The ‘Little Ice Age’ – only temperature?

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Abstract: Understanding the climate of the last few centuries, including the ‘Little Ice Age’, may help us better understand modern-day natural climate variability and make climate predictions. The conventional view of the climate development during the last millennium has been that it followed the simple sequence of a ‘Medieval Warm Period’, a cool ‘Little Ice Age’ followed by warming in the later part of the nineteenth century and during the twentieth century. This view was mainly based on evidence from western Europe and the North Atlantic region. Recent research has, however, challenged this rather simple sequence of climate development in the recent past. Data presented here indicate that the rapid glacier advance in the early eighteenth century in southern Norway was mainly due to increased winter precipitation; mild, wet winters due to prevailing ‘positive North Atlantic Oscillation (NAO) weather mode’ in the first half of the eighteenth century; and not only lower summer temperatures. A comparison of recent mass-balance records and ‘Little Ice Age’ glacier fluctuations in southern Norway and the European Alps suggests that the asynchronous ‘Little Ice Age’ maxima in the two regions may be attributed to mid-decadal trends in the north-south dipole NAO pattern.

Keywords: ‘Little Ice Age’, glacier variations, North Atlantic Oscillation, NAO, Norway, European Alps.

Introduction

The conventional perception of the climate development during the last millennium has been that it followed the simple sequence of a ‘Medieval Warm Period’ (MWP), a cool ‘Little Ice Age’ (LIA) followed by global warming since the latter part of the nineteenth century and especially in the latter part of the twentieth century. The climate development during the MWP and the LIA was mainly based on Lamb (1963; 1965; 1977) on evidence from western Europe and the North Atlantic region (e.g., Bradley, 2000). Recent research has, however, challenged this sequence of climate development in the recent past.

Lamb (1965; 1977) defined the ‘Medieval Period’ (MP) as a period of high temperatures during the eleventh to thirteenth centuries. In a review of a range of palaeoclimatic data, Hughes and Diaz (1994), however, found no clear evidence for a long-lasting, globally uniform, warm epoch in the MP. Crowley and Lowery (2000) did not find any support either for higher global or hemispheric mean temperatures in the MP compared to the twentieth century. There were, however, significant precipitation anomalies during the MP. Many areas, especially in the USA, experienced drought episodes far beyond the range recorded during the period of instrumental records (e.g., Stine, 1994).

Numerous studies have demonstrated cooler climate and advancing glaciers subsequent to the MP – a period termed the ‘Little Ice Age’ (e.g., Grove, 1988). Due to regional differences in the climate development, it has, however, been difficult to define the ‘initiation’ (Grove, 2001) and ‘termination’ of the ‘Little Ice Age’. Traditionally, AD 1550–1850 has been applied for the duration of the LIA (Jones and Bradley, 1992), but glacier-front variations and temperature records from Scandinavia indicate that the ‘Little Ice Age’ lasted until ~AD 1920. There is, however, evidence of significant cooling prior to AD 1550, at AD 1450, or even AD 1250 (Grove and Switsur, 1994; Luckman, 1994). Records of glacier variations show that most Scandinavian glaciers reached their LIA maximum during the mid-eighteenth century. There is, however, evidence that outlet glaciers from Folgefonna, a maritime glacier in western Norway, reached their LIA maximum position in the 1890s, or even as late as around 1940 (Tvede, 1973; Tvede and Liestol, 1977). In the Alps, the majority of glaciers reached the maximum LIA position in the mid-nineteenth century (e.g., Grove, 1988).

The objective of this paper is to assess what climatic factors caused the extensive glacier advance during the first half of the eighteenth century in southern Norway and to discuss why the ‘Little Ice Age’ glacier maxima did not occur simultaneously in Scandinavia and in the European Alps.

