NICOLAUS COPERNICUS UNIVERSITY IN TORUŃ

TOPOCLIMATIC DIVERSITY IN FORLANDSUNDET REGION (NW SPITSBERGEN) IN GLOBAL WARMING CONDITIONS

Editors
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PREFACE

A considerable warming of the Arctic, noted particularly intensively since the mid-1990s, has resulted in dramatic changes in all components of the climate system, not just in the Arctic but also globally. It is enough to mention that in September 2011 the sea ice extent was recorded at its lowest in the history of satellite observations (the previous record low was observed in 2007), and most probably in the last few hundred years, as well. Close correlations between the climates in the Arctic and elsewhere on the globe have been known about for a long time. The Arctic is considered to be the key region shaping global climate, and an indicator when predicting the directions of climate changes. What follows from these facts is the vital importance of Arctic research to various fields of human activity in the world (economic, social, etc.). The high rate of changes occurring in the Arctic environment calls for a need to activate world financial and human resources in order to gain a better insight into the mechanisms of the Arctic Climate System, which are still not fully understood. This awareness must have been fundamental to the organisation of the 4th International Polar Year (IPY) in 2007–2009 and the decision to continue intensive studies of the area as part of the International Polar Decade initiative.

The Polish-Norwegian research project *Arctic Climate and Environment of the Nordic Seas and the Svalbard-Greenland Area* (*AWAKE*), initiated in 2010, has become a part of this trend to carry on extensive interdisciplinary studies started during the IPY by scientists from different countries, including Poland and Norway. Within the project, researchers and students of the Nicolaus Copernicus University (NCU) Institute of Geography continue long-term studies of the climate of Spitsbergen and the topoclimates in the area of the Forlandsundet. Their topoclimatic studies have noted substantial progress, mainly thanks to recent technological developments in measuring instruments (particularly miniaturisation and electronic data recording). In the summer of 2010 as many as 18 measurement sites were established over an area that largely exceeded the area of observations carried out before. Ten of the sites were equipped with automatic meteorological stations. To the best of our knowledge, even though this kind of observation was initiated at two sites on Spitsbergen as early as during the Russian-Swedish expedition of 1899/1900, it has never been extended over an area as big as it is now. This article attempts to present the most important results of the studies, obtained through measurement and observation conducted in the Forlandsundet region (NW Spitsbergen) from July 2010 to August 2011.

The authors would not have been able to undertake the work without financial support from the Polish-Norwegian research fund operating within the framework of the above-mentioned research project. The authors would also like to thank the students of the NCU Institute of Geography, Ms. Aleksandra Pospieszyńska, and Mr. Edward Łaszyca, for their assistance in field studies

carried out in the summer seasons of 2010 and 2011, respectively. We also appreciate the help given by the other participants of the Toruń Polar Expeditions and by Ms. Katarzyna Huzarska. Finally, we would like to thank the reviewers for their material input and constructive comments, which have added considerable value to the text.

Rajmund Przybylak

Toruń, December 2011

Chapter 1

INTRODUCTION

1.1. Research purpose

Topoclimatic studies in the area of the Forlandsundet were initiated at the time of the 1st Toruń Polar Expedition (TPE), launched in the summer of 1975. That year measurements of some of the meteorological elements were carried out in the northern part of the Kaffiøyra Plain at four sites, selected to represent different physiographical characteristics: on the coast, a beach, a moraine and in the tundra. However, regular standardised measurements of all meteorological elements were performed only at the beach site (Jan Leszkiewicz, personal comm.). An instrument shelter containing a thermo-hygrograph was placed on the tongue of the Aavatsmark Glacier (Leszkiewicz 1977; Olszewski 1977), although the observations lasted there only a short time (Jan Leszkiewicz, personal comm.). Unfortunately, as yet no meteorological data from the measurements have been published, with the exception of the results obtained at the beach site (Leszkiewicz 1977; Wójcik et al. 1997). During the 3rd TPE (1978), the main location of the measurements was moved from the beach to the terminal/lateral moraine of the Aavatsmark Glacier, and two further sites were established on the Waldemar Glacier – on its head and in the firn field (Wójcik and Marciniak 1983). All subsequent TPEs in which climatologists participated continued the observations at the above-mentioned sites. In the course of some of the expeditions, topoclimatic studies were extended to include the area of St. Jonsfjorden (1979), the Elise Glacier (1980) (Marciniak 1983; Wójcik et al. 1997), and in 1989 the first measurements were taken on the ridge of Gråfjellet Mountain. In that summer season the first ever measurements of the air temperature were carried out at 20 cm at a number of points between the shore of the Forlandsundet and the moraines of the Waldemar Glacier. The results of those measurements were later used to identify the mesoclimates of Kaffiøyra (Wójcik et al. 1991, 1993).

The most extensive topoclimatic research in the area of the Waldemar Glacier took place in 2005 (Przybylak et al. 2008, 2010; Kejna et al. 2010) and was made possible by the introduction of automatic measurement systems (automatic weather stations and temperature and humidity recorders). At the same time, the longest-established sites extended the scope of their observations to include the measurement of atmospheric pressure and wind speed and direction (Przybylak and Araźny 2007; Przybylak et al. 2007), ground temperature and permafrost (Przybylak et al. 2010), air temperature and precipitation (Przybylak et al. 2011).

In the 1975–2009 period, referred to above, a gradual increase in topoclimatic studies can be seen. In the following years of 2010–2011, they were intensified even further when large-scale topoclimatic research was carried out as part of the Polish-Norwegian project, *Arctic Climate and Environment of the Nordic Seas and the Svalbard-Greenland Area (AWAKE).* In the summer of 2010 as many as 18 measurement points (10 of which were equipped with automatic stations) were sited in an area that went largely beyond the previous boundaries (Przybylak et al. 2011). The observations included, for example, the area of Prins Karls Forland, and covered the area of St. Jonsfjorden to a much larger extent than before. Moreover, at the main meteorological station (also referred to as the base station) situated at the Polar Station of the Nicolaus Copernicus University (NCU), and in front of the head of the Waldemar Glacier (2010) and on its firn field (2010–2011), the first measurements of radiation balance and its components were performed in the summer, using a CNR 4 net radiometer (Kipp&Zonen) – Kejna et al. (2011). In the summer season of 2011, the site in front of the glacier was moved to the tundra, as it yielded similar results to those obtained from the site located at the base station.

