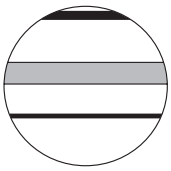

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Historical glacier fluctuations of Jostedalsbreen and Folgefonna (southern Norway) reassessed by new pictorial and written evidence

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Abstract

Glaciers are sensitive indicators of past climate and thus valuable sources of climate history. Unfortunately, direct determinations of glacier changes (variations in length and mass balance) did not start with increasing accuracy before the end of the nineteenth century. Therefore, historical and geomorphological evidence has to be used to reconstruct glacier variability for preceding time periods. Here we present new glacier length reconstructions for selected outlet glaciers of Jostedalsbreen and Folgefonna (two ice caps in southern Norway). A wealth of different historical sources (drawings, paintings, prints, photographs, maps, written accounts; about 400 documents) allows reconstruction of glacier length variations for the last 300 (Jostedalsbreen), and 200 years (Folgefonna), respectively. We present historical material newly collected for Briksdalsbreen, Bøyabreen, Store Supphellebreen, Bergsetbreen, Nigardsbreen, Lodalsbreen (all Jostedalsbreen), and Bondhusbrea, Buerbreen (both southern Folgefonna). At Jostedalsbreen, glaciers reached their 'Little Ice Age' (LIA) maximum extent around AD 1750. Nigardsbreen is best documented, where also the advance in the mid-eighteenth century can be quantified. However, the nearby Bergsetbreen shows more distinct glacier advances and retreats since the LIA maximum extent. A minor peak is documented in the 1870s for all outlet glaciers of Jostedalsbreen studied. At southern Folgefonna, the LIA maximum was attained in the late 1870s (second peak around 1890). So far, there is no direct historical evidence for the time before AD 1800.

Keywords

Folgefonna, glacier reconstructions, historical data, Jostedalsbreen, 'Little Ice Age' (LIA), southern Norway

Introduction

Improved understanding of long-term, natural climate variability on different spatial and temporal scales is crucial in order to place the recent climate change in a longer-term context (e.g. Jones and Mann, 2004; Osborn and Briffa, 2006). Since glaciers are considered as very important climate indicators (Lemke et al., 2007), the understanding of past and present glacier variations is a key task for evaluating (current) climate change.

Cumulative glacier length variations have been used to model global temperature variations during the last centuries (Oerlemans, 2005), and length change measurements are considered as one of the most important variables in future glacier monitoring strategies (Hoelzle et al., 2003). Equilibrium-line altitude reconstructions have been shown to be useful when investigating long-term accumulation-season precipitation anomalies in Scandinavia (Nesje et al., 2008a). Glacier records are used when discussing long-term, regional and global climate trends (e.g. Moberg et al., 2005). However, direct determinations of glacier changes (length variations and mass changes) did not start with increasing accuracy before the end of the nineteenth century (Andreassen et al., 2005; Forel, 1895; Haeberli, 1998). Hence, historical and geomorphological evidence has to be used to reconstruct glacier variability for the preceding time periods, such as the 'Little Ice Age' (LIA).

The LIA was the latest cold phase of the Neoglacial (Wanner et al., 2008) and lasted from the late Middle Ages until the warming of the first half of the twentieth century (about AD 1300–1860 in the Alps; Grove, 2004; Pfister, 1999). The term was first introduced by Matthes (1939) to describe the moderate re-advances of glaciers in the Sierra Nevada, California, subsequent to the early/mid-Holocene Hypsithermal. The usage of the term has been discussed, depending on whether it is referred to the LIA 'glacierization' or 'climate', and regarding the timing in different mountain regions (Grove, 2004; Matthews and Briffa, 2005).

In the European Alps, historical evidence shows that there was no uniform climate during the LIA (Pfister, 1999), with distinct glacier advances peaking around AD 1350, 1600 and 1850–1860 (Holzhauser et al., 2005). In Scandinavia, on the other hand, most glaciers experienced their maximum LIA position during the mid-eighteenth century (Grove, 2004). Scandinavian glaciers started advancing during the fourteenth–sixteenth centuries, but with a rapid growth not until the later part of the seventeenth and early

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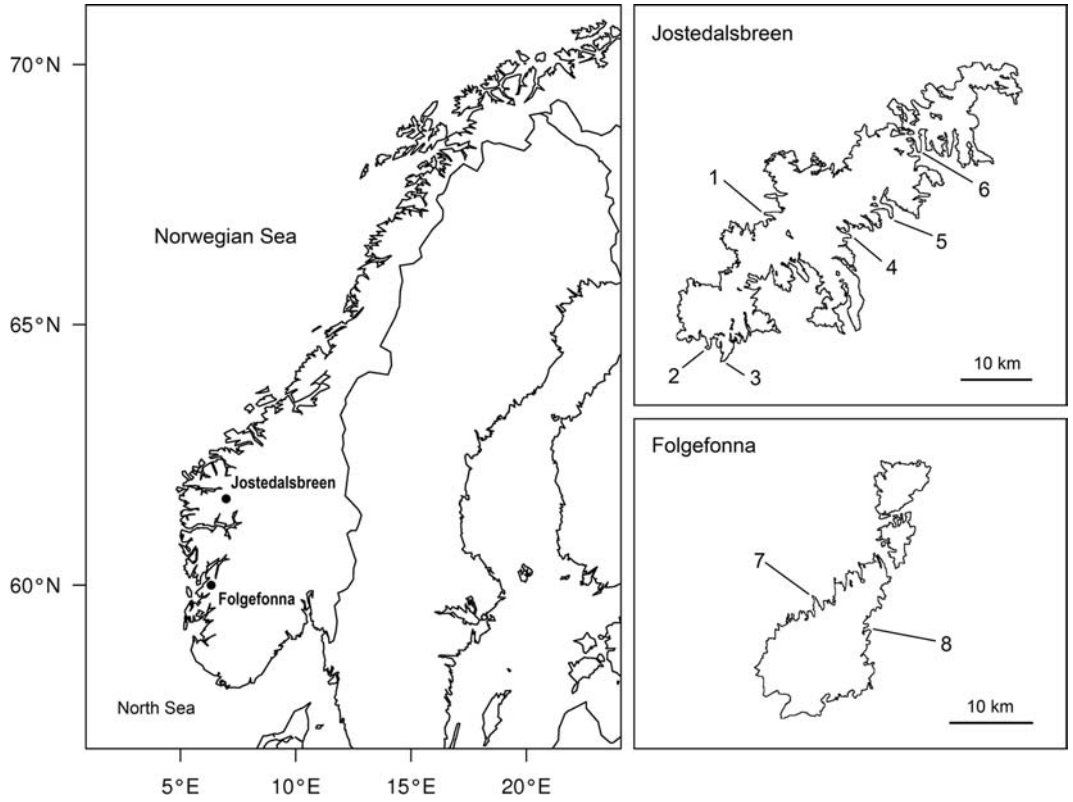

Figure 1. Geographical locations of the studied outlet glaciers of Jostedalsbreen (1, Briksdalsbreen; 2, Bøyabreen; 3, Store Supphellebreen; 4, Bergsetbreen; 5, Nigardsbreen; 6, Lodalsbreen) and southern Folgefonna (7, Bondhusbrea; 8, Buerbreen). Glacier outlines after Kjøllmoen (2009). Note that Folgefonna consists of three ice caps

eighteenth century (Grove, 2001). The rapid glacier retreat initiated in the 1930s is commonly considered to terminate the LIA 'glacierization' in Scandinavia (Oerlemans, 2005). Northern Hemisphere and Norwegian temperature records show colder climate conditions from ~1460 to 1920, however, interrupted by milder periods (Mann and Jones, 2003; Nordli et al., 2003).

An overview of historical glacier changes and the history of glaciological research in Norway can be found in Bogen et al. (1989) and Østrem and Haakensen (1993). An excellent and comprehensive summary of literature, including some works of art, is given by Hoel and Norvik (1962). The review of Scandinavian glacial fluctuations during the Holocene by Karlén (1988) includes a summary on historical information. Grove (2004) presents written and pictorial historical evidence for certain glaciers in southern Norway, among many other mountain areas. In addition, nearly complete records of century- to millennial-scale Holocene glacier variations are available from glacio-lacustrine sediment records (Bakke et al., 2005a, b, 2010; Dahl et al., 2003; Nesje, 2009; Nesje et al., 2001).

Historical records give possibilities for a detailed record of glacier fluctuations on the decadal (eventually even annual) timescale (e.g. Holzhauser et al., 2005). Hence, they allow assessing the timing of LIA glacier advances. For example, empirical qualitative or quantitative data on the length, area and volume of glaciers can be derived from these sources (Steiner et al., 2008b).

Beside historical records, field or glacio-geomorphological evidence is widely used to reconstruct glaciers that penetrated deeply into wooded land, covered soil and overrode numerous trees (Holzhauser, 2007; Luckman et al., 1993). Major glacier advances are reflected in moraines in the glacier foreland (proglacial area), where also fossil soils (palaeosols) and trees may be found once the ice has retreated (e.g. Luckman, 2006). Moraine sequences of large outlet glaciers of Jostedalsbreen have been dated thoroughly using lichenometric dating (Bickerton and Matthews, 1992, 1993; Erikstad and Sollid, 1986; Trenbirth and Matthews, 2010).

The aim of this study is to thoroughly compile historical (pictorial) documents from different archives, many of them unevaluated so far. These documents are used to determine glacier length changes. Our study focuses on eight outlet glaciers of Jostedalsbreen and southern Folgefonna, the two largest ice caps in southern Norway. Finally, the historical sources allow a comparison of the evolution of the two ice caps over the last centuries.

Materials and methods

Study sites: Jostedalsbreen and Folgefonna

Our study comprises eight outlet glaciers from the Jostedalsbreen and Folgefonna ice caps, both situated in southern Norway (Figure 1): Briksdalsbreen, Bøyabreen, Store Supphellebreen, Bergsetbreen, Nigardsbreen, Lodalsbreen (all Jostedalsbreen), and Bondhusbrea, Buerbreen (both Folgefonna). These glaciers are best documented regarding historical evidence.

A large proportion of the total glacier-covered area of Scandinavia is made up of Jostedalsbreen ice cap, which, with its 487 km^2, is the largest ice mass in continental Europe (Østrem et al., 1988). Situated in the county of Sogn og Fjordane, it feeds numerous outlet glaciers with separate names, flowing through valleys in all directions. The outlet glaciers are regarded as individual glaciers and are separated according to their specific drainage sector of the central ice plateau (Elvehøy et al., 2009; Østrem et al., 1988). Changes in mass balance of the ice cap are reflected in

Table 1. Overview of the studied outlet glaciers of Jostedalsbreen and southern Folgefonna. Data are from the glacier inventory of southern Norway (Østrem et al., 1988)

Name of glacier	Area [km^2]	Length [km]	Elevation [m asl.]
Briksdalsbreen	11.9	6.0	350–1910
Bøyabreen	13.9	5.7	490–1730
Store Supphellebreen	11.8	8.4	720–1730
Bergsetbreen	10.5	4.8	560–1960
Nigardsbreen	48.2	9.6	355–1950
Lodalsbreen	12.2	6.0	860–1960
Bondhusbrea	17.3	7.8	480–1660
Buerbreen	15.2	7.5	620–1640

fluctuations of the outlet glaciers. Briksdalsbreen overlooks the cultivated fields of Oldedalen, a valley in the north tributary to inner Nordfjord. Bøyabreen and Store Supphellebreen drain into the head of Fjærlandsfjorden. At last, Bergsetbreen, Nigardsbreen and Lodalsbreen finger down into Jostedalen in the east. Table 1 gives a summary of the characteristics of those glaciers.

Southern Folgefonna is the third largest ice mass in mainland Norway, situated in the district of Hardanger, on the peninsula between Hardangerfjorden, Sørfjorden and Åkrafjorden. Folgefonna consists of three ice caps, whereas the southern ice field (Søndre Folgefonna) is the largest one (168 km^2), and also the origin of several outlet glaciers. Most historical information is available for two outlet glaciers of Søndre Folgefonna, Bondhusbrea in the west, and Buerbreen in the east. Both flow from the ice cap down towards populated valleys. Characteristics of the glaciers are shown in Table 1.

Methods and data

If sufficient in quality and quantity, written documents and pictorial historical records (drawings, paintings, sketches, engravings, photographs, chronicles, topographic maps, reliefs) provide a detailed picture of glacier fluctuations over the last few centuries. Using these data, a resolution of decades can be achieved or, in some cases, even individual years of ice margin positions are known (Holzhauser et al., 2005; Zumbühl, 1980). In this study, marginal moraines and other geomorphologic evidence were used as complementary information to reconstruct the history of glaciers over the last few centuries.

The density of historical material prior to AD 1800 highly depends on the elevation of the glacier tongue and the relationship between settlements and cultivated land and the glacier's advances. Historical data have to be treated carefully, taking local conditions into account. The evaluation of historical sources, the so-called historical method, has to fulfil the following standards in order to obtain reliable results concerning former glacier extents (Zumbühl and Holzhauser, 1988): First, the date of the document has to be known or reconstructed. This often includes time-consuming archive work. Second, the glacier and its surroundings have to be represented realistically and topographically correctly which requires certain skills of the artist concerned. Third, the artist's topographic position should be known.

Pictorial documents are evaluated with the help of distinctive elements in the glacier's surroundings, such as rock steps or mountain peaks in the background. The geographical setting on the picture is compared with today's situation, and the location of the former glacier front is thus derived. For each historical document, there is an error bar that indicates the range of possible positions of the glacier tongue, depending on the quality and quantity of available documents.

For selected outlet glaciers both for Jostedalsbreen and Folgefonna, there are historical (pictorial) documents that prove direct evidence of past glacier extents back to the seventeenth century. However, this is only the case for glaciers visited by the first travellers (scientists, artists, tourists), or when devastation occurred because of glacier advances into farmland. Since Norwegian glaciers were relatively far from populated areas and generally of little interest to people, the amount of historical data is much less than in the Alps (Le Roy Ladurie, 1967; Nicolussi, 1990; Nussbaumer *et al.*, 2007; Zumbühl and Holzhauser, 1988). No direct historical evidence has yet been found concerning the expansion of Scandinavian glaciers before the seventeenth century (e.g. Grove, 2004).

For the glaciers mentioned above, we compiled and evaluated (mainly pictorial) documents from different archives, museums, libraries, and (private) collections (about 400 documents). Written accounts are available back to the seventeenth century, whereas the oldest drawings date back to about AD 1800. Since the 1860s many photographs enrich the glacier's documentation. Especially the Knud Knudsen collection (University of Bergen Library, Norway) was a very precious source.

The focus of our study is on the time before the onset of systematic (annual) length measurements. Data from the latter have been adopted from NVE (Norwegian Water Resources and Energy Directorate, Oslo). There is a long tradition of measurements of glacier-front positions in Norway (Andreassen et al., 2005). First observations at Jostedalsbreen and Folgefonna were performed about 1900 on the initiative of the geologist John Bernhard Rekstad (Hoel and Werenskiold, 1962; Øyen, 1906; Rekstad, 1902). Unfortunately, the size of the monitoring programme has varied according to levels of funding and dedication. The Bergen Museum (under the supervision of Knut Fægri after 1931) was first responsible for the measurements. After 1945, the charge was at the Norwegian Polar Institute. In 1996, the length measurement programme was revitalized in the light of the glacier advances at that time (Winkler et al., 2009). The monitoring programme is nowadays coordinated by NVE (Andreassen et al., 2005).

