Perception, history, and science: coherence or disparity in the timing of the Little Ice Age maximum in southeast Iceland?

Citation for published version:
Mckinzey, KM, Ólafsdóttir, R & Dugmore, AJ 2005, 'Perception, history, and science: coherence or disparity in the timing of the Little Ice Age maximum in southeast Iceland?', *Polar Record*, vol. 41, no. 4, pp. 319-334.
https://doi.org/10.1017/S0032247405004687

Digital Object Identifier (DOI):
10.1017/S0032247405004687

Link:
Link to publication record in Edinburgh Research Explorer

Document Version:
Publisher's PDF, also known as Version of record

Published In:
Polar Record

Perception, history, and science: coherence or disparity in the timing of the Little Ice Age maximum in southeast Iceland?

Krista M. McKinzey
Institute of Geography, School of GeoSciences, University of Edinburgh,
Drummond Street, Edinburgh EH8 9XP (Krista.McKinzey@ed.ac.uk)

Rannveig Ólafsdóttir
University of Iceland, Hornafjörður University Centre, Nyheimar,
Litlubrú 2, 780 Höfn, Iceland (ranny@hi.is)

Andrew J. Dugmore
Institute of Geography, School of GeoSciences, University of Edinburgh,
Drummond Street, Edinburgh EH8 9XP (ajd@geo.ed.ac.uk)

Received March 2005

ABSTRACT. In Iceland, studies that integrate local perceptions about the landscape with scientific evidence of change have been few. This article presents a case study from southeast Iceland that has two main objectives. Firstly, ethnographic data is used to explore the human dimension of the Little Ice Age through perceptions of landscape and climatic change and to describe the impacts that these changes had on life and livelihood. Secondly, the paper critically assesses the coherence of the scientific record regarding the Little Ice Age glacial maximum with evidence gained from the ethnographic survey and the local historical record. Although climatic deterioration from the seventeenth through nineteenth centuries ultimately affected farming viability, it was the interplay of climate with concomitant cultural and socio-economic factors that ensured effective strategies were emplaced to preserve life and livelihood in southeast Iceland. Furthermore, despite different trajectories of perception emanating from either the scientific or the local points of view, data from all sources are strongly coherent and point to a Little Ice Age maximum during the late eighteenth to early nineteenth centuries. This study also illustrates that sensitive landscapes can 'store memories' through the cumulative accumulation of disturbances during periods of climatic variability, eventually reaching a critical threshold and inducing landscape instability, such as occurred during the nineteenth century.

Contents

Introduction

The 'Little Ice Age' (LIA) is a widely used term for the period *c*. AD 1300–1900, which was notable for worldwide glacier expansion (Grove 2004). Across historical, archaeological, and environmental sciences, the LIA term has been used with differing emphasis and different connotations. A fundamental reason is that the LIA was not a time of uniform cold at either the regional or the hemispheric scale (see Jones and Mann 2004). Rather, the period encompassed considerable climatic variability, and, as a consequence, glacier termini fluctuated around advanced positions for several centuries, although the timing and magnitude of expansion were not necessarily synchronous worldwide (for example, Gellatly and others 1988; Karlén 1988; McKinzey and others 2004a). The variability of climate during the LIA commonly features in studies of historical climatology (Ladurie 1971; Lamb 1977), and 'variability' rather than simply 'cold' may be seen as a key characteristic. In addition, the temporal and spatial variations in climate, combined with different environmental response rates and sensitivities to climate change, indicate that the LIA record is complex (Bradwell 2001a; Kirkbride and Dugmore 2001; McKinzey and others 2004b).

When attempting to gauge the potential cultural, socio-economic impact of LIA climate change on human beings, a number of issues are brought to light. Firstly, the issue of significance, which may be linked to problems of circularity: historical records of certain events (such as harvest times) may be used to reconstruct details of LIA climate, although these proxy records could also be used to argue for a climatic role in the development of such events — for example, the harvest timing, which may actually be determined by other non-climatic factors. Secondly, the issue of quality, illustrated by status given to either an environmental proxy record of past changes or human experience of the past. In this context, travellers' tales or farmers' diaries noting past glacial positions may be argued to be 'superior' or 'inferior' to records derived from other methodologies, such as lichenometrically dated geomorphology. People, socio-economic systems, and facets of the natural environment

