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RECESSION OF KAFFIØYRA REGION GLACIERS, OSCAR II LAND, SVALBARD

Abstract: The main aim of this research was to describe the course of the glacier retreat in the Kaffiøyra Region, starting from the maximum advance of the glaciers to the year 2009. From maps and archival data as well as the results of the field measurements and GPS measurements carried out in the years 1977–2009, the authors present the retreat histories for six glaciers. The smallest retreat was recorded for Waldemarbreen (8 m a^{-1}), while Elisebreen retreated at the fastest rate of 18 m a^{-1}. Since 1909 the area of Kaffiøyra glaciers has decreased by 37% on average. The smallest change was recorded in the case of Irenebreen and Waldemarbreen, while the largest was in the case of Oliverbreen and Einvindbreen. As the analysis of the glacier extension in the valley areas of the Kaffiøyra Region indicates, all of them have been in the same recession stage since 1909.

Key words: recession, area changes, glacier, Svalbard

Introduction

The recession of glaciers is an important indicator of climate changes. The extent of glacier recession and the changes to their areas result from many processes connected with the changes in the glacier mass balance and the dynamics of ice.

The Little Ice Age, the cooling of the climate of the northern hemisphere, was recorded in Europe from about the 16th century to the 19th century.

However, in Northern Europe, and especially in some areas of Svalbard, the Little Ice Age lasted until the beginning of the 20th century. During this period both the areas and the lengths of glaciers grew. Since the end of the Little Ice Age the climate warmed, which led to the recession of glaciers. In Svalbard the beginning of this recession took place in the years 1880–1915 (Lefauconnier and Hagen 1991).

The changes in the position of the tongues of the glaciers on Oscar II Land in the Kaffiøyra area, which took place between 1909 and the present, are described. Changes in glacier geometry are predominantly influenced by mass balance, directly by the changes in glacier thickness and, indirectly, by the dynamics of the glacier. This is why the studies of mass balance changes are a crucial element of research on glacier recession. The ongoing studies on the recession of glaciers in the Kaffiøyra Region thus constitute an element of investigation into modern changes in the cryosphere of this area.

The changes in the geometry of Svalbard glaciers, mainly their recession and decreasing area, have been studied by numerous scientists (Bamber et al. 2005; Hagen et al. 2005; Puczko et al. 2006; Nuth et al. 2007, 2010; Rachlewicz et al. 2007; Zagórski et al. 2008a, b; Błaszczyk et al. 2009). Detailed studies of the recession of Kaffiøyra glaciers were also conducted and later described by Lankauf (1982, 1997, 2002, 2005), as well as by Bartkowiak et al. (2003) and Sobota (2007a, d, e).

Methodology

The main factor that causes the recession of glaciers is climatic change, especially climate warming. The size of the recession is also influenced by the orography of the area, the development of glacier valleys, exposition of individual glaciers, shadowing by mountain walls, as well as by the very size of a glacier and the coverage of the glacier tongue by moraine material.

The attempt to assess the changes in the tongues of Kaffiøyra glaciers and all the calculations were based on the cartographic method. The maps we used (incl. Isachsen 1912; Zapolski 1977 and the maps by Lankauf (2002)) were made between 1909 and 2000. The history of the cartographic representation of Spitsbergen, with particular reference to the area of Oscar II Land and the Kaffiøyra Region, and the possibilities of using aerial photographs and thematic maps, especially geologic and geomorphologic ones in relation to glacier fluctuations, were discussed in "Recession of Kaffiøyra

Region glaciers (Oscar II Land – Spitsbergen) in 20th century*"* (Lankauf 2002). The main sources of methodological data and cartographic materials are presented in Table 1.

Table 1. The main sources of methodological data and cartographic materials

Year of analysis	Source	Published
1909	*Mapa-Spitsberg (Partie Nord-Quest)*, 1:200 000 scale. All the glaciers of studied area were demonstrated for the first time.	Isachsen 1912
1936	The Norwegian archival topographical map 1:100 000 scale, depicting the state of glaciers in 1936.	1950s
1938	The results of investigations carried out by the Polish Glaciological Expedition in 1938.	Klimaszewski 1960
1966, 1969, 1990	Norwegian aerial photographs of 1966,1969 and 1990, as well as tables based upon these photographs or the maps mentioned beforehand.	
1975	*Marginal zone of the Elise Glacier.* Map 1:5 000 scale.	Zapolski 1977
1978	*Waldemar Glacier*. Topographical map 1:5 000 scale.	Lankauf 1982
1909–2000	**Recession of Kaffiøyra Region glaciers (Oscar II Land – Spitsbergen) in 20th century.**	Lankauf 2002
1977–2009	**The investigation results obtained and field measurements performed by the authors in 1977–2009.**	

