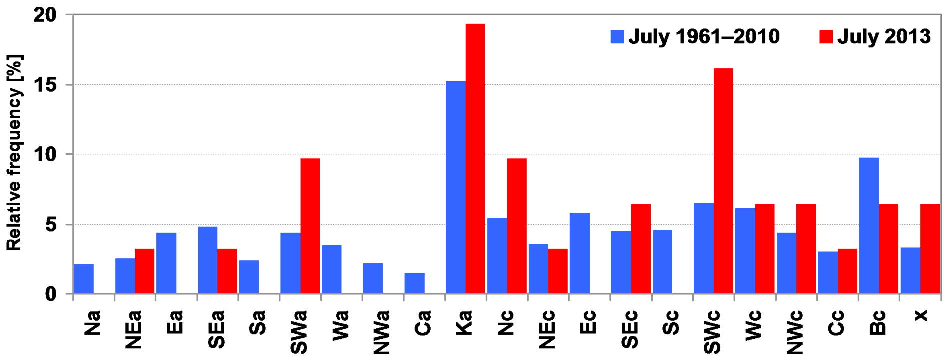

Fig. 3. Relative frequency of the occurrence of circulation types over Svalbard in July 2013, as compared with the long-term average from 1961 to 2010. See text for further explanation of the circulation types.

The atmospheric circulation and pressure pattern changed three times during the study period. Between July 6 and 11, 2013, a cyclone moved from Iceland northeastwards over the Svalbard archipelago and then over Franz Josef Land at the 850 hPa geopotential height (Fig. 5). A SWc type prevailed at the beginning of the study period (July 6–7). This circulation type was characterized by a deep cyclone moving rapidly from Iceland and the North Atlantic to Svalbard at the 850 hPa level. On July 8, the cyclone centered over Spitsbergen Island. This resulted in the prevailing cloudy weather conditions in Spitsbergen and Petuniabukta, with cloudiness of 6–8 oktas, and the presence of typical cloud types: *stratus nebulosus opacus*, *altostratus* and *altocumulus*. Circulation types NWc, NEc and Nc occurred from June 9 to 11, when the cyclone slowly moved and centered over the northeast part of Svalbard.

During the second period (July 12–14, 2013), the anticyclonic type of circulation started to prevail (Fig. 5). The pressure field at the 850 hPa level was characterized by a high-pressure ridge stretching from the North Pole over Svalbard and a deep cyclone formed over Novaya Zemlya and the North Atlantic between Greenland and the Scandinavian Peninsula. During this period, a considerable increase of SLP from 990 to 1010 hPa was observed over Spitsbergen. The anticyclonic wedge (circulation type Ka) on July 12 and 13 was transformed to the NEa type on July 14, when the cyclone from Novaya Zemlya moved towards the west of Svalbard. This period was characterized by a radiation type of weather and high cloudiness variation ranging from 1 to 8 oktas. *Cirrus*, *cirrostratus*, *altocumulus lenticularis*, *cumulus humilis* and *cumulus mediocris* clouds occurred in the air masses flowing over Spitsbergen. Moreover, halo phenomena and cloud irisation were observed in Petuniabukta within this situation.

In the third period from July 15 to 17, 2013, the cyclonic type of circulation prevailed. The cyclone over the North Atlantic disappeared and the cyclone over Novaya Zemlya moved northwestwards over the North Pole (Fig. 5). At the beginning of the period, a northern cyclonic circulation (Nc type) formed over Svalbard from July 15 to 16. Consequently, the circulation pattern at the geopotential height of 850 hPa changed to the northwestern cyclonic type (NWc) due to the cyclone being centered over the North Pole on July 17, 2013. The previous radiation weather (July 14) changed rapidly to an advection type with high cloudiness ranging from 6 to 8 oktas. The occurrence of *stratus* and *stratocumulus* cloud types was observed at Petuniabukta in these days.

Weather conditions and local phenomena

Five selected cases from July 2013, representing the most common synoptic situations over Svalbard, were chosen for detailed analysis. The type of atmospheric circulation and time series of observed cloudiness, atmospheric pressure, 2-m air temperature, precipitation, 6-m wind speed and wind direction at Petuniabukta are shown in Fig. 4 and Table 1.

