Chapter 5

HIGRIC CONDITIONS

5.1. Relative air humidity

5.1.1. Introduction

The humidity of air is a very sensitive topoclimatic element, subject to spatial diversity to a greater extent than the temperature of air. Changes result from a number of reasons, including the influences of ground moisture, absolute height, surface relief features and vegetation on the water vapour content in the near-ground layer of the air. General and local atmospheric circulation plays a significant role, as well. Learning about the temporal and spatial variability of air humidity (described with the example of relative humidity in this Chapter) is very useful for bioclimatic and topoclimatic research. Too-low air humidity, just as too-high, disturbs the process of heat release by the human body (Kozłowska-Szczęsna et al. 1997).

Information about air humidity can be found in monographic studies of the Arctic climate (for example, Vowinckel and Orvig 1970; Przybylak 2003; Marsz 2007; Araźny 2008). Relative humidity on Spitsbergen has rarely been the core of thorough analysis (e.g. Niedźwiedź and Ustrnul 1989; Przybylak 1992a, b; Araźny 2003). In the area of the Forlandsundet, the problem of spatial diversity in air humidity has only been researched since summer 1978 (Wójcik et al. 1997). Results from this research work have been published in numerous books and articles, for example Wójcik et al. 1983, 1993; Kejna 2001; Kejna et al. 2010; Kejna and Maszewski 2007; Przybylak et al. 2007; Araźny et al. 2011.

5.1.2. Annual course (August 2010–August 2011)

Extensive observations of relative air humidity had never been conducted on Spitsbergen before. In this Section then, initial results are presented, showing the diversity in relative air humidity in the area of the Forlandsundet (NW Spitsbergen). From July 2010 until August 2011, relevant measurement data were collected at 12 sites. The data were complete, except for one site, where a recorder fault or site damage made it impossible to collect necessary information about relative air humidity.

Monthly and seasonal values of relative humidity at the measurement points located in the area of the Forlandsundet are shown in Tables 5.1 and 5.2 and Figures 5.1 and 5.2, for all months and seasons of the year. The seasons have been distinguished according to the proposition offered by Putnins et al. (1959) and Gavrilova and Sokolov (1969) (*cf*. Section 4.2 of this work), which defines autumn as the months of September and October, winter as the period from November to March, spring as April and May, and summer as the three months of June, July and August.

Table 5.1. Mean monthly values of relative humidity (%) in the area of the Forlandsundet in the period from 1 August 2010 to 31 August 2011

Sites	2010					2011							
	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
SAT	95	96	83	81	82	84	81	80	84	86	91	91	92
SAO	92	95	83	81	81	82	87	88	89	89	92	93	92
KT	90	91	79	74	77	76	77	78	80	77	79	82	82
ATA	86	93	82	78	77	79	79	81	83	81	85	87	86
KU	90	94	81	76	77	78	77	80	85	85	89	91	88
GF	93	94	87	85	84	84	84	90	92	95	93	94	89
LW1	87	92	81	78	78	77	78	82	83	80	85	89	87
LW2	87	93	86	81	81	80	81	84	87	83	86	94	90
PK1	90	92	84	82	82	83	84	90	89	88	87	89	89
PK4	90	93	83	81	80	83	84	88	87	85	85	89	89
SJ1	89	89	81	76	78	79	–	–	–	–	–	–	86
SJ3	88	87	79	75	72	73	77	77	79	77	82	85	84

Table 5.2. Mean seasonal values of relative humidity (%) in the autumn, winter, spring, summer, and in the period from September 2010 to August 2011

Sites	Autumn	Winter	Spring	Summer	Year
SAT	90	81	85	91	86
SAO	89	84	89	92	88
KT	85	76	79	81	79
ATA	87	79	82	86	83
KU	88	78	85	89	83
GF	90	85	94	92	89
LW1	87	79	81	87	82
LW2	90	82	85	90	86
PK1	88	84	88	88	86
PK4	88	83	86	88	86
SJ3	83	75	78	84	79

The values of relative humidity are correlated with the course of air temperature (*cf.* Section 4.2 of this work). Based on the monthly mean data from the Ny-Ålesund station (situated approx. 30 km from Kaffiøyra station), it was observed that in an annual course, the lowest mean values of relative humidity (72%) occurred in November and December (Araźny 2008). This is connected with an advection of dry Arctic air masses. A similar situation took place in the area of the Forlandsundet in the period from August 2010 to August 2011 (Tab. 5.1, Fig. 5.1). In November 2010, the highest mean relative humidity occurred at the mountain top (GF; 85%), and the lowest – on the terrace in front of the Waldemar Glacier (KT; 74%). Relative humidity gradually increased from the beginning of winter through the summer months, with its highest long-term mean values (86%) recorded in that area (Ny-Ålesund) in July (Araźny 2008). The reason for this is the south-westerly influx of warm and humid air masses from the sea to the cold land. In an annual course, the relative humidity of air in the area of the Forlandsundet was the greatest in September, while in 2010, the highest mean value was recorded at the sites located near the sea (SAT 96% and SAO 95%), and the lowest in the southern part of the area of observations, the St. Jonsfjorden, in front of the Konow and Osborne glaciers (SJ3; 87%).

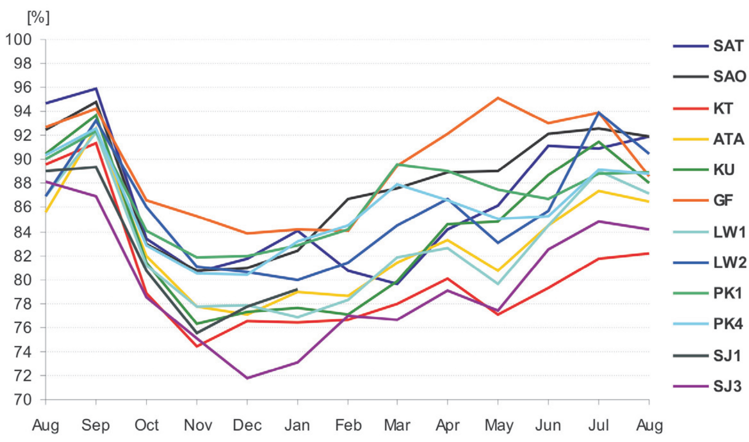

Figure 5.1. Annual course of relative humidity (%) in the area of the Forlandsundet in the period from August 2010 to August 2011

During the year, the most humid air was generally observed at the GF site (a mountain top at 345 m a.s.l.) and the SAO site (on the coast) (Tab. 5.2), whereas the lowest humidity values were measured at the SJ3 site (on glacial polish in front of the Konow and Osborne glaciers) and at KT (on a terrace in front of the Waldemar Glacier). The lowest air humidity was observed in the winter season, when it is usually a dozen or so per cent lower than in the autumn or the summer (Tab. 5.2). In the area of Spitsbergen, full-bodied maritime air masses exhibit a relative humidity of 80-85% (Marsz 2007). The mean monthly and seasonal values shown in Tables 5.1 and 5.2 come within the range, or tend to be a little higher. This means that fresh masses of maritime air prevail in the area of the Forlandsundet.

The smallest spatial diversity (8%) of this humidity index (according to mean monthly values) was observed in October between the mountain site, GF, and the terrace site, KT, whereas the greatest (18%) was seen in May, between the same measurement points. Based on the mean seasonal values, the diversity was the smallest (8%) in the autumn, between the GF and the SJ3 sites, and the greatest (15%) in the spring, at the same pair of measurement points.

Over the whole year, the mean diurnal and fixed-interval values of relative humidity in the area of the Forlandsundet reached 100% at all sites. The lowest diurnal means were observed at that time at the region of the Waldemar Glacier (KU, GF, KT and LW1: 42%, 42%, 44% and 45%, respectively). Also, absolute fixed-interval value drops (to 27-29%) were mainly noted in that area (Fig. 5.2), both during the warm and the cold season, during the polar day and during the polar night alike. However, relative humidity did not decrease so significantly in the autumn. The summer drops were predominantly a result of the foehnic effect, whereas those that occurred during the polar night can be explained by a flow of chilled air from the uppermost areas of the Waldemar and Aavatsmark glaciers. Cold air flowing down undergoes adiabatic warming, which can lead to a decrease in relative air humidity.