The ‘Little Ice Age’

During the Holocene, a number of abrupt and widespread climatic variations are recorded around the world (e.g., Lockwood, 2001). In the North Atlantic region, it has been claimed that these changes have an approximate 1500 (1470 ± 500)-yr periodicity (Bond et al., 1997; Campbell et al., 1998). The most recent cold
Historic evidence shows that Nigardsbreen, an eastern outlet glacier from Jostedalsbreen in western Norway, advanced 150 m between 1710 and 1735 (Mann et al., 1998). Since these forcing factors, together with ‘greenhouse’ gases, are suggested by the Third Assessment IPCC Report, published in 2001, to play a role in future climatic variations, it is important to obtain better records of climatic change in the recent past and a better understanding of the relative contribution of these forcing factors.

The early eighteenth-century glacier advance of Nigardsbreen – summer temperature or winter precipitation?

Historic evidence shows that Nigardsbreen, an eastern outlet glacier from Jostedalsbreen in western Norway (46°39' N, 8°37' E), advanced 2800 m between AD 1710 and 1735 (Figure 1, upper panel), giving a mean annual advance rate of ~110 m. Between AD 1735 and the historically documented ‘Little Ice Age’ maximum in AD 1748, the glacier advanced 150 m. Subsequently, the lichenometrically and historically dated terminal moraines demonstrate the rate of retreat (Figure 1, lower panel). Annual frontal measurements of Nigardsbreen started in AD 1907. No annual frontal measurements were, however, carried out between AD 1964 and 1995 in western Norway shows that these are highly correlated (r = 0.77) (Hurrell, 1995). Variations in NAO are also reflected in the mass-balance records of Scandinavian glaciers (Nesje et al., 2000; Reichert et al., 2001; Six et al., 2001). The highest correlation is with winter and net mass balance on the maritime Ålfotbreen in western Norway (r = 0.79 and 0.72, respectively, observation period AD 1963–2000). Reichert et al. (2001) inferred that precipitation is the dominant factor (1.6 times higher than the impact of temperature) for the relationship (r = 0.60) between net mass balance on Nigardsbreen and the NAO index (observation period AD 1962–2000). For Nigardsbreen and Rhönegletscher (46°37' N, 8°24' E, Switzerland) they also found a high correlation (r = 0.55) and anticorrelation (r = -0.64), respectively, between decadal variations in the NAO index and in glacier mass-balance model experiments.

Observed or reconstructed glacier fluctuations provide important information on natural climatic variations as a result of changes in the mass and energy balance at the earth’s surface. Variations in glacier mass balance (e.g., Paterson, 1994) is the direct reaction of a glacier to climatic variations. On valley and cirque glaciers, variations in glacier length are the indirect, filtered and commonly enhanced response. Available mass-balance records are, however, relatively short compared to the longer records of glacier-length variations. A high correlation between decadal variations in the NAO and glacier mass balance in Europe has been demonstrated (Nesje et al., 2000; Reichert et al., 2001; Six et al., 2001), the dominant factor being the strong relationship between winter precipitation associated with the NAO. A positive NAO phase means enhanced winter precipitation for maritime glaciers in Scandinavia and reduced winter precipitation on glaciers in the European Alps (Reichert et al., 2001). This internal climate-system mechanism explains observed strong positive mass balance on maritime glaciers in western Scandinavia and partly (also due to high summer temperatures) strong negative mass balance of glaciers in the European Alps.

