



Invited review article

Long-term changes of glaciers in north-western Spitsbergen

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ABSTRACT

This paper comprises a detailed description of glaciers of the Kaffiøyra region, an area of Svalbard, located in north-western Spitsbergen. The primary objective of this work is to present the essential conditions and characteristics of changes in the dynamics and spatial extent of the glaciers in that region. Most of the research consisted in direct field measurements carried out in 1996–2015, and the investigated changes were mainly related to the mass balance on the Waldemarbreen, the Irenebreen and the Elisebreen. In order to identify the changes of the glaciated area of the studied region, a detailed analysis of the degree of changes in the glaciers' surface area and recession was carried out, starting with the period of their maximum extent in the late 19th and early 20th centuries, i.e. by the end of the Little Ice Age. Statistical analysis of measurement data from 1970 to 2015 enabled the development of a simple empirical formula used to work out the mass balance with a similar accuracy to that achieved using direct methods. The mean annual mass balance of the three analysed glaciers was: -0.72 m w.e. in the case of the Waldemarbreen in 1996–2015, -0.84 m w.e. in the case of the Irenebreen in 2002–2015, and -0.65 m w.e. in the case of the Elisebreen in 2006–2013. For the Waldemarbreen the change of mass balance with time was estimated to be $-0.040 (\pm 0.003)$ m w.e. a^{-1} . In the same period for the Irenebreen it was $-0.052 (\pm 0.024)$ m w.e. a^{-1} . From the time of their maximum reach in the late 19th and early 20th centuries to 2015, the total area of the Kaffiøyra region valley glaciers decreased by about 43.0% on average. Glaciers in the region retreated at an average rate of 12 m a^{-1} . The changes of the glaciers' front positions, which make the north-western coast of Spitsbergen, are similar to the changes observed for other Svalbard glaciers of this type. The investigations of the glacier mass balance in the Kaffiøyra region are especially important, being some of only a few long-term mass balance records available regarding Svalbard.

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1. Introduction

Changes in the length of glaciers have been observed around the globe since the 19th century. Generally, a clear retreat of glaciers was observed in the 1920s and 1940s, followed by a period of either

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stagnation or advancement of glaciers until the 1970s, and a dramatic recession in the mid-1980s. Over shorter periods, distinctive deviations from these trends have often been observed in a number of regions (Zemp et al., 2008). The cooling of the climate in the northern hemisphere, called the 'Little Ice Age' (LIA), lasted in Central Europe more or less from the 16th century to the end of the 19th century. In northern parts of Europe, on the other hand, and in some areas of Svalbard in particular, the Little Ice Age continued until the early 20th century. The period was distinguished by a substantial increase in the surface and length of glaciers. After the LIA, the climate warmed and one of the effects of that warming was a noticeable recession of glaciers, which for the majority of Svalbard glaciers began around 1880–1915 (Lefauconnier and Hagen, 1990).

Glaciers are widespread in Svalbard, covering over 60% of the archipelago. However, systematic studies of their mass balance have only been performed on a few Svalbard glaciers (Hagen et al., 2003a, 2003b, 2012; Jania and Hagen, 1996; Sobota, 2000, 2011, 2013, 2014; Haerberli et al., 2007; Zemp et al., 2008, 2009; Grabiec, 2005; Nuth et al., 2012; Christianson et al., 2015; Małeck, 2015). This is mainly due to the isolated location of the islands and its severe climatic conditions. Many glaciers are located in inaccessible places, therefore this kind of research is quite limited as compared to one conducted on continental, mountain-type glaciers.

Some Svalbard glaciers were monitored, either permanently or periodically, for the mass balance until 2015. There are about 30 glaciers for which the mass balance record exceeds 1 year (Fig. 1). In the area of Kaffiøyra measurement series are available for the Waldemarbreen,

the Irenebreen and the Elisebreen. For a majority of these glaciers, individual balance components were measured by means of standard glaciological methods (cf. Hagen et al., 2003a, 2003b, 2005; Jania and Hagen, 1996; Dowdeswell et al., 1997; Kohler et al., 2007; Sobota, 2011, 2013). In some cases, the mass balance of the whole glacier was determined using the accumulation-area ratio (Lefauconnier et al., 1999) or by correlation with selected climatic parameters (Hagen and Liestøl, 1990; Sobota, 1999, 2007; Szafraniec, 2002; Schuler et al., 2007; Rye et al., 2010; Grabiec et al., 2012; Van Pelt and Kohler, 2015; Aas et al., 2016). Attempts have also been made to estimate the changes in the mass of Svalbard glaciers on the basis of geodetic methods and analysis of satellite images (for example: Eiken et al., 1997; Vieli et al., 2002; Nuth et al., 2012; Sobota, 2007, 2013; Błaszczyk et al., 2009; Sobota et al., 2016). It must be noted that most of the Svalbard glaciers where mass balance measurements are carried out are rather small; their area does not often exceed 10 km² and they are situated below 500 m a.s.l.