In the years 2000–2009 GPS measurements were also taken. Clear delimitation of the range of the glaciers was possible thanks to the optical differentiation of the areas of uncovered glacier and the areas covered with moraine which ended with a clear edge or were cut off by the bed of the outflow stream (Bartkowiak et al. 2004). It was a conscious decision to exclude the large area of ice 'masked' with moraine and partly fed or only connected with the active part of the tongue of a glacier. The measurements were made with the use of the WGS84 system in accordance with the UTM Zone 32.

The front position of the tongue of a glacier was mainly calculated using Forel's method (1895). The distance and direction from fixed positions in the glacier forefield to the ice front are measured in meters and can be

compared with the values from previous years, increasingly by means of universal surveying instruments and global positioning systems. The percentage area changes quoted were relative to the 1909 map (Isachsen 1912), which was used as the basis for initial areas.

Study Area

The total area of Oscar II Land is 2 582 km^2, of which about 1 600 km^2 is glaciated. Glaciers cover almost 70% of the total area. The center of glaciation in Oscar II Land is Plateau Løvenskiold. In total, Oscar II Land has 51 glaciers which are over 1 km^2.

The studied glaciers are located in the northern part of Oscar II Land, adjacent to Kaffiøyra (Fig. 1). Kaffiøyra is a coastal lowland situated on Forlandsundet. To the north it is bordered by Aavatsmarkbreen, which terminates in Hornbaek Bay, and to the south by Dahlbreen and a bay of the same name. The area of Kaffiøyra is about 103 km^2.

Waldemarbreen is about 3.3 km long and has an area of 2.5 km^2. The ice originates in one cirque and flows from an elevation of more than 500 m to the present terminus at 150 m a.s.l. (Table 2).

Irenebreen is a valley glacier of 4.1 km^2 located to the south of Waldemarbreen. It is about 4 km in length, while its width ranges from about 1 km in its frontal zone to about 1.5 km in the eastern section. Irenebreen has two significant accumulation zones. Ice masses flowing from them join into a glacier tongue which moves to the south-west and ends on Kaffiøyra.

The area of Elisebreen is 10.2 km^2; it is over 6 km in length, while its width is up to 1.8 km. To the north lies Agnorbreen, which is often treated as part of Elisebreen (Table 2). The glacier to the north borders with the ranges of Prinsesserygen and Prins Heinrichfjella, and to the south with the ranges of Jarlsbergryggen, Kysa and Askerfjellet. To the east the glacier is connected with Løvenskiold Plateau. The altitude of the front of Elisebreen is about 30–60 m a.s.l.

Eivindbreen flows to the SW, through a 4 km long and 750 m wide valley. The area of Eivindbreen is estimated to be 1.9 km^2 with a length of 3.2 km, while its width ranges from approximately 250 m at the front to 500–700 m farther towards the east.