Winter (DJFM) air temperature in Bergen (western Norway) shows a high correlation (r ~ 0.8) with central England (T. Fure-
vik, personal communication). The 95 and 99% confidence levels are at 0.27 and 0.35 correlation. This means that a central-England temperature series (Manley, 1974; Parker et al., 1992; with later updates by the Hadley Centre), going back to AD 1659, can be used to test whether the significant early eighteenth-century glacier advance in western Norway may have been caused by summer temperature and/or winter precipitation. The cold winters in the late seventeenth and early eighteenth centuries when the Dutch canals were frozen (e.g., Grove, 1988) are evident in the central-England temperature record (Figure 4, upper panel). Standardized central-England mean December–March temperatures show strong coherence ($r = 0.72$) with the winter (D–M) NAO index by Jones et al. (1997, with later updates; Figure 4, middle panel), indicating that the standardized December–March central-England temperature record may be used to indicate variations in the NAO weather mode over England and western Norway back to the initiation of the central-England temperature series in AD 1659 (Manley, 1974; Figure 4, lower panel). Neither the central-England summer (May–September) temperature record (Manley, 1974; Parker et al., 1992; with later updates by the Hadley Centre; the correlation between summer temperature in Bergen and central England is ~0.5; the 95 and 99% confidence levels are at 0.27 and 0.35 correlation; T. Furevik, personal communication; Figure 5, upper panel), nor a July–August temperature reconstruction from tree rings in eastern Norway (Kalela-Brundin, 1999; Figure 5, middle panel), nor a ‘northern’ chronology average of normalized mean tree-ring density anomalies (Briffa, 2000; Figure 5, lower panel), indicate that the early eighteenth-century summers were sufficiently cold to explain the rapid early eighteenth-century glacier advance recorded in western Norway. Instead, the three
records indicate a general summer-temperature rise in the first part of the eighteenth century. A similar trend is seen in northern Fennoscandian pine chronologies in the first part of the eighteenth century (Briffa et al., 1988; 1992; Eronen et al., 1999) and in a Northern Hemisphere (14 chronologies) tree-ring-based temperature reconstruction (Esper et al., 2002). Four tree-ring chronologies from coastal northern Norway (Kirschhefer, 2001) show that the summers in the first half of the eighteenth century were not especially cold. The central-England winter (October–April) temperature record (Manley, 1974; Parker et al., 1992; with later updates by the Hadley Centre), on the other hand, indicates a significant rise in winter temperatures (indicating mild and humid winters; positive ‘NAO weather mode’) in NW Europe in the first half of the eighteenth century (between 1690 and 1740 mean ~2°C; Figure 6). A similar pattern is also indicated by a reconstruction of winter (December–February) temperatures from three European sites (central England, Holland and Zürich) for the period AD 1684–1783 (Ingram et al., 1978), reconstructed winter temperatures at De Bilt, Holland, inferred from historical records of canal freezing (van den Dool et al., 1978) and a reconstruction of the NAO index back to AD 1429 (Glueck and Stockton, 2001) and AD 1300 (Luterbacher et al., 2002). The NAO index of Luterbacher et al. (2002) included, however, the central-England temperature data. A reconstruction of winter temperature in Tallin, Estonia, also indicates an increasing winter-temperature trend in the southern Baltic region during the first half of the eighteenth century (Tarand and Nordli, 2001). This is further supported by an increase in the number of historically reported incidents of major physical hazards (e.g., snow avalanches and river floods), especially between AD 1650 and 1750, leading to tax reduction for farms in the vicinity to the glaciers Jostedalsbreen and Folgefonna in western Norway (Grove and Battagel, 1983; Nesje, 1994).

Why did the LIA glacier maxima in Scandinavia and the European Alps not occur simultaneously?

Maritime glaciers in Scandinavia experienced a significant increase in winter and net balance in the 1990s due to increased...
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Figure 5 Upper panel: central-England summer (May–September) temperature record (Manley, 1974; Parker et al., 1992; with later updates by the Hadley Centre). Middle panel: July–August temperature deviation from the 1951–70 mean... (adapted from Briffa, 2000).