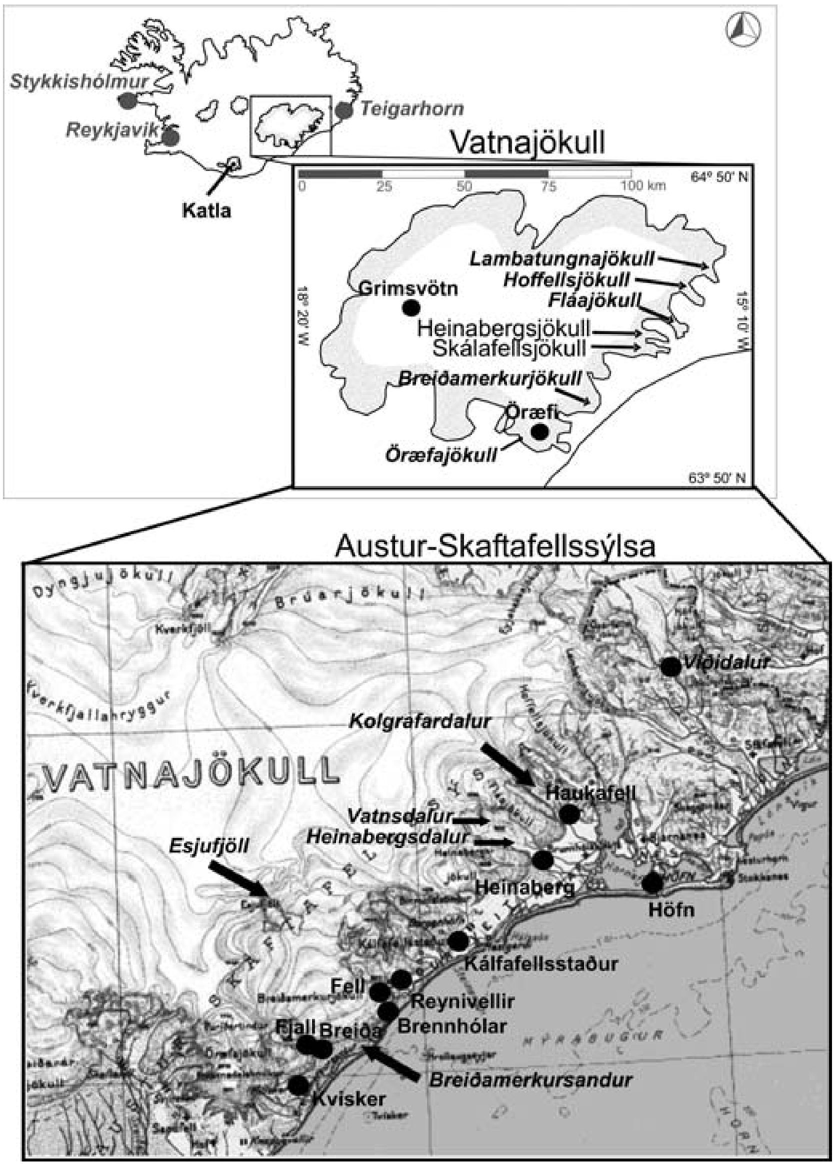

Fig. 1. Location maps of Iceland: Vatnajökull, including its major southeastern outlets and Öræfajökull, and the county of Austur-Skaftafellssýsla. Key farms and places are shown (named valleys and sandur are italicized). Volcanic centres mentioned in the text are also displayed. Annotated map of Austur-Skaftafellssýsla from the Landmælinger Íslands 1:750,000 (1945 edition) series.

may 'sense' climate change in different ways, and these differences may be very revealing. Various combinations of annual precipitation and summer temperature may strongly determine glacier response (Oerlemans and others 1998), but are these aspects of climate that people necessarily notice? And are the most memorable climatic changes actually the ones that have the most profound effects on human interactions with environment?

Thus, the degree of 'coherence' across different data sources relating to the LIA becomes crucially important. One possibility is that the scale of LIA climatic variation is such that nuances are swamped by the strength of the change. In this case, human perceptions, written sources, and environmental data should present a strongly coherent, synchronized story. Alternatively, as data sources range from 'cultural' to 'environmental,' key periods of time may reveal distinct differences in the perception of and sensitivities to change. Awareness of these nuances may be a key factor in effective interpretation of past interactions between climate and people (Crumley 1994).

Study aims

Studies that integrate local perceptions about the landscape with scientific evidence of change have been few in Iceland (for example, Ólafsdóttir and Júlíusson 2000). Therefore, the aims of this study are two-fold. First, an ethnographic case study from Austur-Skaftafellssýsla, southeast Iceland (Fig. 1), is used to explore the human dimension of the LIA through perceptions of landscape and climate change (Fig. 2) and to describe the impacts

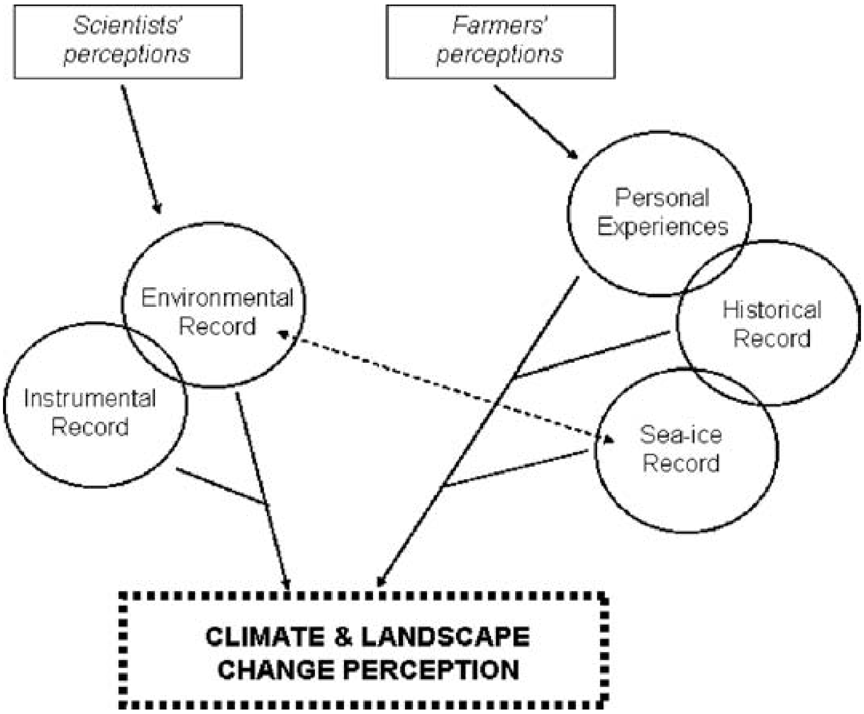

Fig. 2. A conceptual model that illustrates how perceived climatic and landscape changes result from two different trajectories of perception. The farmer's perceptions are formed through personal experiences that may become incorporated into the historical record, and from which the sea-ice record has been extracted. Collectively, this information provides a meaningful interpretation of past climate that has been passed down through written and oral transmissions. In contrast, the scientific method utilizes the physical environment, including sea-ice records, as indicators of change. This study presents an holistic approach that integrates all sources of information relevant to the impact and magnitude of LIA changes in southeast Iceland in order to assess whether these different perception trajectories do, in fact, corroborate one another.

that these changes had on life and livelihood. Second, this paper critically assesses the coherence of environmental records of glacier expansion, instrumental records of temperature and precipitation, proxy records of sea-ice extent based on written sources, reconstructions of contemporaneous synoptic conditions, the historical record, and results from the ethnographic survey. Additionally, environmental changes not directly related to climate, such as volcanic eruptions, which may have impacted personal welfare in the region, are also discussed. This second objective not only permits an analysis of the integration of the scientific record with mostly qualitative indications of change, but also examines the way in which different trajectories of perception may converge on similar conclusions regarding both the LIA climate and environment (Fig. 2).