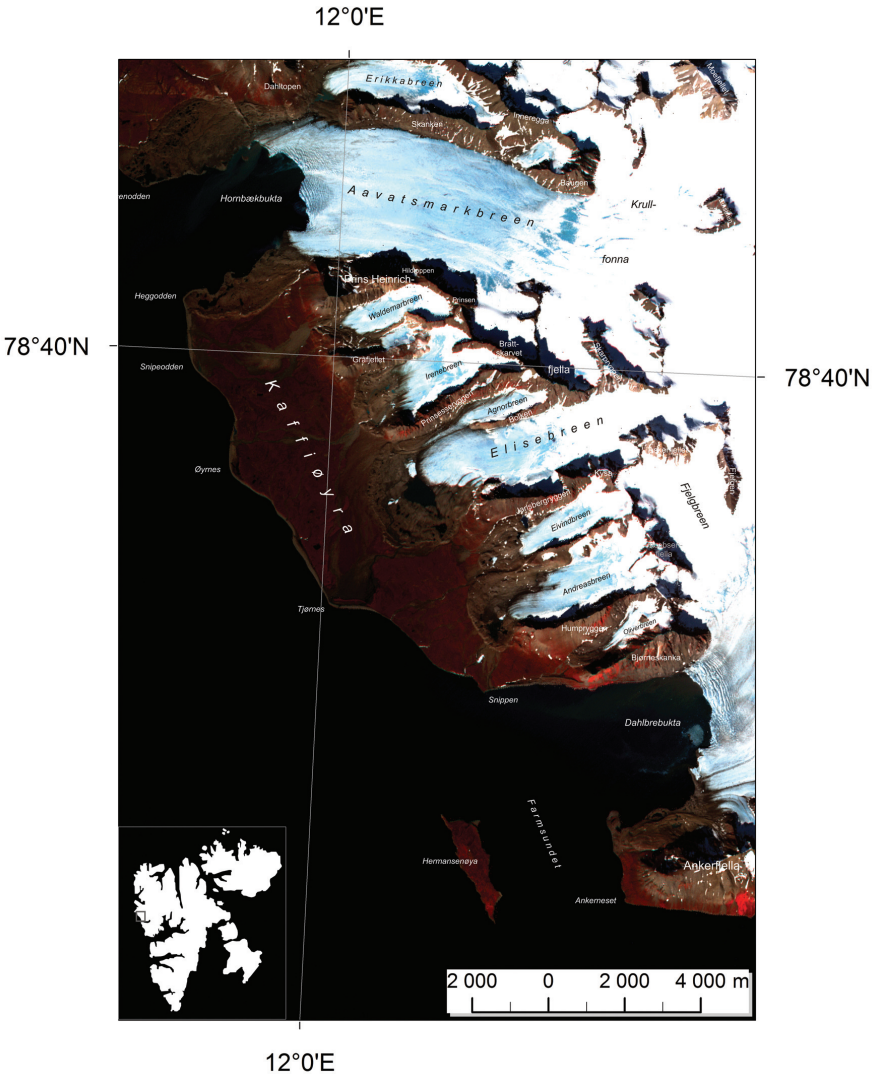

Fig. 1. Location of Kaffiøyra Region glaciers. Based on a map in Król and Ćmielewski (2010)

Andreasbreen covers an area of 4.7 km^2. The glacier is about 4 km long and its width reaches nearly 0.8 km at the front, and approximately 1.5 km farther towards the east.

Table 2. Summarized data of Kaffiøyra Region glaciers

Name	Area [km^2]	Width [km]	Length [km]
Waldemarbreen	2.5	0.7–1.3	3.3
Irenebreen	4.1	1–1.5	3.9
Elisebreen	10.2	1.2–1.8	6.3
Eivindbreen	1.9	0.2–0.7	3.2
Andreasbreen	4.7	0.8–1.5	3.9
Oliverbreen	1.9	0.1–0.7	1.6(2000)

Oliverbreen has an area of 0.9 km^2 (2000). The glacier runs down through a valley slightly over 2 km in length and 850 m wide. The glacier is about 1.6 km long, and its width ranges between several metres and 100 m at the front (Table 2).

Results

Waldemarbreen

In the 27 years between 1909 and 1936 Waldemarbreen retreated only by about 50 m and lost 0.14 km^2 (i.e. 4%) of its area. However, the position of the tongue of the glacier visible on a satellite image taken in 1966 shows a significant recession of the glacier tongue. It is estimated to be over 400 m along the valley axis, i.e. in the most advanced part of the tongue, and much smaller in the other sections of the glacier. Since then the glacier has been retreating rather steadily, but the rate of retreat has increased recently (Fig. 2).

The tongue of the glacier has retreated over 750 m since the beginning of the process. Over this time the area of the glacier decreased by almost 1 km^2, i.e. by 29%. Starting in 1909, the glacier was receding by 8 m a^{-1}, while in the years 1995–2009 it accelerated to 10 m per year and in the years 2000–2009 to 11 m a^{-1}. This process proves that the the glacier recession has

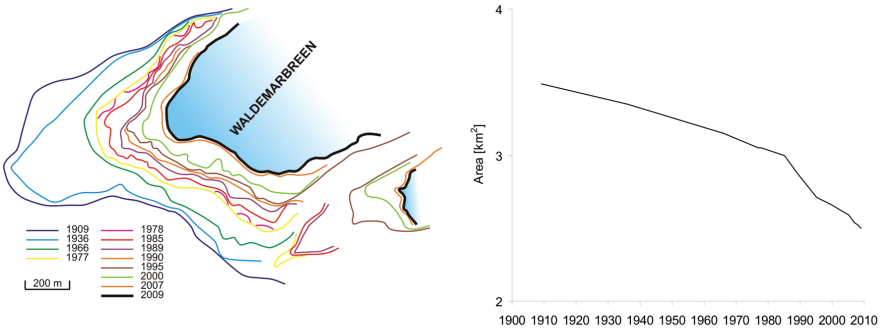

Fig. 2. Recession and area changes of Waldemarbreen in the period from 1909 to 2009

Fig. 3. Waldemarbreen in 1978 (photo by K.R. Lankauf) and in 2006 (photo by I. Sobota). Frames on fotos denote the same area

intensified recently (Fig. 3). In relation to the maximum advance in the years 1995–2000, the glacier area decreased by 1.4%, while in the years 2000–2009 the process was more intensive and the area decreased by 4.7%.