Historical glacier length fluctuations

Owing to shortage of space, only a very small choice of historical documents is presented in this section (Figures 3–10). We therefore refer to the online supplementary material, where there is a complete list of all historical sources that have been evaluated for the eight glaciers studied (Tables 3–10). All those

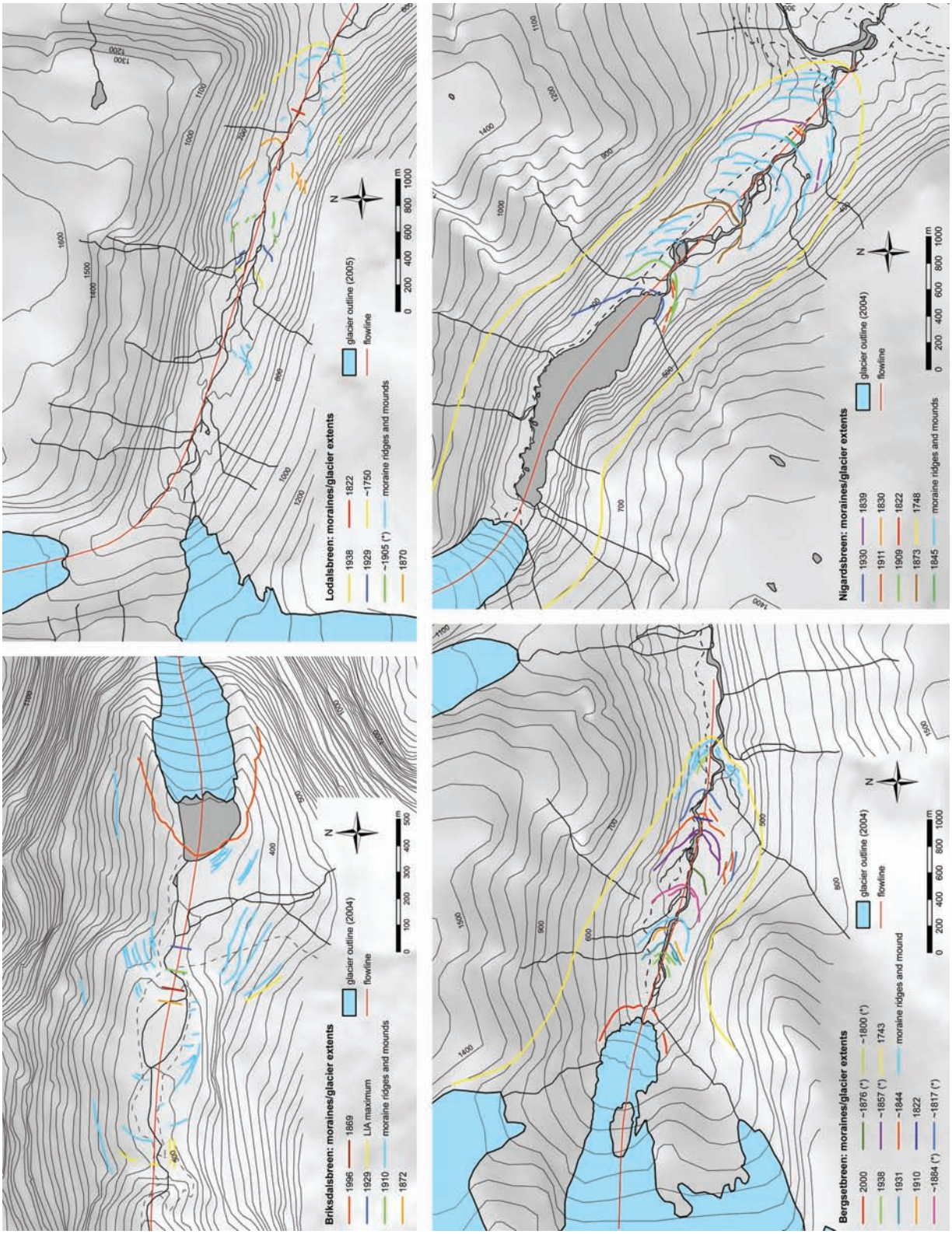

Figure 2. Glacier forelands of Briksdalsbreen, Bergsetbreen, Nigardsbreen and Lodalsbreen. Moraine mapping modified after Andersen and Sollid (1971), Pedersen (1976), Bickerton and Matthews (1993). *Lichenometric date by Bickerton and Matthews (1993)

documents give direct or indirect evidence of former glacier front positions. The glacier curves are summarized in Figure 11 (Discussion section). A detailed length reconstruction curve for each glacier can be found in the online supplementary material (Figures 12–18). For each glacier length reconstruction, there is a corresponding map of the glacier foreland (Figure 2, and online supplementary material, Figures 19 and 20).

Jostedalsbreen

Briksdalsbreen. There is no direct historical evidence for Briksdalsbreen before the nineteenth century (Pedersen, 1976). However, there are indications for a general glacier advance in Oldedalen from about 1700 to 1740 (Rekstad, 1902). Very well documented is the devastation of Tungøyane farm by the advance

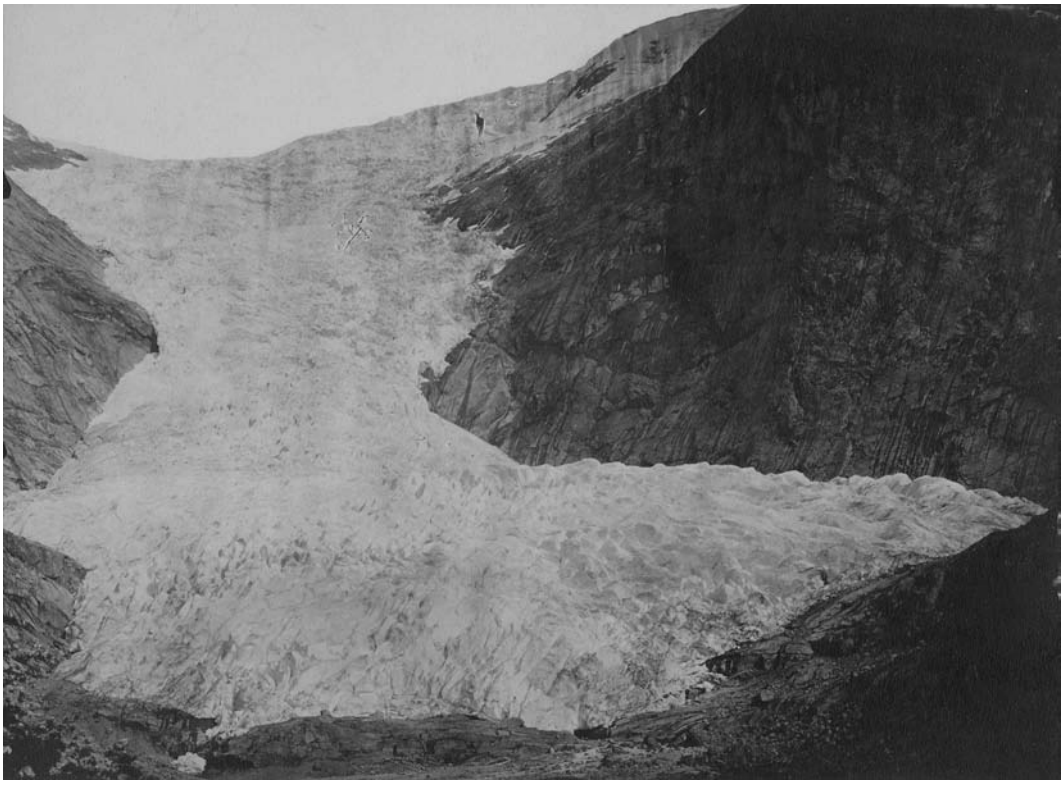

Figure 3. First photograph of Briksdalsbreen, taken on 29 July 1869 by Christen de Seue ('Brigsdalsbræen i Olden (Nordfjord)'; photograph; 12.1 cm × 16.5 cm; Prof. Hiortdahls samlinger; Norges geologiske undersøkelse (NGU), Trondheim, fotoarkiv, C29.93, NGU 001686)

of Brenndalsbreen (situated northerly, next to Briksdalsbreen) at that time (1725–1730; Eide, 1955; Rekstad, 1902). In 1743, the farm was definitively destroyed by the glacier, which indicates an advance of about 4.5 km over a 50 year period (Nesje, 1994). According to Rekstad (1902) who refers to local oral tradition, the glaciers in Oldedalen remained in an advanced position up to 1800.

Christen de Seue, meteorologist at the Meteorologisk institutt in Christiania (Oslo), conducted a detailed survey of Jostedalsbreen from 1867 to 1869. He observed selected outlet glaciers, where he also made meteorological observations (de Seue, 1870). Armed with a photographic equipment, de Seue notably took some of the first photographs of Norwegian glaciers during his journeys. He portrayed Briksdalsbreen on 29 July 1869 (Figure 3) and stated that the glacier was advancing, but had been in retreat the time before (de Seue, 1870). This is the first direct historical evidence on Briksdalsbreen.

The advance of Briksdalsbreen lasted until 1872 as documented by a photograph by Knud Knudsen (1832–1915), a well-known pioneering photographer from Bergen (Morgenstern, 1993). The subsequent glacier retreat can be quantified by other photographs by Knud Knudsen, Axel Lindahl and William Dobson Valentine. From 1891 to 1905, qualitative frontal variations of Briksdalsbreen are observed by Øyen (1906) and show an overall retreat until the beginning of systematic annual measurements of the glacier front in 1900 (Nesje, 2005). This retreat was only interrupted by a slight advance in 1894–1895 (Øyen, 1900; Rabot, 1900).

In summary, the length record of Briksdalsbreen could be extended back to 1869 thanks to historical data. The fully detailed length curve can be found in the online supplementary material (Figure 12). Rather few historical sources are available for Briksdalsbreen (online supplementary material, Table 3). This is due to the fact that the glacier was not a direct threat to people and their farmland (e.g. compared with the nearby Brenndalsbreen), and the first travellers did not arrive until the end of the nineteenth century in the inner fjord. Therefore, only the small glacier advance peaking in 1872 is historically well documented.

Bøyabreen. The history of Bøyabreen prior the the mid-nineteenth century is ambiguous. According to Rekstad (1900, 1905a), the LIA maximum of Bøyabreen occurred between 1740 and 1750, whereas Rabot (1900) assumes a maximum about 1720. Following Aa and Sjåstad (2000) who investigated the moraine sequence in front of Bøyabreen, the outmost moraine ridges probably date to the early Holocene, and two inner ridges (not very well pronounced) can be attributed to the LIA.

Direct historical evidence is not available until 1819, when bishop Jacob Neumann visited the glacier and reported a retreat of about 900 footsteps during the last 100 years (Øyen, 1900). Rekstad (1905a) refers to historical tradition in Fjærland and mentions a moraine from around 1825.

This early information is delicate for interpretation. Reliable sources are abundant only from 1867 onwards. The glacier was portrayed in detail by de Seue on 7 August 1867 and 27 July 1868 (de Seue, 1870), and also studied thoroughly in July 1868 by Sexe (1869). De Seue (1870) quantifies the glacier retreat of the last 150 years to about 600 m (distance to the LIA maximum moraines). Until 1867, Bøyabreen was retreating (Rekstad, 1900). During the subsequent years until 1872, the glacier was advancing and forming a distinct moraine (de Seue, 1870; Rekstad, 1902).

The following retreat of Bøyabreen is documented by photographs by Knud Knudsen in 1874 and by a description of Rekstad (1900) for 1880 (relative minimum extension reached). Subsequent documentation of the glacier reveals an advance from 1800 to 1888, thanks to the photographs by the geologist Knud

Figure 4. Frontal view of Bøyabreen in 1896, painted by Haakon Jensen Kaulum ('Bøyabreen 1896'; oil on canvas; 154 cm × 225 cm; Hotel Mundal, Fjærland; photograph by SU Nussbaumer)

Steenstrup (July 1884), Axel Lindahl (1886), and Knud Knudsen (1888). The glacier retreat from 1889 onwards (Rekstad, 1900) is nicely documented by an oil painting of Haakon Jensen Kaulum (1896; Figure 4), a photograph by Knud Knudsen (1896), and by a photochrom print from 1897 (first coloured photo print).

To sum up, the historical (pictorial) evidence allowed quantifying the two pronounced advances that culminated in 1872 and 1888. Systematic measurements of the glacier front were initiated in 1899 by Rekstad (1900, 1905a) and maintained until 1953 (although with some gaps). In 2003, the series was resumed (Kjøllmoen, 2009).

Store Supphellebreen. Store Supphellebreen consists of two parts: an upper glacier called Flatbreen that is calving off a steep rock slope, nourishing a regenerated glacier in the valley bottom. Glaciological observations and the history of the glacier are treated in detail by Orheim (1970). For topographical reasons, the exact delineation of quantitative glacier changes before 1899 (start of systematic measurements; Rekstad, 1902) was not possible. However, the glacier has been frequently visited which explains the wealth of (pictorial) documents, e.g. by Jacob Neumann for 1819 (Øyen, 1900), Hans Fredrik Gude for 1845 (Messel, 2008), James David Forbes for 1851 (Forbes, 1853), Christen de Seue for 1867 (de Seue, 1870), and by many others. Table 5 (online supplementary material) shows the historical documents available for Store Supphellebreen for completeness. Figure 5 shows the impressive arcade of the glacier front in 1897 (photochrom print).

Bergsetbreen. For Bergsetbreen in Krundalen (side valley to Jostedalen), historical evidence is more plentiful compared with other glaciers. There is even the earliest reliable written evidence of direct damage to farmland by an advancing glacier in Scandinavia (Grove, 2004). According to this document from 1684, the summer pastures (on the higher ground) of the farms Grov and Bergset (both located in inner Krundalen) were overrun by Tuftebreen (Eide, 1955; Grove and Battagel, 1983; Øyane, 1994). Tuftebreen is located next to Bergsetbreen, and we can thus assume that a dramatic glacier advance had begun by the end of the seventeenth century. According to Rekstad (1905a), the advance of Bergsetbreen lasted until 1743, when people complained about burdensome and cold years prevailing over Jostedalen.

Damages by the advancing Tuftebreen were appraised on 21 August 1742. According to this documentation, Tuftebreen was only 880 feet (~270 m) away from the hamlet of Bergset, and the inward valley in the west was completely filled by ice (Bergsetbreen). As a consequence, the tax load was reduced (Bohr, 1820; Eide, 1955). The menacing proximity of the glacier to settlements in Krundalen is also stated by Foss (1802) (more details about Matthias Foss, vicar of Jostedalen, can be found in the section 'Nigardsbreen').

In 1806, the German geologist Leopold von Buch visited Krundalen. Concerning Bergsetbreen, he found only one but mighty moraine (the mid-eighteenth century moraine) in front of the glacier. Hence, Bergsetbreen seemed to persist in a stationary maximum (Rabot, 1900; von Buch, 1810). Also Christen Smith reports that in 1812, the glacier was still very large (Rabot, 1900; Smith, 1817).