Study area

Due to its position astride the atmospheric Arctic Front (the convergence zone between temperate, maritime and cold, polar air masses) and the oceanic Polar Front (the boundary between warm waters of the Atlantic and cold Arctic waters; Björnsson 1979; Ogilvie 1992), Iceland is well placed to experience climatic shifts of the scale typical of the late Holocene. These climate changes are registered in the fluctuations of Icelandic glaciers. Accurate age-dating of glaciogenic deposits associated with the former extent of ice margins provides a means of establishing the timing of maximum terminus positions and allows inferences about the prevailing climate to be made.

Vatnajökull, the largest European ice cap ($\sim$8100 km^2), is located in southeast Iceland (Fig. 1) and has been the focus of much geomorphologically based research into the timing and magnitude of LIA glacier fluctuations (for example, Guðmundsson 1997; Evans and others 1999; Bradwell 2001b, 2004; Kirkbride and Dugmore 2001; McKinzey and others 2004b, in press). Although these studies have narrowed the window regarding the timing of the LIA glacier maximum in southeast Iceland to the late eighteenth to early nineteenth centuries, little emphasis has been placed on local knowledge of the environment and human perception of LIA climatic changes since Þórarinsson's pioneering study in 1943. Austur-Skaftafellssýsla, which, until recent decades was one of the more isolated locations in the country due to fluctuations of the large Vatnajökull outlet glaciers, jökulhlaups, and frequent

Table 1. Major environmental indications obtained from questionnaires, interviews, and literature study.

AD 1600–1700: environment 'stable'
Breiðamerkursandur inhabited
Rivers navigable
Glaciers begin to expand and slowly advance
AD 1700–1750: environment 'moderately stable'
Rivers remain relatively navigable
Glaciers continue to grow larger and advance quickens
AD 1750–1800: environment 'unstable'
Breiðamerkursandur abandoned in AD 1750
Jökulhlaups noted for the first time as a hazard (details regarding where they emanated from are lacking)
Widespread and major glacier advance during later part of period (~1780s–1790s); some reach LIA maximum
Breiðamerkurjökull is 7.5 km from the coastline in AD 1756, although by AD 1794 it is 1880 m from the coastline
AD 1800–1850: environment 'unstable'
Glacier retreat and obvious glacier moraines are noted for the first time
Milder climate
Viðidalur inhabited AD 1835–38 and AD 1847–49
AD 1850–1900: environment 'extremely unstable'
Widespread glacier fluctuations with major advance during second half of the period; others reach their LIA maximum, or extend to nearly the same length as in the late eighteenth century
The farm Fell is destroyed by flooding and subsequently buried by Breiðamerkurjökull in AD 1869
In AD 1874, Breiðamerkurjökull is 228 m from the coastline
Ice-dammed lakes Dalvatn and Vatnsdalur form and frequent jökulhlaups. In AD 1894 Heinabergsjökull extends onto the sandur, but still significant land between the glacier terminus and the older (eighteenth-century) moraines
Fláajökull almost crosses Kolgrafardalur. The farm Haukafell is moved because of steady advance during the last decade of the twentieth century

volcanic activity, has long experienced an intimate relationship between its occupants and the marginal land on which humans have depended for their survival (þórarinsson 1956).

Methods

During autumn 2003, a questionnaire was distributed to 100 farmers in the county of Austur-Skaftafellssýsla (Fig. 1). This sample represented 50% of all farmers in the county, selected as every second name on the register list. The questionnaire was made up of open-ended questions aimed to focus on the recipients' own comments and perceptions. It consisted of three sections, of which the first asked seven questions regarding interpretation of climate-change indicators (for example, 'what makes a "bad season" bad?'), the second asked four questions regarding interpretation of historical (environmental) events (for example, the timing of the maximum historical advance of Vatnajökull glaciers), and the third had one entry ('other information'). Twenty-five of the questionnaires were returned. All respondents were subsequently interviewed during summer 2004. The interview involved a more detailed discussion about individual interpretation and memories of historical environmental changes in southeast Iceland. Each interview was conducted in Icelandic and responses were later translated into English. The interview was structured around five questions, although any description concerning the glaciers — such as extent, distribution, outlook, or difficulties of crossing or climbing — was also noted. Information collected from each technique was then assessed for reliability through comparison with each relevant questionnaire or interview, as well as across all questionnaires and interviews.

Subsequently, an investigation into local Icelandic literature was undertaken to compare the farmers' knowledge and perceptions to an independent study of historical documents and data. The literature studied included travel books, biographies, parish records, and local researches. All of the data (questionnaire, interview, and literature) were classified into time periods from AD 1600 to 1900 in order to recognize any 'synchroneity' in the diverse range of qualitative sources, as well as to collate implications regarding climate, environmental changes, and fluctuations of the glaciers during the most critical LIA period (Table 1). Overall, this plethora of information was then compared to the scientific record available for the same time period.

Evidence for the LIA glacial maximum

Human perception of climate-change indicators

As expected, the farmers' interpretation of climate-change indicators suggests a deep understanding that climate ultimately determined survival in Austur-Skaftafellssýsla. Hence, 'bad seasons' included any factor that reduced their personal well-being and economic wealth, particularly with regard to haymaking and livestock, such as prolonged winters, chilly springs with severe frosts, and rainy or cool summers. Critically, they perceived 'changeable weather' (variability) during all seasons to be responsible for 'bad seasons' and 'bad years.'

Farmers noted changes to the landscape after periods of 'bad weather.' These changes included frost damage to grass swards that had a direct impact on the quantity and quality of haymaking, and changes in the glacial rivers directly associated with fluctuations of the glaciers. Although not a direct result of 'bad weather,' climatic conditions that were responsible for jökulhlaups (glacier outburst floods) became a significant hazard to life and livelihood in Austur-Skaftafellssýsla, in terms of property destruction caused by the flood itself and river channel movements. In particular, changes across the county lowlands after a jökulhlaup from Breiðamerkurjökull, Heinabergsjökull, and Skálafellsjökull (Fig. 1) were remembered. Sandar (glacier outwash plains; singular 'sandur') in the county are riddled with palaeochannels, glaciofluvial terraces and old lake shorelines that are a reminder to the farmers of the destructive power of jökulhlaups.