Irenebreen

At its maximum, Irenebreen advanced further than Waldemarbreen in relation to the mountain ridges: down to about 60 m a.s.l. The low location of the tongue of the glacier probably significantly influenced the recession (Lankauf 2005). Between 1909 and 1936 a recession took place, which led to a withdrawal of the tongue of the glacier by almost 400 m. This recession amounted to 0.45 km^2, i.e. 8.5% of the area of the glacier (Fig. 4).

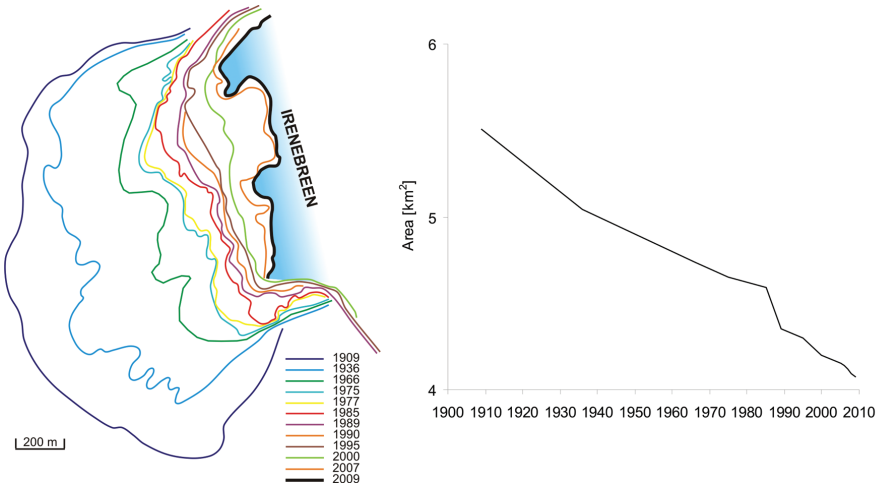

Fig. 4. Recession and area changes of Irenebreen in the period from 1909 to 2009

In the following years, the recession of the glacier proceeded at a similar rate with no sudden events. In the years 1909–1995 Irenebreen lost 22% of its area in relation to its maximum extent, and the tongue of the glacier retreated across its entire width, by almost 1200 m (Lankauf 2002). By 2009 the recession increased to about 1300 m. The average retreat rate of Irenebreen throughout the entire analyzed period was 13 m a^{-1}.

Between 2000 and 2009 the tongue retreated by 90 m and the area of the glacier decreased by 2.3% in relation to its maximum advance (Fig. 4). Such a significant level of recession was partly due to a large loss of ice in the central part of the glacier tongue (Fig. 5). This is also the part of the glacier which had a high negative mass balance (Sobota 2005, 2007a, b, c, d).

Elisebreen

In 1909 Elisebreen had a wide, flat tongue accompanied by a complex of moraines. A long profile of the glacier from that time shows that it had an evenly ascending area, which is proof of either a thinning or a recessing or a stagnating phase (Lankauf 2002, 2005). In the years 1909–1936 the tongue of the glacier was convex although it retreated by 125 m. It was found that in the tongue part of the glacier its mass increased, sometimes by as much as 50 m (Lankauf 2002). This means that in the years 1909–1936, apart from

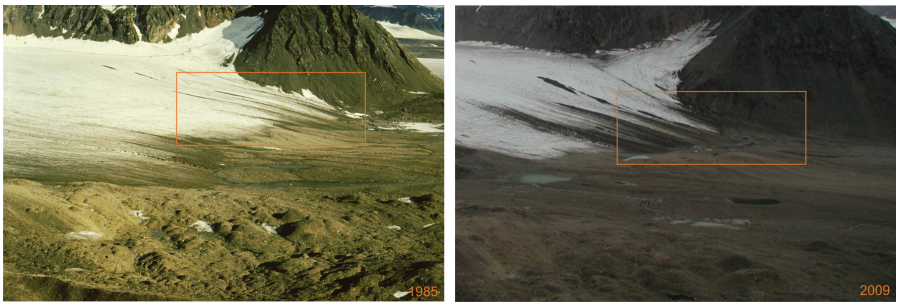

Fig. 5. The tongue of Irenebreen in 1985 (photo by K.R. Lankauf) and in 2009 (photo by I. Sobota). Frames on fotos denote the same area

