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Coreless winters in the European sector of the Arctic and their synoptic conditions

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Abstract: The coreless winters (*i.e.* not having a cold core) were distinguished in four stations within the European sector of the Arctic. Anomalies of the frequency of the Niedźwiedź's (2011) circulation types were calculated separately for the mid-winter warm months and for cold months preceding and following the warm-spells. Furthermore, composite and anomaly maps of the sea level pressure as s well as anomaly maps of the air temperature at 850 gpm (geopotential meters) were constructed separately for the mid-winter warm events and for the cold months before and after warming. Different pressure patterns were recognized among the days of mid-winter warm spells, using the clustering method. The occurrence of coreless winters in the study area seems to be highly controlled by the position, extension and intensity of large scale atmospheric systems, mainly the Icelandic Low. When the Low spreads to the east and its centre locates over the Barents Sea the inflow of air masses from the northern quadrant is observed over the North Atlantic. This brings cold air of Arctic origin to the islands and causes an essential drop in the air temperature. Such situation takes place during the cold months preceding and following the warm mid-winter events. During the warm spells the Icelandic Low gets deeper-than-usual and it is pushed to the northeast, which contributes to the air inflow from the southern quadrant.

Key words: Arctic, North Atlantic, Svalbard, winter air temperature, circulation, polar climate.

Introduction

The weather and climate at higher latitudes are strongly controlled by the air circulation, particularly in winter, when the inflow of solar irradiation vanishes. During the polar night, atmospheric circulation accounts for 95% of the warmth advection to the Arctic, while the other 5% is due to oceanic circulation (Alekseev *et al.* 1991, cited in Przybylak 2000). The intense cyclonic activity in the European sector of the

Arctic and in consequence quick exchange of the air masses, originating from the northeast and southwest, causes the great variation in the weather and temperature conditions (Steffensen 1982; Nordli 1990; Serreze *et al.* 1993; Førland *et al.* 1997; Zhang *et al.* 2004; Marsz and Styszyńska 2007; Rachlewicz and Styszyńska 2007). The intra- and inter-annual variability in surface temperature caused by synoptic activity is most noticeable in winter. Over several years, very cold winters may be followed by the mild ones and within a season periods with deep frost may alternate with the warmer spells. Sometimes, an extending warm spell appears in the middle of winter instead of the lowest temperatures, and this phenomenon is called a "coreless winter" *i.e.* winter not having a cold core (Van Loon 1967). It was first recognized in the Antarctic and named "kernlose winter" (Wexler 1958), but the phenomenon concerns all polar regions with an extending polar night.

Most of the previous studies concerning coreless winters (CW) relate to the continental climate of the Antarctic (Van Loon 1967; Dolgin 1976; Wendler and Kodama 1993; Kejna 2002; Lipowska 2004; Styszyńska 2004; Chen *et al.* 2010 *etc.*). This phenomenon is rather weakly recognized in maritime climate of the polar regions of the Northern Hemisphere and much fewer works deal with the occurrence of CW in the Arctic (Rubinshteyn 1962; Umemoto 1998; Bednorz and Fortuniak 2011).

Two principal mechanisms are discussed as the origin of the CW phenomenon. The first is the influence of the air circulation, contributing to warm advection from lower latitudes in the time of polar winter (Wexler 1958; Rubinshteyn 1962; Dolgin 1976; Dolganov 1986; Wendler and Kodama 1993; King and Turner 1997; Styszyńska 2004). The second reason is a specific characteristics of the radiation balance during polar nights *i.e.* presence of a deep inversion reaching the level of 2 km (and amounting to 25°C) in the Antarctic (Connolley 1996) and about 1 km over the Arctic Basin (Serreze *et al.* 1992). The upper and medium layers of the troposphere, being warmer than the layer close to the ground, are the source of a flux of long wave radiation, which warms up the lower layers and increases the surface temperature. Additionally, the mountain waves of the high speed, which are typical for mountainous climates in cold zones, may cause disturbances in the inversion layer and mix the upper (warmer) air masses with the lower, primarily colder ones. Other possible mechanism over the Arctic is the release of latent heat at sea ice formation in winter and the sensible heat transport from the Arctic Ocean through the sea ice (Rubinshteyn 1962).

In this study, the circulation reasons of occurrence of CW in the maritime climate of the Arctic is assumed. Firstly, the episodes of mid-winter warm spells in four locations within the European sector of the Arctic were detected and then the pressure fields and circulation factors responsible for the events of mid-winter warming were recognized.

Considering the interest in the climate changes of the Northern Hemisphere polar regions, which are most vulnerable to contemporary warming, this contribution to the discussion on the winter temperature in these regions and its circulation feedback seems to be essential.

Data and methods

Four stations, located on four North Atlantic islands, belonging to the Norwegian Svalbard, namely: Svalbard Airport station, representing Spitsbergen, Hopen, Bjørnøya and southernmost Jan Mayen, were taken into consideration (Fig. 1). Data concerning daily mean surface air temperature were collected from the Norwegian Meteorological Institute database, available at the eKlima web portal (http://sharki.oslo. dnmi.no/portal/page?_pageid=73,39035,73_39049&_dad=portal&_schema=PORTAL). Stations' coordinates and periods of available data are given in the Table 1.