'Bad years' of prolonged extreme weather impacted farmers mostly in terms of changing wealth and mortality. Successive years of 'bad [cold]' winters and springs were deadly for young livestock, and wet summers or cool autumns decreased the fodder yield, thus threatening social status and the regional economy. Furthermore, 'bad years' were also characterized as successive short, cold summers and long, cold stormy winters. One respondent mentioned that this part of Iceland (due to its extreme environment) was traditionally poor during the historical period. 'People were poor, had little clothing, hypothermia and pneumonia were common . . . ' hence population mortality was also perceived to increase during 'bad years.'

The farmers believe that they have 'good knowledge' of the landscape primarily because of their constant interaction with the environment (for example, annual sheep gathering). Images of landscape are remembered by farmers as a mixture of mental 'maps' and oral descriptions of the land and travel routes throughout the county.

Ethnographic survey and local written sources AD 1600–1900

AD 1600–1700

The respondents' knowledge of this period mostly comes from oral transmittance and historical travel books written about Breiðamerkursandur (Fig. 1; Eyþórsson 1952; Þórarinsson 1956; Björnsson 1998). During the seventeenth century, farms and vegetation were widespread on sandar, and glacial rivers could usually be crossed. Therefore, the environment seems to have mainly been 'stable.' However, noticeable glacier advances began ~AD 1650, and ice began to block previously used mountain roads and traditional grazing routes that had been in existence since before AD 1600.

Overall, most of the historical accounts describe the landscape around Breiðamerkurjökull (Fig. 1), probably because of its role as a barrier to the only route between west and east (Eyþórsson 1952). Travelers into Austur-Skaftafellssýsla either had to cross the glacial river, Jökulsá, or hike across the glacier itself. Either option was daunting, as Jökulsá was reputed to be one of the most difficult and dangerous rivers to cross in the country, although during periods of glacier advance, glacial rivers are usually smaller or of less volume than during periods of retreat, when substantial flows of meltwater occur. Traversing Breiðamerkurjökull took several hours due to the development of crevasses, a common characteristic of glacial advance. Therefore, the more advanced Breiðamerkurjökull became, the more difficult it became to cross, and farmers' trade that took place in the villages of Papós or Djúpivogur on the east coast was hindered. By AD 1695 and 1698, the farms Fjall and Breiðá, established shortly after the Viking settlement (AD 874) on the western part of Breiðamerkursandur, were abandoned along with their grazing lands due to encroaching ice (Þórarinsson 1956; Björnsson 1998). Fjall was located at the southeast foot of the mountain Breiðamerkurfjall and Breiðá somewhat farther east. Breiðamerkurfjall is recorded to have been surrounded by ice around AD 1700 (for example, Björnsson 1998).

AD 1700–1750

According to the survey and literature investigations, the environment seems to have been 'moderately stable' during the first half of the eighteenth century. Most farms remained intact, and, according to the first population census taken in Iceland in AD 1703, the remaining farms in Breiðamerkursandur contained 39 residents (Statistical Bureau of Iceland 1960). However, it appears that glacier advance, as indicated by Breiðamerkurjökull, quickened during this period. For example, Breiðamerkurjökull was seen for the first time in ~AD 1730 from the farm Reynivellir (Fig. 1; Þórðarson 1993), and a county description of the area dating to AD 1744–49 described Breiðamerkurjökull as 'large and horrible' (Sýslulýsingar 1744–49). The registry clerk also noted that the glacial rivers were not so dangerous or difficult to cross as later became dominant in the area descriptions. Furthermore, prominent or notable moraines did not exist on Breiðamerkursandur during this time, and indications were given of moraines being absent from elsewhere on the sandar in Austur-Skaftafellssýsla. Overall, it does not seem as though the glaciers had much social or economic impact on the residents of southeast Iceland during the first half of the eighteenth century, apart from the difficulties of glacier crossings and the knock-on effects in trade with the smaller communities farther east.

AD 1750–1800

Overall, a transition to environmental 'instability' may be inferred during this period. Firstly, the respondents considered that glaciers in the region were at their 'greatest' during the second half of the eighteenth century. This interval included a visit of the Icelandic pioneers in natural sciences, Eggert Ólafsson and Bjarni Pálsson, to Austur-Skaftafellssýsla in AD 1756 (Ólafsson and Pálsson 1981), who described the edge of Breiðamerkurjökull as very steep, but crevasse-free. Such conditions indicate continuing advance from earlier in the century. Breiðamerkursandur had already been abandoned by AD 1750, which implies reduced viability of the previously prosperous farms. Ólafsson and Pálsson also confirmed the lack of notable or prominent moraines around the edge of the glacier. Additionally, they mentioned a glacier called Kálfafellsjökull (this name no longer exists), which terminated close to the church farm, Kálfafellsstaður in Kálfafellsdalur (Fig. 1). They may have been referring to the present-day small ice tongue, Brokarjökull, which currently hangs over a spur ~15 km distant at the valley head, or Sultartungnajökull (also called Eyvindstungnajökull), a small lobe that diverges from the south margin of Skálafellsjökull. Ólafsson and Pálsson further noted that Heinabergsjökull (then coalesced with Skálafellsjökull) terminated adjacent to the farm Heinaberg in AD 1756 (Fig. 1).

During the summers of AD 1793 and 1794, the geologist Sveinn Pálsson travelled throughout Austur-Skaftafellssýsla (Pálsson 1983). During his first visit, he observed that part of Breiðamerkursandur was vegetated and that these fields were used for grazing by the farmers in the districts of Hornafjörður and Öræfi. He also noted that most of the rivers were 'calm and small.' However, he mentioned that this situation had changed dramatically a year later during the summer of AD 1794, and his writings imply significant climatic variability. For example, he described 'turbulence' (crevasses) in many glaciers, thus suggesting rapid advance, especially at Kvíárjökull near the farm Kvísker and at Breiðamerkurjökull (Fig. 1). More specifically, Breiðamerkurjökull probably advanced 5.7 km between Ólafsson and Pálsson's reference in AD 1756 (terminus 7.5 km from the coastline) and Pálsson's description in AD 1794 (terminus 1880 m from the coastline). However, distances measured using the coastline as a reference must be interpreted with caution, because it is formed from 'soft sediment' potentially subject to either aggradation (from glacial outwash) or erosion (from coastal process). However, despite this caveat, Breiðamerkurjökull clearly advanced a considerable distance between the mid and late eighteenth century. Brennhólar, a tenant farm of Fell, was also abandoned in AD 1794 due to advancing ice (Björnsson 1998; Fig. 1). Additionally, Pálsson noted that local residents complained about increasingly cold and foggy conditions in the time that Breiðamerkurjökull underwent rapid advance towards the end of the century.