Fig. 6. The tongue of Elisebreen in 2009 (photo by I. Sobota)

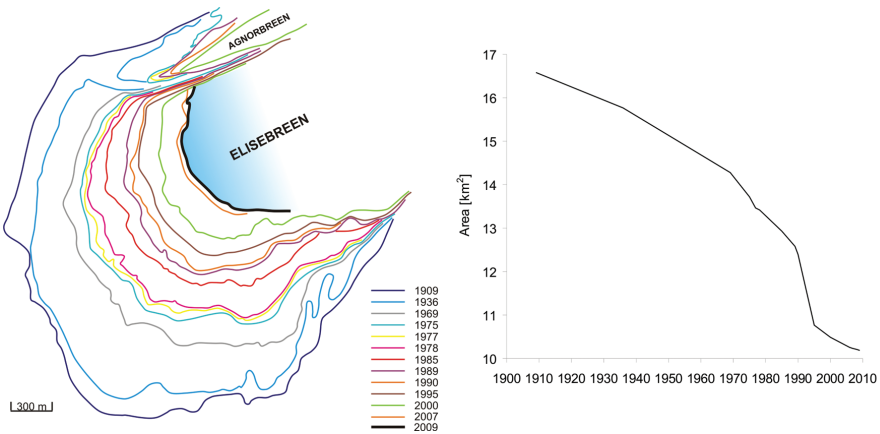

Fig. 7. Recession of Elisebreen in the period from 1909 to 2009 (from 1995 the area of the glacier does not include Agnorbreen)

a recession of the tongue of the glacier and a lowering of its northern section, there was a general increase in the mass of the glacier moving towards the tongue. The area of the glacier decreased by almost 5% (Fig. 7).

Between the time of its maximum extent and 1995 the glacier decreased by 4.4 km^2, i.e. by 28%, and the front of the glacier retreated by 1400 m (Lankauf 2005).

From 2000 to 2009 Elisebreen (Fig. 6) continued its recession, which amounted to 252 m, i.e. 28 m on average per year (Fig. 7). The area of the glacier decreased by 1.8% in this period relative to its maximum advance, and the retreat was about 1800 m (18 m a^{-1}). The intensive recession of this glacier is also confirmed by the mass balance measurements (Sobota 2007c, d), which show consistently negative net mass balance, especially in the front part.

Eivindbreen

Between 1909 and 1936 Einvindbreen decreased by 19%, while between 1936 and 1985 the recession was 1.1 km^2, i.e. 28% in relation to the initial area (Fig. 8).

Fig. 8. The southern part of tongue of Einvindbreen in 1985 (photo by K.R. Lankauf) and in 2009 (photo by I. Sobota). Frames on fotos denote the same area

From the beginning of its retreat to 2009 the area of Eivindbreen decreased by 2.2 km^2, while the recession amounted to over 1100 m (Figs. 8, 9). The most rapid retreat rates occurred at the beginning when the thin tongues surrounding the dividing ridge were melting out. After 1985, the retreat is similar to those of other Kaffiøyra Region glaciers. In the years 2000–2009 the area of the glacier decreased by 0.04 km^2, which was 1% in relation to its maximum advance. At that time the size of the recession of tongue of the glacier amounted to 53 m, i.e. 6 m a^{-1}. From 1909 the area of Eivindbreen decreased by nearly 54%.