The area of our interest, the Forlandsundet (Forland Sound), includes all types of surface (beaches, tundra, moraines, glacial ice) and surface features (lowlands, terminal moraine, mountain ridges), representative of other areas on Spitsbergen. Another important research task undertaken as part of the project is definition of the factors causing increasing or decreasing topoclimatic diversity in the area of Forlandsundet, and the roles they have in the process.

1.2. Research area and methodology

The topoclimatic research was conducted on Spitsbergen (the biggest island in the Norwegian province of Svalbard), in Oscar II Land and on Prins Karls Forland (Fig. 3.1). Oscar II Land stretches from Isfjorden to Kongsfjorden. It has a surface area of 2,582 km^2, approximately 1,600 km^2 of which is covered with glaciers (62%) (Lankauf 2002). The area has a diverse geological structure – on the west coast pre-Cambrian Hecla Hoek rocks can be found, consisting of metamorphic shale, quartzite, sandstone, limestone, dolomite, and even marbles (Wójcik 1981). Similar rock formations occur on Prins Karls Forland island. The pattern of the mountain ranges in Oscar II Land refers to its major tectonic lines with the main ranges running from the SSE to the NNW and branching transversely into secondary mountain ranges. The highest mountains in Oscar II Land are over 1,000 m a.s.l. high, for example Dronningfjella (1,263 m) or TreKroner (1,225 m). Oscar II Land is carved by deep bays and fjords, such as St. Jonsfjorden, Dahlbukta, Hornbaekbukta, and Engelsbukta, which divide the area along with the glaciers heading towards the sea into coastal plains, such as the Kaffiøyra and the Sarsøyra. The substratum of these plains is composed of tertiary and quaternary formations related to glacial accumulation and marine sedimentation, mainly from the Holocene. As a result of glacial isostatic adjustment, the coastal plains have become terraced (Niewiarowski et al. 1993). Nowadays, they are covered with tundra vegetation (Barcikowski et al. 2005) and crisscrossed by glacial rivers forming outwash fans. In Oscar II Land sub-polar glaciers occur, which are typical of Spitsbergen and other high latitudes (Baranowski 1977). The glaciers cover the inner part of the land and usually run out towards the sea. There are also smaller alpine glaciers, which fill mountain valleys and have firn fields and glacial tongues. The snowline on Spitsbergen runs at a level of 300 m a.s.l. (Hisdal 1985). Intensive deglaciation occurs on Spitsbergen with the glaciers retreating at a fast pace, e.g. 8–18 m/year in the area of the Kaffiøyra (Sobota and Lankauf 2010).

The Forlandsundet stretches from the north to the south across over 80 km and is 15 to 25 km wide. Geologically, the sound is a graben (Lankauf 2002). Its depth varies from 200 to 250 m at both ends. Currents and waves from the Sarsøyra and the Prins Karls Forland have formed sand spits, narrowing and shallowing the Sound, occasionally to just a few meters, which makes it inaccessible to larger ships.

Prins Karls Forland is an island situated west of Spitsbergen. It is 86 km long but quite narrow, so has a total area of just 640 km^2 (Stange 2008).The west coast of the island is subject to the influence of the Greenland Sea and its warm West Spitsbergen Current. The geological structure of the island is reflected in its surface features. On the foundation of hard crystalline rocks mountain ranges exceeding 1,000 m have been formed (the highest mountain being Mt. Monacofjellet, 1,081 m a.s.l.). Among the mountain ranges there are flat coastal plains. The relief of the middle part of the island is characteristic of high mountains (alpine) and features glaciers heading to the east, towards the Forlandsundet. However, the area is generally non-glaciated, covered by vast coastal plains and even non-glaciated valleys crossing the whole island from the west to the east.

In the area described above three research zones (A, B and C) were established, distinguished by dissimilar environmental conditions (Fig. 1.1):

Zone A covers the north of Kaffiøyra and the south of Sarsøyra with Sarstangen. The measurement sites were located on the coast: on the beach (SAT), on tundra-grown terraces (SAO, KHT, KT), on moraines (KH, ATA, LW1), on glaciers (LWm, LW2) and in the mountains (KU, GF, PH1 and PH2). Basic information about individual points is shown in Table 1.1, with their exact locations in Figure 1.1, and images of the sites in Photographs 1.1-1.30. The variety of ground cover, distances from the sea, elevations, exposure to the sun and influences of atmospheric circulation all make the Zone topoclimatically diversified.

Zone B is situated on Prins Karls Forland. The measurement points were located along the profile from the west to the east coast. The first site (PK1) was situated on a coastal plain, approx. 3 km from the shore of the Greenland Sea. The second site, in the middle of the valley crossing the island from the north to the south (PK2, 68 m a.s.l.), and the last two sites on the coast of the Klubben (PK3 and PK4). The area is non-glaciated, and the narrow valley, surrounded by 500 to 600-m high mountains supports the development of local weather and climatic conditions.

Zone C had measurement points located on the edge of St. Jonsfjorden, which is approx. 20 km long (Stange 2008). The fjord is surrounded by high mountains, among which glacial tongues emerge. Sites SJ1 and SJ2 were located on the south and north sides of the fjord, respectively, whereas SJ3 was situated at the end, in a spot where it was subject to strong influence by the air masses inflowing from the Osborne and Konow glaciers.

Topoclimatic measurements were carried out using the following automatic instruments:

– Vantage Pro 2 weather station, recording speed and direction of wind, atmospheric pressure, air temperature and humidity, precipitation and UV/solar radiation,
– MadgeTech data loggers, recording air temperature and relative humidity,
– CNR 4 radiometer (Kipp&Zonen), consisting of two pyranometers and two pyrgeometers pointing up and down, which enabled measurement of the short- and long-wave components of the radiation balance.