Later, the important Danish-Norwegian painter Johannes Flintoe (1787–1870) made a drawing of Bergsetbreen in August 1822 (Figure 6). Produced at a time of national romanticism, this work of art depicts the glacier in great detail and is typical of landscape painting in nineteenth-century Norway. In 1822, also Carl Friedrich Naumann, geologist from Germany, studied the retreating Bergsetbreen and found a distance of 2000 feet (~610 m) between the glacier front and the terminal moraine (Naumann,

Figure 5. Frontal view of Supphellebreen in 1897 ('7057. P. Z. – CAVE IN SUPHELLEBRÄE. SOGN.'; photochrom print; 16.1 cm × 22.1 cm; private collection; reproduction by SU Nussbaumer)

Figure 6. Vetledalsbreen (left), Bergsetbreen (middle) and Tuftebreen (right), seen from Bergset in Krundalen by Johannes Flintoe in August 1822 ('Jostedalsbreen sett fra Bergset i Krundalen'; pencil, pen and watercolour; 26.3 cm × 41.0 cm; Bergen Kunstmuseum; photograph by SU Nussbaumer)

1824b). Although Naumann (1824b) describes both Bergsetbreen and Nigardsbreen, the information mentioned can be clearly attributed to Bergsetbreen in the context of the report.

Joseph Marie Elisabeth Durocher, a French mining engineer and geologist, visited Norway in 1845, when he also made a sketch of the inner Krundalen. Durocher (1847) measured the frontal position of Bergsetbreen and stated a retreat by 600 m since the LIA maximum. Accordingly, Forbes (1853) made a sketch of the glacier tongue in 1851 and measured the distance between the glacier front and the outermost moraine (900 yards = 823 m). In combination with historical indication by Rekstad (1905a), we can assume an advance of Bergsetbreen from 1829 to 1844, followed by a subsequent retreat until 1868 (description by de Seue (1870) and corresponding photographs). This overall retreat since the LIA maximum must have been interrupted by a short advance around 1857, as there is geomorphological evidence to this effect (distinct moraine; Bickerton and Matthews, 1993).

A slightly advanced glacier position later on is proved by Leonard Holmström, who measured the distance to the great terminal moraine in 1878 (about 1000 m; Øyen, 1900; Rabot, 1900). Photographs by Axel Lindahl, likely from 1890, and a photograph by Knud Knudsen from 1896 complete the historical record.

In 1899, 1903, and 1907, John Rekstad took glacier photographs from different points of view and measured the frontal length changes (Rekstad, 1905a; Winkler, 1996). Systematic length measurements had been continued (though no measurements are available from 1945 to 1996; Andreassen et al., 2005) and prove subsequent minor glacier advances culminating in 1910, 1931/1938 and 2000. Length measurements stopped in 2006 because the glacier tongue separated in a lower, rather stagnant, and an upper, active part (Winkler et al., 2009).

The foreland of Bergsetbreen contains many well-formed moraine ridges. This sequence has been studied using lichenometric dating by Bickerton and Matthews (1993). The historical evidence is in agreement with those results and allowed a refinement of the glacier length record.

Nigardsbreen. Nigardsbreen is the best-documented glacier in Norway, not only regarding historical data, and many studies have therefore been performed on that glacier. The series of small moraine ridges in front of the glacier was dated and described in detail by Fægri (1934) and Andersen and Sollid (1971). Historical evidence was recapitulated by Østrem et al. (1976) and Grove (2004). The length change curve for Nigardsbreen made by Østrem et al. (1976) extends back to 1710. According to Nesje et al. (2008b), a pine stump found in the foreland was overrun by the glacier between 1668 and 1682 (1 sigma range of the radiocarbon date). Uniquely at Nigardsbreen it is possible also to quantify the impressive 1750 glacier advance. In the following, we discuss the most important and newly available historical documents. For a complete list of the historical material we refer to the online supplementary material (Table 7).

In accordance with an old legend, Rekstad (1900) assumes an advance of Nigardsbreen no later than the sixteenth century. During the seventeenth century, no destruction and a rather small glacier extent is proved (Eide, 1955; Rekstad, 1900). The description of the advance of Nigardsbreen by Gottfried Bohr is the first direct historical evidence that allows locating the position of the glacier front around 1710 (Bohr, 1820; Østrem et al., 1976). According to Hans Hansen Wiingaard, vicar in Jostedalen from 1725 to 1731, Nigardsbreen started its advance about 1712 (Rekstad, 1902).

In 1735, the first known piece of written information reveals that the glacier was 'only a stone's throw away from a nearby farm' (Eide, 1955). The farm was destroyed by the advancing glacier in 1742–1743, as depicted by Matthias Foss, local minister of Jostedalen from 1741 to 1792. This document by Foss is a unique source for the early history of Jostedalen, and it is also a paramount work in the historic-topographic literature of Norway. The original account was written in 1750 (Foss, 1750), and published in 1802 for the first time (Foss, 1802). The work contains a detailed description of the valley and its glaciers, not only of Nigardsbreen, whose advance ended in 1748 (Foss, 1802).

The subsequent glacier retreat is described in 1812 by Smith (1817), and in a detailed manner in 1819 by Bohr (1820). On the drawing by Johannes Flintoe made in August 1822, the barren land left by the retreating glacier is clearly visible (Figure 7a). Flintoe used this motif also for a gouache presented in 1834 (Figure 7b). An oil painting by Knud Baade shows the front of the glacier in 1830 (Figure 7c), and another work of art by Baade presents the glacier on 1 August 1839 (Figure 7d). The two well-known oil paintings by the great Johan Christian Dahl (1788–1857) from 1844, and 1847, respectively, are based upon a sketch (drawing) made in August 1839 (Lange, 1988; Figures 7e/f). Those documents prove a slight advance of the glacier until 1839.

The following retreat is documented by a lithograph of Joachim Frich from the 1840s (possibly from 1843; Messel, 1990), that was published for the first time in Asbjørnsen and Tønsberg (1848). When Joseph Durocher visited the glacier in 1845, the glacier was debris-covered and 700 m smaller than in 1748 (Durocher, 1847; Figure 7g). Also Forbes (1853) investigated Nigardsbreen on his journey through Norway in 1851 and reports on the retreat of the glacier. A lithograph is added to his comprehensive volume, though it is too rough for an exact determination of the glacier front.

The retreat of Nigardsbreen lasted until 1867. De Seue (1870) found the glacier advancing again in 1868, when he took one of the first photographs of the glacier. The advance was only short and ended in 1873, but led to the formation of a remarkable moraine system (Rekstad, 1902). Several photographs by Knud Knudsen (1874, 1896), Axel Lindahl (1890), William Dobson Valentine (1890) and John Rekstad (1899, 1903, 1907) document the subsequent glacier retreat. Frontal measurements were performed by Rekstad in 1899, 1903, and 1907. Since then, an almost complete series of annual frontal measurements of Nigardsbreen is available. No annual frontal measurements were carried out between 1964 and 1972, but the retreat in this period was photogrammetrically determined to be 515 m (Østrem et al., 1976).

Lodalsbreen. Lodalsbreen is situated at the very end of Jostedalen and is more difficult to access. The historical record is sparse and has not been evaluated so far. Distinct are the LIA maximum moraines, but of the younger moraines only fragments are preserved (Bickerton and Matthews, 1993). The first detailed description of the glacier is given by Bohr (1820) who measured the distance between the glacier front and the large moraine (1700 feet) in 1819.

Naumann (1824a, b) undertook extensive study trips to Norway in 1821 and 1822. According to Rekstad (1902), Naumann was in Jostedalen in August 1822. Wilhelm Maximilian Carpelan must have had access to the travel sketches by Naumann (Messel, 2008). We can therefore attribute a fine drawing by Carpelan to the visit of Naumann to Lodalsbreen in August 1822. This work of art shows Lodalsbreen in an advanced position with a steep ice

Figure 7. Iconography of Nigardsbreen as seen by various authors, observed from 1822 to 1845: (a) Johannes Flintoe, August 1822 ('Mjølvirsdalen med Nigardsbreen'; pencil, pen and watercolour; 26.3 cm × 41.0 cm; Bergen Kunstmuseum, BB.B.1050; photograph by SU Nussbaumer). (b) Johannes Flintoe, 1822/1834 ('Nigardsbreen'; gouache; 62.5 cm × 94.0 cm; Norske Prospecter, nr. 21; Nasjonalmuseet Oslo, NG.M.04327; Messel, 2008). (c) Knud Baade, 1830 ('Bondhusbreen' [sic!]; oil on cardboard; 19.5 cm × 33.5 cm; Bergen Kunstmuseum, BB.M.573; photograph by SU Nussbaumer). (d) Knud Baade, 1 August 1839 ('Nigardsbræen, Jostedalen'; pencil and watercolour; 28.0 cm × 40.5 cm; Nasjonalmuseet Oslo, NG.K.&H.A.04203; photograph by SU Nussbaumer). (e) Johan Christian Dahl, 1839/1844 ('Nigardsbreen'; oil on canvas; 100 cm × 136 cm; Bergen Kunstmuseum, Rasmus Meyers Samlinger, RMS.M.92; photograph by SU Nussbaumer). (f) Johan Christian Dahl, 1839/1847 ('Nigardsbreen'; oil on canvas; 25.5 cm × 35.5 cm; Nasjonalmuseet Oslo, NG.M.01477; Messel, 2008). (g) Joseph Durocher, 1845 ('Vue de l'extrémité du glacier de Nygaard, prise du côté droit.'; etching; 4.4 cm × 12.5 cm; Durocher, 1847)

Figure 8. Frontal view of Lodalsbreen (left), Stegholtbreen (right), and Lodalskåpa (background) in 1822 by Wilhelm Maximilian Carpelan, after Carl Friedrich Naumann ('Lodalskåpa'; watercolour, pen and pencil; 11.0 cm × 19.0 cm; Plansjeverk 2218-nr. 13; Nasjonalbiblioteket, Oslo, Håndskriftsamlingen; photograph by SU Nussbaumer)

front, and the eye-catching Lodalskåpa, the highest point of Jostedalsbreen (nunatak), in the background (Figure 8).

A similar view is presented in the sketch (etching) by Durocher (1847) that can be found as a supplement to his report. The glacier is retreated by 600–700 m with reference to the LIA maximum and shows considerable medial moraines (Durocher, 1847). Further historical evidence, for 1864, is given by the sketch and description of Doughty (1866). In August 1869, Christen de Seue took three photographs (which do not show the very end of the glacier) and especially gave an accurate description of his visit to Lodalsbreen. De Seue (1870) finds the glacier advancing and with a length of about 3000 m, measured from the bend valley-upwards to the glacier end. The glacier front position thus obtained is also confirmed by the manuscript for the first official map of Norway ('amtskart'), which was drawn by lieutenant K. Lorange after his surveys in 1870.

A report by Leonard Holmström states that in 1878, the glacier had been retreating since a couple of years, but not remarkably (Øyen, 1900; Rabot, 1900). In 1899, photographs and measurements by Rekstad (1902) further document the constant retreat of Lodalsbreen. As can be seen in Figure 11, the retreat is increased from about 1940 to 1970.

Folgefonna

Bondhusbrea. The oldest historical information for Folgefonna, and Bondhusbrea in particular, is owed to Niels Hertzberg, famous vicar and dean in Hardanger. Hertzberg indicates in 1817/1818 that for several hundred years before, Folgefonna was much smaller (Øyen, 1900). Erik Pontoppidan writes in 1752 in his renowned 'Natural History of Norway' that Folgefonna is said to have covered a whole parish (Pontoppidan, 1752).

The first explicit mention of Bondhusbrea is the watercolour by Niels Hertzberg showing the tail of the glacier in the valley bottom on 8 August 1801 (Brekke and Nord, 2008; Østrem and Haakensen, 1993). Note that it is the oldest known pictorial document of a Norwegian glacier (an older document representing ice in Scandinavia is the famous map of northern Europe, 'Carta Marina', by the Swedish cleric Olaus Magnus from 1539, showing sea ice). Hertzberg specifies in an accompanying text beneath the drawing that the altitude of the front is 489 alen (old Danish/Norwegian unit of distance, corresponding to about 307 m a.s.l.). A chain of large boulders encompasses the glacier terminus, and is only breached by the glacier river to the left.

The glacier was slightly advancing in the following years, as described by Hertzberg in 1807 (Øyen, 1900). In 1812, it was retreating again according to Christen Smith (Øyen, 1900; Rabot, 1900). For 1817/1818, again a relatively large extent of Folgefonna in general is proved by Hertzberg (Øyen, 1900); as for Bondhusbrea in particular, some years later when Naumann tramped through Norway during the summers 1821 and 1822. In June 1822, Naumann (1824a) reports that the glacier in Bondhusdalen is pushing its moraines.

Rekstad (1905b) postulates a minimum state of the glacier around 1835 (perhaps referring to oral tradition), but unfortunately no revealing details could be found on that. However, significant evidence for the glacier retreat at that time is the report by Hans Konow in 1845. The glacier has considerably retreated and large ice masses of the lower part of the glacier have tumbled down the steep gradient (Konow, 1845; Øyen, 1900).

A wealth of historical documents is available for the mid nineteenth century, all dating between 1850 and 1864. These are oil paintings by Joachim Frich and Anders Monsen Askevold, a drawing by Franz Wilhelm Schiertz, and a lithograph published by Forbes (1853; Figure 9). From 1859 to 1861, extensive studies of Folgefonna were performed by Sjur Aasmundsen Sexe, professor in physical geography at the University of Christiania (Oslo). A result was the map 'Kart over Folgefon med nærmeste omegn' at the scale of 1:200 000, published by Sexe (1864). Another map (manuscript for the 'amtskart') surveyed in 1860 was made by lieutenant H. Fougner at the scale of 1:100 000, representing the northern half of southern Folgefonna including Bondhusbrea and

Figure 9. Ice fall of Bondhusbrea, as observed in 1851 by James David Forbes ('Glacier of Bondhuus'; lithograph; 13.5 cm × 20.7 cm; Forbes, 1853: plate VI; reproduction by SU Nussbaumer)

Buerbreen. All these documents (see the online supplementary material, Table 9, for a complete overview) reveal a minor glacier advance around 1855 and a subsequent retreat until 1865.

Knud Knudsen captured Bondhusbrea on glass plate in 1869 when the glacier was re-advancing. This advance culminated in 1875, as documented by the local Anders Torbjørnsen Bondhus, and left a clear moraine (LIA maximum; Rekstad, 1905b). A series of photographs by Axel Lindahl shows that the glacier was only slightly retreated during the 1880s.

In 1889/1890, the glacier was peaking for a second time. It nearly reached the extent of 1875 as proved by photographs by Knud Knudsen. Annual qualitative observations of the glacier front by Øyen (1906) show a continuous retreat from 1892 to 1900. This can be confirmed by diverse photographs such as a photochrom print from 1897, or classical pictures from 1898 and 1900 taken by Lauritz Bekker Larsen, an amateur photographer from Bergen.

In summary, historical evidence allowed the delineation of the glacier's changes from 1802 to 1901. Since 1901, the glacier length changes have been monitored more or less continuously until the present (Kjøllmoen, 2009).

Buerbreen. Buerbreen, an eastern outlet of southern Folgefonna, is a typical valley glacier with the tongue flowing downwards with a constant slope (in contrast to the steep ice fall of Bondhusbrea). Many landmarks allow a precise delineation of former glacier extents based on historical pictures. Remarkable is the amount of historical photographs available for Buerbreen, hardly evaluated so far. From 1869 until the start of systematic measurements in 1900, the glacier was captured nearly annually by various photographers, first of all by Knud Knudsen.