<u>July 7 (advection weather)</u>

The synoptic situation was classified as the southwest cyclonic type (SWc). The cyclone occurred in the northern part of the Atlantic Ocean between Greenland and the Svalbard archipelago at the 850 hPa geopotential height (Fig. 5). The SLP ranged between 990 and 995 hPa. The frontal zone connected with the pressure pattern caused intensive precipitation in Petuniabukta. The highest daily mean precipitation (0.8 mm) was measured during this event. *Stratus nebulosus*, *stratus fractus* and *stratocumulus* cloud types with cloud-base height from 400 to 700 meters were observed in Petuniabukta with a cloudiness of 8 oktas. The 6-m wind speed was weak, reaching up to 2 ms^{-1}. Daily mean air temperature was 8.9°C, while the daily maximum reached 11.4°C. The diurnal temperature range exceeded 4.7°C (*see* Fig. 4).

<u>July 10 (advection weather)</u>

A northeastern cyclonic situation (NEc type) was identified over the Svalbard archipelago. The cyclone deepened over Nordaustlandet Island (Fig. 5). The advection type of weather prevailed over Spitsbergen and Petuniabukta. Daily mean precipitation reached up to 0.6 mm. The liquid precipitation (light rain) that fell on the coastal zone of Petuniabukta changed to a solid state (snow) above 400 m a.s.l. Occasional hydrometeors in the form of drizzle were recorded during that day. The overcast sky with invariable cloudiness between 7 and 8 oktas was formed by *stratus nebulosus*, *stratus fractus* and *stratocumulus* clouds. The cloud-base height ranged from 200 to 700 meters. *Stratocumulus lenticularis* clouds with the cloud base at 700 meters were observed between 16 and 20 UTC. Wind speed rose from 4 ms^{-1} up to 10 ms^{-1} during the day. Daily mean wind speed was 5.2 ms^{-1}, while the highest wind gust exceeded 10.2 ms^{-1}. Daily mean temperature dropped to 4.5°C and the diurnal temperature range (1.6°C) was suppressed due to non-radiation weather conditions.