Table 1.1. Meteorological sites in Forlandsundet region in 2010–2011

Sites		φ	λ	h (m a.s.l.)	Measurements range	
					Summer	Year
KH	Kaffiøyra-Heggodden	78°40′34″ N	11°49′38″ E	11	C, T, F, V, AP, P, SS, SR, UV, BR, ST, PL	T, F
SAT	Sarstangen	78°43′38″ N	11°28′50″ E	2	T, F, V, AP, P, SR, UV	T, F
SAO	Sarsøyra	78°42′55″ N	11°43′26″ E	9	T, F	T, F
KHT	Tundra	78°40′25″ N	11°52′01″ E	8	BR**	
KT	Terasa	78°40′34″ N	11°58′04″ E	90	T, F, P	T, F
ATA	ATA	78°40′31″ N	11°59′30″ E	137	T, F, V, AP, P, SR, UV	T, F
KU	Kuven	78°40′53″ N	12°00′53″ E	193	T, F	T, F
GF	Gråfjellet	78°39′59″ N	12°00′33″ E	345	T, F, V, AP, P, SR, UV*	T, F
LW1	Waldemar Glacier-Front	78°40′31″ N	12°00′01″ E	130	T, F, V, AP, P, SR, UV, BR*	T, F
LWm	Waldemar Glacier -Middle	78°40′38″ N	12°01′50″ E	211	P	
LW2	Waldemar Glacier-Firn field	78°40′54″ N* 78°40′59″ N**	12°05′16″ E* 12°05′15″ E**	375	T, F, V, AP, P, SR, UV, BR	T, F
PH1	Prins Heinrichfjella-1	78°40′51″ N	11°59′28″ E	500	P, F	T, F
PH2	Prins Heinrichfjella-2	78°41′01″ N	12°06′25″ E	590	P, F	T, F
PK1	Prins Karls Forland-West	78°28′10″ N	11°11′56″ E	9	T, F*T, F, V, AP, P, SR, UV**	T, F
PK2	Prins Karls Forland-Middle	78°30′18″ N	11°12′47″ E	68	T, F, V, AP, P, SR, UV* T, F**	T, F
PK3	Prins Karls Forland-Klubben	78°32′46″ N	11°14′42″ E	8	T, F, V, AP, P, SR, UV	T, F
PK4	Prins Karls Forland-East	78°40′52″ N	11°59′28″ E	6	T, F	T, F
SJ1	St. Jonsfjord-Cooper	78°30′10″ N	12°43′03″ E	2	T, F	T, F
SJ2	St. Jonsfjord-Hus	78°31′36″ N	12°51′53″ E	4	T, F, V, AP, P, SR, UV	T, F
SJ3	St. Jonsfjord-Muton	78°34′10″ N	13°09′22″ E	14	T, F	T, F

Explanations: C - cloudiness, T - air temperature, F - relative air humidity, V - wind velocity and direction, AP - air pressure, P - precipitation, SS - sunshine duration, SR - solar radiation, UV - UV radiation, BR - radiation balance, ST - soil temperature, PL - permafrost layer, *-2010, **- 2011

Figure 1.1. Location of meteorological sites used in this study shown on a topographic map produced by the Norwegian Polar Institute (for explanations see Tab. 1.1)

Photo 1.1.
Nicolaus Copernicus University
Polar Station on Kaffiøyra
(Photo by A. Araźny)

Photo 1.2.
Meteorological garden - KH
(Photo by A. Araźny)

Photo 1.3.
Automatic weather station
Vantage Pro (Photo by M. Kejna)

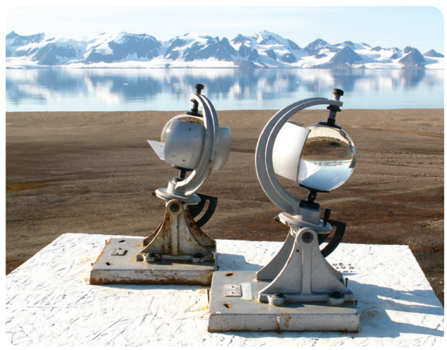


Photo 1.4.
Heliographs
(Photo by A. Araźny)

Photo 1.5.
Ground temperature sites:
M - Moraine, T - Tundra, B - Beach
(Photo by A. Araźny)

Photo 1.6.
Ground temperature site Beach
(Photo by A. Araźny)

Photo 1.7.
Ground temperature site Moraine,
(Photo by A. Araźny)

Photo 1.8.
Ground temperature site Tundra
(Photo by A. Araźny)

Photo 1.9.
Radiation balance measuring site (CNR 4)
- KH (Photo by M. Kejna)

Photo 1.10.
Radiation balance measuring site
(CNR 4) - KHT (Photo by M. Kejna)

Photo 1.11.
Radiation balance measuring site
(CNR 4) - LW1 (Photo by A. Araźny)

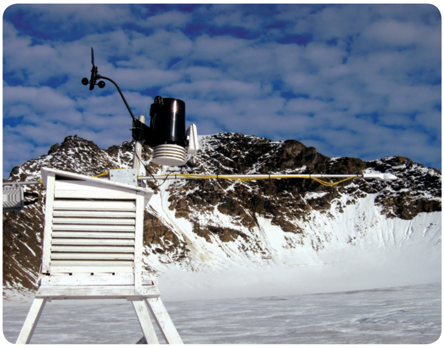


Photo 1.12.
Radiation balance measuring site
(CNR 4) - LW2 (Photo by M. Kejna)

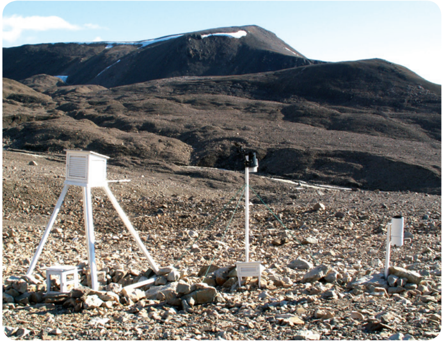


Photo 1.13.
Measuring site ATA
(Photo by A. Araźny)

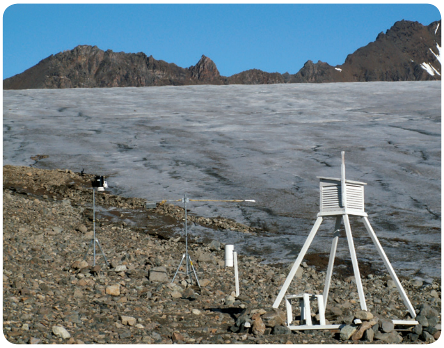


Photo 1.14.
Measuring site LW1
(Photo by A. Araźny)

Photo 1.15.
Measuring site LWm
(Photo by A. Araźny)

Photo 1.16.
Measuring site LW2
(Photo by M. Kejna)