On Spitsbergen, both in a multi-annual period (Araźny 2008) and in the period analysed here, the greatest variability of relative humidity in an annual course occurred in the winter months. This is due to a considerable irregularity of the baric systems, which bring – often alternating – influxes of dry and wet air masses. The standard deviation determined on the basis of the diurnal means reaches the highest value during the year at KU (13%), and the most balanced environment as regards humidity was found at SAT (9%) and at PK1 and PK4 (9%).

On individual days the pattern of spatial diversity of air humidity may reveal considerable differences. In a day-by-day course, the relative humidity in the area of the Forlandsundet, even at the same temperature, shows various values depending on the direction of advection. More details of the influence of atmospheric circulation on relative humidity have been provided in Chapter 6.

The mean diurnal course of relative humidity in the area of the Forlandsundet is opposite to the mean diurnal course of air temperature (*cf*. Section 4.2), and is quite diversified in the analysed area. In the autumn and winter, when the amount of solar radiation is largely reduced or absent, mean courses (Figs. 5.3 and 5.4) show a lack of daily variability of relative humidity at all sites. The diurnal ranges in the two seasons do not exceed 1-2% at all sites. In the autumn and winter months, the occurrence of average highest and lowest values of air humidity at fixed hours is random, as it is in the case of air temperature (Figs. 5.3 and 5.4).

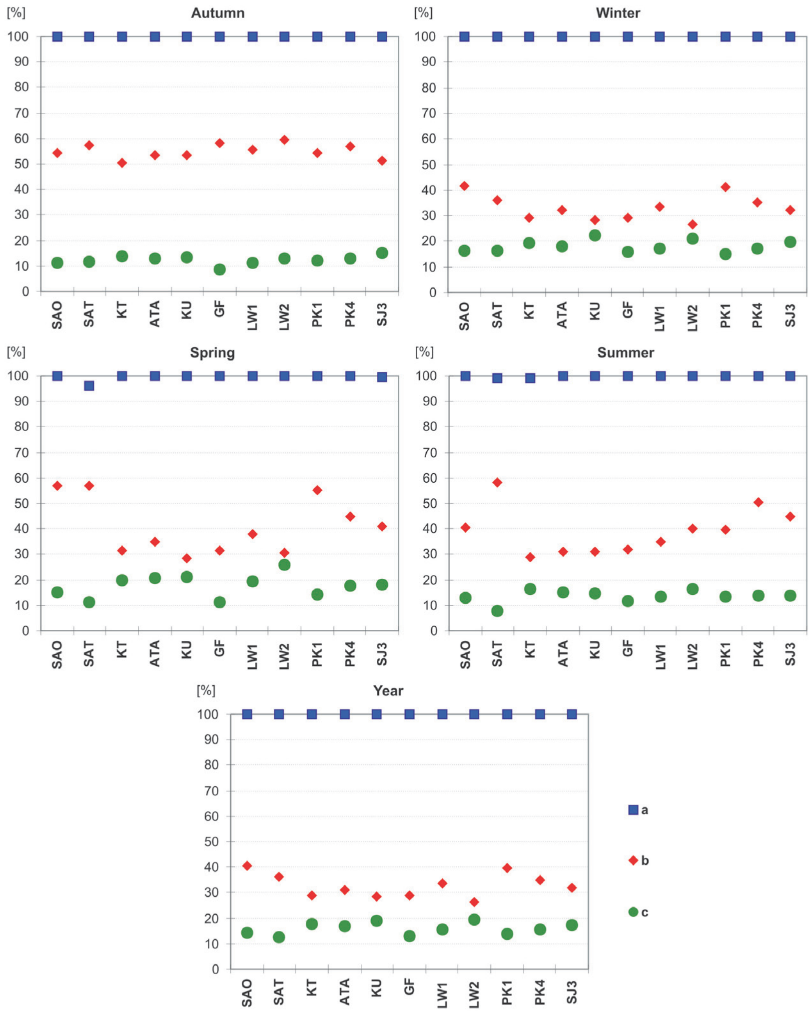

Figure 5.2. Values of relative humidity: absolute maximum (a), absolute minimum (b) and mean diurnal range (c) in the area of the Forlandsundet in the autumn (Sep-Oct) of 2010, winter (Nov-Mar) of 2010/2011, spring (Apr-May) of 2011, summer (Jun-Aug) of 2011 and in the year (Sep 2010 – Aug 2011)

In the spring, mean diurnal ranges of relative humidity were the highest of all seasons. The mean diurnal courses of this element in the spring were also the most evident (Fig. 5.5), as their range exceeded the 5% of the relative humidity range observed in the area of the Waldemar Glacier (ATA, LW1 and LW2 - 6, 7 and 11%, respectively). At the other sites, the ranges were greater in the spring than in the autumn or winter (except for SAT, GF and PK4). In the summer season, diurnal courses of air humidity were still developed, but to a lesser degree than in the spring, with the exception of the SAT and GF sites. At the latter, an inversed pattern could even be observed (Fig. 5.6).

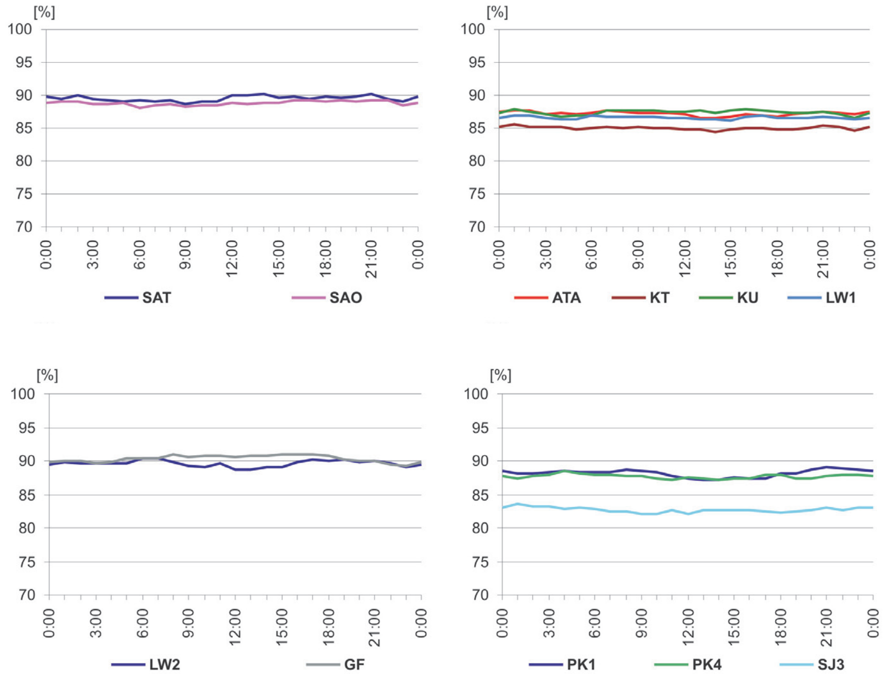

Figure 5.3. Mean diurnal course of relative humidity (%) in the autumn (Sep–Oct) of 2010 in the area of the Forlandsundet