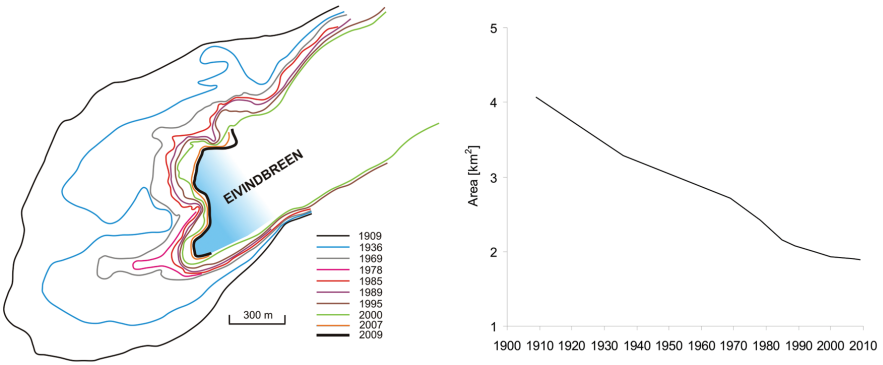

Fig. 9. The recession of Einvindbreen from 1909 to 2009

Andreasbreen

The glacier recession understood as the retreat of the front of the glacier began slightly later than in the case of the other Kaffiøyra Region glaciers. In 1909 the tongue of Andreasbreen apparently extended high above the massive ice-cored front moraine created on the marine terraces at altitudes of 30 m and 40 m (Lankauf 2005). This first stage of the retreat meant mainly the lowering of the surface of the glacier with comparatively small frontal retreats.

From 1909 to 1995 Andreasbreen lost nearly 26% of its initial area and its tongue retreated by about 800 m (Lankauf 2002). The tongue recession took place later than in the case of the other Kaffiøyra Region glaciers. Between 1969 and 1995 the intensity of the recession was variable, but the area of the glacier was systematically decreasing (Fig. 10). In the years 1995–2009 there was a particularly significant decrease in the area of the glacier in relation to its maximum advance, reaching 14.3%; in the years 2000–2009 it decreased by as much as 4.1% (Figs. 10, 11). It is also characteristic that this data mainly refers to the northern section of the tongue of the glacier. From 1909 the area of Andreasbreen decreased by 40% and it retreated by over 1170 m (12 m a^{-1}).

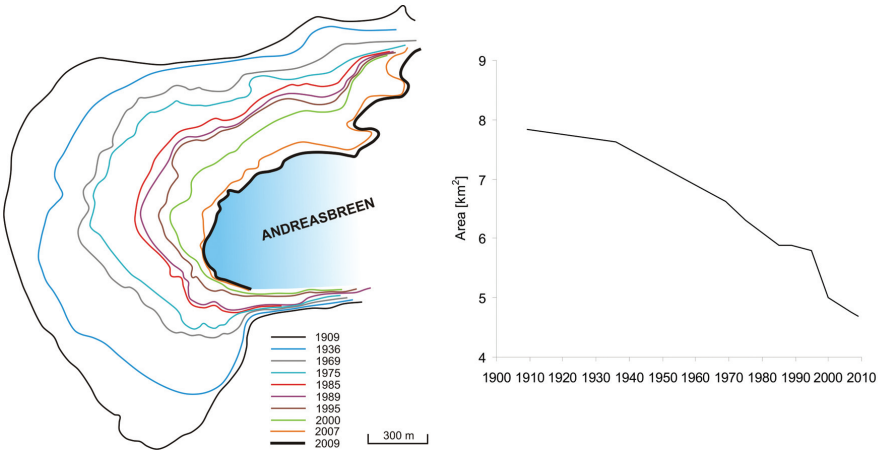

Fig. 10. Recession of Andreasbreen from 1909 to 2009

Fig. 11. The southern part of the tongue of Andreasbreen in 1998 and in 2009 (photo by I. Sobota). Frames on fotos denote the same area

Oliverbreen

Until 1936 the retreat of Oliverbreen mainly meant the lowering of its tongue, while both the decrease of the area and the recession of the tongue were relatively small. A much larger loss took place in the years 1936–1969.

Between 1909 and 2000 the area of the glacier decreased by 59% (1.4 km^2) in relation to its maximum advance, and the tongue of the glacier retreated by over 820 m (Fig. 12). Such an intensive retreat must have been connected with the size of the glacier and its relatively small accumulation area. If the current rate of retreat continues Oliverbreen will become a cirque glacier.