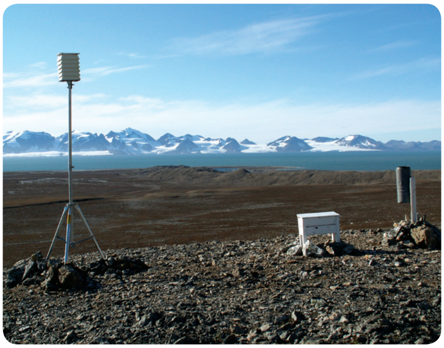


Photo 1.17.
Measuring site KT
(Photo by A. Araźny)

Photo 1.18.
Measuring site KU
(Photo by M. Kejna)

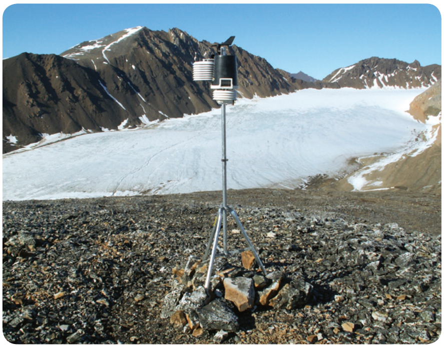


Photo 1.19.
Measuring site GF
(Photo by A. Araźny)

Photo 1.20.
Measuring site PH1
(Photo by M. Kejna)

Photo 1.21.
Measuring site PH2
(Photo by A. Araźny)

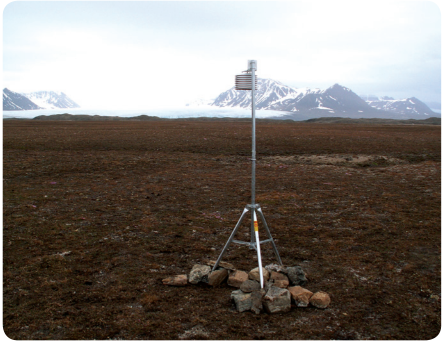


Photo 1.22.
Measuring site SAO
(Photo by A. Araźny)

Photo 1.23.
Measuring site SAT
(Photo by A. Araźny)

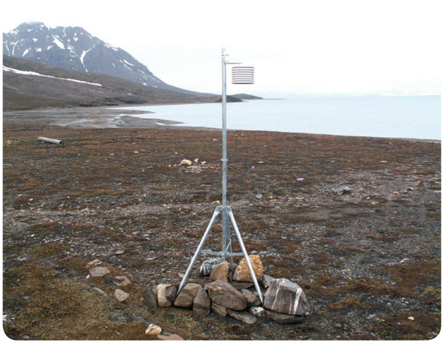


Photo 1.24.
Measuring site SJ1
(Photo by A. Araźny)

Photo 1.25.
Measuring site SJ2
(Photo by M. Kejna)

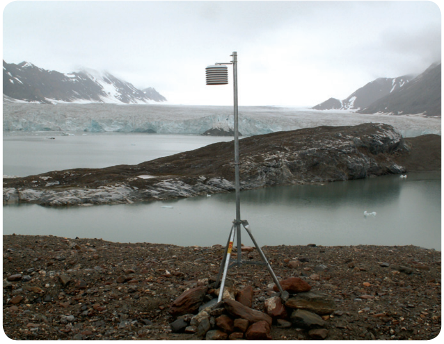


Photo 1.26.
Measuring site SJ3
(Photo by A. Araźny)

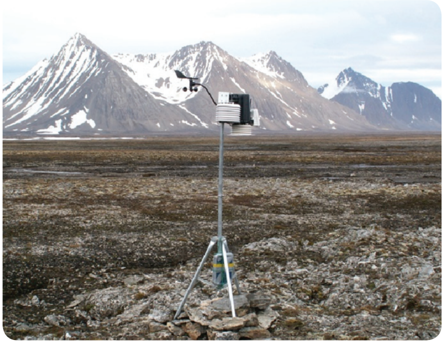


Photo 1.27.
Measuring site PK1
(Photo by A. Araźny)

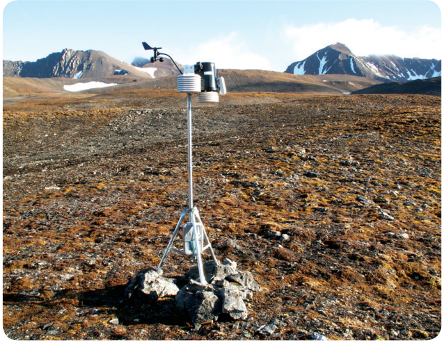


Photo 1.28.
Measuring site PK2
(Photo by A. Araźny)

Photo 1.29.
Measuring site PK3
(Photo by A. Araźny)

Photo 1.30.
Measuring site PK4
(Photo by A. Araźny)

All sensors were placed 2 m over ground level. In the summer seasons of 2010 (7 July–2 September) and 2011 (11 July–31 August) readings were recorded at an interval of 10 minutes, or every minute in the case of CNR 4. In the rest of the year the MadgeTech loggers recorded air temperature and relative humidity every hour.

The results obtained were compared with the data from the base station on the Kaffiøyra Plain, where meteorological observations were carried out every 6 hours (at 01:00, 07:00, 13:00 and 19:00 LMT), besides automatic registration. The observations concerned the cloud cover (using the scale of 0-10), air temperature and humidity, as well as wind speed and direction (using WindMaster hand held anemometer). Moreover, sunshine duration was recorded using a Campbell-Stokes heliograph. Atmospheric precipitation in profile from the coast (KH) to the firn field of the Waldemar Glacier was measured using Hellmann rain gauges (7 units), in order to support the automatic instruments. At KH (moraine, beach) the precipitation was measured daily at 07:00 LMT, whereas at the other sites the measurements were taken at least every 5 days.

Additionally, the ground temperature was measured 4 times a day, at three sites: M (moraine), B (beach) and T (tundra). Mercury thermometers were used to take the measurements at depths of 1, 5, 10, 20, and 50 cm, whereas at 100 cm a deep soil thermometer was used (readings at 13:00 LMT). At 13:00 LMT the ground thawing depth (thickness of the active layer) was measured on the beach, as well.

The meteorological observations and topoclimatic studies were carried out by Andrzej Araźny, Aleksandra Pospieszyńska and Rajmund Przybylak from 7 July to 4 September 2010, and by Marek Kejna and Edwad Łaszyca from 11 July to 2 September 2011.