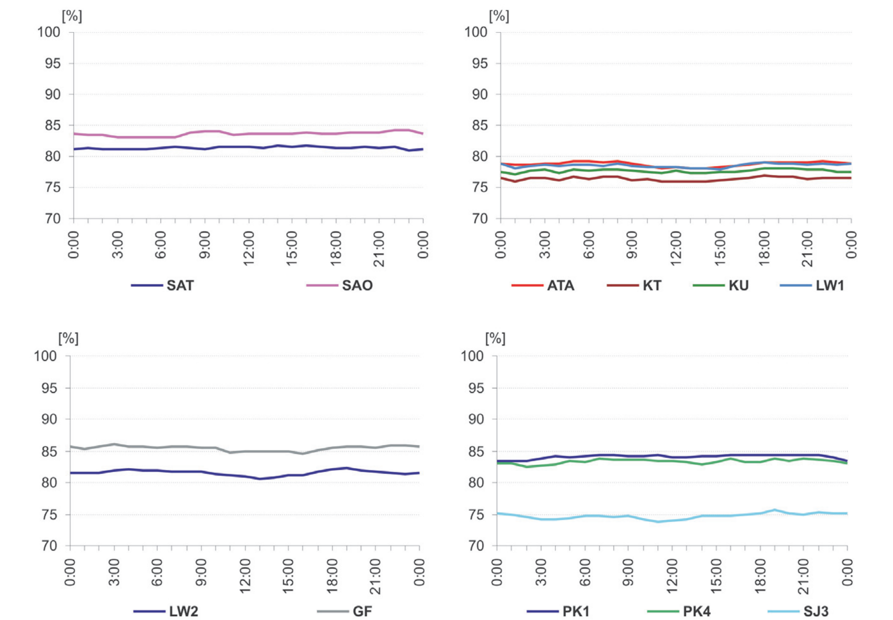

Figure 5.4. Mean diurnal course of relative humidity (%) in the winter (Nov-Mar) of 2010/2011 in the area of the Forlandsundet

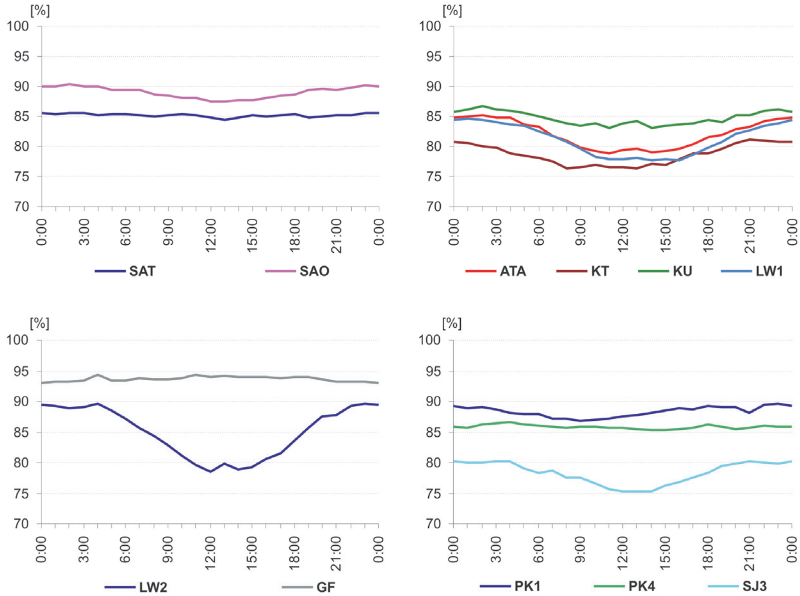

Figure 5.5. Mean diurnal course of relative humidity (%) in the spring (Apr-May) of 2011 in the area of the Forlandsundet

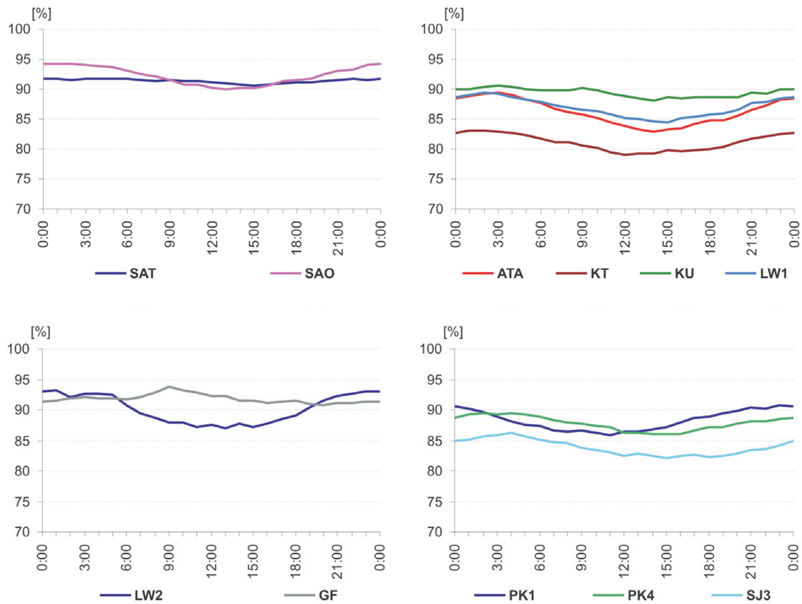

Figure 5.6. Mean diurnal course of relative humidity (%) in the summer (Jun-Aug) of 2011 in the area of the Forlandsundet

On the basis of mean diurnal values of relative humidity, an analysis of the frequency of days with different characteristic values that occurred throughout the year. Kozłowska-Szczęsna et al. (1997) assumed that with relative humidity below 56% the air is dry; between 56 and 70% it is moderately dry; between 71 and 85% it is humid, and above 85% - very humid. Long-lasting days of high relative humidity impair bioclimatic conditions, particularly with low air temperatures and high wind speeds (Araźny 2008).

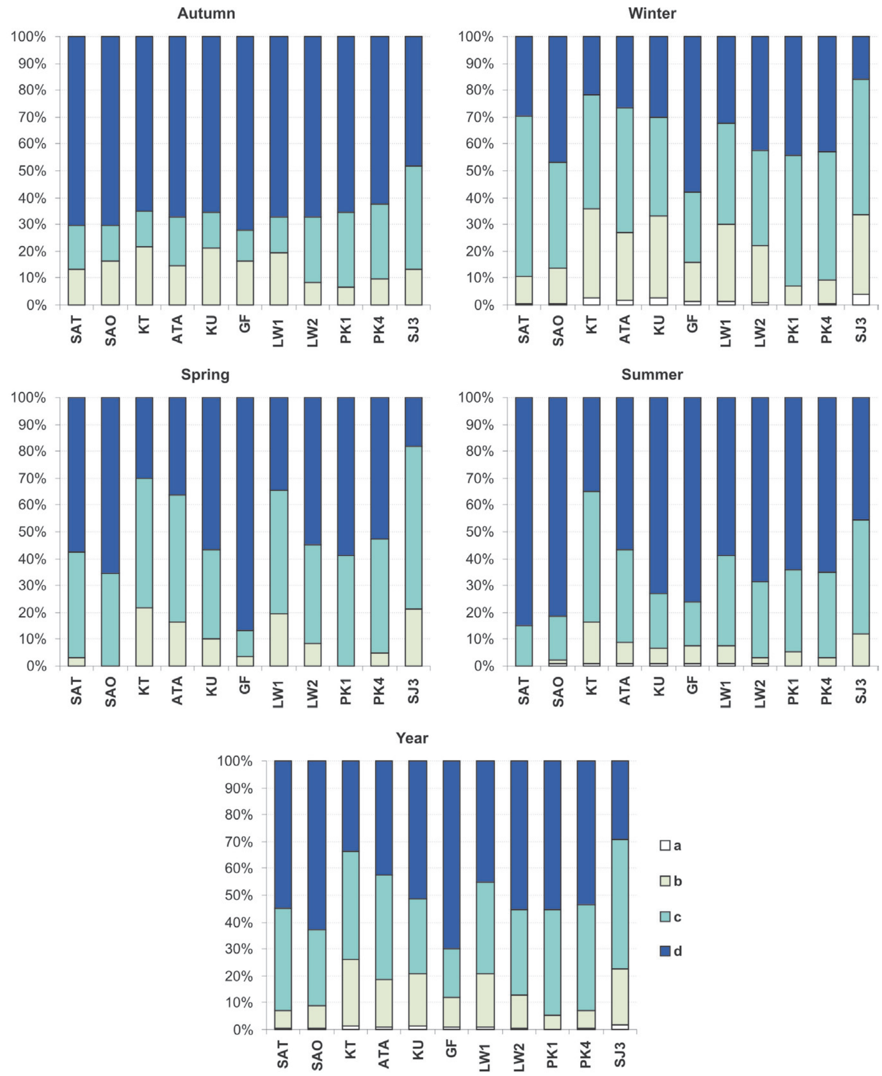

Figure 5.7. Relative frequency of occurrence (%) of dry air (a), moderately dry air (b), humid air (c) and very humid air (d) in the area of the Forlandsundet in the autumn (Sep-Oct) of 2010, in the winter (Nov-Mar) of 2010/2011, in the spring (Apr-May) of 2011, in the summer (Jun-Aug) of 2011, and in the year (Sep 2010 – Aug 2011)

According to the classification described above, in the period from September 2010 to August 2011, the air in the area of the Forlandsundet was predominantly very humid (Fig. 5.7). On average, throughout the year, this kind of air occurred at all sites for 50% of days. Very humid air was the most uncommon at the SJ3 site (29% of days), located on muton in the forefield of the Konow and Osborne glaciers. On the other hand, this type of air was the most frequent (70% of days) at the mountainous GF site, which is often covered by low-level clouds of the *Stratus* and *Stratocumulus* types. In the area of the Forlandsundet, very humid air was the least common in the winter (36%), and the most recurrent in the autumn (66%) and summer (64%).