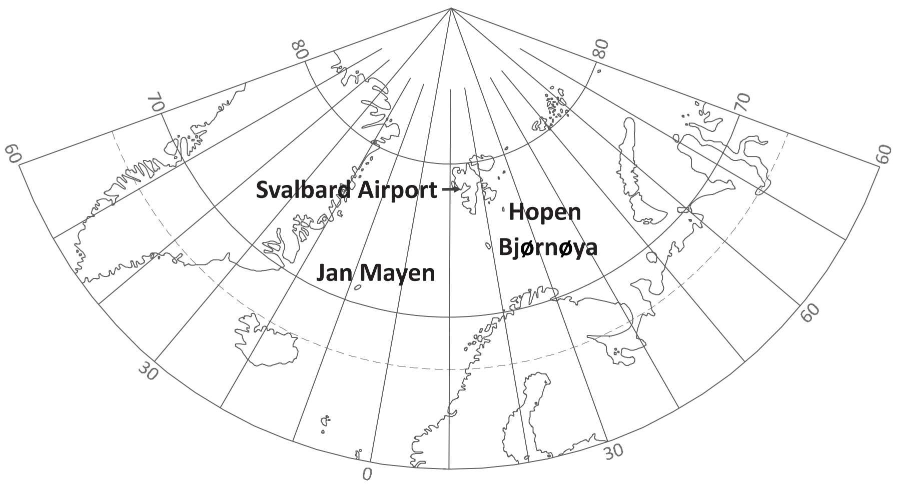

Fig. 1. Area of the study and location of the stations.

A basic condition in recognizing a winter as a coreless one is a simple formula: $t_{m-1} < t_m$ and $t_m > t_{m+1}$, where t is the monthly mean temperature while m-1, m and $m+1$ denote the previous month, the very month and the following month, respectively (Umemoto 1998). The occurrence and intensity of the CW can also be determined by a parameter of a coreless rate, c_r, which is defined as the ratio of the second, a_2, to the first, a_1, harmonic of the annual temperature wave (Allison *et al.* 1993; Wendler and Kodama 1993; Chen *et al.* 2010). A coreless rate $c_r > 0.25$ denotes a typical CW. First and second harmonics of annual temperature wave were found by least square data fitting to the model:

$$t_i = a_0 + a_1 \cos(2\,\pi\, i/12+c_1) + a_2 \cos(2\,\pi\, i/6+c_2),$$

where t_i is mean monthly temperature of month i (i = 1...12).

Table 1

Stations used in the study and available periods of data

Station name	Latitude	Longitude	Altitude (m a.s.l.)	Period (winters)	Missing data
Svalbard Airport	78.25°N	15.47°E	28	1957/1958–2010/2011	
Hopen	76.51°N	25.01°E	9	1946/1947–2010/2011	
Bjørnøya	74.52°N	19.01°E	16	1923/1924–2010/2011	1941/1942–1944/1945
Jan Mayen	70.93°N	8.67°W	10	1921/1922–2010/2011	

Both criterion of monthly mean temperature and coreless rate were used to identify CW in this study, however, stricter criterion for the c_r value was applied ($c_r > 0.3$).

Having recognized the CW at each station, the warm months within each indicated winter were separated from the previous and following cold months. Circulation patterns for both warm and cold episodes were analyzed. To this end, firstly the calendar of circulation types worked out by Niedźwiedź (2011), available since 1951, was applied. In the typology, 21 types of synoptic situations (circulation types) are distinguished, using synoptic maps of Europe and taking into account the direction of air masses advection as well as the kind of pressure pattern, *i.e.* cyclonic, anticyclonic. To find out which circulation types may contribute to the intra-winter warming, anomalies of the frequency of the circulation types was calculated separately for the warm months and for cold months preceding and following the warm-spells.

Furthermore, the synoptic conditions during coreless winters were identified using the sea level pressure (SLP) and air temperature from the level of 850 hPa geopotential height (Tz850). The daily gridded data were selected from the National Centres for Environmental Prediction (NCEP) – National Centre for Atmospheric Research (NCAR) reanalysis data (Kalnay *et al.* 1996).

Composite maps of the SLP means as well as anomaly maps of the SLP and Tz500 were constructed for the region 60–90°N latitude by 60°W–80°E longitude, separately for the mid-winter warm events and for the cold months before and after warming. Anomaly maps show the SLP differences between the selected weather situations and winter means (Birkeland and Mock 1996). This part of analysis was performed for the winters, which appeared to be coreless in at least two out of four analyzed stations, and only since 1951/1952. The total list of CW, with the indicated 11 seasons taken to the synoptic analysis, is given in the Table 2.

Furthermore, different pressure patterns were recognized among the days of mid-winter warming. To this end, the clustering techniques were applied to the standardized daily SLP data, to classify the days of mid-winter warm spells (Kalkstein *et al.* 1987). The Ward method (Ward 1963) chosen in this study and other clustering techniques have been used previously to identify the atmospheric

Table 2

Occurrence of the coreless winters during the studied period in all stations, marked with "+"; winters taken to the analysis of synoptic conditions marked in bold.