Hoel and Werenskiold (1962) report on an advance of Buerbreen in 1676, when the Buer farm was devastated by landslides and torrents. This note is not directly related to the glacier itself, but such incidents happened also to other farms in those days, simultaneously with a climate deterioration. Grove (2004) shows a compilation of farmhouses around Folgefonna that were seriously damaged by landslides, avalanching or catastrophic flooding from 1663 to 1815. However, no detailed and explicit description of Buerbreen is available prior to June 1822, when Naumann (1824a) depicts the view into Buerdalen: A wall of ice, jagged and with a gleam of blue, is descending from the eternal snow into the valley gorge. This means that Buerbreen had a considerable extent, otherwise the wall in the inner valley would not have been covered by ice. On the drawings by Catharine Hermine Kølle in 1830, Alfred Smith in 1846, and Jonas Nicolai Prahm on 21 July 1847, the glacier is shown in a considerably retreated shape.

Between 1850 and 1854, a minor advance must have occurred according to Sexe (1864) and Rekstad (1900, 1905b). The subsequent retreat is well documented by early maps (by Fougner and Sexe; see section Bondhusbrea) and measurements by Sexe (1864) from 1859 to 1961 (altitude of the glacier tongue: 1445 feet). In addition, a photograph of the glacier by Knud Knudsen, one of the first glacier photographs in Norway, dates from 1864. It shows the glacier retreated in the inner valley, but with a steep and rugged ice front. At higher elevation, we can observe that the ice is magnified (Figure 10a). It marks the beginning of the advance until 1878/1879 when the glacier reached its maximum extent and formed the outermost LIA moraines.

This impressive advance is depicted meticulously by photographs by Knud Knudsen in the years 1869, 1870, 1871, 1875, and 1876, showing the glacier crushing and overwhelming the land in front. In August 1878, Adolf M.S. Arctander pictured the glacier exactly at its LIA maximum extent. According to the rough measurement of Leonard Holmström, the front was then about 950 m away from the Buer farm (Rabot, 1900). Buerbreen stopped just behind the large rock that shelters the farmland valley-downwards, and held this position also through 1879 (Nielsen, 1880a).

Figure 10. Advance and retreat of Buerbreen in the end of the nineteenth century. All pictures are taken from the Buer farm by Knud Knudsen in: (a) 1864 ('Parti ved Buerbræen i Hardanger'; stereo photograph; 7.8 cm × 15.1 cm; Billedsamlingen, Universitetsbiblioteket i Bergen, UBB-KK-NS-0195). (b) 1889 ('Buerbræen, Odde i Hardanger.'; photograph; 16.8 cm × 22.7 cm; Billedsamlingen, Universitetsbiblioteket i Bergen, UBB-KK-1622-08053). (c) 1897 ('Buerbræen. Odde, Hardanger.'; photograph; 23.0 cm × 28.3 cm; Billedsamlingen, Universitetsbiblioteket i Bergen, UBB-KK-2127-0024)

Table 2. Timing of the advances of the selected outlet glaciers of Jostedalsbreen and Folgefonna (LIA maximum: bold). Years in parentheses are weakly documented

Name of glacier								
Briksdalsbreen				1872		1910	1929	1996
Bøyabreen				1872	1888	1909	1931	
Store Supphellebreen						1912	1929	1996
Bergsetbreen	**1743**	(1844)	(1857)	(1876)		1910	1938	2000
Nigardsbreen	**1748**	1839		1873		1909	1930	2003
Lodalsbreen	**(1750)**			(1870)				
Bondhusbrea		1807	1855	**1875**	1889/1890	1911	1930	(1996)
Buerbreen		(1822)	1852	**1878/1879**	1892/1893	1911	1933	1998

Buerbreen kept its advanced extension until 1892/1893 (second, smaller peak), as captured on the photographs by Knud Steenstrup (1884), Knud Knudsen (1886, 1889, around 1890), William Dobson Valentine (1888, 1890), Axel Lindahl (1890 or earlier), and Henrik Greve Tornøe (1892). Figure 10b shows the glacier in 1889. Kristian Bing from Bergen assigned the maximum to 1893 (Rabot, 1900), and according to the local Jakob Jordal, the glacier was retreating again in 1894 (Øyen, 1900). The subsequent glacier changes are documented by Knud Knudsen (several pictures from 1897; Figure 10c), a photochrom print (presumably from 1897), and Wilhelm Dreesen (presumably from 1898).

Observations of the front in 1900, 1904 and 1905 (Rekstad, 1905b, 1907) mark the beginning of systematic measurements. Pronounced relative maxima occurred in 1911, 1933 and 1998. Since 1900, the glacier has shortened by about 1 km (Kjøllmoen, 2009).

Discussion

Glacier length changes are, in contrast to glacier mass balance data, to be treated as an indirect, delayed and filtered climate signal ('reaction time' of the glacier tongue to a climate signal, based on the kinematic wave velocity; Hoelzle et al., 2003; Nye, 1965; Paterson, 1994). The 'response time' on the other hand is the time required for a glacier to adjust from one 'steady-state' to another, following a change in the mass balance (Jóhannesson et al., 1989). Usually this time is two to three times longer than the 'reaction time' mentioned before (Steiner et al., 2008a). The frontal time lag of Nigardsbreen has been estimated to 20–25 years (Nesje and Dahl, 2003). Laumann and Nesje (2009) indicate a time lag of 4–5 years for maximum advance rates of Briksdalsbreen, in agreement with Oerlemans (2007). However, it must be noted that the reaction to climate perturbations at the glacier snout can also change in some situations, e.g. after runs of cool summers (Matthews and Briffa, 2005; Winkler and Nesje, 2009; Winkler et al., 2009).

The cumulative glacier length fluctuations for the two study areas are presented in Figure 11. Table 2 shows the timing of the advances of the glaciers studied. For uncertainties regarding the reconstructions, see Figures 12–18 in the online supplementary material. Note that for certain time periods, the amount of available historical documents is sparse (e.g. for Lodalsbreen and Nigardsbreen). In these cases, decadal variations of the glaciers may not be reflected by the reconstructions. Additional (pictorial) historical documents including photographs might be found in private collections, but can only give punctual improvement if at all.

The great advantage in using historical documents lies in the fact that minimal glacier extents can be reconstructed. As an example, the new length curves for Bergsetbreen and Bøyabreen show pronounced advance and retreat periods and complement the previous studies dealing with the dating of the moraines (Aa and Sjåstad, 2000; Bickerton and Matthews, 1993). In the case of Bondhusbrea and Buerbreen, completely new length change curves could be deduced for the nineteenth century. A good

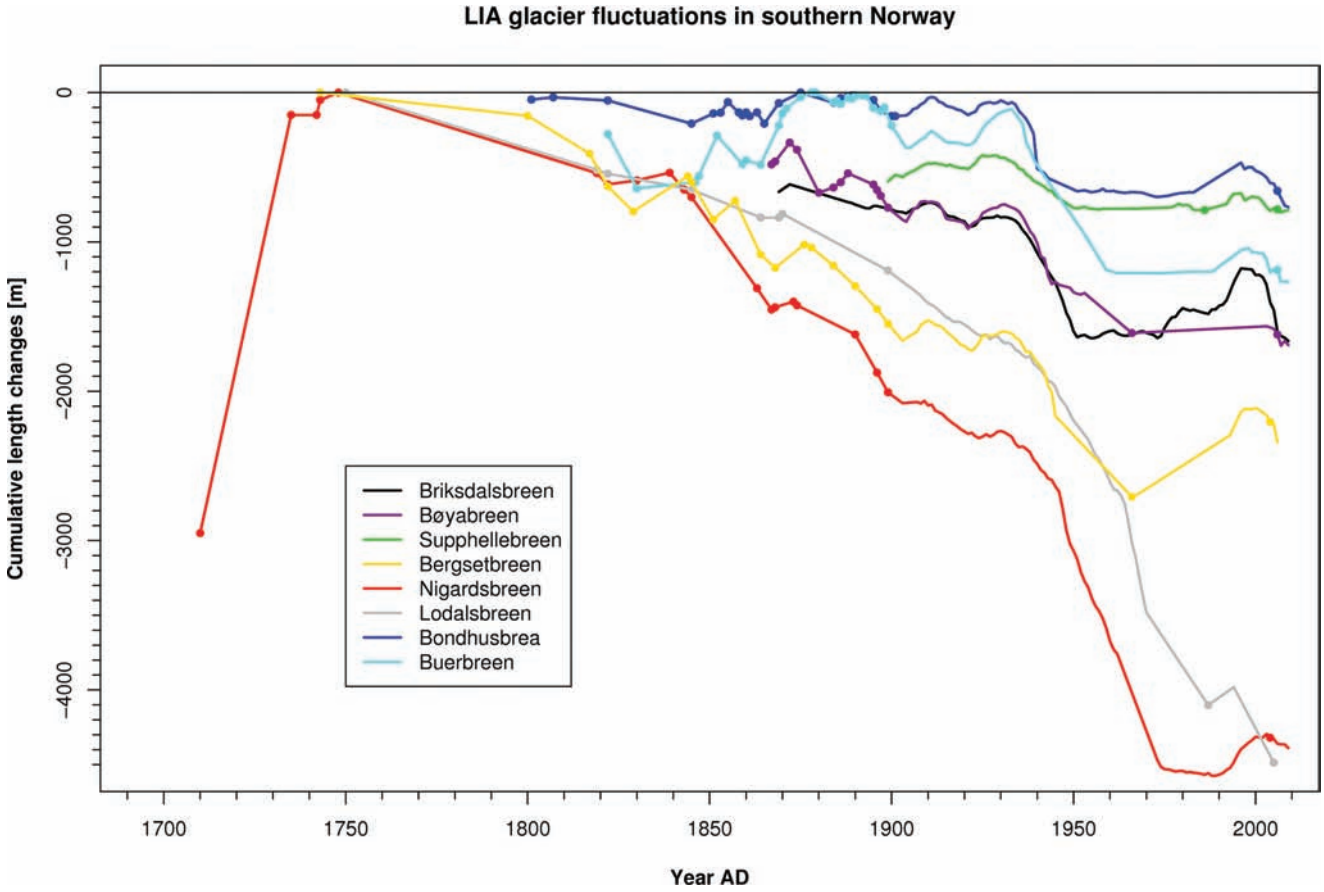

Figure 11. Cumulative length variations of outlet glaciers of Jostedalsbreen and Folgefonna, based on historical evidence (LIA maximum = 0; dots: reconstructed values). Data from 1899/1900/1901–1994/2006/2009: NVE, Oslo

temporal resolution of the reconstructions is finally the prerequisite for the comparison of glacier behaviour in different mountain regions.

For Jostedalsbreen, we can observe an overall retreat from the LIA maximum around 1750 to 1950–1970. After the 1930s–1940s, the retreat was significantly increased. Steep and small outlet glaciers with short frontal time lags (<5 years) started to advance in the 1950s (e.g. Briksdalsbreen), whereas flatter and larger glaciers with longer frontal time lags (>15–20 years; e.g. Nigardsbreen) continued to retreat up to the 1970s.

The short re-advance in the early 1990s can be attributed to higher winter precipitation between 1988/1989 and 1994/1995 (Hanssen-Bauer and Førland, 1998). The subsequent retreat after 2001 was remarkably fast and mainly a response to high summer temperatures. From 2001 to 2006, both low winter accumulation in 2000/2001, 2002/2003, and 2005/2006, and large summer melting in the summers of 2002, 2003, and 2006, were responsible for negative glacier mass balances (Andreassen et al., 2005; Nesje, 2009).

Outlet glaciers of Folgefonna showed a similar behaviour in the twentieth century and up to the present, compared with the outlets of Jostedalsbreen. However, the historical evidence unambiguously shows that the LIA maximum extent was reached at Bondhusbrea and Buerbreen in the late 1870s. A first but smaller LIA peak can be assumed for the mid eighteenth century, although there is no direct historical evidence for the exact timing. This is in agreement with Bakke et al. (2005b) who showed that at northern Folgefonna, the Neoglacial maximum was reached during the LIA, around 1750 and 1870 (two peaks). Note that other outlet glaciers from southern Folgefonna reached their LIA maximum position in the 1890s, or even as late as around 1940 (Tvede, 1973; Tvede and Liestøl, 1977). The question remains what is the trigger for this different glacier behaviour?

There is an apparent accordance of the timing of the LIA maximum of the eastern (not surging) tongues of Vatnajökull in Iceland in the late nineteenth century, at the same time as outlet glaciers of Folgefonna (Grove, 2004). Both ice caps depend on very heavy precipitation, even more pronounced than Jostedalsbreen.

Steiner et al. (2008a) studied the sensitivity of Nigardsbreen to seasonal temperature and precipitation parameters: The 1710–1748 advance was primarily controlled by winter precipitation, but also spring precipitation was important. Also Nesje et al. (2008b) argue that the main cause of the impressive glacier advance was mild and humid winters associated with increased precipitation and high snowfall on Jostedalsbreen. The glacier retreat subsequent to the LIA maximum coincides with an increase in summer and annual temperature in Scandinavia since the mid nineteenth century, especially pronounced in the so-called 'early warming period' (1930s and 1940s) and after 2000 (Nesje, 2009). However, glacier variations are triggered by different combinations of seasonal temperature and precipitation pattern (Steiner et al., 2008a). Nesje et al. (2008a) showed that Norwegian glaciers in particular did not respond uniformly to either summer temperature or winter precipitation, but rather to a complex interplay between different synoptic weather patterns.

Torsnes et al. (1993) calculated modern and LIA equilibrium-line altitudes (ELAs) for 20 of the Jostedalsbreen outlet glaciers

(using an accumulation area ratio (AAR) of 0.6 ± 0.05). The authors found a mean depression of 70 m during the LIA (individual ELA lowerings vary between 30 and 120 m). Differences in the ELA estimates can be attributed to differences in topography and morphology of the glaciers. Another study by Lukas (2007) found an average ELA lowering of about 190 m for the glaciers in Krundalen (e.g. Bergsetbreen). Corresponding air temperature and precipitation conditions indicate that only a small decrease in temperature and a slight increase in winter precipitation occurred at that time (Lukas, 2007; Velle et al., 2005). Wetter winters and milder summers with much reduced ablation might be the cause for the glaciers advancing during the LIA (Nesje and Dahl, 2003).

The net mass balance of the maritime glaciers in southern Norway (including Jostedalsbreen and Folgefonna) is best correlated with the winter balance (Nesje et al., 2000; Six et al., 2001). Interannual variations in the North Atlantic Oscillation (NAO) strongly influence the amount of winter precipitation in western Norway and thus the net mass balance of those glaciers (Chinn et al., 2005; Reichert et al., 2001). Differences in glacier hypsometry, frontal time lags, and different response to winter precipitation and summer temperature in different climate regions in Norway have been suggested by Nesje et al. (2008a) to explain the differences in the glacier variations between the individual glaciers/glacier regions.

Conclusions and outlook

Pictorial sources provide insight into glacier changes as well as changing views on glaciers. The analysis of historical sources and the quantitative data thereby derived are the prerequisite to studying the connection between climatic driving factors and glacier changes during the 'Little Ice Age' (LIA). A new compilation of historical (mainly pictorial) documents has allowed a refinement and prolongation of existing glacier length records.