Humid air occurred in the analysed area, on average, in 35% of days throughout the year. It was mostly observed at SJ3 (48%), and was least common at GF (19%). In individual seasons, this type of air was the least frequent in the autumn (20%), and the most frequent in winter (43%).

Moderately dry air was less common than humid air (Fig. 5.7), occurring at all sites in the area of the Forlandsundet during 14% days of the year. A considerable spatial diversity in the frequency of occurrence of this type of air was observed at individual sites (ranging from 6% at PK1 to 25% at KT). Moderately dry air was observed the least in the summer (6%), and the most in winter (20%).

Dry air occurred in the area of the Forlandsundet only occasionally, averaging at 1% throughout the year. In the autumn and spring, dry air was not observed on any one day at the sites. On the other hand, occasional days with this type of air were noted in the winter and in the summer.

5.1.3. Summer season (21 July–31 August)

Values for individual ten-day periods and for the whole common period (21 July - 31 August) at all observation sites in the area of the Forlandsundet, in the summer seasons of 2010 and 2011, are presented in Table 5.3 and Figures 5.8 and 5.9. The spatial distribution of relative humidity is correlated with the corresponding pattern of air temperature (*cf*. Section 4.2 of this work; Przybylak et al. 2011). The seasonal mean value of the parameter at the Base Station (KH) in the summers of 2010 and 2011 was similar and reached 89 and 90%, respectively (Tab. 5.3).

In the summer season of 2010, higher values than those measured at KH (by at least 2% in a season) were recorded at the sites located near the sea (SAT and SAO) or in the mountains, at a distance from the sea (KU, GF, PH1, PH2 and PK2). At mountain sites, due to the recurrence of lower temperatures and low-level clouds (*Stratus* and *Stratocumulus*), elevated values of relative humidity were observed (Araźny et al. 2011). The lowest saturation of air with water vapour (86%) occurred at the ATA site, located at the front of the Waldemar Glacier, where the ground is a rocky and dry moraine. The low humidity observed at that site was also connected with adiabatic warming of air masses carried by glacial winds (Kejna et al. 2010). Negative differences in relative humidity, calculated for the whole season between KH and the other sites in the area of the

Forlandsundet, were also observed at five other sites (Tab. 5.3), all of which were situated immediately above glacial surfaces (LW2) or in close proximity of the glaciers (LW1, SJ1, SJ2 and SJ3).

Table 5.3. Mean values of relative humidity (%) in the area of the Forlandsundet in the summer seasons of 2010 and 2011

Sites	21-31 Jul		01-10 Aug		11-20 Aug		21-31 Aug		21 Jul-31 Aug	
	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011
KH	91	92	92	88	85	84	89	96	89	90
SAT	94	94	98	91	91	88	96	97	95	92
SAO	94	95	96	90	89	85	92	100	93	93
KT	93	84	95	78	85	75	89	92	90	83
ATA	89	90	90	80	82	80	85	98	86	87
KU	95	94	97	83	86	81	89	99	92	90
GF	99	97	99	84	91	82	88	99	94	91
LW1	90	92	92	81	83	82	86	98	88	88
LW2	93	98	95	85	84	86	83	99	89	92
PH1	99	95	99	86	92	83	84	98	93	91
PH2	99	91	94	81	94	81	80	96	92	87
PK1	94	94	97	81	85	85	88	99	91	90
PK2	95	92	98	78	86	80	89	98	92	88
PK3	93	89	96	74	84	79	90	96	91	85
PK4	93	92	95	83	84	84	92	98	91	90
SJ1	88	84	92	81	84	81	91	95	89	85
SJ2	89	85	92	80	81	79	89	92	88	84
SJ3	89	88	93	78	83	78	88	95	88	85

The weather conditions in the summer season of 2011 were substantially different from those observed in the preceding year. In 2011, the observed average cloud amount was smaller and the mean values of air temperature were much higher than the mean value for the whole summer season of 2010, and the values recorded during all previous expeditions (*cf*. Chapter 7 of this work). As a result, in the summer season of 2011, the values of relative air humidity at certain sites, for example those with a dry, rocky ground surface (e.g. terraces or moraines), were definitely lower (even by a few per cent) than in the preceding season. Examples of such sites include those located on the terrace in the forefield of the Waldemar Glacier (KT), or the mountain sites

(PH1, PH2 and GF). However, changes of the above-mentioned meteorological conditions did not affect the values of relative humidity at the coastal sites: KH, SAT, SAO, PK1 and PK4.

In the analysed seasons, the highest mean diurnal values of relative humidity at most of the sites reached 100%. In 2010, the lowest mean diurnal values ranged from 50% (at the highest-located PH2 site, on 22 August) to 80% (at the coastal SAT site, on 20 August), while the lowest mean diurnal values of relative humidity in 2011 changed from 43% (at the highest-located site on Prins Karls Forland, on 18 August) to 73% (at SAT, on 18 August). The highest range of relative humidity (i.e. the difference between the highest and the lowest mean diurnal value in the studied period) in 2010 was noted at the top of the Prins Heinrichfjella (PH2), and in 2011 – at the site located in the middle of Prins Karls Forland (50 and 57%, respectively). The reason for this must be the strong warming-up of the top parts of the mountain ranges, often situated beyond the reach of low-level clouds, which – on the other hand – prevent the lower situated areas from such warming. The smallest difference between the days with the highest diurnal mean and those with the lowest was, predictably, the SAT site, located at the station with the greatest influence of the sea. The difference in the two subsequent summer seasons was 20 and 26%, respectively. The SAT site is located at the end of the narrow Sarstangen Peninsula, cutting into the Forlandsundet, and therefore is continuously subject to humid air.

The diversity of absolute values of relative humidity is greater than in the case of diurnal means. In the summer season of 2010 it exceeded 38% at all sites, and at 10 measurement points (mostly situated high in the mountains) even 55%. In 2011, the diversity was greater, exceeding 40% at all sites, at 12 of which it reached 60%.

The standard deviation, calculated from the diurnal means of the summer of 2010, reached the highest values (approx. 14%) at the mountain sites (PH1 and PH2), whereas the environment with the most balanced humidity conditions (up to approx. 5%), was found at the sites located near the sea (SAT and KH). These correlations were confirmed by the results obtained in the summer of 2011, where the highest values (approx. 13-14%) were calculated for the mountainous or most elevated sites (PH1, PH2, GF, KU, LW1, ATA and PK2), whereas the most balanced deviation values (approx. 6-8%) were observed for the coastal sites (SAT and KH).

On individual observation days, the characteristics of the spatial diversity of the air humidity can be considerably different (see Appendixes 1 and 2). In a day-by-day course the relative humidity, even at the same air temperature, exhibited various values in the area of the Forlandsundet, depending on the direction of advection of air masses. More information about the influence of atmospheric circulation on relative humidity can be found in Chapter 6 of this work.

A significant anomaly in the humidity conditions was observed, for example, in the last eleven days of August 2010 (Tab. 5.3). At that time, an unusual warming occurred, particularly intensively in the mountainous areas (except the St. Jonsfjorden) (Przybylak et al. 2011). Then, an increase in air temperature and sunny weather between the second and the third ten-day period of August caused a sudden drop in relative air humidity at the highest-elevated sites, i.e. GF, LW2, PH1 and PH2 (Araźny et al. 2011). This example shows that the spatial diversity of relative humidity is modified by weather. In cloudy and cool weather, this diversity decreases, whereas in radiation weather it intensifies.