Year	Svalbard Airport	Hopen	Bjørnøya	Jan Mayen
1921/1922	no data	no data	no data	+
1923/1924	no data	no data	+	+
1925/1926	no data	no data	+	+
1926/1927	no data	no data	+	+
1927/1928	no data	no data	+	
1928/1929	no data	no data	+	+
1929/1930	no data	no data	+	+
1931/1932	no data	no data	+	
1932/1933	no data	no data	+	+
1945/1946	no data	no data		+
1946/1947	no data	+	+	+
1947/1948	no data			+
1948/1949	no data	+	+	+
1949/1950	no data	+		+
1955/1956	no data	+	+	
1963/1964			+	
1968/1969	+	+	+	
1971/1972	+	+	+	+
1973/1974	+	+	+	+
1975/1976		+	+	
1983/1984	+	+	+	+
1984/1985	+			
1989/1990	+	+	+	+
1990/1991	+	+		+
1995/1996		+	+	
1999/2000	+			
2004/2005	+	+	+	+
2005/2006				+
2006/2007	+	+		
2007/2008				+
2008/2009	+			
Total	11	14	20	20

circulation patterns associated with the occurrence of specific weather phenomena (*e.g.* Birkeland and Mock 1996; Esteban *et al.* 2005; Bednorz and Fortuniak 2011). The composite SLP contour maps and Tz850 anomaly maps were constructed for each distinguished group.

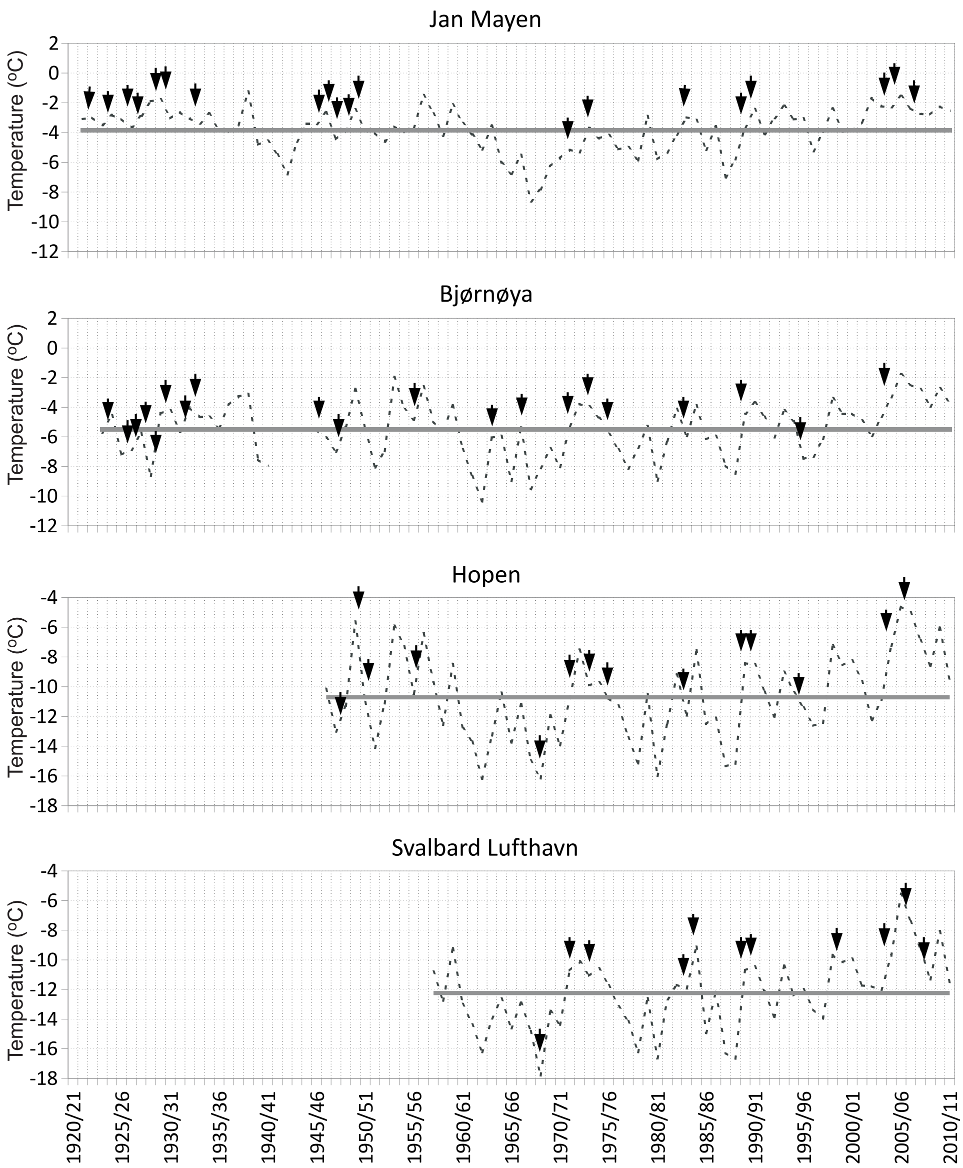

Fig. 2. Multiannual course of winter (November–April) mean air temperatures (dashed line) with the mean for the entire analyzed period marked with solid line. For example winter 1920/21 means period between November 1920 and April 1921. Coreless winters indicated with arrows.