The oldest historical information is available for Nigardsbreen and Bergsetbreen (Jostedalsbreen) in the eighteenth century, when the glacier advances devastated farms and their arable land. Later on, first scientists and explorers arrived in the 1820s and documented the glacier retreat in southern Norway subsequent to the 1750 maximum. Since the 1860s, a wealth of photographs is available, especially for Buerbreen (Folgefonna). For both Bondhusbrea and Buerbreen, new length curves were established for the nineteenth century.

Besides the frontal positions given by moraines, the new glacier length curves show also minimal extents. According to historical evidence, LIA maximum glacier extents in different parts of southern Norway varied considerably from the mid-eighteenth century (Jostedalsbreen) to the late nineteenth century (Folgefonna). The new length curves with pronounced advance and retreat periods may thus be used as a base for further studies dealing with the link between glacier variations and climate, or modelling of glacier changes.

The eight glaciers selected in this study are best documented regarding historical evidence mainly because of their easy accessibility. However, there is (unevaluated) historical material (e.g. photographs by Knud Knudsen) for other Norwegian glaciers, e.g. for other outlets from Jostedalsbreen, and particularly for Engabreen (Svartisen).

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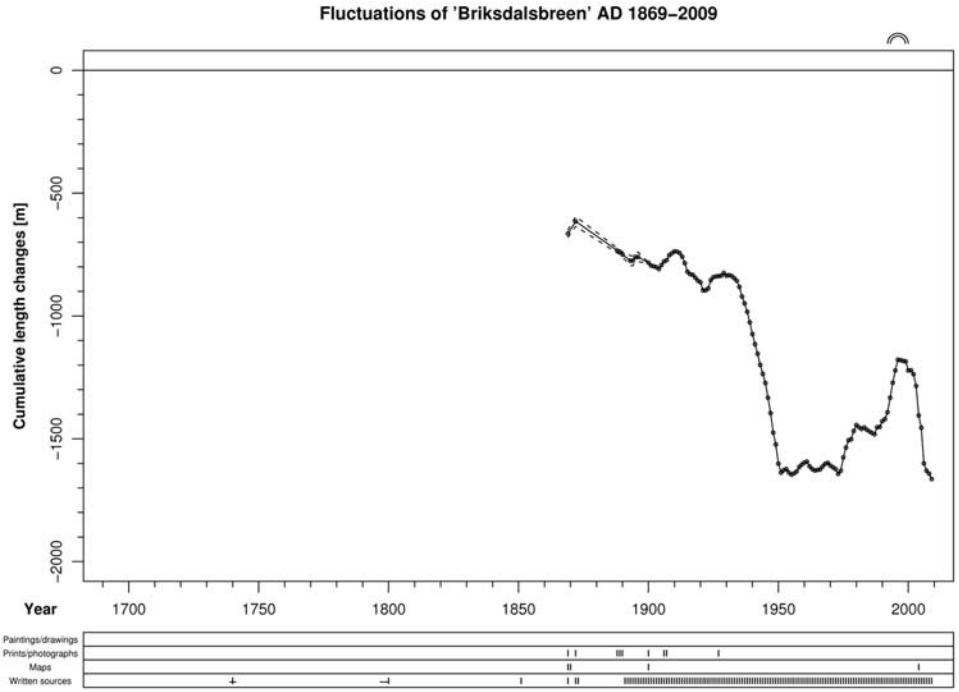

Figure 12. Cumulative length variations of Briksdalsbreen from 1869–2009, determined on the basis of historical documents (LIA maximum = 0). For each data point, the uncertainty is specified by the dashed lines (possible range of former glacier front positions). The frontal moraine from 1995 is shown by the semicircle. The summation of the historical sources is marked with lines below the plot. Horizontal lines indicate dating uncertainties. Note that there are some documents that only gave qualitative information. Data from 1900 to 2009: NVE, Oslo

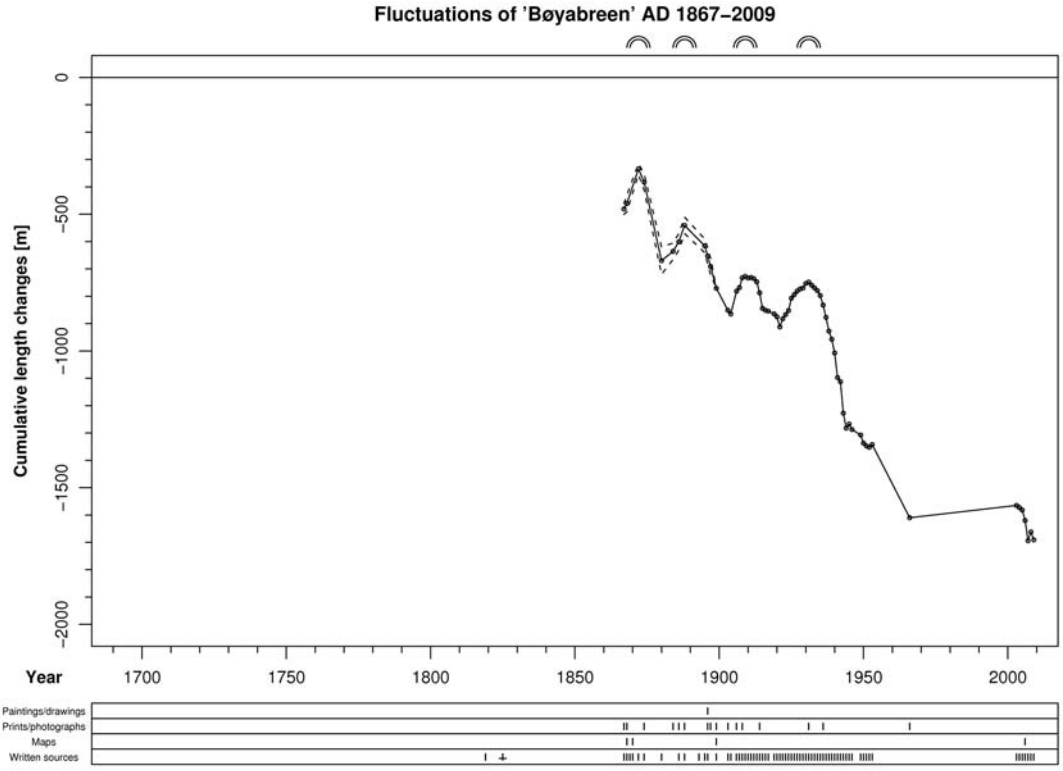

Figure 13. Cumulative length variations of Bøyabreen according to historical evidence from 1867–2009, similar to Figure 12. Frontal moraines (cf. Aa and Sjåstad, 2000; Mjanger and Hofsøy, 1989) are indicated by semicircles. Data from 1899 to 2009: NVE, Oslo

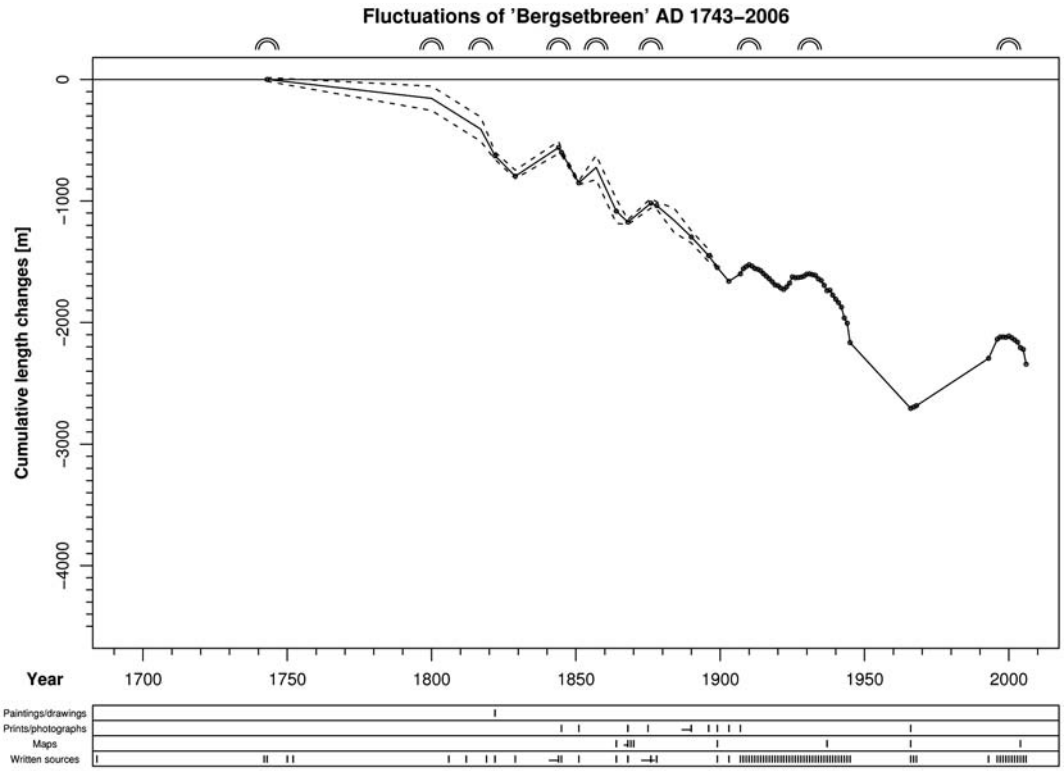

Figure 14. Cumulative length variations of Bergsetbreen according to historical evidence from 1743 to 2006, similar to Figure 12. Frontal moraines (cf. Bickerton and Matthews, 1993) are indicated by semicircles. Data from 1899 to 2006: NVE, Oslo

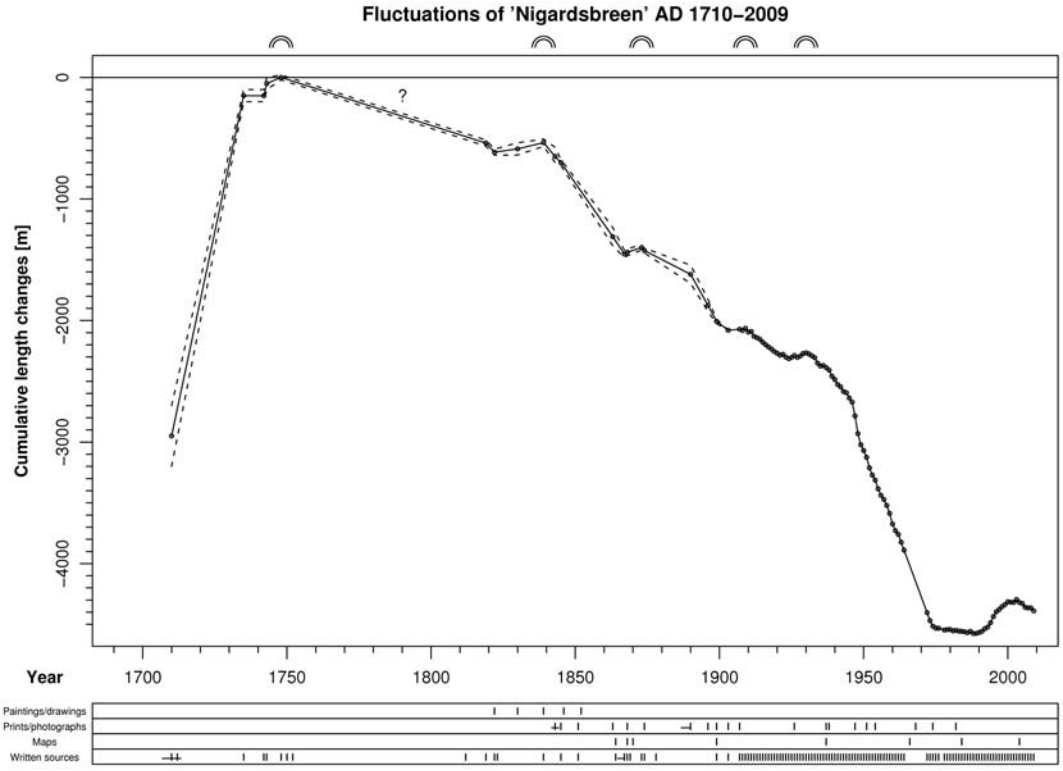

Figure 15. Cumulative length variations of Nigardsbreen according to historical evidence from 1710 to 2009, similar to Figure 12. Frontal moraines (cf. Andersen and Sollid, 1971; Nesjeet al., 2008b) are indicated by semicircles. Note that there are no historical documents between 1752 and 1812. Data from 1899 to 2009: NVE, Oslo

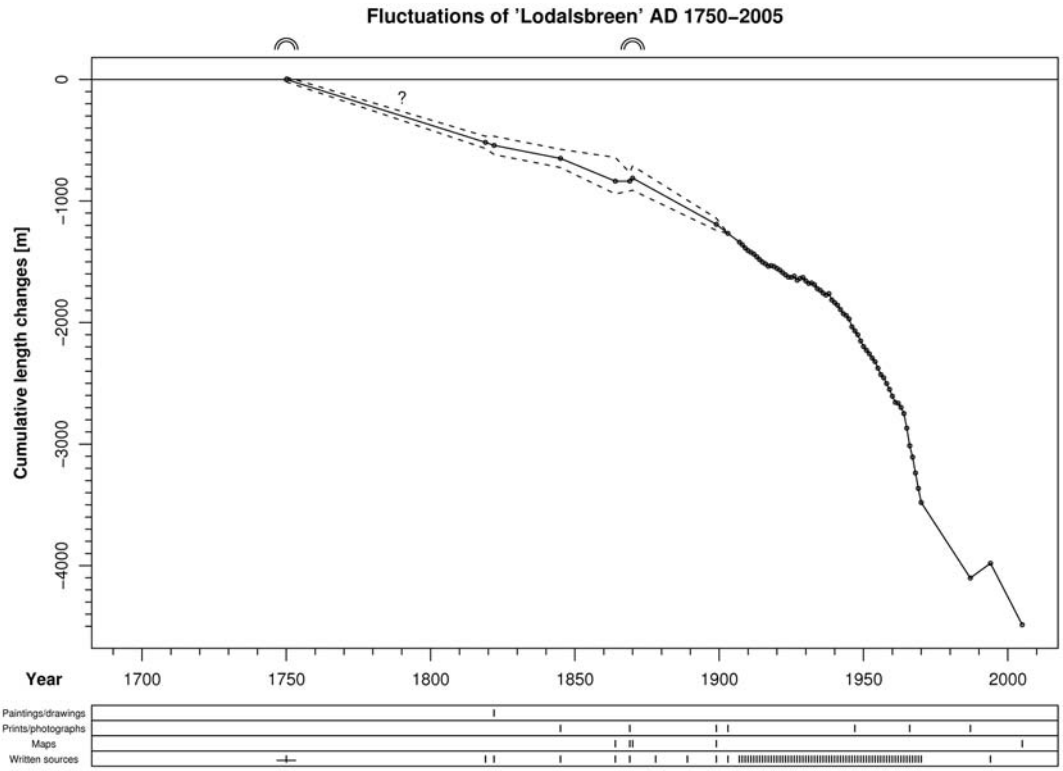

Figure 16. Cumulative length variations of Lodalsbreen according to historical evidence from 1750 to 2005, similar to Figure 12. Frontal moraines (cf. Bickerton and Matthews, 1993) are indicated by semicircles. Note that there are no historical documents between 1750 and 1819. Data from 1899 to 1970(1994): NVE, Oslo