The mean diurnal course of relative humidity is the opposite of the mean diurnal course of air temperature. The latter is presented in Section 4.2 of this work and describes the summer seasons of 2010 and 2011. The diversity of air temperature between individual sites is greater at the daytime than during the 'night' hours. It is also much greater and more complex (being more influenced by local conditions) on sunny days than on cloudy days. The averaged diurnal courses of relative humidity at individual sites revealed one diurnal minimum and one maximum value (Figs. 5.8 and 5.9). In the two analysed periods, the smallest mean hourly value of relative humidity usually fell between 13:00 and 17:00 LMT, when the highest air temperature was also measured. The maximum relative humidity during the 'night' hours and in the morning was connected with a cooling-off of the air. The mean diurnal ranges in 2010 and 2011 were small (< 8% at all sites), with the smallest values observed at the mountain sites of GF and PH1 (up to approx. 3%). At all analysed sites and at all times of observation, the mean relative humidity exceeded 83% (Figs. 5.8 and 5.9). The averaged diagrams of the diurnal course in the analysed summer seasons are asymmetrical and show that a greater relative humidity occurred at all sites in the first half of the day (except for GF and LW2 in 2010, and PK1 in 2011), which is connected with lower air temperature in that part of the day.

On individual days, the diurnal courses of relative humidity often markedly deviated from the average course, which was basically caused by the occurrence of various synoptic situations. Measurements taken on two specific days, 5 August 2010 and 18 August 2011 were selected for a detailed analysis. The first day was characterised by overcast weather with a Ka synoptic pattern, and the other was very sunny (18.9 h of effective sunshine duration) with an SEa pattern (Fig. 5.10).

On the overcast day (5 August 2010), the values of relative humidity barely changed during the 24 hours, and the recorded diurnal ranges of air temperature at all sites were up to approx. 2°C. On that day, considering the lack of direct solar radiation at the sites, the instantaneous values of relative humidity recorded were similar and its range did not exceed a few per cent in the whole area of observations (Araźny et al. 2011). An exception to this was the area of the St. Jonsfjorden, where the cloud cover must have been smaller, because on 5 August the relative humidity ranges reached approximately 15% there (Fig. 5.10). An analysis verified earlier observations (e.g. Przybylak 1992b), that the distinctiveness of diurnal courses of relative humidity increased with decreasing cloudiness.

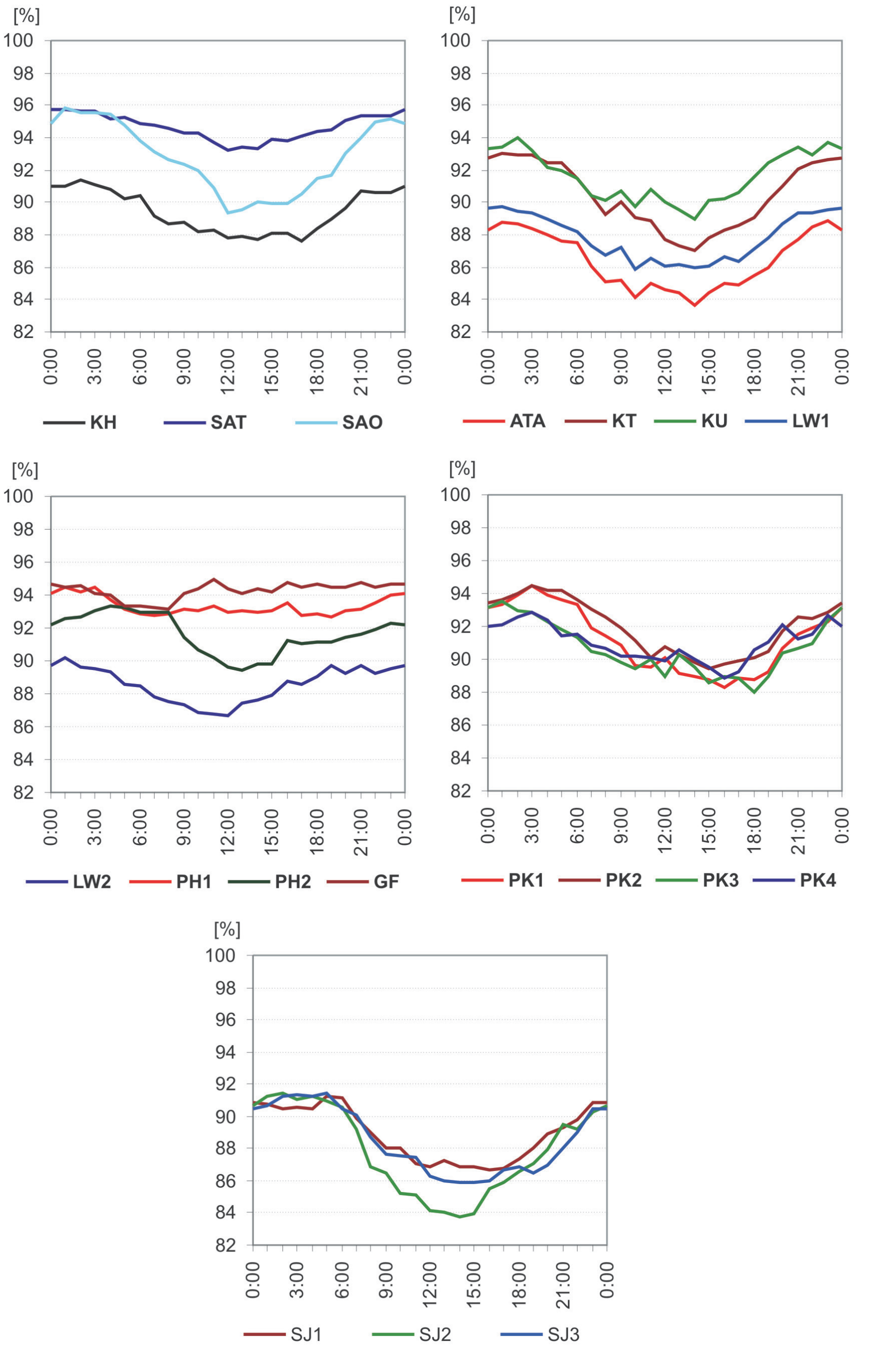

Figure 5.8. Mean diurnal course of relative humidity (%) in the area of the Forlandsundet in the summer season (21 July–31 August) of 2010