The second half of the eighteenth century also yields the first mention of jökulhlaups in Austur-Skaftafellssýsla by the respondents. Additionally, some referred to the 'great sea-ice years' at the end of the eighteenth century, when, for example, it was possible to walk on ice to the offshore island, Papey. A story has also been passed down from the respondents that tells of a man who killed a polar bear with a home-made gun during this period.

AD 1800–1850

It appears that the environment continued to be 'unstable' and variable during the early nineteenth century. Overall, respondents referred to a period of milder weather that they said allowed previously uninhabitable locations — such as Víðidalur, an isolated valley near Vatnajökull (Fig. 1) — to be occupied and farmed during AD 1835–38 and again in 1847–49 (Geirsson 1995). The literature also indicates that the glaciers generally retreated during the first half of the nineteenth century. Ebenezer Henderson, a traveller to Austur-Skaftafellssýsla during AD 1814 and 1815 (Henderson 1957) specifically referred to moraines observed for the first time, which indicates glacier retreat from the late eighteenth-century advance. Henderson described them as 'large loads of clay, sand and grassroots [that] have been mounded up and thus formed a chain of small hills along the glacier edge.'

AD 1850–1900

Environmental 'instability' appears to have been at its peak during the last half of the nineteenth century. Glacier termini in Austur-Skaftafellssýsla apparently fluctuated between AD 1850 and 1870, thus causing havoc for farmers and their fields due to the constantly changing glaciers, rivers, and sandar. For instance, Nils Ohlsson Gadde, who travelled across the area during summer AD 1857, described Breiðamerkursandur as 'a vast sand desert' and stated that the Breiðamerkurjökull terminus changed position 'about every fifth year' (Gadde 1983).

However, another period of major advance seems to have begun along the southeastern margin of Vatnajökull ~AD 1870 to 1900. All respondents believed that, with few exceptions, 'the glaciers reached the furthermost moraines' during this period, thus referring to older outermost moraines deposited before the end of the nineteenth century. Breiðamerkurjökull apparently was one exception, and it seems to have reached its greatest extent ~AD 1870. The site of the farm Fell was destroyed by the glacier in AD 1869, as the glacial river broke through the older moraines, and thus was moved higher upslope for safety. The tenant farms were also destroyed, and the grazing lands were then subsequently inundated by ice (Björnsson 1998). Additionally, William Lord Watts, who visited Austur-Skaftafellssýsla in AD 1874 recorded that Breiðmerkurjökull was only 228 m from the coastline, and farmers were anxious that the glacier would finally reach the coast and 'completely cut off access from west to east' (Watts 1962).

Þorvaldur Thoroddsen, an Icelandic naturalist who traversed Austur-Skaftafellssýsla in AD 1894 (Thoroddsen 1959), wrote that Fláajökull had reached the outermost glacier moraines by this time (Fig. 1). This clearly indicates that Fláajökull had been just as extensive sometime prior to the late nineteenth century and contradicts recent investigations using lichenometrically dated moraines (for example, Dabski 2002). Furthermore, a local farmer informed Thoroddsen that Fláajökull had advanced and retreated on three occasions between AD 1882 and 1894 and had reached approximately the same extent each time. During this time, the farm Haukafell was moved farther west and to a higher elevation to 'escape' the advancing Fláajökull, which nearly closed the entrance to Kolgrafardalur ~AD 1900 (Benediktsson 1977; Fig. 1).

Thoroddsen (1959) also noted that in AD 1894, Heinabergsjökull (still coalesced with Skálafellsjökull) extended onto the sandur, although it was a considerable distance from the *outermost* moraines, which were likely deposited around the abandoned farm Heinaberg sometime during the late eighteenth century. Þórarinsson (1943) also recorded accounts by local farmers that Heinabergsjökull was close to these 'outwash moraines' during the 1860s and 1870s. This implies that the glacier had advanced to similar, but subsequently less-extended limits during the waning stages of the LIA and does not corroborate a late nineteenth-century LIA maximum (Evans and others 1999). During the end of the nineteenth century, Heinabergsjökull had also created an ice-dammed lake, Dalvatn, in Heinabergsdalur and another one in Vatnsdalur (Fig. 1), the latter full of water up to the col at 464 m asl. As the glacier thinned and began to retreat during the late nineteenth and early twentieth centuries, either or both of these lakes would burst as a jökulhlaup (~1 per year in the late summer or early autumn). One respondent stated that 'Mýrar [a district of Austur-Skaftafellssýsla] was like an ocean.' These floods lasted for a couple of days with a maximum runoff ~3000 m^3 sec^1 and obviously caused much damage to the surrounding farms (Þórarinsson 1956). Floods emanating from Vatnsdalur, rather than those spawned by a burst from Dalvatn, were perceived as the most dangerous.

Overall, the evidence for the last half of the nineteenth century implies an extremely variable climate. For instance, Víðidalur was resettled in AD 1883–97, when grazing was possible in the highland valley, although cold years, such as in AD 1884, resulted in sea ice that reached all the way to the village of Vík on the south coast and persisted until late summer (Jónsson 1954). Glacier retreat was extensive by the turn of the twentieth century, as one resident recalled that fishermen off the coast of Kvísker told of seeing 'black mountain tops' (the nunataks of Esjufjöl; Fig. 1) for the first time protruding from Breiðamerkurjökull in AD 1907.