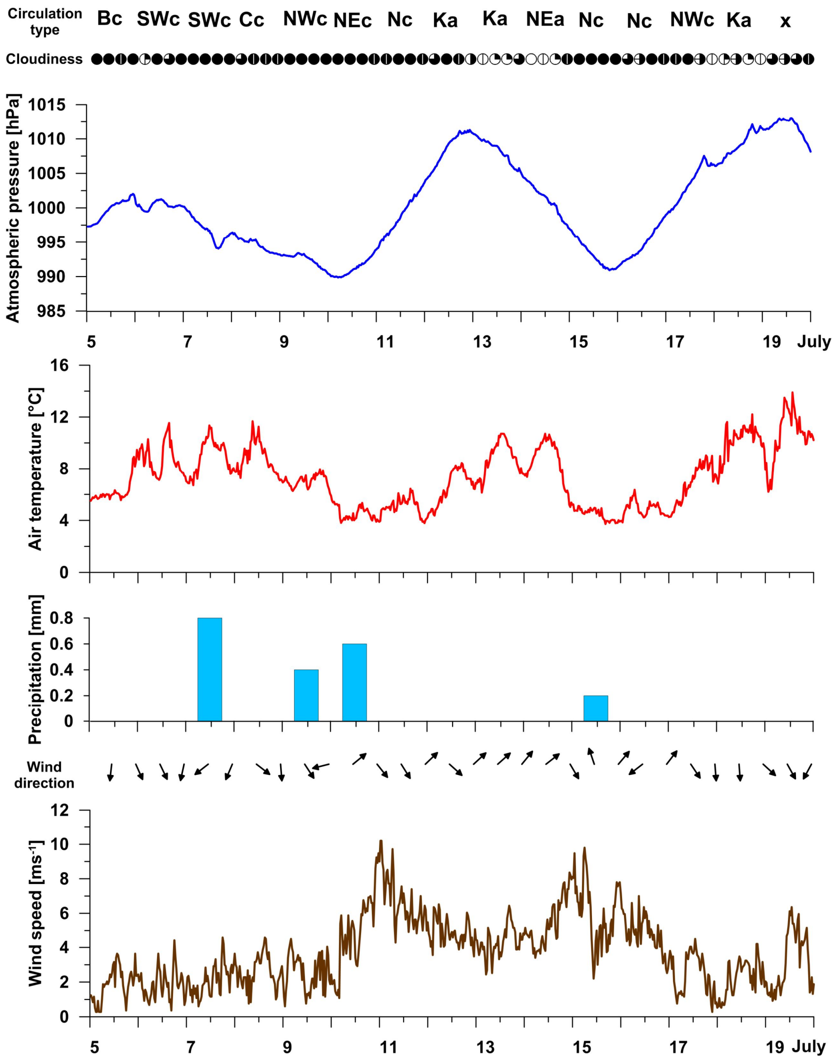

Fig. 4. Interdiurnal variation of cloudiness, atmospheric pressure, 2-m air temperature, precipitation, 6-m wind direction and wind speed at Petuniabukta in the period July 5–19, 2013. Types of atmospheric circulation according to Niedźwiedź (2007) are described on the top line. See text for further details.

July 12 (radiation weather)

The synoptic situation over Svalbard was formed by a cyclone situated westward from Novaya Zemlya while a second cyclone over the North Pole occurred at the 850 hPa geopotential height. A high-pressure area (Ka type – anticyclone wedge) moved from the southwest over Spitsbergen and Petuniabukta (Fig. 5). The radiation type of weather led to labilisation of the atmospheric boundary layer and intensified the convective processes during the afternoon. *Cumulus humilis* and c*umulus mediocris* cloud types with cloud base at 1000 and 1200 meters were observed between 16 and 22 UTC. Cloudiness varied between 1 and 3 oktas over the whole day with a weak daily course. Similarly, the highest variation of cloud types was observed at Petuniabukta, composed of *cumulus*, *stratocumulus*, *altocumulus*, *altostratus*, *cirrostratus* and *cirrus* clouds (*see* Fig. 6). Moreover, foehn type of clouds was observed in the northeast part of Petuniabukta over the Ragnardalen and Ragnarbreen areas. On the same day, irisation on the *cirrostratus* cloud type was observed over the Bertilbreen (Fig. 6). The radiation type of weather led to rising air temperatures to 8.7°C in the afternoon, while daily mean temperature was 6.6°C. Diurnal temperature range, due to clear sky conditions, exceeded more than 4°C.

July 14 (radiation weather)

A northeastern anticyclonic situation (NEa type) with two deep cyclones centered between Iceland and the Scandinavian Peninsula, and northwest from Novaya Zemlya formed a high-pressure ridge situated at 850 hPa geopotential height northwestward from the Svalbard archipelago. SLP dropped from 1005 to 998 hPa during the day. It was also pronounced with increased cloudiness from 0 up to 8 oktas and the sequence of cloud types, from *cirrus* to *cirrocumulus*, then *cumulus*, *altocumulus* and finally *stratocumulus* in the afternoon. Moreover, the wind speed gradually rose during the day, with daily maximum wind speed reaching up to 8.4 ms^{-1}. Both daily mean temperature (8.5°C) and daily maximum temperature (10.7°C) were very high. The diurnal temperature range reached the highest value of all (5.7°C). This was connected with a sudden temperature fall caused by changes in pressure pattern and increased surface wind speed.

July 16 (advection weather)

A northern cyclonic situation (Nc type) over Spitsbergen was formed by a deep cyclone between Novaya Zemlya and the Svalbard archipelago at 850 hPa geopotential height. SLP fell rapidly to 990 hPa. The prevailing clouds types were *stratocumulus* and *altocumulus* with cloudiness ranging between 5 and 8 oktas. *Altocumulus lenticularis* was observed over the east part of Petuniabukta above the Ragnarbreen and Ebbabreen glaciers, caused by an orographic effect on the southeastern flow. The surface wind direction (*see* wind flag in Fig. 4) rapidly changed from southwest to northeast, due to the fast transformation and re-development of the pressure field and frontal system over Spitsbergen. The wind speed rapidly weakened from 8 to 4 ms^{-1}. Mean daily temperature was 4.9°C and the diurnal temperature range of 2.6°C corresponded to a weak surface wind and advection weather conditions.

Besides the above mentioned meteorological measurements and weather observations, the occurrence of hydrometeors in the form of drizzle was observed due to prevailing *stratus* and *stratocumulus* cloud types (*see* Fig. 5). Their cloud-base height was often at 200–400 meters.