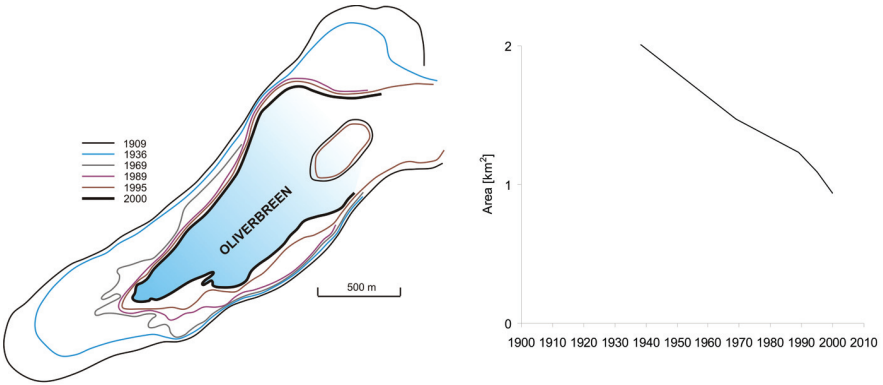

Fig. 12. Recession of Oliverbreen from 1909 to 2000

Disccusion and conlusions

The negative net mass balance of the Kaffiøyra Region glaciers recorded in recent years influences their geometry (leading in particular to changes in their area and a lowering of their surface) and also introduces changes in their front positions. The studies of the recession of the glaciers in the Kaffiøyra Region were conducted by Lankauf (1982, 1993, 1996, 1997, 2002, 2005), Bartkowiak et al. (2004), Grześ et al. (2008) and Sobota (2007d).

The glaciers of the Kaffiøyra Region cover a small area. They are all exposed in almost the same way and their firn fields are at the same altitude. The main differences between these glaciers include the altitude of their tongues and the size of their feeding areas.

Naledies at the forefields and sometimes on the surface of these glaciers are among the factors which significantly determine glacier recession. They can cover and thus temporarily isolate a thin layer of ice. As they melt out, the area of the glacier may decrease faster than on average. For instance, the largest recession of the tongue of Waldemarbreen took place in the central and northern sections of the glacier. These areas were partly concordant with the places where naledies were found. It must be stressed that since 2003 the area of naledies in the inner marginal zone of this glacier has reduced by about 90%.

The assessment of the rate of the recession is often complicated by the uneven recession of the tongues of the glaciers. For instance, in the years

2000–2009 the extension of the tongue of Irenebreen decreased by almost 100 m on average. However, its highest values were recorded in the central part of this glacier where there is a significant amount of moraine material deposited. It forms an ice-cored moraine which cuts off this central part from the rest of the glacier. Despite the fact that there is ice under this material, it was established, on the basis of the annual observations, that it is no longer connected to the main body of the glacier. On the other hand, regardless of the presence of this characteristic part of the glacier, its recession is more even than that of the other glaciers, such as Waldemarbreen.

From 1909 the largest recession has been recorded for the Elisebreen (above 1800 m). Such a large recession of this glacier was mainly caused by its location at a low altitude. This rapid recession in recent years was caused by a significantly negative mass balance of the ablation part of this glacier. The smallest retreat was recorded for Waldemarbreen (above 750 m). This glacier also showed the lowest mean annual recession (8 m a^{-1}), while Elisebreen retreated at the fastest rate of 18 m a^{-1} (Fig. 13). In general, the mean annual values of the glacier recession were recorded in the decades of 1985–1995 and 2000–2009. It is evident that the tongue areas of the glaciers located in the southern part of Kaffiøyra decreased more than those located in the northern part of the plain (Fig. 14). As the analysis of the glacier extension in the valley areas of the Kaffiøyra Region indicates, all of them have been in the some form of recession stage since 1909. In the first phase of the recession of smaller glaciers there were changes in the volume, followed by the recession of their tongues.

It is evident that an exceptionally rapid decrease in the area of the glaciers was recorded in recent years. Also in the years 1985–1995 the glaciers showed a large loss in their tongue areas. This, however, might have been caused by the thinning of the glaciers in the preceding years and not directly by the weather conditions at that time.

Since the maximum advance of the Kaffiøyra Region glaciers the area decreased by about 37% on average. The smallest changes were recorded for Irenebreen (26%) and Waldemarbreen (28%), while the largest changes were for Oliverbreen (59% up to the year 2000) and Eivindbreen (54%).

A similar rate and trends of recession and decrease of the areas of the Svalbard glaciers, regardless of their type and size is given by other authors (Rachlewicz et al. 2007; Zagórski et al. 2008a, b; Nuth et al. 2010). For example: Scottbreen decrased by 22.9% in the period from the LIA to 2006