The Svalbard glaciers, whether they are large tidewater glaciers or smaller valley ones, have a clearly negative mass balance. Glacier mass reduction is a phenomenon which has been occurring on Svalbard for decades; however, in recent years these changes have clearly been largest.

Observations of the changes in the geometry, and the recession and shrinking in particular, of the surface area of Svalbard glaciers have been analysed by a few authors (cf. Ziaja, 2001; Hagen et al., 2005; Rachlewicz et al., 2007; Zagórski et al., 2008; Błaszczyk et al., 2009). Detailed studies of the glacial recession occurring in the area of the Kaffiøyra region have been carried out and published by Lankauf

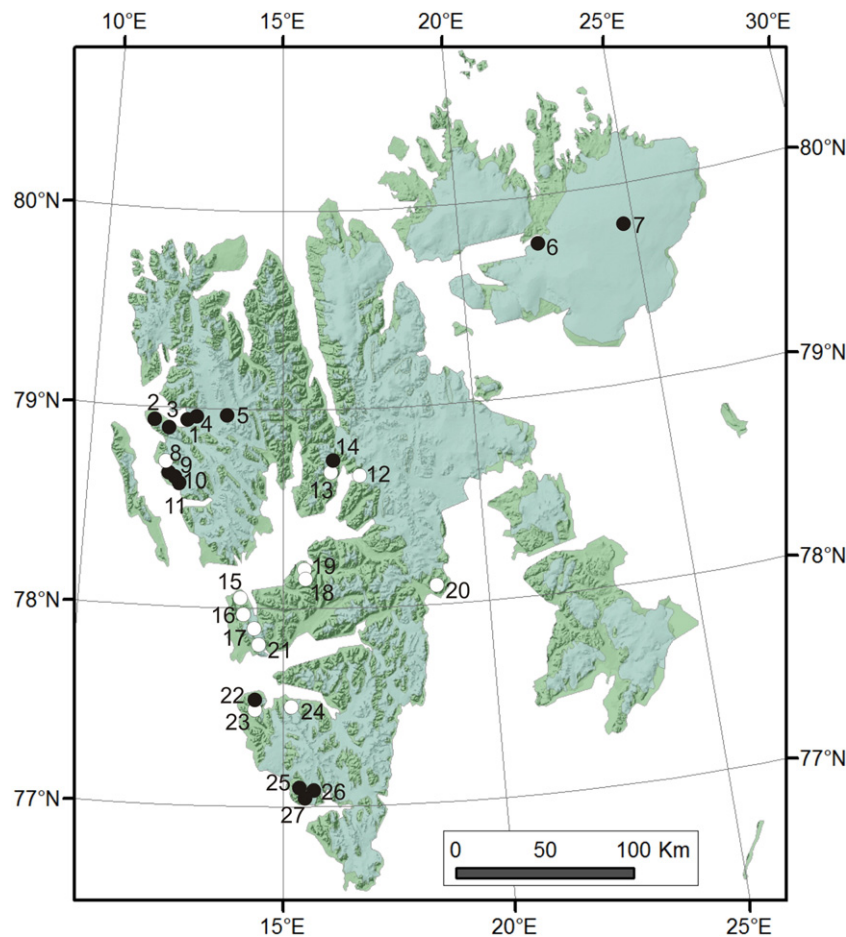


Fig. 1. Location of the glaciers for which systematic and regular investigations of the mass balance were carried out on Svalbard until 2015. Glaciers with ongoing investigations are marked in black. 1. Kongsvegen, 2. Austre Brøggerbreen, 3. Midre Lovénbreen, 4. Kronebreen, 5. Holtedahlfonna, 6. Etonbreen, 7. Austfonna, 8. Aavatsmarkbreen, 9. Waldemarbreen, 10. Irenebreen, 11. Elisebreen, 12. Nordenskiöldbreen, 13. Bertilbreen, 14. Svenbreen, 15. Vöringbreen, 16. Aldegondabreen, 17. Grønfjordbreen, 18. Bogerbreen, 19. Longyearbreen, 20. Daudbreen, 21. Fridtjovbreen, 22. Scottbreen, 23. Renardbreen, 24. Finsterwalderbreen, 25. Werenskiöldbreen, 26. Hansbreen, 27. Ariebreen.

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