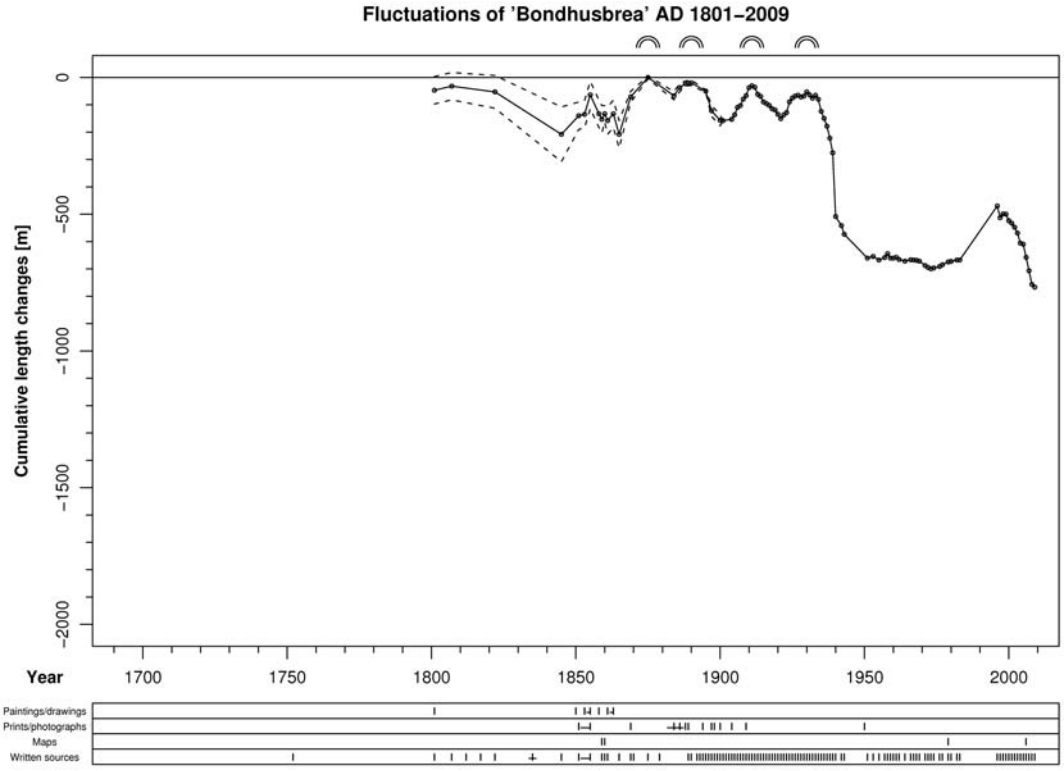

Figure 17. Cumulative length variations of Bondhusbrea according to historical evidence from 1801 to 2009, similar to Figure 12. Frontal moraines are indicated by semicircles. Data from 1901 to 2009: NVE, Oslo

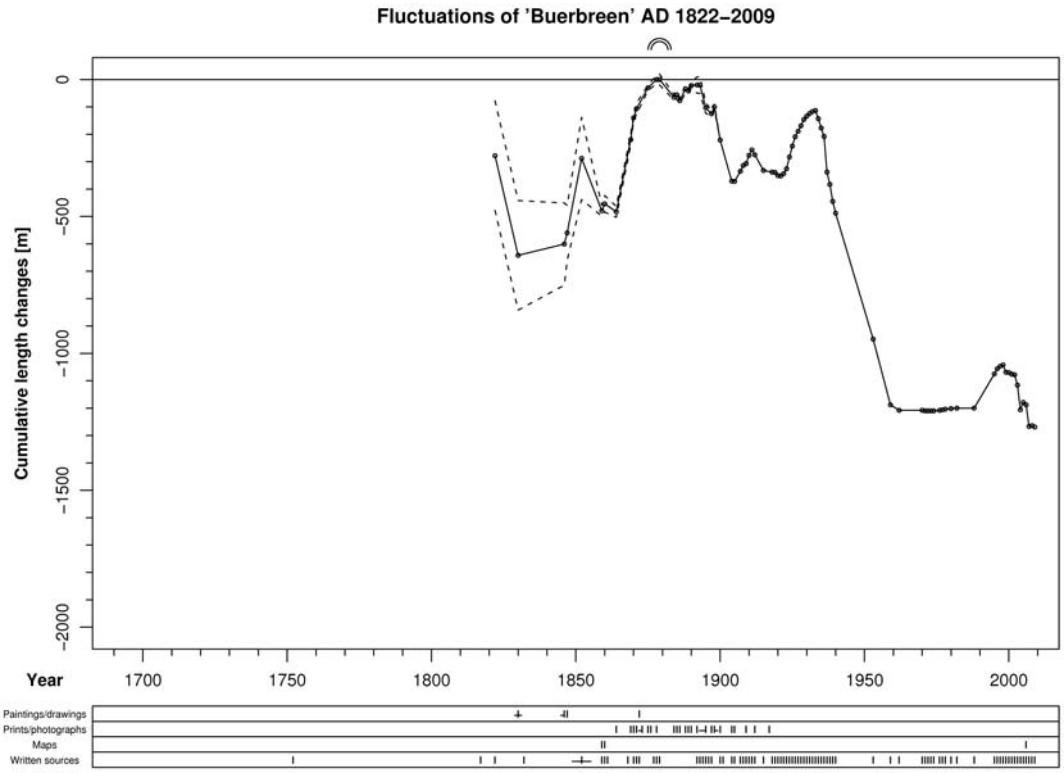

Figure 18. Cumulative length variations of Buerbreen according to historical evidence from 1822 to 2009, similar to Figure 12. The LIA maximum moraine is indicated by the semicircle. Data from 1900 to 2009: NVE, Oslo

Table 3. Summation of historical documents that have been used to reconstruct front variations of Briksdalsbreen within this study. Systematic frontal measurements (starting in 1900, written sources; NVE, Oslo) are not included in the list

Date	Type of document	Observer/author	Owner	Literature
1740 (?)	written source	local/J. Rekstad		Rekstad (1900, 1902); Eide (1955)
1775–1800	written source	M. E. Bødal/J. Rekstad		Rekstad (1902)
1851	written source	local/P.A. Munch		Forbes (1853)
29 July 1869	photograph	C. de Seue	NGU (fotoarkiv), Trondheim	de Seue (1870)
July 1869	written source	C. de Seue		de Seue (1870)
1869	written source	J. Rekstad		Rekstad (1902)
1869/1870	map (manuscript)	K. Lorange	Statens kartverk, Hønefoss	
1870 (1867–1869)	map	C. de Seue	Statens kartverk, Hønefoss	de Seue (1870)
1872	photograph (~5)	K. Knudsen	Universitetsbiblioteket (Billedsamlingen), Bergen	
1872	written source	J. Rekstad		Rekstad (1902)
1873	written source	K. Bing		Rabot (1900); Øyen (1900, 1901)
1888	photograph (~10)	A. Lindahl	Norsk Folkemuseum, Oslo	
1889 (?)	photograph (~5)	K. Knudsen	Universitetsbiblioteket (Billedsamlingen), Bergen	
1890	photograph	W. D. Valentine	Universitetsbiblioteket (Billedsamlingen), Bergen	Meyer (1989)
1891	written source	P.A. Øyen		Øyen (1906)
1892	written source	P.A. Øyen		Øyen (1906)
1893	written source	K. Bing; A. Briksdal; Y. Nielsen		Øyen (1900, 1906)
1894	written source	K. Bing		Rabot (1900); Øyen (1900, 1906)
1895	written source	K. Bing; E. Richter		Øyen (1900, 1901, 1906); Pedersen (1976)
1896	written source	P.A. Øyen		Øyen (1900, 1901, 1906)
1897	written source	A. Briksdal		Øyen (1900, 1906)
1898	written source	P.A. Øyen		Øyen (1906)
1899	written source	P.A. Øyen		Øyen (1906)
14/15 September 1900	photograph (3)	J. Rekstad	Universitetsbiblioteket (Billedsamlingen), Bergen	Rekstad (1902, 1905a)
14 September 1900	written source	J. Rekstad		Rekstad (1902, 1905a)
1900	map	J. Rekstad		Rekstad (1905a)
June 1906	photograph (~10)	A. B. Wilse	Norsk Folkemuseum, Oslo	
July 1907	photograph	anonymous	Universitetsbiblioteket (Billedsamlingen), Bergen	
1907	photograph	J. Rekstad	Universitetsbiblioteket (Billedsamlingen), Bergen	
1927	photograph (3)	A. B. Wilse	Norsk Folkemuseum, Oslo	
12 August 2004	map	Norwegian Mapping Authority	Statens kartverk, Hønefoss	

Table 4. Summation of historical documents that have been used to reconstruct front variations of Bøyabreen within this study. Systematic frontal measurements (starting in 1899, written sources; NVE, Oslo) are not included in the list

Date	Type of document	Observer/author	Owner	Literature
1819	written source	J. Neumann		Øyen (1900)
1825 (?)	written source	local/J. Rekstad		Rekstad (1900, 1905a)
7 August 1867	photograph (2)	C. de Seue	NGU (fotoarkiv), Trondheim	Rekstad (1900)
27 July 1868	photograph (3)	C. de Seue	NGU (fotoarkiv), Trondheim	de Seue (1870)
July 1868	written source	C. de Seue		de Seue (1870)
1868	map	C. de Seue		de Seue (1870)
July 1868	written source	S. A. Sexe		Sexe (1869)
1868	written source	H. A. Tufte		Rekstad (1900)
1868	map (manuscript)	G. Lorange	Statens kartverk, Hønefoss	
1869	written source	C. de Seue		de Seue (1870); Rekstad (1902)
1870 (1867–1869)	map	C. de Seue	Statens kartverk, Hønefoss	de Seue (1870)
1870	written source	J. Rekstad		Rekstad (1900)
1872	written source	J. Rekstad		Rekstad (1902)
1874	photograph (~15)	K. Knudsen	Universitetsbiblioteket (Billedsamlingen), Bergen	Rekstad (1900)
1874	written source	J. Rekstad		Rekstad (1900)
1880	written source	J. Rekstad		Rekstad (1900)
July 1884	photograph	K. Steenstrup	NGU (fotoarkiv), Trondheim	
1886	photograph (5)	A. Lindahl	Norsk Folkemuseum, Oslo	Rekstad (1900)
1886	written source	J. Rekstad		Rekstad (1900)
1888	photograph (~10)	K. Knudsen	Universitetsbiblioteket (Billedsamlingen), Bergen	Rekstad (1900)
1888	written source	J. Rekstad		Rekstad (1900)
1893	written source	P. A. Øyen		Øyen (1900)
1895	written source	E. Richter		Rabot (1900); Øyen (1900)
1896	oil painting	H. J. Kaulum	Hotel Mundal, Fjærland	
1896	photograph	K. Knudsen	Universitetsbiblioteket (Billedsamlingen), Bergen	Rekstad (1900)
1896	written source	J. Rekstad		Rekstad (1900)
1897	photograph	Photochrom Zürich	The Library of Congress, Washington DC	Arqué et al. (2009)
30 August 1899	photograph (8)	J. Rekstad	Universitetsbiblioteket (Billedsamlingen), Bergen	Rekstad (1900, 1905a)
30 August 1899	written source	J. Rekstad		Rekstad (1900, 1902, 1905a)
1899	map	J. Rekstad		Rekstad (1905a)
17 September 1903	photograph (2)	J. Rekstad	Universitetsbiblioteket (Billedsamlingen), Bergen	Rekstad (1905a)
30 August 1906	photograph (2)	J. Rekstad	Universitetsbiblioteket (Billedsamlingen), Bergen	Rekstad (1907)
1908	photograph	J. Rekstad	Universitetsbiblioteket (Billedsamlingen), Bergen	
1914	photograph (5)	A. B. Wilse	Norsk Folkemuseum, Oslo	
July 1931	photograph	K. Fægri		Fægri (1934)
June 1936	photograph (6)	A. B. Wilse	Norsk Folkemuseum, Oslo	
19 July 1966	aerial photograph	Norsk Luftfoto og Fjernmåling		
16 September 2006	map	Norwegian Mapping Authority	Statens kartverk, Hønefoss	

Table 5. Summation of historical documents available for Store Supphellebreen. Systematic frontal measurements (starting in 1899, written sources; NVE, Oslo) are not included in the list

Date	Type of document	Observer/author	Owner	Literature
1819	written source	J. Neumann		Øyen (1900)
29 July 1845	drawing	H. F. Gude	Nasjonalmuseet, Oslo	Messel (2008)
August 1849	oil painting	H. F. Gude	private collection	
1851	print (2)	J. D. Forbes		Forbes (1853)
1851	written source	J. D. Forbes		Forbes (1853)
1857	oil painting	H. F. Gude	private collection	
1867	photograph	C. de Seue	NGU (fotoarkiv), Trondheim	de Seue (1870)
1868	photograph	C. de Seue (?)	NGU (fotoarkiv), Trondheim	
1868	written source	C. de Seue		de Seue (1870)
1868	map (manuscript)	G. Lorange	Statens kartverk, Hønefoss	
1869	written source	C. de Seue		de Seue (1870)
1870 (1867–1869)	map	C. de Seue	Statens kartverk, Hønefoss	de Seue (1870)
1873	oil painting	A. M. Askevold	private collection	
July 1884	photograph (2)	K. Steenstrup	NGU (fotoarkiv), Trondheim	
1888	photograph (~10)	K. Knudsen	Universitetsbiblioteket (Billedsamlingen), Bergen	
9 August 1889	written source	W. C. Slingsby		Slingsby (1891); Rabot (1900)
1890	photograph (~10)	A. Lindahl	Norsk Folkemuseum, Oslo	
1890	photograph (2)	W. D. Valentine	NVE, Oslo	Meyer (1989)
1893	written source	P. A. Øyen		Øyen (1900)

(Continued)

Table 5. *(Continued)*

Date	Type of document	Observer/author	Owner	Literature
28 July 1895	written source	E. Richter		Rabot (1900); Øyen (1900)
1896	oil painting	J. M. Grimelund	Hotel Mundal, Fjærland	
5 August 1896	photograph	H.W. Monckton	NGU (fotoarkiv), Trondheim	
1897	photograph (3)	Photochrom Zürich	private collection	Arqué et al. (2009)
September 1899	photograph (8)	J. Rekstad	Universitetsbiblioteket (Billedsamlingen), Bergen	Rekstad (1902, 1905a)
September 1899	written source	J. Rekstad		Rekstad (1902)
1899	map	J. Rekstad		Rekstad (1905a)
18 July 1901	photograph	H.W. Monckton	NGU (fotoarkiv), Trondheim	
18/19 September 1903	photograph (7)	J. Rekstad	Universitetsbiblioteket (Billedsamlingen), Bergen	Rekstad (1905a)
August 1905	photograph	anonymous	NGU (fotoarkiv), Trondheim	
29 August 1906	photograph (3)	J. Rekstad	Universitetsbiblioteket (Billedsamlingen), Bergen	
1908	photograph (2)	J. Rekstad	Universitetsbiblioteket (Billedsamlingen), Bergen	
10 June 1941	photograph	A. B. Wilse	Norsk Folkemuseum, Oslo	
25 October 1986	photograph	anonymous	Norsk Bremuseum, Fjærland	
16 September 2006	map	Norwegian Mapping Authority	Statens kartverk, Hønefoss	