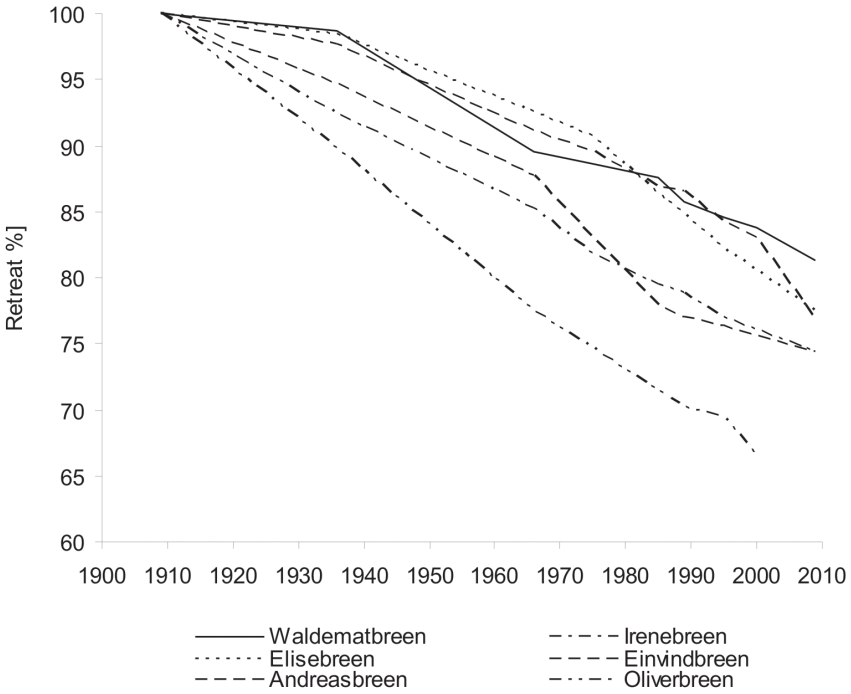

Fig. 13. Recession of the Kaffiøyra Region glaciers in the period 1909–2009 relative to the initial areas in 1909 (Oliverbreen from 1909 to 2000)

(Zagórski et al. 2008b) and Mc Whaebreen by 24.3% in the period from the LIA to 2002 (Rachlewicz et al. 2007).

Those Kaffiøyra Region glaciers which end up on land show significant recession caused by climatic changes. However, individual glaciers show a diverse course of this recession, which is conditioned mainly by various topographic, climatic and geomorphological factors. These include the exposition of particular parts of the glaciers; the development of the glacier valley, especially of its bottom; the size of the glaciers and particularly the size of the feeding area.

In recent years Kaffiøyra Region glaciers have shown negative changes. Glacier recession in the Kaffiøyra area in this time is the result of intensive changes in the mass balance (negative trend) and the dynamics of the Svalbard glaciers.

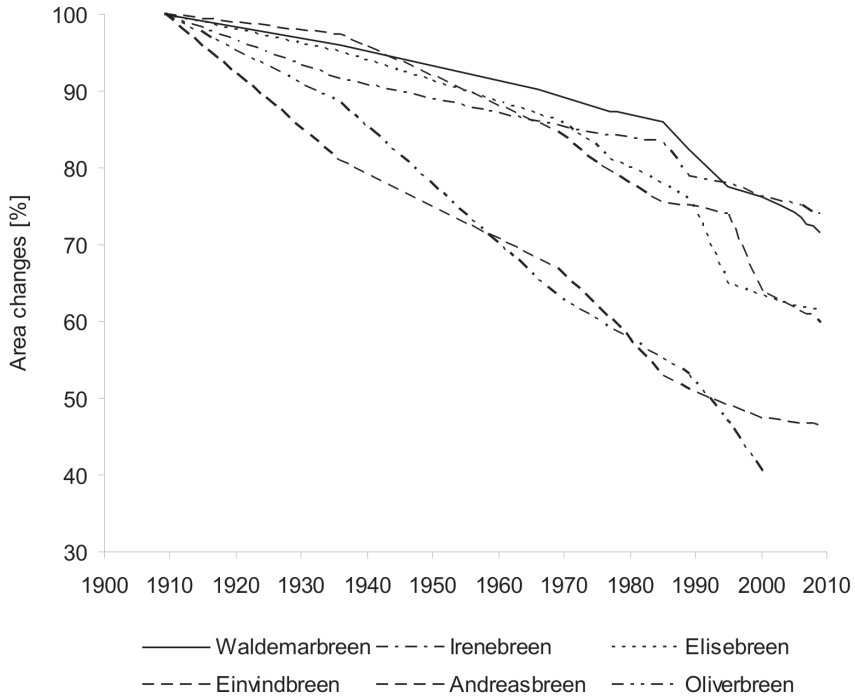

Fig. 14. Area changes of the Kaffiøyra Region glaciers in the period from 1909 to 2009 relative to the initial areas in 1909 (Oliverbreen from 1909 to 2000; from 1995 an area of Elisebreen without Agnorbreen)

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