Synthesis of environmental indicators

Environmental data derived from proxy sources, including glacier chronology, instrumental climate records, sea-ice indices, reconstructions of the North Atlantic Oscillation (NAO), and volcanic frequency, have been collated to present a new synthesis of environmental and climatic changes during the past few hundred years (Figs 3, 4, 5). Previous glacier chronologies based on tephrochronologically constrained lichenometry (for example, Bradwell 2001a; McKinzey and others 2004b) suggest a late eighteenth- or early nineteenth-century LIA glacier maximum in Austur-Skaftafellssýsla. However, the instrumental climate record, which began in AD 1823, shows significant climatic variability during the waning stages of the LIA in the late nineteenth century. Reconstructions of Icelandic sea-ice extent based on indices unequivocally sourced from documentary records and annals that span the last ~1000 years indicate a strong correlation between sea-ice incidence and land surface temperature (Bergþórsson 1969; Ogilvie 1984). Cold periods involving extreme sea-ice conditions seem to develop most readily during negative NAO years when westerly winds decrease due to a weakened pressure gradient across the North Atlantic. Hence, Iceland becomes colder and more arid as the Polar Front moves south (Glueck and Stockton 2001; Bradwell 2001a). During the LIA, residents of Austur-Skaftafellssýsla also had to cope with frequently occurring volcanic eruptions that often deposited tephra (volcanic ash) across the area. Tephra may act as an agent of environmental and cultural change, either directly from fallout onto settlements (for example, the Öræfajökull eruption in AD 1362; Þórarinsson 1956), or indirectly, such as large-scale animal mortality and related famine caused by fluorosis (for example, the Katla eruption in AD 1755 and Laki in AD 1783; Vasey 1996).

To permit quantitative assessment of the most to least extreme periods of environmental change between AD 1600 and 1900, environmental indicators were ranked and divided by their relevant period (for example, 50 or 100 years; Table 2). Ranks were provided equally for each indicator (that is, 1 = lowest/least extreme, to 5 = highest/most extreme) so that all indicators maintained equal importance. For indicators that could not be calculated, rank was based on qualitative interpretation. The following sections describe LIA environmental change in southeast Iceland based on the collective information gained from a consideration of all indicators

Table 2. Summary of environmental-change indicators, AD 1600–1900. Ranks (italicized) were provided equally for each indicator (1 = lowest/least extreme to 5 = highest/most extreme). *Numbers in brackets exclude ranks for the landscape stability indicator to illustrate the extent to which local perceptions modify the scientific view of change. †Denotes the period with the coldest temperatures during the LIA (1780s) according to the sea-ice record. ‡Denotes the period with the coldest temperatures after instrumental records began (1870s and 1880s).

Period (years AD)	Volcanic frequency	Sea-ice index	NAO index (negative)	Glacier extent or advance rate	Landscape stability	Total*
1600–1700	0.13; *2*	*2*	0.606; *5*	*2*	*1*	*12(11)*
1700–1750	0.24; *5*	*1*	0.571; *2*	*3*	*2*	*13(11)*
1750–1800	0.18; *3*	*5*	0.592; *4*	*5*	*3*	*20(17)*†
1800–1850	0.08; *1*	*3*	0.531; *1*	*1*	*4*	*10(6)*
1850–1900	0.20; *4*	*4*	0.580; *3*	*4*	*5*	*20(15)*‡

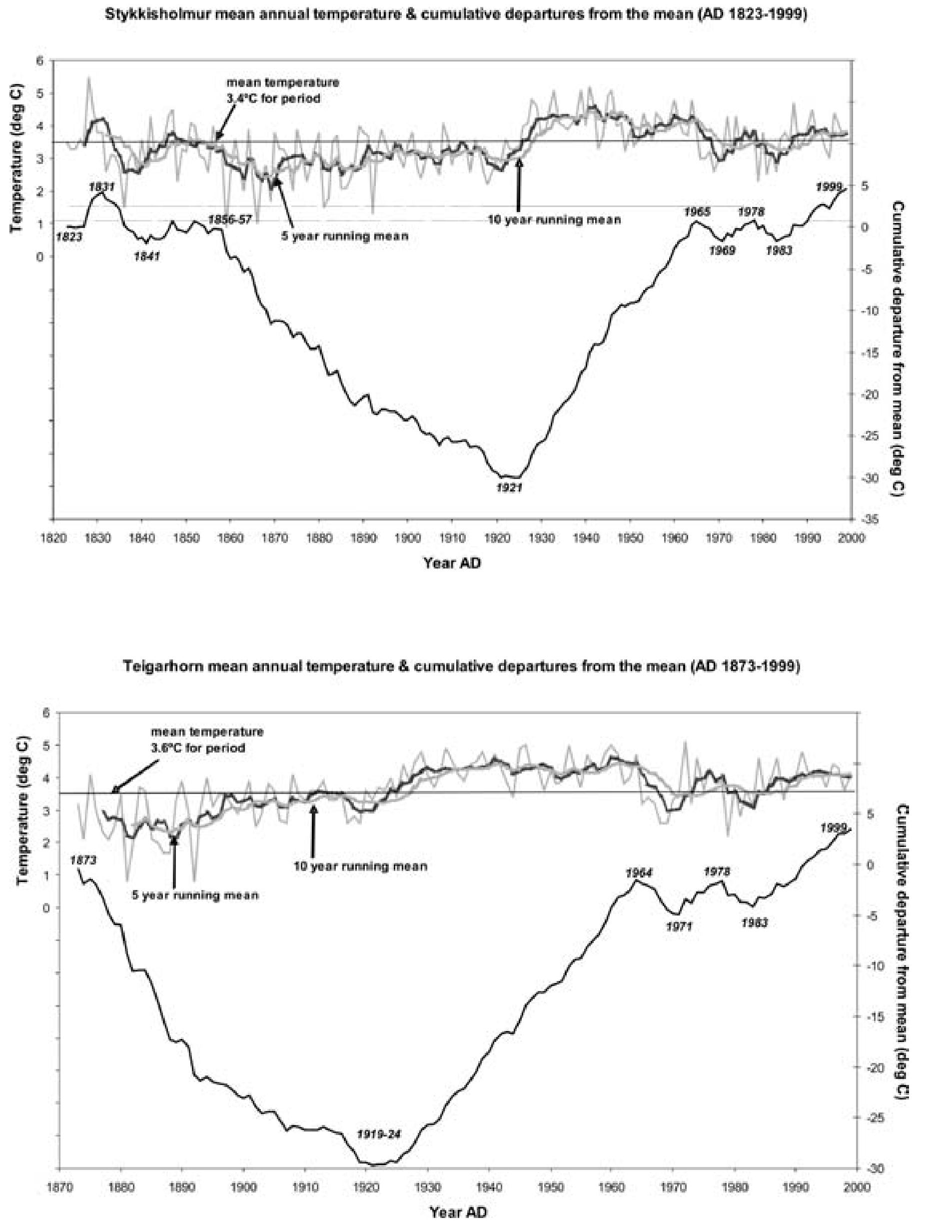

Fig. 3. Trends in Stykkisholmur and Teigarhorn mean annual temperature for AD 1823–1999 and 1873–1999, respectively, along with the cumulative departures from the means. Note that the early 1920s was a critical 'turnaround' period, that is, the end of the 'Little Ice Age,' after which climate in southeast Iceland became significantly warmer. However, significant and widespread glacier retreat had already begun by the end of the nineteenth century. Data from the Icelandic Meteorological Office.

used in this study separated into the same periods as that of the previous section.