Results

According to the different length of the available data period, 11 to 20 CW were identified in analyzed stations, using the criteria described in the previous chapter (Table 2, Fig. 2). No trend of the frequency of CW occurrence could be detected.

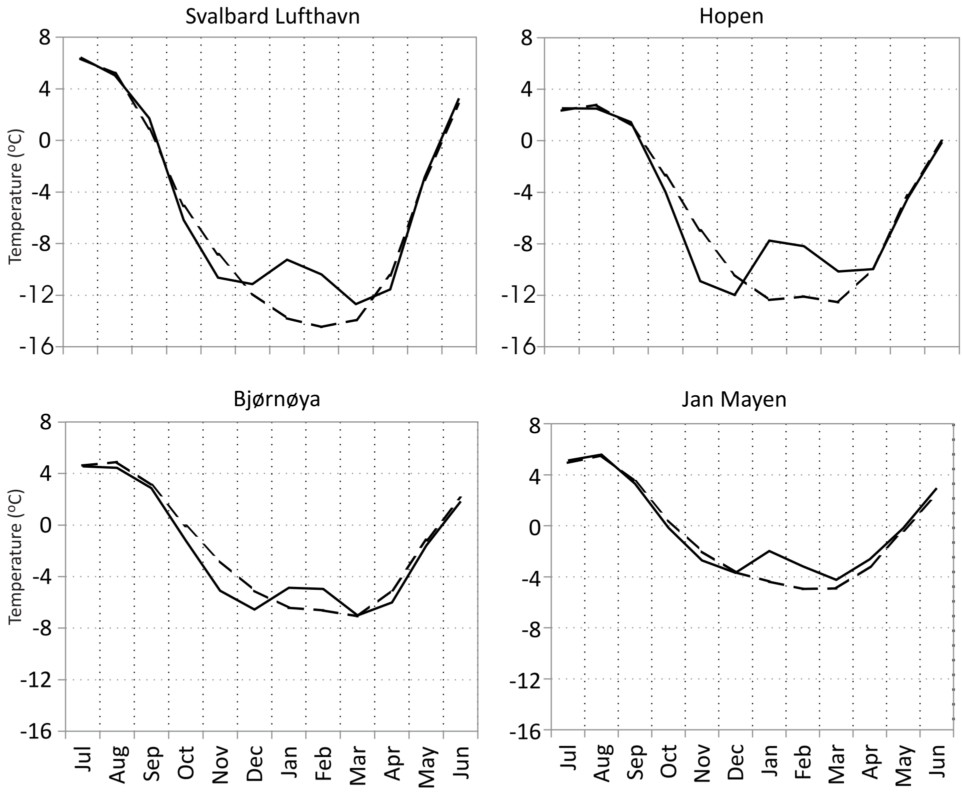

Fig. 3. Mean annual course of the air temperature for the entire period of study (dashed lines) and for coreless winters (solid lines).

However, they occur mostly in the warmer époques, as winters not having the cold core usually tend to be warmer, by their nature. The mean temperature course for CW show more rapid, than normal temperature drop in autumn, in comparison to multiannual average course, with the annual minimum value in November–December. The November temperature averaged for CW can be even more than 4°C lower, than the multiannual average for this month, like in the case of Hopen (Fig. 3). After a rapid autumn cooling, a temperature increase is observed in mid-winter months. The warming is most spectacular in January and February, when the average temperature increase exceeds 4°C like in Hopen (Fig. 3). In particular winters, it may increase even by more than 10°C. Afterwards, usually in March, just before the beginning of the polar day, a secondary decrease in the surface temperature occurs. Such dramatic warming, occurring from time to time in the middle of winter, may influence the average multiannual temperature pattern, expressing itself as a secondary small wave in February (Hoppen). The annual temperature patterns in stations with mild oceanic climate (Jan Mayen, Bjørnøya) characterizes with low annual temperature range and show smaller secondary temperature waves during CW.

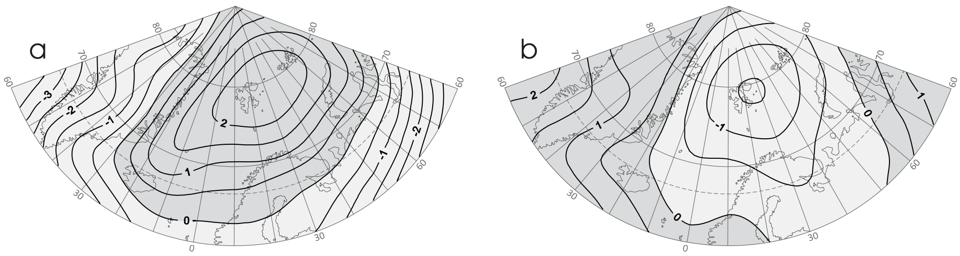

Fig. 4. Anomalies of the air temperature at 850 gpm (in degrees), a – for mid-winter warm spells during coreless winters; b – for the cold months preceding and following the mid-winter warm spells (positive anomalies shaded dark grey, negative anomalies shaded light grey).