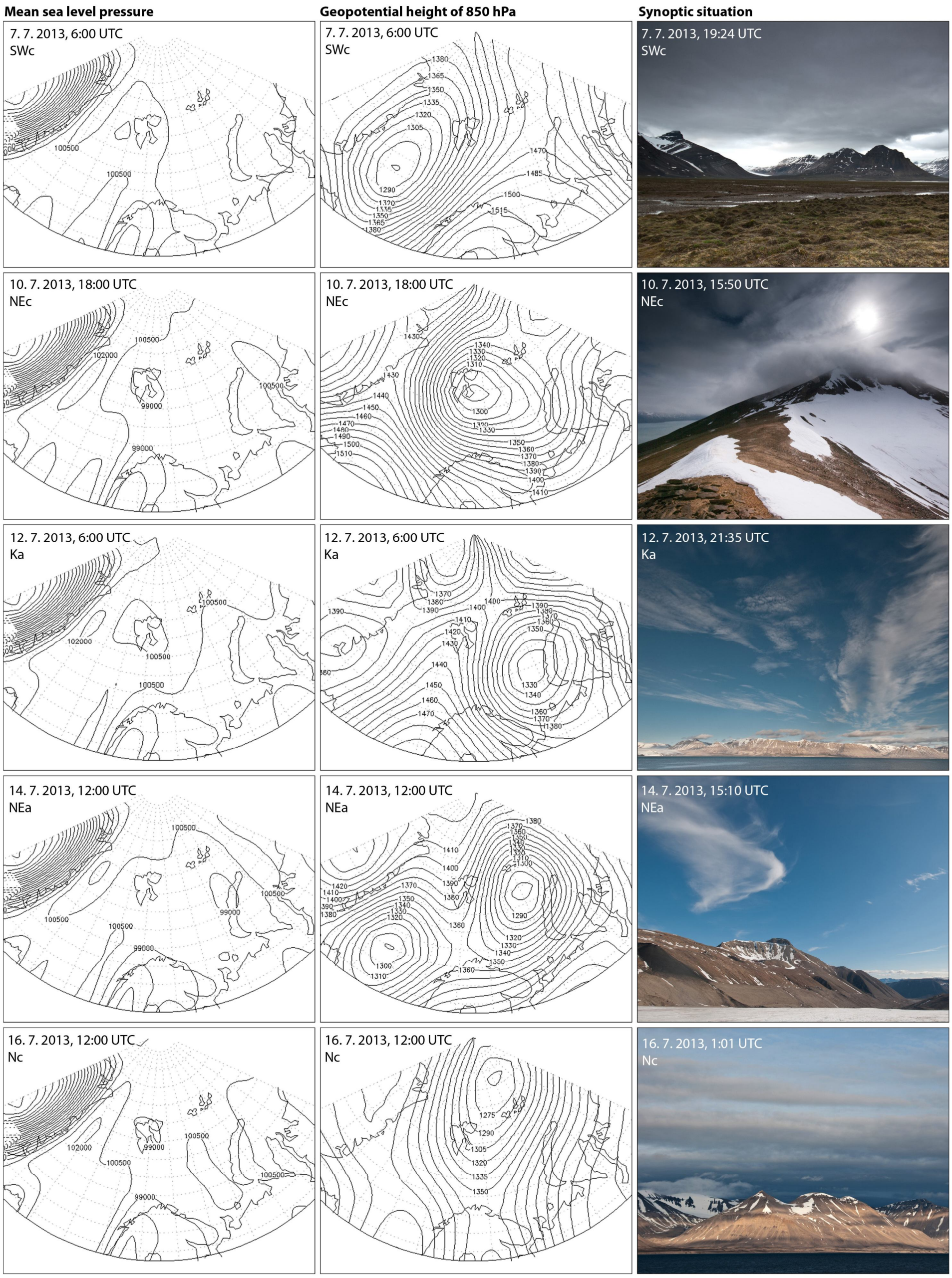

Fig. 5. NCAR/NCEP reanalysis maps of sea level pressure, geopotential height at 850 hPa level, and selected cloud types and forms occurring at Petuniabukta in the period July 5–19, 2013.