AD 1600–1700

Sea-ice incidence gradually increased towards the end of the seventeenth century (Ogilvie 1992). Additionally, the NAO index was mostly negative during this period and reached its lowest value in the LIA ~AD 1695 (Cook and others 2002). However, positive indices also occurred around the 1650s. These proxies indicate cold and dry conditions for most of the century, which, when summers were short and cool, were conducive to glacier expansion. Dendrochronologically reconstructed mean April–September temperatures by Briffa and others (2002) also generally show that the seventeenth century was cold across northern Europe, with the most negative anomalies (–1°C below the AD 1961–90 mean) ~AD 1640, 1660–70, and ~1700. Ethnographic and historical evidence supports the idea of a landscape that, although beginning to change, remained relatively 'stable' throughout most of the century, and the main indication of LIA climatic deterioration pertained to slow expansion and advance of glaciers in Austur-Skaftafellssýsla. Eruption frequency of the Vatnajökull volcanic system was moderate (Larsen

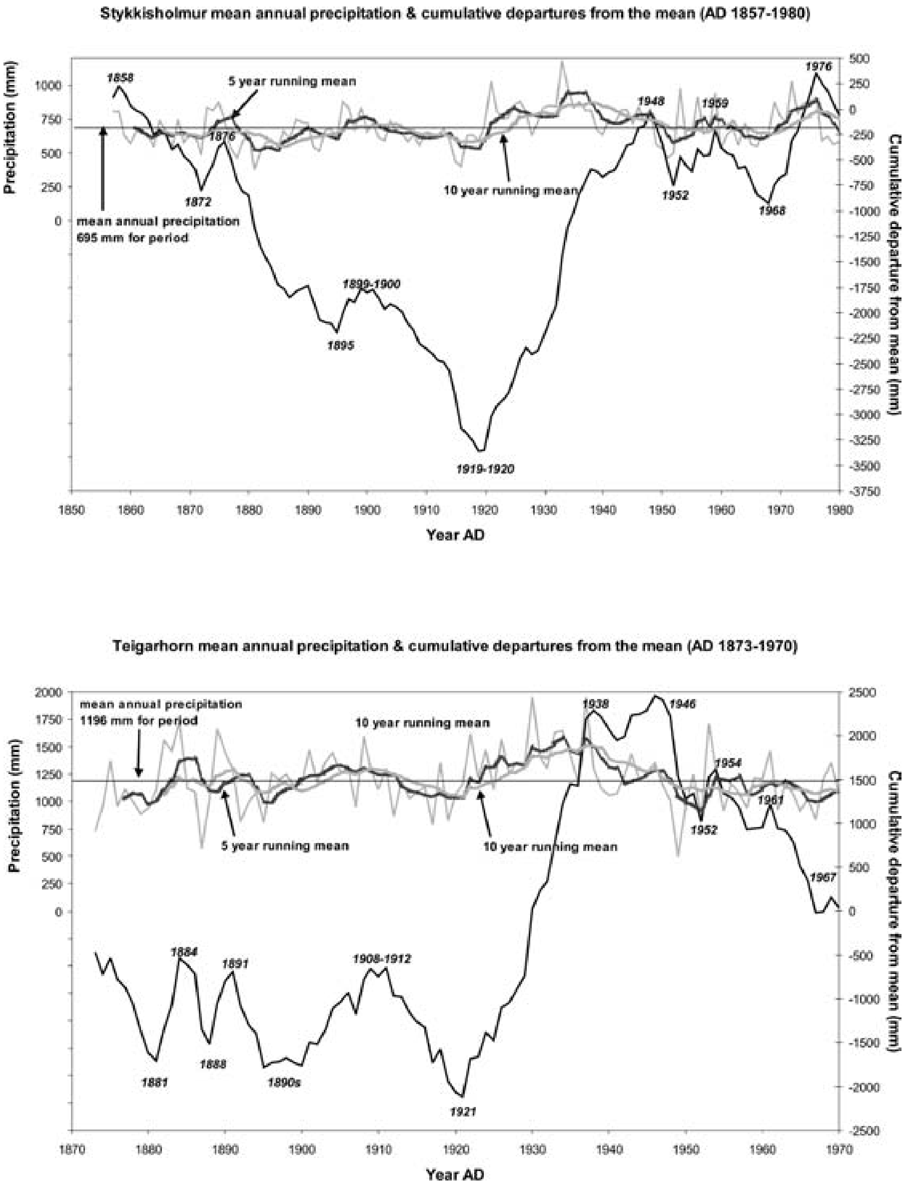

Fig. 4. Trends in Stykkisholmur and Teigarhorn mean annual precipitation for AD 1857–1980 and 1873–1970, respectively, along with the cumulative departures from the means. Note that subsequent to the critical 'turnaround' period signalling the end of the 'Little Ice Age' in the 1920s, the climate in southeast Iceland became significantly wetter. Data from the Icelandic Meteorological Office.

and others 1998), although the impact of the Grímsvötn eruption during AD 1619 was widespread (þórarinsson 1958). A tephra layer ~0.5 to 1 cm thick relating to this event is found throughout the county, as is a layer of the same thickness from the Katla eruption in AD 1625 (McKinzey and others, in press). However, from the farmers' point of view, tephra deposition in this order of magnitude was not detrimental to their livelihood, as fluorosis was not mentioned as a hazard to livestock. Crucially, tephra fallout in Austur-Skaftafellssýsla may have occurred at a time that minimized potential problems with fluorosis.