Anomaly maps of Tz850 were constructed, separately for the months of mid-winter warm spells and for the cold months preceding and following the warm-spells (Fig. 4). The 850 hPa level is roughly at 1500 m above the atmospheric boundary layer and much lower (about 1250 gpm) over the polar regions boundary layer. At this height, there is no impact of the underlying surface on the temperature and therefore, Tz850 is often used to distinguish cold and warm air masses, which are affected only by the air circulation.

During the warm spells the positive temperature anomalies spread over the entire North Atlantic sector of the Arctic, covering eastern Greenland, Iceland, northern Scandinavia and reaching northern ridges of east Europe (Fig. 4a). Anomalies of more than 1° are observed over all analyzed stations and the centre of positive anomalies with the values exceeding 2° drops right over the area around the Spitsbergen Island. The rest of the studied area experiences the negative Tz850 anomalies which increase towards the southwest and southeast. The opposite pattern of Tz850 anomalies can be observed during the cold months of CW winters (Fig. 4b).

Circulation is the main factor explaining the Tz850 layout during the warm and cold months of CW. During the warm spells, the higher-than-normal frequency of cyclonal circulation types bringing air masses from the southern sector (SEc, Sc, SWc) appear by over 15% more frequently than average. At the same time, northern and eastern antycyclonal types (Na, NEa, Ea) are less frequent (by about 10%, see Fig. 5). Decrease of temperature during cold months are related mainly to higher by 10–15% frequency of northern and eastern cyclonic types (Nc, NEc, Ec). It suggests, that the cyclonal activity is the main factor causing temperature changes during the cold season in the polar regions. The position of the cyclonal centres and in consequence the direction of airflow have an impact on the pattern of the temperature layout and its changes in winter.

As circulation factors are supposed be the main reason for the anomalous pattern of the winter temperature, the average pressure fields and their changes during the eleven CW, selected according to the criterion given in the previous chapter, were analyzed.

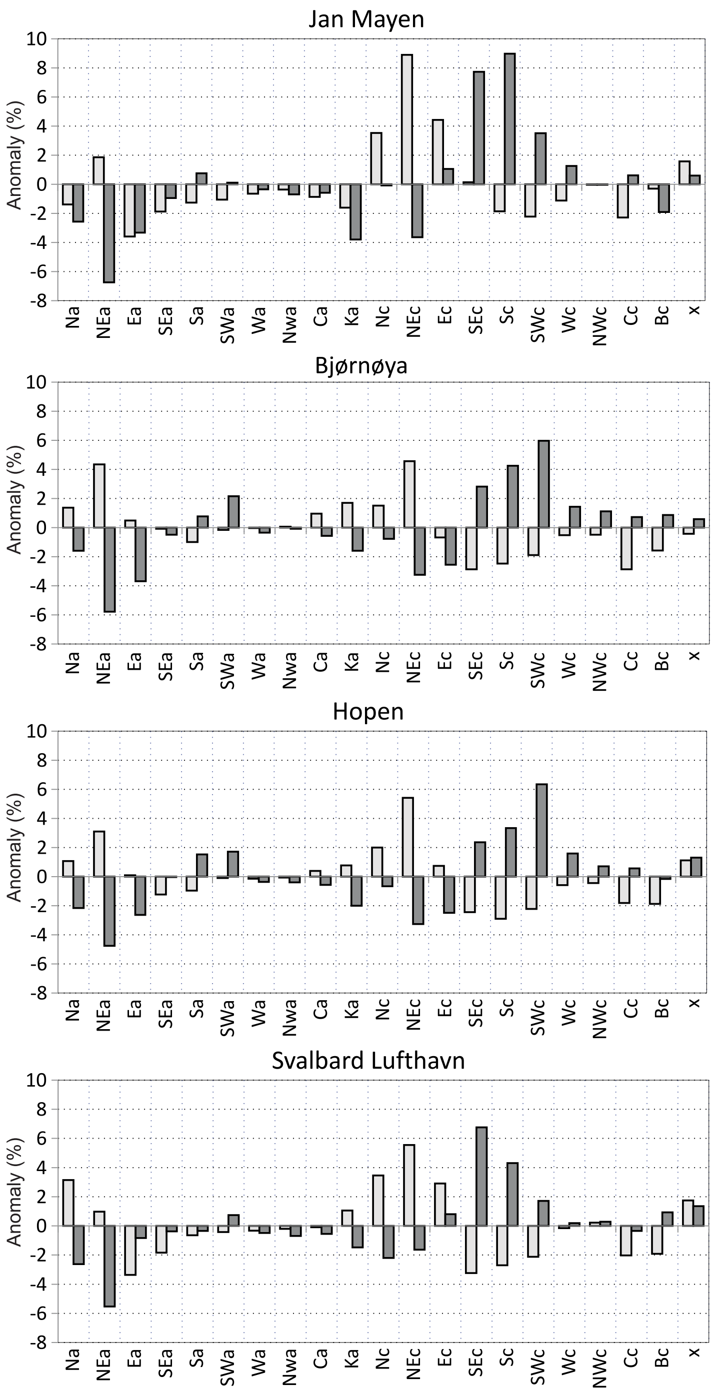

Fig. 5. Anomalies of Niedźwiedź's (2011) circulation types frequency in mid-winter warm spells during coreless winters (dark grey shade) and in the cold months preceding and following the mid-winter warm spells (light grey shade).