Table 6. Summation of historical documents that have been used to reconstruct front variations of Bergsetbreen within this study. Systematic frontal measurements (starting in 1899, written sources; NVE, Oslo) are not included in the list

Date	Type of document	Observer/author	Owner	Literature
1684	written source	B. Munthe		Eide (1955); Grove and Battagel (1983); Øyane (1994); Grove (2004)
21 August 1742	written source	local/G. Bohr		Bohr (1820); Eide (1955)
1743	written source	local/J. Rekstad	Statsarkivet, Bergen	Rekstad (1900, 1905a)
11 May 1750	written source	M. Foss		Foss (1750, 1802)
1752	written source	E. Pontoppidan		Pontoppidan (1752); Hoel and Norvik (1962)
1806	written source	L. von Buch		von Buch (1810); Rabot (1900); Næess et al. (1989)
1812	written source	C. Smith		Smith (1817); Rabot (1900); Næess et al. (1989)
1819	written source	G. Bohr		Bohr (1820); Naumann (1824b)
August 1822	drawing	J. Flintoe	Bergen Kunstmuseum	Messel (2008)
August 1822	written source	J. Flintoe		Messel (2008)
1822	written source	C. F. Naumann		Naumann (1824b); Rabot (1900); Rekstad (1902)
1829	written source	local/J. Rekstad		Rekstad (1900, 1905a)
1834 (1822)	gouache	J. Flintoe	Bergen Kunstmuseum	Messel (2008)
1844 (?)	written source	J. Rekstad		Rekstad (1905a); Bickerton and Matthews (1993)
1845	print	J. Durocher		Durocher (1847)
1845	written source	J. Durocher		Durocher (1847); Rekstad (1905a)
1851	print	J. D. Forbes		Forbes (1853)
1851	written source	J. D. Forbes		Forbes (1853); Rekstad (1905a)
July/August 1864	map	C. M. Doughty		Doughty (1866)
July/August 1864	written source	C. M. Doughty		Doughty (1866)
1868	photograph (2)	C. de Seue	NGU (fotoarkiv), Trondheim	de Seue (1870)
6 September 1868	written source	C. de Seue		de Seue (1870)
1868 (1867)	map (manuscript)	H. Lund	Statens kartverk, Hønefoss	Horgen (1999)
1869/1870	map (manuscript)	K. Lorange	Statens kartverk, Hønefoss	
1870 (1867–1869)	map	C. de Seue	Statens kartverk, Hønefoss	de Seue (1870)
1875	print	anonymous	private collection	
1876 (?)	written source	C. de Seue		de Seue (1870); Bickerton and Matthews (1993)
1878	written source	L. Holmström		Rabot (1900); Øyen (1900)
1890 (?)	photograph (2)	A. Lindahl	Norsk Folkemuseum, Oslo	
1896	photograph	K. Knudsen	Universitetsbiblioteket (Billedsamlingen), Bergen	
14/15 September 1899	photograph (2)	J. Rekstad	Universitetsbiblioteket (Billedsamlingen), Bergen	Rekstad (1905a)
14 September 1899	written source	J. Rekstad		Rekstad (1905a)
1899	map	J. Rekstad		Rekstad (1905a)
11 September 1903	photograph (3)	J. Rekstad	Universitetsbiblioteket (Billedsamlingen), Bergen	Rekstad (1905a)
20 August 1907	photograph (2)	J. Rekstad	Universitetsbiblioteket (Billedsamlingen), Bergen	
1937	map	W. Pillewizer		Pillewizer (1950)
19 July 1966	aerial photograph	Norsk Luftfoto og Fjernmåling		
1973 (1966)	map	Norges geografiske oppmåling	Statens kartverk, Hønefoss	Østrem and Haakensen (1993)
12 August 2004	map	Norwegian Mapping Authority	Statens kartverk, Hønefoss	

Table 7. Summation of historical documents that have been used to reconstruct front variations of Nigardsbreen within this study. Systematic frontal measurements (starting in 1899, written sources; NVE, Oslo) are not included in the list

Date	Type of document	Observer/author	Owner	Literature
1710/1712 (?)	written source	local/G. Bohr; H. Wiingaard		Bohr (1820); Rekstad (1902); Østrem et al. (1976)
16 November 1735	written source	local		Eide (1955); Østrem et al. (1976)
August 1742	written source	M. Foss		Foss (1750, 1802); Østrem et al. (1976)
1742	written source	local/G. Bohr		Bohr (1820)
1743	written source	M. Foss		Foss (1750, 1802); Rekstad (1900); Østrem et al. (1976)
1748	written source	M. Foss		Foss (1750, 1802); Rekstad (1900); Østrem et al. (1976)
11 May 1750	written source	M. Foss		Foss (1750, 1802)
1752	written source	E. Pontoppidan		Pontoppidan (1752); Hoel and Norvik (1962)
1812	written source	C. Smith		Smith (1817); Østrem et al. (1976)
14 July 1819	written source	G. Bohr		Bohr (1820); Naumann (1824b); Rekstad (1902, 1905a); Østrem et al. (1976)
August 1822	drawing	J. Flintoe	Bergen Kunstmuseum	Messel (2008)
August 1822	written source	J. Flintoe		Messel (2008)
July 1823	written source	J. Neumann		Neumann (1824); Grove (2004)
1830	oil painting	K. Baade	Bergen Kunstmuseum	
1834 (1822)	gouache	J. Flintoe	Nasjonalmuseet, Oslo	Messel (2008)
1 August 1839	drawing	K. Baade	Nasjonalmuseet, Oslo	Messel (2008)
August 1839	drawing	J. C. Dahl	Nasjonalmuseet, Oslo	Grove (2004)
1839	written source	A. E. Lindblom/J. Rekstad		Lindblom (1841); Rekstad (1905a); Østrem et al. (1976)
1843 (?)	print	J. Frich	private collection	Asbjørnsen and Tønsberg (1848); Messel (1990)
1844 (1839)	oil painting	J. C. Dahl	Bergen Kunstmuseum	Lange (1988)
1845	print	J. Durocher		Durocher (1847)
1845	written source	J. Durocher		Durocher (1847); Rekstad (1902); Østrem et al. (1976)
1846	oil painting	K. Baade	Nasjonalmuseet, Oslo	Hellandsjø (2008); Messel (2008)
1847 (1839)	oil painting	J. C. Dahl	Nasjonalmuseet, Oslo	Lange (1988); Messel (2008)
1851	print	J. D. Forbes		Forbes (1853); Østrem et al. (1976)
1851	written source	J. D. Forbes		Forbes (1853); Østrem et al. (1976)
23 July 1852	gouache	F.W. Schiertz	Nasjonalmuseet, Oslo	Messel (2008)
1864 (1863)	print	after M. Selmer	Nasjonalbiblioteket, Oslo	Østrem and Haakensen (1993)
July/August 1864	map	C. M. Doughty		Doughty (1866)
July/August 1864	written source	C. M. Doughty		Doughty (1866)
1864	written source	local/P.A. Øyen		Øyen (1901)
1867 (?)	written source	A. Blytt		Blytt (1869); Østrem et al. (1976)
9 August 1868	photograph	C. de Seue	NGU (fotoarkiv), Trondheim	de Seue (1870)
9 August 1868	written source	C. de Seue		de Seue (1870)
1868	map (manuscript)	H. Lund	Statens kartverk, Hønefoss	Horgen (1999)
1868	written source	local/P.A. Øyen		Øyen (1901)
1869	written source	J. Rekstad		Rekstad (1902)
1870 (1867–1869)	map	C. de Seue	Statens kartverk, Hønefoss	de Seue (1870)
1873	written source	local/J. Rekstad		Rekstad (1902, 1905a); Østrem et al. (1976)
1873	written source	J. Larsen		Larsen (1875); Østrem et al. (1976)
1874	photograph (~20)	K. Knudsen	Universitetsbiblioteket (Billedsamlingen), Bergen	

(Continued)

Table 7. *(Continued)*

Date	Type of document	Observer/author	Owner	Literature
1874	print	G. Studer		Studer (1877)
1874	written source	G. Studer		Studer (1877)
1878	written source	L. Holmström		Øyen (1900)
1890 (?)	photograph (~10)	A. Lindahl	Norsk Folkemuseum, Oslo	
1890	photograph	W. D. Valentine	Breheimsenteret, Jostedal	Meyer (1989)
1896	photograph (2)	K. Knudsen	Universitetsbiblioteket (Billedsamlingen), Bergen	
10 September 1899	photograph (6)	J. Rekstad	Universitetsbiblioteket (Billedsamlingen), Bergen	Rekstad (1900, 1905c); Østrem et al. (1976)
10 September 1899	written source	J. Rekstad		Rekstad (1900, 1902)
1899	map	J. Rekstad		Rekstad (1905a)
4 September 1903	photograph (2)	J. Rekstad	Universitetsbiblioteket (Billedsamlingen), Bergen	Rekstad (1905a)
1907	photograph (2)	J. Rekstad	Universitetsbiblioteket (Billedsamlingen), Bergen	
1926	photograph (3)	A. B. Wilse	Norsk Folkemuseum, Oslo	
1937	photograph	W. Pillewizer		Pillewizer (1950)
1937	map	W. Pillewizer		Pillewizer (1950)
22 July 1938	aerial photograph	Fjellanger Widerøe		Østrem and Haakensen (1993)
28 August 1947	photograph	Fjellanger Widerøe		Østrem et al. (1988)
1951	photograph	O. Liestøl		Østrem et al. (1988)
24 August 1954	photograph	Fjellanger Widerøe		Østrem and Ziegler (1969)
1968	photograph	O. Liestøl		Østrem et al. (1988)
1973 (1966)	map	Norges geografiske oppmåling	Statens kartverk, Hønefoss	Østrem and Haakensen (1993)
29 August 1974	aerial photograph	Fjellanger Widerøe		Østrem and Haakensen (1993)
1982	photograph	O. Liestøl		Østrem et al. (1988)
1984	map	NVE	NVE, Oslo	Østrem et al. (1988)
12 August 2004	map	Norwegian Mapping Authority	Statens kartverk, Hønefoss	

Table 8. Summation of historical documents that have been used to reconstruct front variations of Lodalsbreen within this study. Systematic frontal measurements (starting in 1899, written sources; NVE, Oslo) are not included in the list

Date	Type of document	Observer/author	Owner	Literature
1750 (?)	written source	M. Foss		Foss (1750, 1802); Rekstad (1900, 1905a)
1819	written source	G. Bohr		Bohr (1820); Naumann (1824b); Rekstad (1902)
1822	drawing	W. M. Carpelan	Nasjonalbiblioteket, Oslo	Rekstad (1902); Messel (2008)
1822	written source	C. F. Naumann		Naumann (1824b); Rekstad (1902)
1845	print	J. Durocher		Durocher (1847)
1845	written source	J. Durocher		Durocher (1847)
July/August 1864	map	C. M. Doughty		Doughty (1866)
July/August 1864	written source	C. M. Doughty		Doughty (1866)
August 1869	photograph (3)	C. de Seue	NGU (fotoarkiv), Trondheim	de Seue (1870)
August 1869	written source	C. de Seue		de Seue (1870)
August 1869	map	C. de Seue		de Seue (1870)
1870 (1867–1869)	map	C. de Seue	Statens kartverk, Hønefoss	de Seue (1870)
1870	map (manuscript)	K. Lorange	Statens kartverk, Hønefoss	
1878	written source	L. Holmström		Rabot (1900); Øyen (1900)
1889	written source	W. C. Slingsby		Slingsby (1891)
13 September 1899	photograph (2)	J. Rekstad	Universitetsbiblioteket (Billedsamlingen), Bergen	Rekstad (1902)
12/13 September 1899	written source	J. Rekstad		Rekstad (1902)
1899	map	J. Rekstad		Rekstad (1902)
7 September 1903	photograph	J. Rekstad	Universitetsbiblioteket (Billedsamlingen), Bergen	Rekstad (1905a)
28 August 1947	photograph	Fjellanger Widerøe	NVE, Oslo	Østrem et al. (1988)
19 July 1966	aerial photograph	Norsk Luftfoto og Fjernmåling		
22 July 1987	satellite image	SPOT	Spot Image, Toulouse	Østrem et al. (1988)
10 September 2005	map	Norwegian Mapping Authority	Statens kartverk, Hønefoss	

Table 9. Summation of historical documents that have been used to reconstruct front variations of Bondhusbrea within this study. Systematic frontal measurements (starting in 1901, written sources; NVE, Oslo) are not included in the list

Date	Type of document	Observer/author	Owner	Literature
1752	written source	E. Pontoppidan		Pontoppidan (1752); Hoel and Norvik (1962)
8 August 1801	drawing	N. Hertzberg		Østrem and Haakensen (1993); Brekke and Nord (2008)
8 August 1801	written source	N. Hertzberg		Østrem and Haakensen (1993); Brekke and Nord (2008)
1807	written source	N. Hertzberg		Øyen (1900, 1901)
1812	written source	C. Smith		Rabot (1900); Øyen (1900, 1901)
1817/1818	written source	N. Hertzberg		Øyen (1900)
June 1822	written source	C. F. Naumann		Naumann (1824a); Kolltveit (1963)
1835 (?)	written source	J. Rekstad		Rekstad (1905b)
1845	written source	H. Konow		Konow (1845); Øyen (1900, 1901); Hoel and Norvik (1962)
1850	oil painting	J. Frich	Bergen Kunstmuseum	
1851	print	J. D. Forbes		Forbes (1853)
1851	written source	J. D. Forbes		Forbes (1853); Sexe (1864); Øyen (1901)
13 September 1853	drawing	F.W. Schiertz	Nasjonalmuseet, Oslo	Messel (2008)
1855 (?)	oil painting	J. Frich	private collection	Messel (2008)
1855 (?)	print	J. Frich		Messel (1990)
1855 (?)	written source	J. Frich		Messel (1990)
1858	oil painting	A. M. Askevold	private collection	
1859	written source	S. A. Sexe		Sexe (1864)
1860	map (manuscript)	H. Fougner	Statens kartverk, Hønefoss	
1860	written source	S. A. Sexe		Sexe (1864)
1861	oil painting	A. M. Askevold	private collection	
1861	written source	S. A. Sexe		Sexe (1864)
1863 (?)	oil painting	A. M. Askevold	Lillehammer Kunstmuseum	Brekke and Nord (2008)
1864 (1859–1861)	map	S. A. Sexe	Statens kartverk, Hønefoss	Sexe (1864)
1865	written source	Meidell/P. A. Øyen		Rekstad (1905b)
1866 (1859–1861)	map	S. A. Sexe	Statens kartverk, Hønefoss	Sexe (1866)
1869	photograph (~10)	K. Knudsen	Universitetsbiblioteket (Billedsamlingen), Bergen	Rekstad (1900)
1869	written source	J. Rekstad		Rekstad (1900)
5 August 1870	written source	A. Helland		Rekstad (1905b)
1875	written source	A. T. Bondhus/J. Rekstad		Rekstad (1905b)
1879	written source	Y. Nielsen		Nielsen (1880b); Øyen (1901)
1884 (?)	photograph (6)	A. Lindahl	Norsk Folkemuseum, Oslo	Meyer (1989)
1886 (?)	photograph (6)	A. Lindahl	Norsk Folkemuseum, Oslo	Meyer (1989)
1888	photograph (2)	W. D. Valentine	NVE, Oslo	Meyer (1989)
1889	photograph (~10)	K. Knudsen	Universitetsbiblioteket (Billedsamlingen), Bergen	Rekstad (1900)
1889	written source	J. Rekstad		Rekstad (1905b)
1890	written source	J. Rekstad		Rekstad (1905b)
1892	written source	A. Bondhus		Øyen (1900, 1906)
1893	written source	A. Bondhus		Øyen (1900, 1906)
25 June 1894	photograph	H. G. Tornøe	NGU (fotoarkiv), Trondheim	
1894	written source	P. A. Øyen		Øyen (1906)
1895	written source	E. Richter		Øyen (1900, 1906); Rekstad (1905b)
1896	written source	P. A. Øyen		Øyen (1906)
1897	photograph	Photochrom Zürich	private collection	Arqué et al. (2009)
1897	written source	Gausvik/P. A. Øyen		Øyen (1900, 1906)
1898	photograph	L. Bekker Larsen	Universitetsbiblioteket (Billedsamlingen), Bergen	
1898	written source	P. A. Øyen		Øyen (1906)
1899	written source	P. A. Øyen		Øyen (1906)
1900	photograph	L. Bekker Larsen	Universitetsbiblioteket (Billedsamlingen), Bergen	
1900	written source	P. A. Øyen		Øyen (1906)
1901	written source	P. A. Øyen		Øyen (1902)
1902	written source	A. Bondhus		Rekstad (1905b); Øyen (1906)
1903	written source	P. A. Øyen		Øyen (1906)
26 June 1904	photograph (6)	J. Rekstad	Universitetsbiblioteket (Billedsamlingen), Bergen	Rekstad (1905b)
1909	photograph (3)	J. Rekstad	Universitetsbiblioteket (Billedsamlingen), Bergen	
7 July 1950	photograph	Fjellanger Widerøe	NVE, Oslo	Østrem and Ziegler (1969)
1979	map	NVE	NVE, Oslo	Østrem et al. (1988)
16 July 2006	map	Norwegian Mapping Authority	Statens kartverk, Hønefoss	