1.3. Primary climatic controls

Maritime properties of the climate in the area of Forlandsundet and the whole of Spitsbergen make it stand out from the rest of the Arctic. Significant positive anomalies in the air temperature occur there along with greater cloudiness and precipitation and increased atmospheric dynamics. The main climatic controls in the area are the latitude and the related possible influx of solar radiation, the kind of active surface whose diverse albedo affects the amount of absorbed energy, and the atmospheric circulation and the influence of oceanic waters, the properties of which depend on oceanic currents and the reach of sea ice, among other things. From the topoclimatic point of view the significant factors include the absolute height, the arrangement of mountain ranges and the relief, the exposure of mountain slopes and the distance from the sea. On a local scale, a specific atmospheric circulation is formed there, orographically and thermally conditioned by the interaction of the sea, the non-glaciated land and the glaciers.

The location of the research area in a polar region determines the amount of solar radiation reaching the ground. Disproportions in the annual solar radiation balance are enhanced by the phenomena of the polar day and the polar night. At the Nicolaus Copernicus University Polar Station on the Kaffiøyra (78°40'34"N, 11°49'38"E) the polar night lasts from 26 October to 16 February (114 days) and the polar day from 17 April to 25 August (131 days). In the remaining parts of the year the day and the night occurred normally, during each 24 hours (Tab. 1.2).

Table 1.2. Sunrises, sunsets and the solar altitude at midday on the Kaffiøyra Plain (times for 15°E)

Days	Sunrise	Sunset	Days duration (hours)	Sun above the horizon (°)
15 Jan	Polar night			-9.9
15 Feb	Polar night			-1.6
15 Mar	06:50	17:57	11:07	8.9
15 Apr	01:46	22:58	21:12	20.9
15 May	Polar day			30.0
15 Jun	Polar day			34.6
15 Jul	Polar day			32.6
15 Aug	Polar day			25.5
15 Sep	04:46	19:25	14:39	14.6
15 Oct	08:45	15:09	06:24	3.0
15 Nov	Polar night			-7.0
15 Dec	Polar night			-11.9

The actual times of sunrise and sunset also depend on the extent of the horizon of an observation point. At the NCU Polar Station the horizon is favourable, except for to north and the northeast where mountain ranges obscure the sun, which is particularly noticeable at the lower culmination of the sun in the second half of August. On the Kaffiøyra Plain, the sun reaches its culmination at midday on 22 June, at the time of the summer solstice (34.8°), whereas at the time of spring and autumn equinox the angle of the midday sun is 11.3°.

The low altitude of the sun means that the potentially available amount of solar radiation (determined by the angle of solar rays and the optical mass of the atmosphere) reaching the ground is very small. Nevertheless, during the polar day and the 24-hour influx of solar radiation the sums are comparable with those for Poland (Bogdańska and Podogrocki 2000). During the polar night, on the other hand, the only components of solar radiation balance are the outgoing longwave (terrestrial) radiation and the downward atmospheric radiation. As a result, the net radiation balance is remarkably negative in that season of the year. The balance is also unfavourable because of the long-term snow cover duration (September through May or June), which has a high albedo, allowing only a little portion of solar radiation to be absorbed by the ground. Additionally, a lot of the energy is used to melt the snow and glacial and sea ice.

The weather and climate conditions on Spitsbergen are largely affected by the oceanic waters, surrounding the island, the Greenland Sea in the west, the Barents Sea in the east, the Norwegian Sea in the south, and the Arctic Ocean in the north. A warm West Spitsbergen Current (WSC), with average water temperature of 5-7°C, runs along the western coastline of Spitsbergen (Walczowski and Piechura 2006). On the east side of the island, however, some of the ice-cold waters of the East Spitsbergen Current (ESC) flow round the south end of Spitsbergen and head north as the so-called Sørkapp Current (Fig. 1.2).

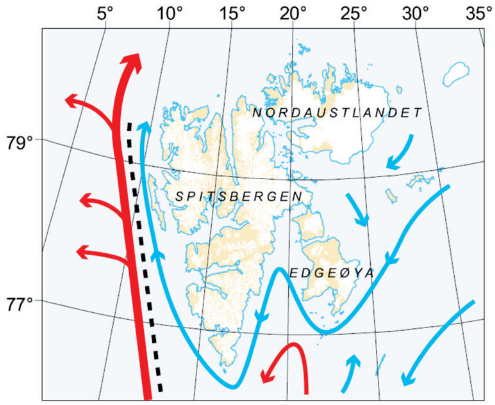


Figure 1.2. Map of Svalbard showing the major currents: the warm West Spitsbergen Current (red), the cold East Spitsbergen Current (blue) and the Sørkapp Current. The dashed black line indicates the frontal area between the two types of currents (after Swendsen et al. 2002)

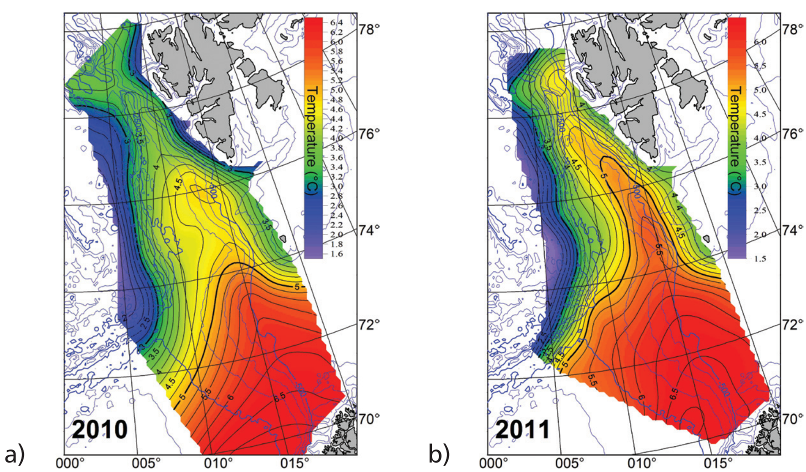
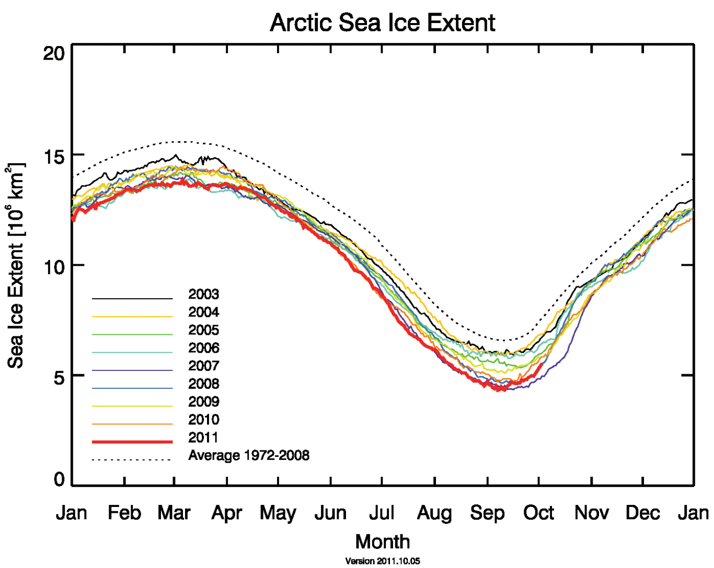