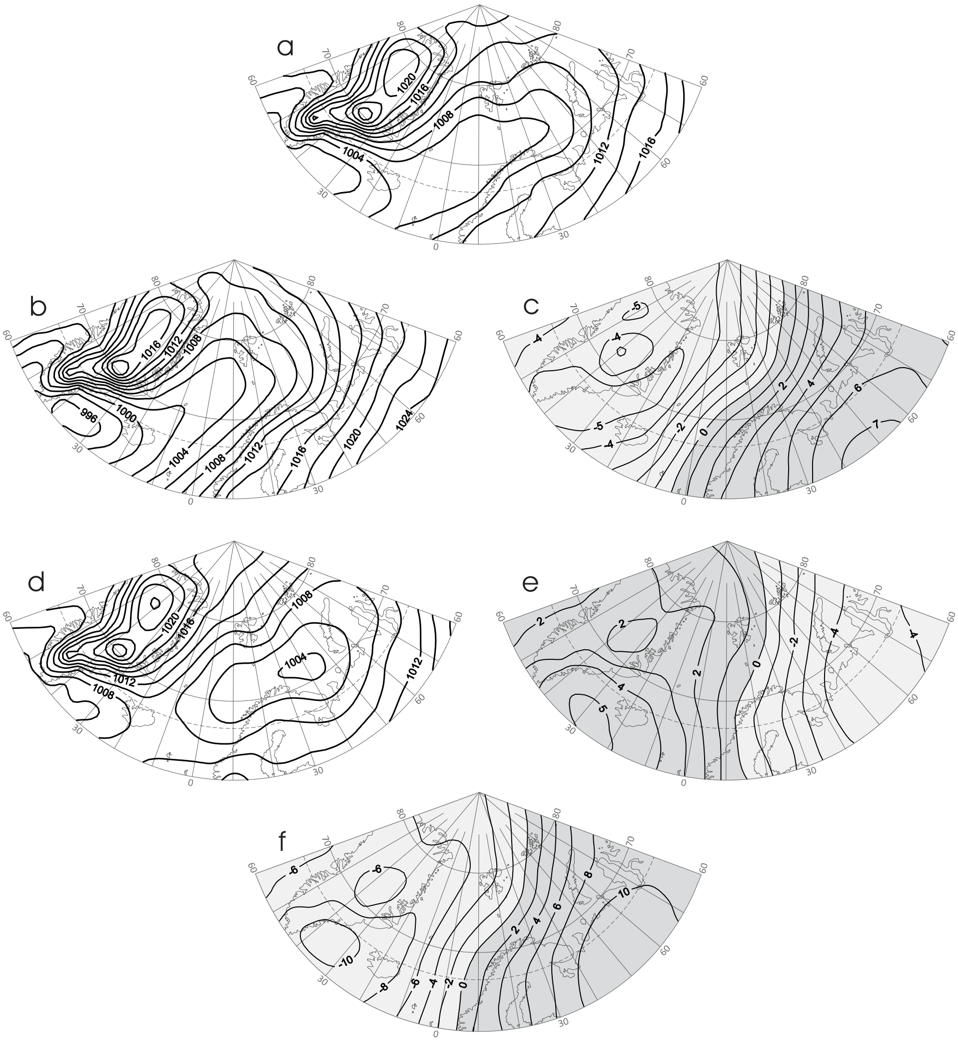

Fig. 6. Sea level pressure patterns in hPa; a – mean for winter seasons 1950/1951–2009/2010; b – composite map for the months of mid-winter warm periods; c – anomaly map for the months of mid-winter warm periods; d – composite map for the cold months preceding and following the mid-winter warm spells; e – anomaly map for the cold months preceding and following the mid-winter warm spells; f – difference between mid-winter warm periods composites and cold months composites. At anomaly maps positive anomalies shaded dark grey, negative anomalies shaded light grey.

The pattern of the mean SLP in winter shows two main centers in the Atlantic sector of the Northern Hemisphere (Fig. 6a). One of them is the constant Greenland High with the pressure of approximately 1020 hPa in the centre. The other one is the Icelandic Low, located southwest to Iceland, with the pressure of about 1000 hPa in the centre, which spreads to the northeast and forms a wide through over the Northern Atlantic. There is a big pressure gradient between the aforementioned