Figure 6 The central-England winter (October–April) temperature record (Manley, 1974; Parker et al., 1992; with later updates by the Hadley Centre) for the period AD 1650–2000 (upper panel) and for the period AD 1690–1740 (lower panel).

winter precipitation associated with prevailing positive NAO index (Nesje et al., 2000; Reichert et al., 2001) which caused annual frontal-advance rates unprecedented since the ‘Little Ice Age’. Glaciers in the European Alps, on the other hand, have lost approximately 30–40% of their surface area and about 50% of their volume since the ‘Little Ice Age’ maximum around the mid-nineteenth century. Since 1980 the glaciers have lost in the order of 10–20% of their volume (Haeberli and Beniston, 1998) because the average mass-balance value has been strongly negative (Haeberli et al., 1999). This can partly be attributed to the generally strong positive phase of the NAO during this period (Reichert et al., 2001) and a general positive temperature trend in this region during the 1980s and 1990s (Beniston et al., 1994a, 1994b). The pressure field is well correlated with the NAO index for distinct periods of the twentieth century (1931–50 and 1971–90) and is almost decorrelated from the NAO index for the other decades (Beniston et al., 1994b). The mass loss on the glaciers in the Alps over the last decades due to reduced winter precipitation (prevailing positive NAO index) are therefore superimposed on the temperature variations.

A glacier mass-balance record (AD 1949–1999; Figure 7) from the Sarennes glacier (45°07′9″ N, 6°10′9″ E) in the French Alps (data from World Glacier Monitoring Service (WGMS)), shows that the net balance of the Sarennes glacier is anticorrelated with the NAO index (positive net mass balance in negative NAO index years, and vice versa) and with the glacier mass balance in western Norway, reflecting the general NAO influence on winter climates of different parts of Europe (e.g., Hurrell, 1995; Nesje et al., 2000; Reichert et al., 2001; Six et al., 2001). An unexplained paradox has been that the LIA glacier maxima in Scandinavia and the Alps were not contemporaneous. Might the NAO pattern also explain why the LIA maxima in southern Norway and the Alps are asynchronous? In order to test this, the historic record of glacier-front variations and a simulation of frontal variations based on meteorological data from adjacent sites of Unterer Grindelwaldgletscher, Switzerland (data from WGMS and Schmelt et al., 1997), which is representative for the historic glacier variations in the western Alps (Mont Blanc Massif), were used (Figure 8, upper and middle panels). A comparison with the central-England December–March temperature record (11-yr running mean) (Figure 8, lower panel) shows that the two records are in general anticorrelated, i.e., that Unterer Grindelwaldgletscher was in an advanced position when the winter temperatures over England were low, and vice versa, which is in accordance with the modern NAO north–south dipole pattern in Europe (Reichert et al., 2001; Six et al., 2001). A winter-precipitation index for the northern Swiss Alpine foreshore between AD 1550 and 1995 (Pfister, 1995; Wanner et al., 2000) shows that the early eighteenth century period of significant glacier growth in Scandinavia was characterized by a decreasing winter-precipitation trend. Climatic variability over the last 600 years in the northwest...
ern Alps in France, as reconstructed from terrigenous sedimentation in Lake Le Bourget, indicates a strong link with the NAO (Chapron et al., 2002). The asynchronous behaviour of LIA glacier variations in Scandinavia and the European Alps may thus mainly be explained by this NAO pattern in NW Europe.

Conclusions

Until recently, and mainly based on evidence from western Europe and the North Atlantic region, the conventional view of the climate development during the last millennium has been that it followed the simple sequence of a warm Medievaal period, then a cool ‘Little Ice Age’, followed by global warming. However, climate reconstructions obtained recently have challenged this rather simple sequence of climate development. The central-England temperature record going back to the late 1650s indicates that the rapid glacier advance which is historically documented in the early eighteenth century in western Norway may be explained mainly by increased winter precipitation (mild and humid) due to prevailing ‘positive NAO weather mode’ in the first half of the eighteenth century. Lower summer temperatures alone cannot explain such a significant glacier advance over a few decades. A comparison of records from southern Norway and the European Alps of annual mass-balance data and records of ‘Little Ice Age’ glacier fluctuations may indicate that the asynchronous LIA pattern in the two regions may be attributed to multidecadal trends in the NAO.

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