Figure 1.3. Temperature (color scale) and baroclinic currents at 100 dbar in (a) summer 2010 and (b) summer 2011 (Institute of Oceanology, Polish Academy of Sciences in Sopot)

Warm Atlantic waters coming with the WSC are particularly important in the shaping of the island's climatic conditions. In recent years the temperature (Fig. 1.3) and salinity of the waters have significantly risen. This affects weather and climate conditions both globally and locally, especially on the west coast of Spitsbergen (Walczowski and Piechura 2006, 2011; Piechura and Walczowski 2009; Styszyńska 2011).

The system of oceanic currents and the heat exchange between the ocean and the atmosphere influence the range and concentration of sea ice. At the time of its maximum extent (i.e. in March/April), sea ice envelops the whole of Spitsbergen. Towards the end of summer, however, there is a substantial difference between the west and the east coasts of the Svalbard archipelago. In the west, the sea is often free from sea ice as far as northernmost Spitsbergen, whereas in the east, sea ice flows from the north and, having passed the Sørkapp, is driven far along the west coast of Spitsbergen in a northward direction.

In the analysed years (2010 and 2011) the area of sea ice cover in the Arctic remained below the long-term average value (1978–2008). A trend to reduce the amount of sea ice in the Arctic was continued (Marsz and Styszyńska 2007) and thus, in 2011, the total area of sea ice in all months was smaller than in 2010 (Fig. 1.4).



The extent of sea ice varies regionally. In 2010, in the area of Spitsbergen, at the time of the most intense propagation of sea ice (April), the west coast was free of ice, while in the east it reached the Sørkapp (Fig. 1.5). In July that year most of the ice melted and in October the sea ice moved away from the archipelago to the north, allowing ships to travel round Spitsbergen.

However, in January 2011 sea ice reoccurred, covering the sea east of Spitsbergen and spreading to the northeast coast in April. In July the sea ice remained along the east coast (Fig. 1.5) and, floating with the oceanic currents, went around the Sørkapp, blocked the entrance of the Isfjorden and reached the Kaffiøyra. In spite of this, in September 2011 the sea ice extent in the Arctic had shrunk to its record low of 4,240 million km^2, or 0.6% less than in the previous record-breaking summer of 2007 (G. Heygster 2011, http://www.iup.uni-bremen.de:8084/amsr/minimum2011-en.pdf).

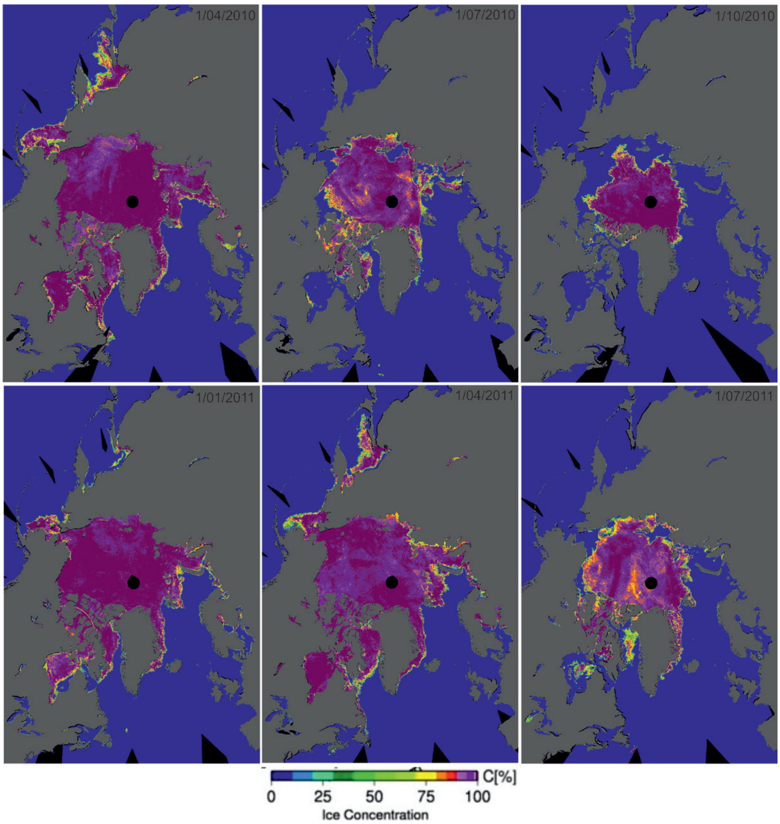
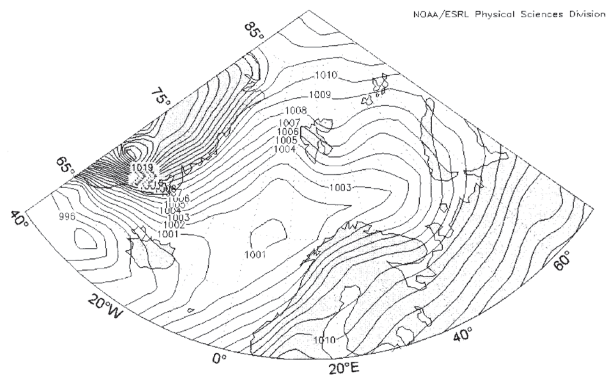