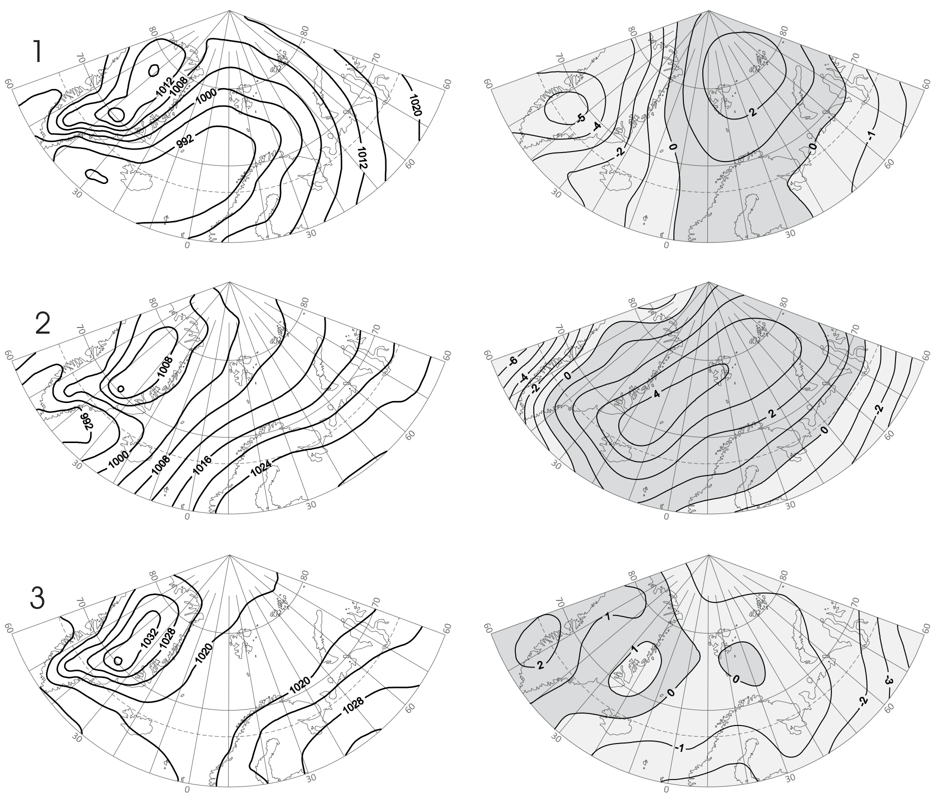

Fig. 7. Three circulation types distinguished among the days of mid-winter warm spells, using the clustering techniques (explanation in the text). The left column – the pattern of the sea level pressure (in hPa); the right column anomalies of the air temperature at the level of 850 gpm (in degrees). At anomaly maps positive anomalies shaded dark grey, negative anomalies shaded light grey.

baric centers. A smaller pressure gradient is observed towards the northeastern Europe where the SLP increases gradually.

The composite map and the anomaly map of the SLP were constructed for the warm mid-winter months of CW (Fig. 6b, c). Map b in Fig. 6 shows stronger-than-usual Icelandic Low, possibly the positive phase of NAO. The area of lower-than-normal SLP encompasses most of the North Atlantic, particularly in the western part, where anomalies amount to -5 hPa (in the area between Greenland and Iceland). At the same time, positive SLP anomalies (up to 7 hPa) are observed in the southeast, which indicates a stronger-than-usual high pressure system developed over the continental Europe. Consequently, the air circulation during the warm mid-winter events is characterized by a strong southwesterly flow component, in contrast to the average winter circulation over the North Atlantic. Stronger-than-usual air flow from the southern quadrant brings about warmer-than-usual air masses over the European sector of the Arctic, causing a significant mid-winter warming.

Quite different synoptic situations underlie the cold months preceding and following the mid-winter warm spells. In the contour map of SLP, constructed for the cold months, the North Atlantic cyclone is shifted to the east, and its centre locates over the Barents Sea (Fig. 6d). The low pressure system is vast, but not very deep and covers the region of negative SLP anomalies, which encompasses the south eastern part of the studied area (Fig. 6e). The pattern of the SLP anomalies in cold CW month is right opposite to the one occurring in the warm months. Strong positive SLP anomalies (up to 5 hPa) appear southwest to Iceland, which indicate weakening of the Icelandic Low. This would suggest the negative phase of the North Atlantic Oscillation (NAO), although, the map does not reach the opposite NAO centre over Azores. Such pressure pattern at the sea level implies the northern and northeastern flow, which brings cold Arctic air to the North Atlantic.

Presented maps prove that winter cyclonic activity in the polar regions explains and determines the occurrence of CW. The main factor for a constant warming in middle of winter is the air circulation, which is determined by the position of the low pressure systems. If a particular shift of the pressure patterns takes place during a cold season, it results in a temperature increase. This shift is shown in Fig. 6f, where the pressure difference between warm and cold months of the selected winters is depicted. It may be assumed, that after the cold months the Icelandic Low gets deeper by more than 10 hPa in the center and it spreads widely over the western part of the North Atlantic. At the same time, the continental anticyclone over northern Europe strengthens by 8–10 hPa, forming a blocking system, which pushes the Icelandic Low to the west. The backward change of the SLP layout brings back the cold weather and the secondary minimum of the surface temperature annual course.

Obviously, the composite maps usually average together a wide range of conditions. Therefore, an attempt was made to classify the pressure patterns occurring during the mid-winter warm spells in the European sector of the Arctic. The days of the mid winter warm spells were clustered basing on the standardized SLP data, into three relevant groups, representing three different pressure patterns. Composite maps of each group were constructed both for the SLP and for the Tz850 anomalies (Fig. 7). In the three obtained types, the SLP patterns differ by the location and intensity of the pressure centers. In type 1, the Icelandic Low is much deeper than usual less than 990 hPa in the center, shifted to the northeast in comparison with the average position, and therefore, extended to the entire Euroatlantic sector of the Arctic. A high pressure gradient over the studied area indicates a very strong southeastern airflow, which brings warm air masses over the three northernmost stations: Svalbard Airport, Hopen and Bjørnøya. Positive anomalies of Tz850 are noted there, while Jan Mayen experiences negative temperature anomalies, due to northeastern flow dominating over the island.