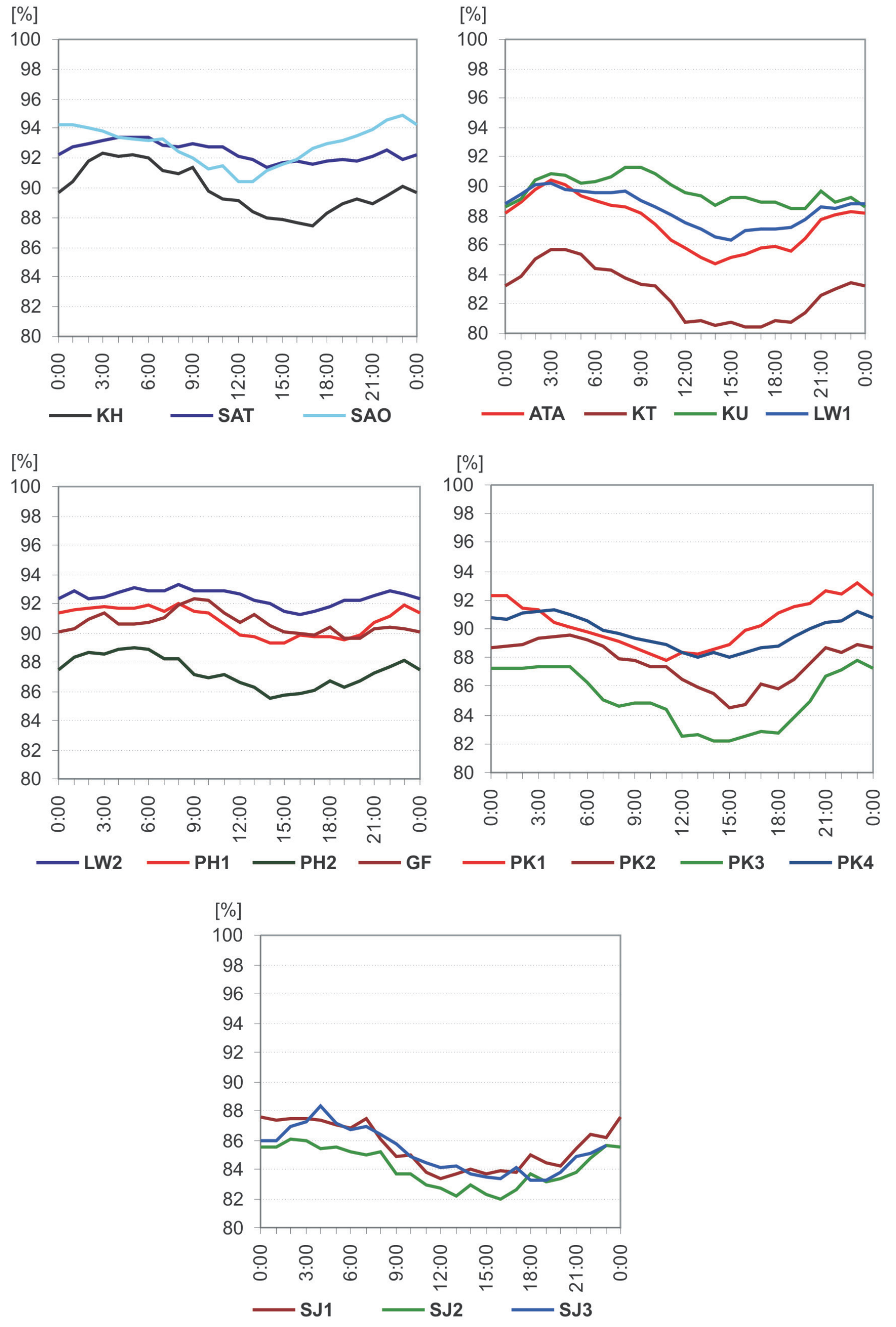

Figure 5.9.Mean diurnal course of relative humidity (%) in the area of the Forlandsundet in the summer season (21 July–31 August) of 2011

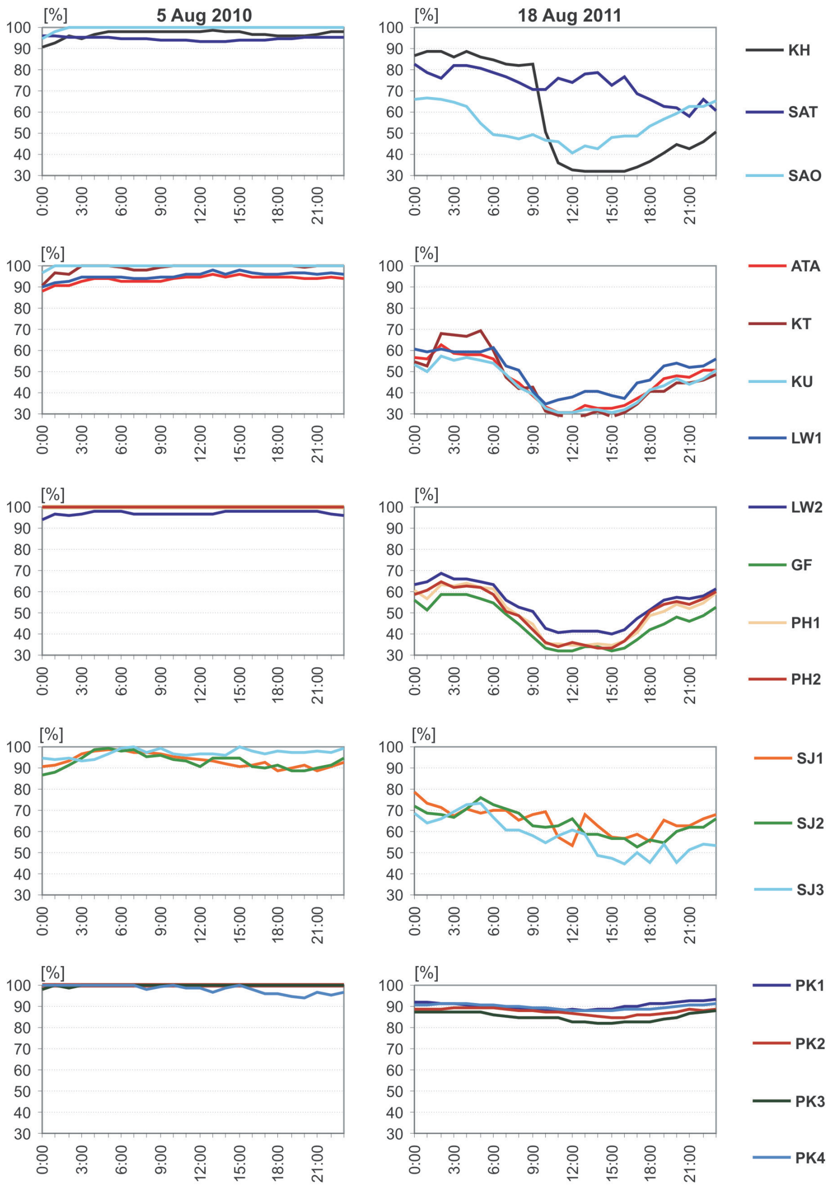

Figure 5.10. Diurnal courses of relative humidity (%) on selected days with overcast weather (5 August 2010), and with little cloudiness (18 August 2011) in the area of the Forlandsundet

On the sunny day, 18 August 2011, the air temperature increased from the 'night' hours until the midday hours. On that day, foehnic wind occurred in the area of the Kaffiøyra Plain and the Waldemar Glacier. Between 09:00 and 10:00

LMT the air temperature rose from 7.8°C to 14.1°C. In the afternoon, the highest temperature values were recorded in that area (e.g. at 15:00 LMT 16.6°C at KH, and 16.5°C at KT). These were the maximum values observed in the whole area of observations on that day, and caused the relative humidity to change dramatically at the sites located in the area of the Kaffiøyra and the Waldemar Glacier (Fig. 5.10). On 18 August 2011, a very great range of relative humidity was noted at KH (57%). At the St. Jonsfjorden site, drops in relative humidity were smaller (max. up to 45% at SJ3). In the area of the last research zone, situated on Prins Karls Forland island, the weather was different - the diurnal courses of relative humidity observed on the island on that day had a very small range (several per cent) and high values (>80%).

The mean diurnal values of relative humidity in the summers of 2010 and 2011 provided the basis for an analysis of frequency of characteristic days. The classification showed that, in the two analysed summer seasons in the area of the Forlandsundet, very humid air prevailed (Fig. 5.11). This type of air occurred there, on average, for 77% (2010) and 68% (2011) of days. Very humid air was the least frequent in the summers of 2010 and 2011 at the ATA and the KT sites (60-71% and 55-67% of days, respectively). The two sites were located on rocky and moraine ground, which warmed considerably, especially in the periods of sunny weather. Very humid air clearly prevailed at the SAT site (95% and 79% of days in respective summer seasons), located near the sea. Such a high frequency of occurrence of very humid air in the area in summer was due to increased evaporation of uncovered bodies of water.