Figure 1.5. Concentration of sea ice in the Arctic in 2010 on 1/04, 1/07, and 1/10, and in 2011 on 1/01, 1/04 and 1/07. University of Bremen, GMES project – Polar View and the Arctic Regional Ocean Observing System (Arctic ROOS), http://www.iup.uni-bremen.de:8084/amsr (Spreen et al. 2008)

Another important climatic control in the area of Spitsbergen is the atmospheric circulation. The Svalbard Archipelago is situated in the impact zone of various barometric centres (Fig. 1.6); the area is affected by Icelandic lows which move eastwards in the so-called 'Iceland-Kara Trough', some of them following the path along the west coast of Spitsbergen (the Spitsbergen Trough). The most intense cyclogenesis connected with the Icelandic Low occurs in the winter half of the year (Käsmacher and Schneider 2011; Turner and Marshall 2011), and in spring, Spitsbergen is often subject to the Greenland High. When the summer comes cyclonic situations become more active, but they are less intense. In the summer season, in the area of Spitsbergen the baric field is dispersed by small pressure gradients (Niedźwiedź 2007). Anticyclonic patterns are often formed over the Barents Sea and the Novaya Zemlya (Przybylak 2003). In the west of Spitsbergen, on the other hand, lows often move far into the Arctic Ocean. In spring, the baric field undergoes reconstruction with increasing thermo-baric contrasts and intensified cyclogenesis.

A)



B)

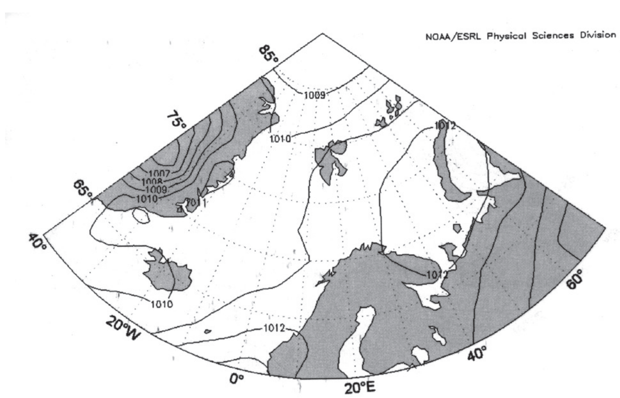


Figure 2.6. Averaged atmospheric pressure field (hPa) in January (A) and July (B) (1968–1996) in the Atlantic sector of the Arctic (acc. to Marsz and Styszyńska 2007)

Changes in the atmospheric circulation system are among the principal factors behind the changing climates in the Arctic (Przybylak 2003; Serreze and Francis 2006).

According to studies by Niedźwiedź (2007), cyclonic patterns are more frequent than anticyclonic patterns on Spitsbergen (56.5% vs. 40.6%, respectively in 1951-2006). In the winter and autumn the share of cyclonic patterns increases (by 64.8% and 56.5%, respectively) and the maximum falls in November (67.5%). In the spring and summer, on the other hand, the contribution of cyclonic and anticyclonic patterns becomes similar with anticyclonic patterns prevailing in May (59.7%). The most frequent situation over Spitsbergen is a high pressure wedge or ridge (Ka – 10.4%) and a cyclonic pattern with an easterly advection (Ec – 9.9%). The baric field arrangement in the area of Spitsbergen is characterised by great dynamics and changeability, both daily and annually.

In an annual take, Spitsbergen is the most often frequented by air masses incoming from the east sector, particularly in the cold half of the year. A warm air influx from the south east reaches its peak in summer (July 11.6%) (Niedźwiedź 2007).

In the area of the Forlandsundet air masses are transformed through the influence of local factors, such as the relief and type of surface. The longitudinal arrangement of the mountain ranges on Prins Karls Forland and on Oscar II Land supports the flow of air from the south and the north. With a westerly or easterly advection foehn processes often take place on the downwind side of the hills. The diverse surfaces, including the sea, glaciers and non-glaciated land provide good conditions for the formation of local air masses, characterised by different temperature and humidity. Local atmospheric circulation types are often formed, for example, on the glaciers – a katabatic flow (glacier winds), on mountain slopes – valley and mountain winds, and in the coast area – even sea-breeze circulation. At mountain tops and in the upper parts of glaciers inverse temperature and humidity situations often occur, which is related to the exposure of the slopes, cloudiness and the local atmospheric circulation.

References

Baranowski S., 1977, The subpolar glaciers of Spitsbergen seen against the climate of this region, Acta Univ. Vratisl., No 410, Results of Investigations of the Polish Scientific Spitsbergen Expeditions, vol. III, Wrocław, 94 pp.

Barcikowski A., Gugnacka–Fiedor W., Zubel P., 2005, Charakterystyka tundry obszaru Kaffiøyry, [in:] Kaffiøyra. Zarys środowiska geograficznego Kaffiøyry (NW Spitsbergen), Grześ M., Sobota I. (eds.), Toruń, 35–36.

Bogdańska B., Podogrocki J., 2000, Zmienność całkowitego promieniowania słonecznego na obszarze Polski w okresie 1961–1995, Mat. Bad. IMGW, Meteorologia 30, 43 pp.

Hisdal V., 1985, Geography of Svalbard, Norsk PolarInstitutt, Oslo, 75 pp.

Käsmacher O., Schneider C., 2011, An objective circulation pattern classification for the region of Svalbard, Geogr. Ann., Series A, Phys. Geogr., 93, 259–271. DOI: 10.1111/j.1468–0459.2011.00431.x.

Kejna M., Przybylak R., Araźny A., 2011, Spatial differentiation of radiation balance in the Kaffiøyra region (Svalbard, Arctic) in the summer season 2010, Probl. Klimatol. Pol., 21, 173–186.