During the study period, precipitation in the form of drizzle was recorded at a frequency of more than 50% on all days, while rainfall days with precipitation amounts equal to or more than 0.1 mm were observed in 28% of the days (Fig. 4). The highest occurrence of low-level clouds and drizzle events at Petuniabukta confirms that such phenomena are controlled by large-scale circulation and advection of relatively warm air-masses from the North Atlantic and/or cooler airflow from the Arctic Ocean extending over Svalbard and individual fjords. These results are in agreement with the previous studies of Bednorz and Kolendowicz (2012) and Kejna et al. (2012), who carried out research in the regions of Ebbadalen (Central Spitsbergen) and Kaffiøyra (Northwestern Spitsbergen).

Day	**CT**	**AT** [°C]			**VS** [ms^{-1}]		**N** [0–8]	**Cloud type**		
		avg	min	max	avg	max		C_L	C_M	C_H
5.7.	Bc	6.4	5.6	9.5	1.9	3.6	7.7	St	.	.
6.7.	SWc	8.7	6.9	11.5	1.9	4.4	7.6	St	.	.
7.7.	SWc	8.9	6.7	11.4	2.1	4.6	7.9	St	.	.
8.7.	Cc	8.8	6.9	11.7	2.6	4.6	6.9	St	Ac	.
9.7.	NWc	7.0	5.5	8.0	2.6	4.5	8.0	St	.	.
10.7.	NEc	4.5	3.8	5.4	5.2	10.2	7.7	St	Ac	.
11.7.	Nc	5.1	3.8	6.4	6.5	10.2	7.4	Sc/St	As	Ci
12.7.	Ka	6.6	4.4	8.4	4.9	6.5	5.7	Sc	Ac/As	Ci
13.7.	Ka	8.8	6.1	10.7	4.4	6.4	2.8	Cu/Sc	As	Ci/Cs
14.7.	NEa	8.5	5.0	10.7	5.6	8.4	3.3	Sc	Ac	Ci
15.7.	Nc	4.4	3.7	5.1	6.0	9.8	7.9	St	Ac	.
16.7.	Nc	4.9	3.8	6.4	4.7	7.0	6.7	St	Ac/As	.
17.7.	NWc	6.9	4.3	9.0	2.3	4.5	5.1	St	Ac	Ci
18.7.	Ka	10.2	7.4	12.2	2.3	4.2	2.9	Cu	Ac	Ci
19.7.	X	10.6	6.2	13.9	3.2	6.4	5.9	St	Ac	.

Tab. 1. Characteristics of prevailing circulation types (CT), daily mean temperature (AT avg), daily minimum (AT min) and maximum temperatures (AT max), average wind speed (VS avg) and maximum gust (VS max), cloudiness (N) and cloud types at low (C_L), middle (C_M) and high level (C_H) at Petuniabukta in the period July 5–19, 2013.

Fig. 6. *Altocumulus lenticularis* cloud types (left) and irisation on *cirrostratus* clouds (right) during a high-pressure ridge (Ka circulation type) at Petuniabukta on July 12, 2013.

Concluding remarks

Measurements of selected meteorological elements and cloud observations over the Arctic bay Petuniabukta (central Spitsbergen) were analyzed and compared with the associated circulation patterns determined from several data sources. We used the sea level pressure and 850 hPa geopotential height maps obtained from the NCEP/NCAR reanalysis data project. Moreover, classification of the circulation types available for the Svalbard area was applied. Compared to the long-term circulation type statistics (1961–2010), the most frequent pressure patterns were the Ka, SWc, SWa, Nc and NEa circulation types, while several types did not occur in July 2013. The weather conditions and interdiurnal variation of the selected meteorological elements (atmospheric pressure, temperature, precipitation, surface wind speed and direction) were described in detail for only five synoptic situations. We documented significant differences in cloudiness variation, formation of low-level clouds and drizzle events based on the prevailing large-scale flow reaching the Svalbard archipelago. Moreover, orographic foehn clouds over Spitsbergen mountain ridges and irisation effect in high *cirrus* clouds were observed frequently within two weeks in July 2013. The results obtained in this study proved that both mesoscale and local thermodynamical processes at high Arctic locations were strongly affected by large-scale circulation systems and the specific topographic features of such sites.

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