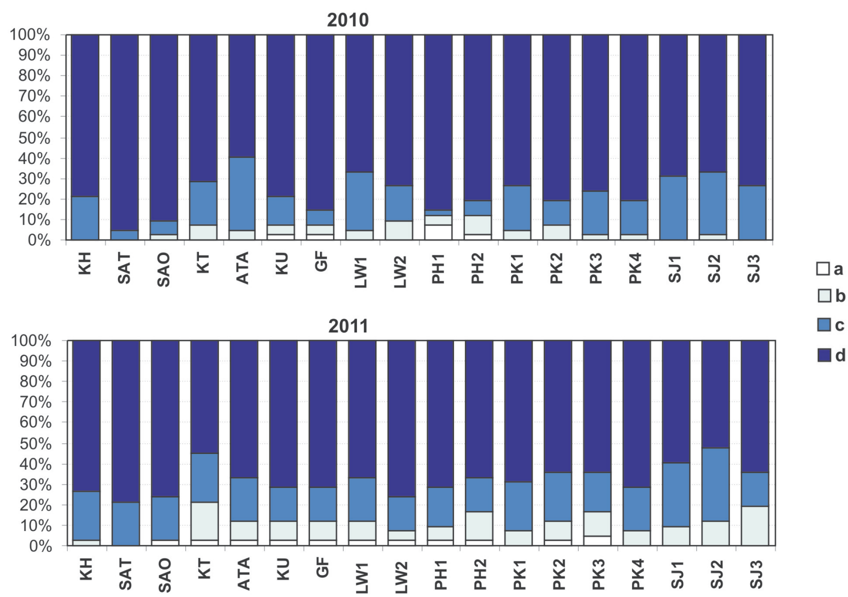

Figure 5.11. Relative frequency of occurrence (%) of dry air (a), moderately dry air (b), humid air (c) and very humid air (d) in the area of the Forlandsundet in the summer seasons (21 July–31 August) of 2010 and 2011

In the summer of 2010, humid air was observed, on average, for 18%, and in 2011 for 22% of the days in the whole area of observations. In the two seasons, humid air was the least common at the sites located on mountain tops or at greater absolute heights (several days). On the other hand, such air was the most frequent (15 days) at ATA in 2010 and at SJ3 in 2011. Overall in 2010, there were only 4% of days on which the air was moderately dry; in 2011 the share of such days increased to 9%. Moderately dry air was not observed at three sites in 2010 (KH, SJ1 and SJ3), and at two in 2011 (SAT and SAO). This type of air was the most common in the mountains and the foothills (10% of the days in the season). Dry air in the area of the Forlandsundet was very infrequent and was observed on single days, only at higher elevations, far from maritime influences.

5.2. Precipitation

The Arctic experiences quite small amounts of precipitation due to the low water vapour content in the air, the stability of the prevalent atmospheric masses and the consequential predominance of such cloud types as *Stratus* and *Stratocumulus*. On Spitsbergen, however, the amount of precipitation is evidently greater (Przybylak 2003). This is due to the considerable influence of the atmospheric circulation on the studied area, connected with the movement of lows fronts along the Icelandic-Kara Trough, which make the area ‘privileged’ as regards temperature and humidity conditions. The precipitation on Spitsbergen is strongly diversified spatially (Marciniak and Przybylak 1985; Araźny 2008; Przybylak et al. 2009). It is an essential element for the development of the biosphere and for the glacier mass balance (Przybylak 1996; Hagen et al. 2003; Sobota 2007). Precipitation participates in the forming of snow cover, whose presence affects the net solar radiation of the polar areas.

General studies of precipitation in the Arctic can be found in works by Przybylak (1996, 1997, 2003). There are also a number of studies describing the meteorological element in the Norwegian Arctic (Hanssen-Bauer and Førland 1998, 2000; Førland and Hanssen-Bauer 2000, 2001, 2002) and on Spitsbergen (Markin 1975; Baranowski 1977; Marciniak and Przybylak 1985; Przybylak and Marciniak 1992; Førland et al. 1997; Hanssen-Bauer 2002; Łupikasza 2002, 2003, 2007, 2008, 2010; Łupikasza and Niedźwiedź 2002). In the area of the Forlandsundet the problem of the spatial diversity of precipitation has been studied since the summer of 1978 (Wójcik et al. 1997). The results have been published in numerous works and articles, for example: Wójcik et al. 1983, 1992, 1993; Marciniak and Przybylak 1985; Kejna 2001, 2010; Kejna and Maszewski 2007; Przybylak et al. 2007, 2009.

The summer seasons of 2010 and 2011 were very deficient in precipitation. In the summer of 2010, the main measurement point (KHm) at the Base of the TPE recorded the smallest amount of precipitation of all the summer observations carried out in the area of Forlandsundet. Between 21 July and 31 August, total precipitation amounted to merely 8.5 mm (Tab. 5.3), whereas in the summer of 2011 it was three times higher (28.1 mm). Nevertheless, the values remained below the mean calculated from all 19 TPEs (40.0 mm). The maximum diurnal amount of precipitation in the two summers was 5.7 mm (11 July 2010) and 22.7 mm (1 September 2011) (Fig. 5.12).

Table 5.3. Precipitation totals (mm) in the area of Forlandsundet in the summer seasons of 2010 and 2011

Site	Period	11-15 Jul	16-20 Jul	21-25 Jul	26-31 Jul	1-5 Aug	6-10 Aug	11-15 Aug	16-20 Aug	21-25 Aug	26-31 Aug	21 Jul-31 Aug
KHp	2010		4.9	2.8	1.2	0.6	1.2	1.5	0.0	0.0	0.2	7.5
KHp	2011	1.3	0.1	0.2	1.4	0.4	0.6	10.9	1.8	3.7	7.1	26.1
KHm	2010		5.3	3.1	1.6	0.8	1.7	1.2	0.0	0.0	0.1	8.5
KHm	2011	1.5	0.1	0.2	2.3	0.6	0.4	10.2	1.8	3.4	9.2	28.1
SAT	2011	0.6	·	·	0.4	0.2	0.8	10.8	0.6	2.8	12.6	28.2
KT	2010		14.5	2.5	12.1	1.1	4.6	2.9	0.0	0.0	2.1	25.3
KT	2011	0.3	0.1	0.3	3.4	0.2	0.0	27.8	2.1	4.6	7.1	45.5
ATA	2010		6.0	2.5	6.4	0.2	0.3	5.6	0.0	0.1	3.9	19.0
ATA	2011	0.9	0.1	0.7	2.7	0.8	0.0	20.9	2.3	4.0	8.1	39.5
LW1	2010		7.1	4.0	9.7	0.6	2.6	5.4	0.0	0.1	3.5	25.9
LW1	2011	1.2	0.1	0.9	4.7	2.0	0.1	20.1	2.5	4.8	9.6	44.7
LW m	2010		7.8	4.6	8.5	0.7	1.1	5.4	0.0	0.2	4.1	24.6
LW m	2011	0.2	0.1	2.4	3.7	1.7	0.1	22.7	2.8	5.4	11.1	49.9
LW2	2010		9.6	7.8	11.2	0.6	2.0	8.2	0.0	1.0	5.7	36.5
LW2	2011		0.2	3.3	6.2	1.2	0.2	46.9	3.4	6.5	13.5	81.2
GF	2010		11.0	4.2	6.8	1.0	11.2	1.6	0.0	0.0	0.2	25.0
PK1	2011	1.5	·	0.8	2.8	1.5	1.0	12.9	6.3	4.3	23.6	53.2
PK2	2010		9.0	3.2	8.2	5.2	13.0	6.2	0.0	0.0	1.0	36.8
PK3	2010		4.2	1.8	4.8	1.0	4.0	5.8	0.0	0.0	0.8	18.2
PK3	2011	3.2	·	0.4	1.0	·	0.6	12.0	1.8	0.2	20.8	36.8
SJ2	2010			1.6	3.4	0.0	1.0	6.2	0.0	0.0	0.4	12.6
SJ2	2011	0.6	·	0.2	0.4	0.4	0.2	10.4	0.4	2.0	5.0	19.0

Explanations: KHp – Kaffiøyra – Heggodden beach, KHm – Kaffiøyra – Heggodden moraine, · - denotes that precipitation did not occur; for other explanations see Table 1.1.