Kejna M., Przybylak R., Araźny A., Jankowska J., Maszewski R., Wyszyński P., 2010, Warunki topoklimatyczne w sezonach letnich w rejonie Kaffiøyry (NW Spitsbergen) w latach 2005–2009, Probl. Klimatol. Pol., 20, 63–81.
Lankauf K.R., 2002, Recesja lodowców rejonu Kaffiøyry (Ziemia Oskara II – Spitsbergen) w XX wieku, Prace Geogr. PAN, 153, 221 pp.
Leszkiewicz J., 1977, Meteorological conditions in the northern part of Kaffiöyra Plain during the period from July 1 to August 31, 1975, Acta Univ. Nic. Copernici, Geogr., XIII, 82, 97–111.
Marciniak K., 1983, Attempt of evaluation of thermic conditions perceptible in summer at the Kaffiöyra (NW Spitsbergen), Acta Univ. Nic. Copernici, Geogr., XVIII, 125–145.
Marsz A. A., Styszyńska A., 2007, Klimat Rejonu Polskiej Stacji Polarnej w Hornsundzie, Wydawnictwo Akademii Morskiej w Gdyni, Gdynia, 376 pp.
Marsz A.A., Styszyńska A., 2011, Rozkład przestrzenny oraz skala ocieplenia Arktyki Atlantyckiej w 30-leciu 1980–2009 i jej porównanie z 'wielkim ociepleniem Arktyki' lat 30, XX wieku, Probl. Klimatol. Pol., 91–114.
Niedźwiedź T., 2007, Cyrkulacja atmosferyczna, [in:] Marsz A. A., Styszyńska A. (eds.), Klimat rejonu Polskiej Stacji Polarnej w Hornsundzie, Gdynia, 45–64.
Niewiarowski W., Pazdur M.F., Sinkiewicz M., 1993, Glacial and marine episodes in Kaffiøyra, northwestern Spitsbergen, during the Vistulian and the Holocene, Polish Polar Res., 14, 243–258.
Piechura J., Walczowski W., 2009, Warming of the West Spitsbergen Current and sea ice north of Svalbard, Oceanologia, 51 (2), 147–164.
Przybylak R., 2003, The Climate of the Arctic. Atmospheric and Oceanographic Sciences Library, 26, Kluwer Academic Publishers, Dordrecht/Boston/London, 288 pp.
Przybylak R., Araźny A., 2006, Climatic conditions of the north–western part of Oscar II Land (Spitsbergen) in the period between 1975 and 2000, Polish Polar Res., 27(2), 133–152.
Przybylak R., Araźny A., Ćwiklińska K., 2007, Warunki meteorologiczne w regionie Lodowca Waldemara (NW Spitsbergen) w sezonie letnim 2005 r., [in:] R. Przybylak, M. Kejna, A. Araźny, P. Głowacki (eds.), Abiotyczne środowisko Spitsbergenu w latach 2005–2006 w warunkach globalnego ocieplenia, Toruń, 51–65.
Przybylak R., Araźny A., Kejna M., 2010, Zróżnicowanie przestrzenne i wieloletnia zmienność temperatury gruntu w rejonie Stacji Polarnej UMK (NW Spitsbergen) w okresie letnim (1975–2009), Probl. Klimatol. Pol., 20, 103–120.
Przybylak R., Kejna M., Araźny A., 2011, Air temperature and precipitation changes in the Kaffiøyra region (NW Spitsbergen) from 1975–2010, Papers Glob. Change IGBP, 18, 7–22.
Przybylak R., Kejna M., Araźny A., Maszewski R., Wyszyński P., 2008, Zróżnicowanie temperatury powietrza w regionie Kaffiøyry (NW Spitsbergen) w sezonach letnich 2005–2007. [in:] A. Kowalska, A. Latocha, H. Marszałek, J. Pereyma (eds.), Środowisko przyrodnicze obszarów polarnych, Wrocław, 150–159.
Serreze M. C., Francis J. A., 2006, The Arctic amplification debate, Climatic Change, 76, 241–264.
Sobota I., Lankauf K.R., 2010, Recession of Kaffiøyra region glaciers, Oscar II Land, Svalbard, Bull. Geogr., Phys. Geogr. Ser., 3, 27–45.
Spreen, G., Kaleschke L., Heygster G., 2008, Sea ice remote sensing using AMSR–E 89 GHz channels, J. Geophys. Res., 113, C02S03, doi:10.1029/2005JC003384.
Stange R., 2008, Spitsbergen – Svalbard: a complete guide around the arctic archipelago. Druckerei Karl Keuer, 540 pp.
Styszyńska A., 2011, Wpływ zmian temperatury wody powierzchniowej mórz Barentsa, Norweskiego i Grenlandzkiego na trend rocznej temperatury powietrza na Spitsbergenie, Probl. Klimatol. Pol., 21, 115–131.
Svendsen H., Beszczynska–Møller A., Hagen J-O., Lefauconnier B., Tverberg V, Gerland S., Ørbæk J.B., Bischof K., Papucci C., Zajaczkowski M., Azzolini R., Bruland O., Wiencke C., Winther J–G., Dallmann W., 2002, The physical environment of Kongsfjorden–Krossfjorden, an Arctic fjord system in Svalbard, Polar Res., 21(1), 133–166.
Turner J., Marshall G.J., 2011, Climate change in the polar regions, Cambridge University Press, 434 pp.
Walczowski W., Piechura J., 2006, New evidence of warming propagating toward the Arctic Ocean, Geophys. Res. Lett., 33, L12601, DOI:10.1029/2006GL025872.
Walczowski W., Piechura J., 2011, Influence of the West Spitsbergen Current on the local climate, Int. J. Climatol, 31, 1088–1093.
Wójcik C., 1981, Geological observations in the eastern part of the Forlandsundet Graben between Dahlbreen and Engelsbukta, Spitsbergen, Stud. Geol. Polonica, LXXII, 23–35.

Wójcik G., Kejna M., Marciniak K., Przybylak R., Vizi Z., 1997, Obserwacje meteorologiczne na Ziemi Oscara II (Spitsbergen) i w Oazie Bungera (Antarktyda), Oficyna Wydawnicza „Turpress", Toruń, 412 pp.
Wójcik G., Marciniak K., 1983, Meteorological conditions at the Kaffiöyra Plain in summer 1978, Acta Univ. Nic. Copernici, Geogr., XVIII, 99–111.
Wójcik G., Marciniak K., Przybylak R., 1991, Mezoklimatyczne i topoklimatyczne jednostki w regionie Kaffiöyry (NW Spitsbergen), Acta Univ. Wratisl., 1213, 323–342.
Wójcik G., Marciniak K., Przybylak R., Kejna M., 1993, Mezo- i topoklimaty północnej części regionu Kaffiøyry (Ziemia Oskara II, NW Spitsbergen), Wyniki Badań VIII Toruńskiej Wyprawy Polarnej Spitsbergen 89, Uniwersytet Mikołaja Kopernika, Toruń, 83–111.