Table 10. Summation of historical documents that have been used to reconstruct front variations of Buerbreen within this study. Systematic frontal measurements (starting in 1900, written sources; NVE, Oslo) are not included in the list

Date	Type of document	Observer/author	Owner	Literature
1677 (1676)	written source	local/O. Kolltveit		Hoel and Werenskiold (1962)
1752	written source	E. Pontoppidan		Pontoppidan (1752); Hoel and Werenskiold (1962)
1817/1818	written source	N. Hertzberg		Øyen (1900)
June 1822	written source	C. F. Naumann		Naumann (1824a); Kolltveit (1963)
1830 (?)	drawing	C. H. Kølle	Bergen Museum	Kolltveit (1963); Brekke and Nord (2008)
1832	written source	local/S. A. Sexe		Øyen (1900)
1846 (?)	drawing	A. Smith		Smith and Warren (1847); Kolltveit (1962)
21 July 1847	drawing	J. N. Prahm	Nasjonalmuseet, Oslo	Messel (2008)
1852 (?)	written source	S. A. Sexe/J. Rekstad		Sexe (1864); Rekstad (1900, 1905b)
1859	written source	S. A. Sexe		Sexe (1864); Rabot (1900); Rekstad (1905b)
1860	map (manuscript)	H. Fougner	Statens kartverk, Hønefoss	
1860	written source	S. A. Sexe		Sexe (1864)
1861	written source	S. A. Sexe		Sexe (1864); Rabot (1900); Rekstad (1900)
1864	photograph (4)	K. Knudsen	Universitetsbiblioteket (Billedsamlingen), Bergen	
1864 (1859–1861)	map	S. A. Sexe	Statens kartverk, Hønefoss	Sexe (1864)
1866 (1859–1861)	map	S. A. Sexe	Statens kartverk, Hønefoss	Sexe (1866)
1868	written source	local/P. A. Øyen		Øyen (1901)
1869	photograph	K. Knudsen	Universitetsbiblioteket (Billedsamlingen), Bergen	
1870	photograph (~10)	K. Knudsen	Universitetsbiblioteket (Billedsamlingen), Bergen	Meyer (1989)
1870	written source	C. Rabot/J. Rekstad/P. A. Øyen		Rabot (1900); Rekstad (1900, 1905b); Øyen (1900, 1901)
1871	photograph	K. Knudsen	Universitetsbiblioteket (Billedsamlingen), Bergen	
1871	written source	C. Rabot/J. Rekstad/P. A. Øyen		Rabot (1900); Rekstad (1900, 1905b); Øyen (1901)
1872	oil painting	G. A. Rasmussen	Bergen Kunstmuseum	
1872	written source	J. M. Wilson		Øyen (1900, 1901)
1873 (?)	print	C. G. Hellqvist	Nasjonalbiblioteket, Oslo	
1875	photograph (~5)	K. Knudsen	Universitetsbiblioteket (Billedsamlingen), Bergen	Rekstad (1905b); Meyer (1989)
1876	photograph	K. Knudsen	Universitetsbiblioteket (Billedsamlingen), Bergen	
1877	written source	S. A. Sexe		Øyen (1900)
August 1878	photograph	A. Arctander	NGU (fotoarkiv), Trondheim	
August 1878	written source	L. Holmström		Credner (1891); Rabot (1900); Rekstad (1900, 1905b); Øyen (1900, 1901)
1879	written source	Y. Nielsen		Nielsen (1880a,b); Øyen (1900, 1901)
July 1884	photograph (3)	K. Steenstrup	NGU (fotoarkiv), Trondheim	
1885 (?)	photograph	A. Brown	Nasjonalmuseet, Oslo	Meyer (1989)
1886	photograph (~5)	K. Knudsen	Universitetsbiblioteket (Billedsamlingen), Bergen	
1888	photograph	W. D. Valentine	NVE, Oslo	Meyer (1989)
1889	photograph (~10)	K. Knudsen	Universitetsbiblioteket (Billedsamlingen), Bergen	Meyer (1989)
1890	photograph	W. D. Valentine	NVE, Oslo	Meyer (1989)
1890 (?)	photograph (~20)	A. Lindahl	Norsk Folkemuseum, Oslo	Meyer (1989); Hellandsjø (2008)
1890 (?)	photograph	K. Knudsen	Universitetsbiblioteket (Billedsamlingen), Bergen	Kolltveit (1967); Brekke and Nord (2008)
28 August 1892	photograph	H. G. Tornøe	NGU (fotoarkiv), Trondheim	
1892	written source	C. Rabot		Rabot (1900)
1893	written source	K. Bing		Rabot (1900); Øyen (1900, 1901)
1894	written source	K. Bing; J. Jordal		Rabot (1900); Øyen (1900, 1901)
1895 (?)	photograph	K. Knudsen	Universitetsbiblioteket (Billedsamlingen), Bergen	
1895	written source	J. Jordal		Rabot (1900); Øyen (1900)
1896	written source	J. Jordal/C. Rabot/J. Rekstad		Rabot (1900); Rekstad (1900); Øyen (1900)

Table 10. *(Continued)*

Date	Type of document	Observer/author	Owner	Literature
1897	photograph (3)	K. Knudsen	Universitetsbiblioteket (Billedsamlingen), Bergen	
1897	photograph (3)	Photochrom Zürich	private collection	Arqué et al. (2009)
1897	written source	J. Jordal		Øyen (1900)
1898 (?)	photograph	W. Dreesen	Universitetsbiblioteket (Billedsamlingen), Bergen	
30 August 1900	photograph (3)	J. Rekstad	Universitetsbiblioteket (Billedsamlingen), Bergen	
1901	written source	P.A. Øyen		Øyen (1902)
6 August 1904	photograph	J. Rekstad	Universitetsbiblioteket (Billedsamlingen), Bergen	Rekstad (1905b)
1905	photograph	J. Rekstad	Universitetsbiblioteket (Billedsamlingen), Bergen	
1909	photograph	J. Rekstad	Universitetsbiblioteket (Billedsamlingen), Bergen	
1912	photograph (15)	A. B. Wilse	Norsk Folkemuseum, Oslo	
1917	photograph (2)	J. Rekstad	Universitetsbiblioteket (Billedsamlingen), Bergen	
16 July 2006	map	Norwegian Mapping Authority	Statens kartverk, Hønefoss	

Additional maps of glacier forelands

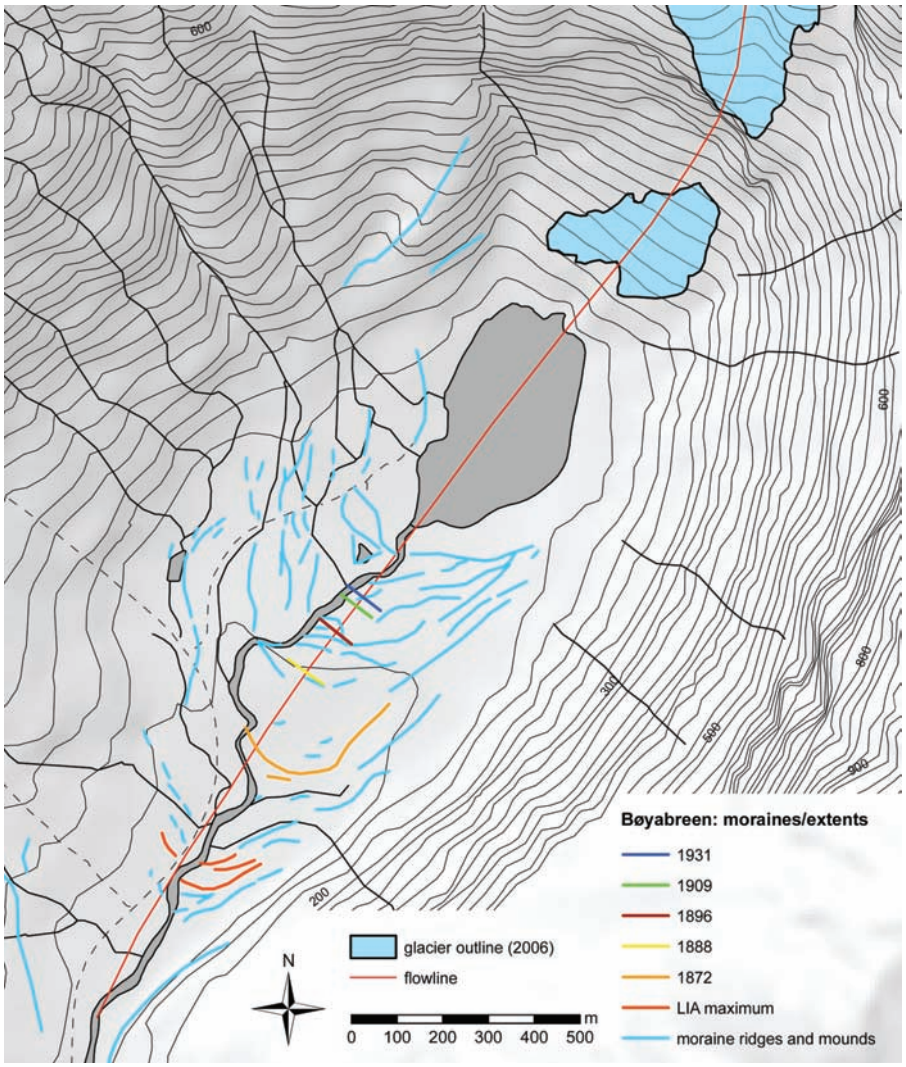

Figure 19. Glacier foreland of Bøyabreen. Moraine mapping modified after Mjanger and Hofsøy (1989), Aa and Sjåstad (2000)

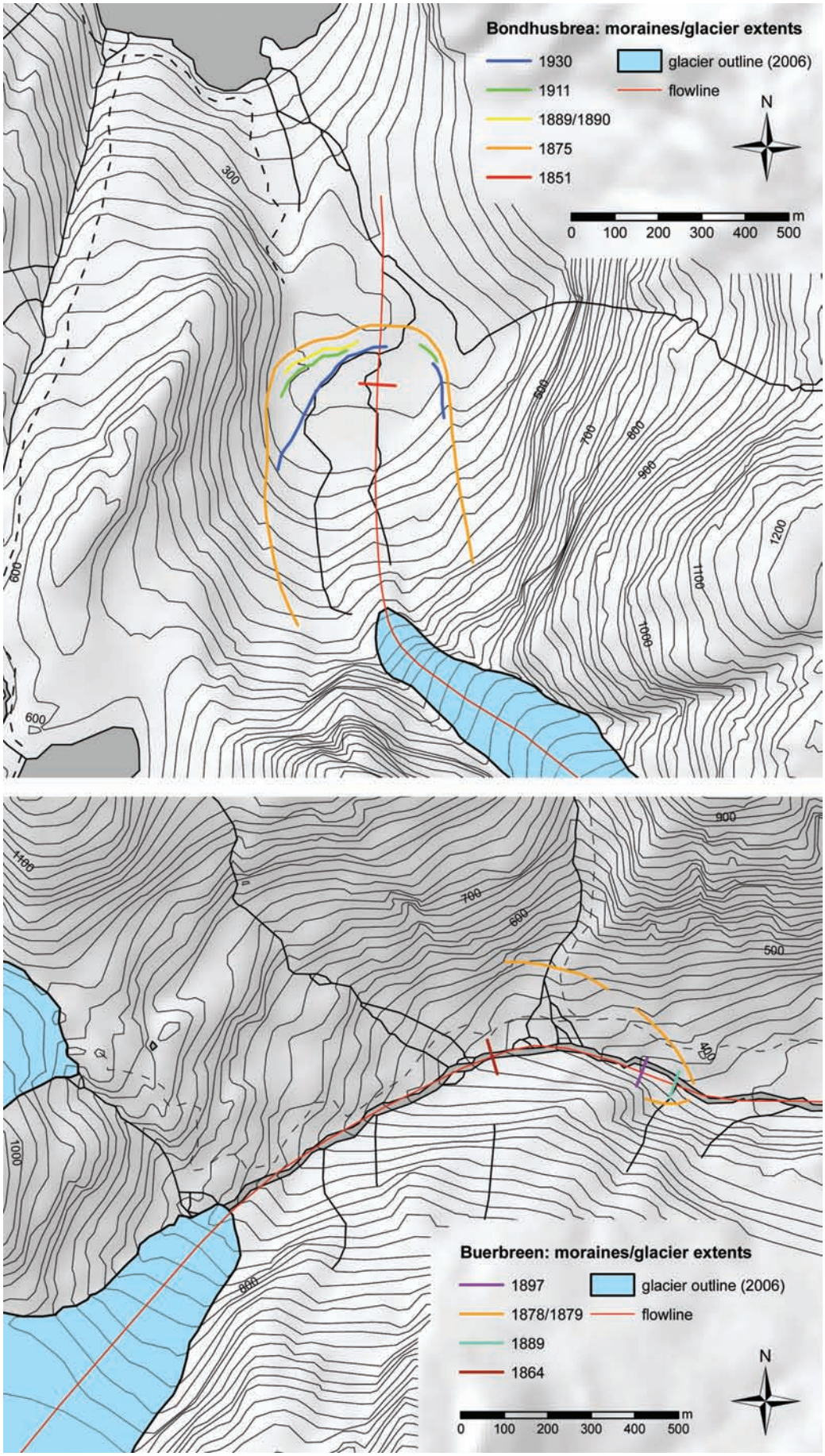

Figure 20. Glacier forelands of Bondhusbrea and Buerbreen