In type 2, the north European anticyclone is much stronger than usual with the SLP positive anomalies exceeding 14 hPa over Scandinavia. The western cyclones form a narrow trough of low pressure spreading along the eastern coast of Greenland, which may be a track of cyclones moving northward through the Fram Strait. Again, a high pressure gradient causes a very intensive airflow over the North Atlantic. Southwestern air masses flow over the Jan Mayen and the Svalbard Archipelago, causing the substantial increase in the air temperature, exceeding 4° (Fig. 7). Among the days of warm spells there are also the least numerous ones with quite different circulation conditions, *i.e.* with positive SLP anomalies and a very small pressure gradient over the entire Euroatlanic sector of the Arctic (type 3 in Fig. 7). Such pressure field results in a very weak eastern airflow, therefore the Tz850 anomalies are very small. Concluding, the majority of the daily circulation patterns among the warm-spell days, are characterised by a high-pressure gradient that causes a very intense airflow from the southern quadrant over the North Atlantic.

Discussion and conclusions

The temperature fluctuations in the Arctic, particularly in winter, when there is no inflow of solar irradiation, are controlled mainly by the atmospheric circulation (Alekseev *et al*. 1991, cited in Przybylak 2000). Over the Atlantic sector of the Arctic, intense cyclonic activity and changes in the extension of air masses, originating from the northeast and southwest, causes a great variation in the weather and in temperature conditions (Steffensen 1982; Nordli 1990; Førland *et al*. 1997). In the same way, the occurrence of coreless winters in the European sector of the Arctic seems to be highly controlled by the air circulation, what has been proved already for the single station in the central Spitsbergen (Bednorz and Fortuniak 2011). The air circulation is a consequence of pressure patterns over the North Atlantic and Eurasia. Therefore, the position, extension and intensity of the large scale atmospheric systems are of crucial importance for controlling the temperature field in winter months over the Atlantic sector of the Arctic.

The main centre of action is the area of intense cyclogenesis related to the Icelandic Low. A change in the position of the latter and in the consequence a change in the cyclone track over the North Atlantic may completely alternate the direction of the airflow to the European sector of the Arctic and in consequence may cause a dramatic change in the air temperature.

During the cold months preceding and following the warm mid-winter events, the North Atlantic low is weaker than usual and it spreads to the east, having a centre located over the Barents Sea. Such pressure pattern causes the inflow of air masses from the northern quadrant, which brings cold air of northernmost origin and contributes to an essential drop in the air temperature in the analyzed islands. Quite different circulation conditions appear when the Icelandic Low gets deeper-than-usual and it is pushed to the east by the blocking system on an intense European anticyclone. The track of the Northern Hemispheric westerlies is modified, *i.e.* shifted to the north, so that they transport sensible heat poleward.

The same winter cyclonal "centres of action", *i.e.* areas of intensive cyclogenesis were indicated by Serreze and Barry (1988), Serreze *et al*. (1993) and Rogers *et al*. (2005). One of the centers is located southwest of Iceland and commonly known as the Icelandic Low, the other one located over the Barents Sea. Their influence on the winter temperature variability is essential, however, they do not play alone, as their position and extent is modified by the range and intensity of anticyclones over the continent of Eurasia. The high pressure areas work as blocking systems and push the cyclone track poleward through the Greenland Sea and Fram Strait. Therefore, while strong Northern Hemisphere blocking systems cause negative temperature anomalies in the middle latitudes, they bring positive temperature anomalies in the high latitudes and contribute to the occurrence of CW (Dole and Gordon 1983; Colucci 1985; Knox and Hay 1985; Umemoto 1998).

It was proved is the study, that synoptic activity that forces the air circulation has major impact on the occurrence of winter temperature extremes in the maritime polar climate of the European sector of the Arctic. It is opposite to the continental climate of the interior of Antarctic or in the northern Asia, where the constant anticyclones prevail in winter. In the stable boundary layer conditions with the temperature inversions, persisting in winter, the mid-winter increase in the surface temperature, which is typical feature of CW, may be caused rather by a flux of long wave radiation from the upper layer or by the mountain waves of the high speed, which mix the upper (warmer) air masses with the lower, primarily colder ones.

The further discussion on coreless winters and their reasons seems to be essential and may contribute to the discussion on the contemporary warming observed in recent years in the Arctic, which expressed itself in the increase in winter temperature, up to approximately 5°C during the past three decades (Rogers *et al*. 2005). It was proved in the study, that the atmospheric circulation is the main reason for the temperature fluctuation in the European sector of the Arctic in the winter season. Consequently, changes in the position, extension and intensity of the large scale atmospheric systems, mainly the Icelandic Low, strongly modifying the track of the northern hemispheric westerlies, should be concidered as the direct reason of warming processes in the Arctic.

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