Photo 5.1. Stratus drizzle at St. Jonsfjorden (left) and Altostratus snow fall in the Kaffiøyra and at the Waldemar Glacier (right) in the summer (Photo by A. Araźny)

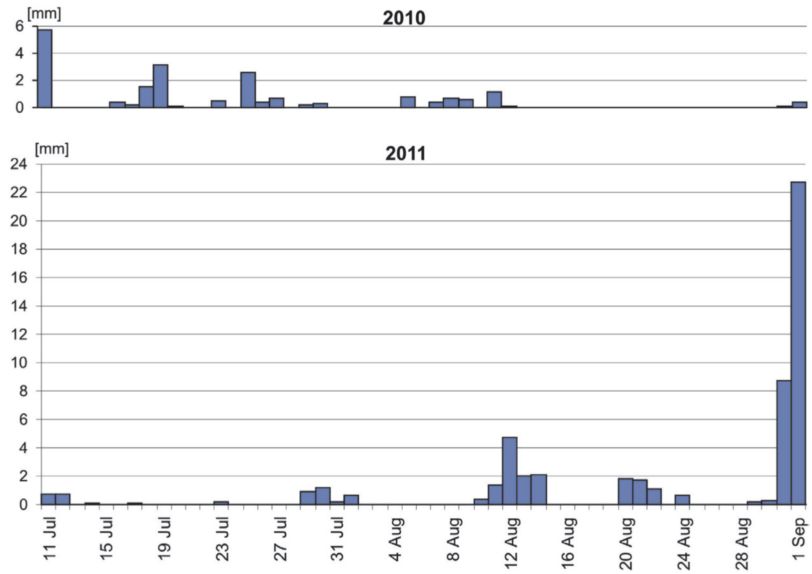

Figure 5.12.Diurnal course of precipitation totals at the Kaffiøyra-Heggodden (KHm) from 11 July to 1 September 2010 and 2011

The Forlandsundet summer of 2010 was characterised by frequent, yet sparse precipitation. At the KHm station, in the period from 11 July to 1 September there were 17 days (32.1%) of trace precipitation (0.0 mm), 20 days (37.7 %) of precipitation (≥ 0.1 mm) and 16 days (30.2%) without precipitation. In the same period of 2011, the following statistics were obtained: 3 days (5.7%) of trace precipitation (0.0 mm), 22 days (41.5%) of precipitation (≥ 0.1 mm) and 28 days (52.8%) without precipitation (Figs. 5.12 and 5.13).

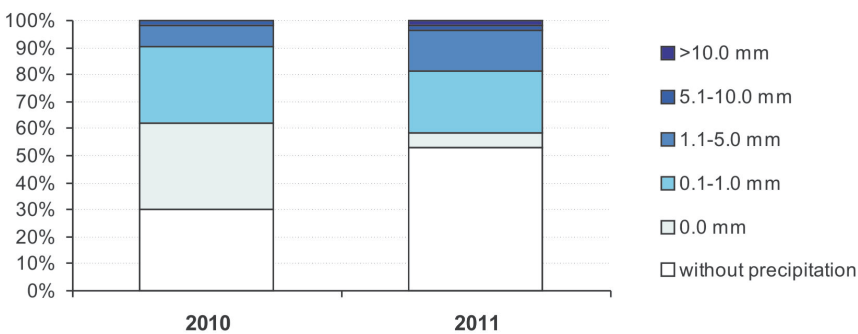

Figure 5.13. Frequency of precipitation (%) at the Base Station, Kaffiøyra-Heggodden (KHm), from 11 July to 1 September 2010 and 2011

The amount of precipitation increases with the altitude, as the air masses rise and get cold over hills and mountains. Similarly to other summertime observations (e.g. in: Marciniak and Przybylak 1985; Kejna and Maszewski 2007; Przybylak et al. 2007, 2009), the measurements taken in 2010 and 2011 confirmed a significant increase in precipitation with the elevation of the measurement point above sea level. Figure 5.14 shows correlations between series of absolute heights (m a.s.l.) and seasonal precipitation totals obtained at operational sites in the common periods of 2010 and 2011. The observed correlations were evidently stronger (r = 0.849) in the wetter season of 2011 than in the dryer summer of 2010 (r = 0.639). Both values are statistically relevant at $p < 0.05$.

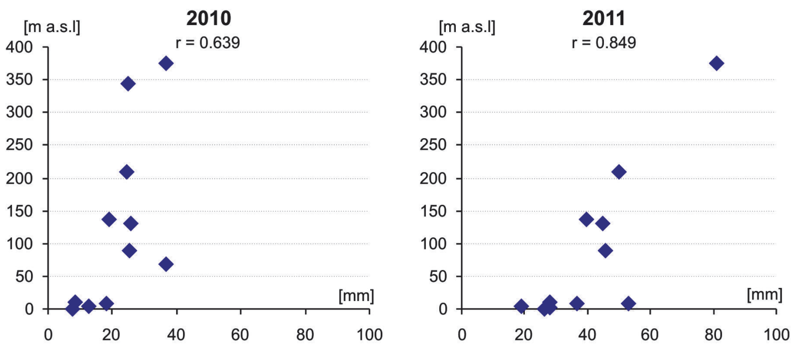

Figure 5.14. Correlations between summer precipitation totals (21 July–31 August) at individual sites and their absolute heights in 2010 and 2011

At the sites located in the mountains (GF) or on the firn field of the Waldemar Glacier (LW2), the measured precipitation was approximately 3-4 times greater than at the coastal lowland sites. In the summer of 2010, in the area of the Kaffiøyra and the Waldemar Glacier the vertical gradient of precipitation between KH and LW1 was twice as large as between KH and LW2 (14.7 and 7.7 mm/100 m, respectively). However in the summer of 2011 it was quite comparable (14.0 and 14.6 mm/100 m, respectively). Substantial differences were found in the values of the vertical gradient of precipitation in the analysed seasons between the lower (LW1) and the higher (LW2) glacier sites. In 2010 it amounted to 4.3 mm/100 m, whereas in 2011 14.9 mm/100 m.

In 2010 the greatest amount of precipitation (36.8 mm) in the whole season was recorded in the central part of Prins Karls Forland (PK2). The precipitation at that station is generally abundant, because it is situated at the highest point of movement of humid air masses along the studied profile (N-S) on Prins Karls Forland (Fig. 1.1 in Chapter 1 of this work). Unfortunately, it was not possible to repeat measurements at that site in the wetter season of 2011. In shorter periods, for example, individual series of 5 or 10 days, one can see relationships that are in opposition to that of the whole season. In 2010, for example, the greatest amounts of precipitation in 5-day periods (14.5 and 12.1 mm) were observed in the middle and at the end of July (Tab. 5.3) on a terrace in front of the Waldemar Glacier (KT). Such elevated values of this meteorological element at that particular location on the interface of the Kaffiøyra Plain and the Waldemar Glacier were caused by the more frequent occurrence of low-level clouds, as mentioned earlier.

In the summer seasons of 2010 and 2011, on the coast of the Forlandsundet the predominant type of precipitation was rain (mainly rain and drizzle), whereas in the mountain areas and on the glaciers, apart from rainfall, snowfall also occurred, forming a snow cover of a few centimetres.

The amount of precipitation is also significantly affected by the direction of air mass advection and the type of baric system. Most of the precipitation on Spitsbergen occurs when the air masses come from the southern and western sector (Niedźwiedź and Ustrnul 1988; Przybylak and Marciniak 1992; Wójcik et al. 1992; Niedźwiedź 2002; Łupikasza and Niedźwiedź 2002). This is due, according to Niedźwiedź (2002), to increased transfer of great amounts of humidity by warmer air incoming from above the vastness of the Atlantic Ocean. The wind directions observed in the area of the Forlandsundet, determined by the atmospheric circulation, show a close correlation with the local orography (cf. Chapter 2 of this work).

The atmospheric circulation and its influence on the precipitation on selected days was characterised using a calendar of circulation types for Spitsbergen (Niedźwiedź 2011). According to Przybylak et al. (2009), the highest diurnal precipitation totals in the summer at KH, in the years of 1980-2008, were recorded at advection of air masses from the southern and south-western sectors (Sa – 6.4 mm, Sc – 4.7 mm, SWc – 3.8 mm). The relationship was verified by the results from two recent summers in the Forlandsundet. In 2010 and 2011, the highest diurnal precipitation total was observed when the air was coming from the south-west at SWc (5.7 and 22.7 mm, respectively). On the other hand, incoming air masses from the north and east bring much less precipitation to Spitsbergen (Przybylak and Marciniak 1992). In the two summer seasons of 2010 and 2011, generally no precipitation was recorded in such circumstances.

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