AD 1700–1750

Sea-ice incidence remained low early in this period, although it increased ~AD 1740–50 (Ogilvie 1992). The NAO index was also variable until it reached a negative phase ~AD 1750 (Cook and others 2002). This suggests a further shift in the climate since the previous century and, according to ethnographic and historical evidence, was manifested as an increase in the rate of glacier expansion and advance across the county during the first half of the eighteenth century. Northern European temperatures also remained cool during this period (Briffa and others 2002). Thus, according to ethnographic

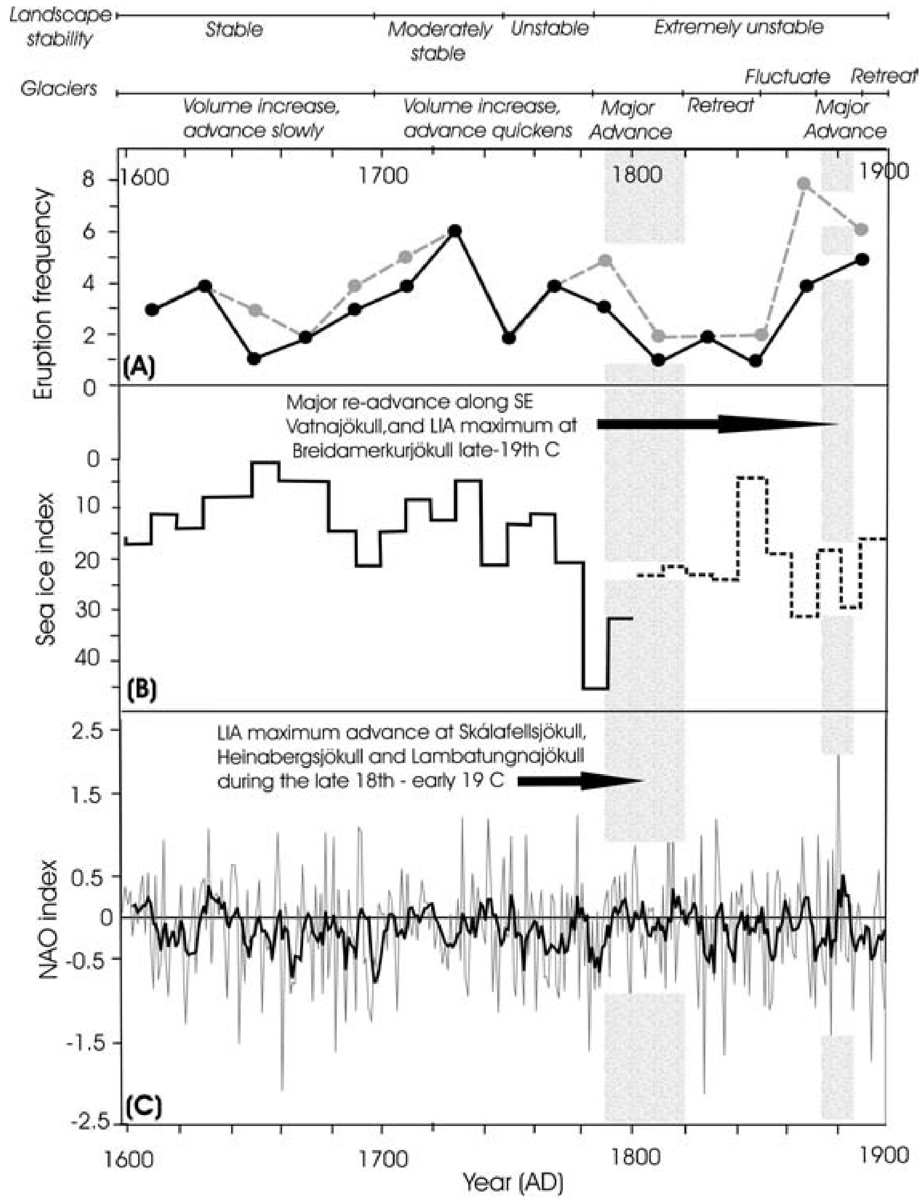

Fig. 5. Combined environmental data between AD 1600 and 1900. Italicized information inferred from contemporary local perspectives and historical documents. Panel (A): eruption frequency per 20-year interval within the Vatnajökull system (black dots/line = verified reports; grey dots/hash = unverified reports) from Larsen and others (1998). Panel (B): Solid line shows reconstructed sea-ice index from Ogilvie (1992) and hashed line from Bergþórsson (1969). Panel (C): NAO reconstruction (December through March) AD 1600–1900 by Cook and others (2002). The period shown has been extracted from the original data set, which included the entire period AD 1400–2001. A five-year running mean has been calculated for the subset of data. Data available online through IGBP PAGES/World Data Center for Paleoclimatology (NOAA/NGDC Paleoclimatology Program, Boulder, CO), Data Contribution Series #2002-059. Grey vertical columns indicate LIA maxima at various glaciers along the southeast margin of Vatnajökull, either geomorphologically dated and constrained by tephrochronology or dated using unequivocal historical sources.

and historical records, the landscape was perceived to be ‘moderately stable,’ although an increasing trend towards change was observed. Eruption frequency from the Vatnajökull system reached its peak during the LIA in this period (Larsen and others 1998), although tephra relating to these events was not found in the Austur-Skaftafellssýsla soils (McKinzey and others, in press).

AD 1750–1800

The latter half of the eighteenth century was characterized by more variable temperatures across northern

Europe, although, by the 1780s, another cold peak of similar magnitude to those during the seventeenth century occurred (Briffa and others 2002). According to Ogilvie (1992), sea-ice incidence around Iceland reached its maximum value during the 1780s (highest in AD 1782), thus indicating extremely cold years. The NAO index was also negative throughout the period, especially during the 1780s (Cook and others 2002). Together, these proxies suggest that the sub-polar storm track was displaced southward due to a blocking high-pressure system across the Greenland–Iceland sector. This scenario would have induced cold temperatures and an expanded sea-ice cover, thus allowing most glaciers in Austur-Skaftafellssýsla, including Lambatungnajökull, Skálafellsjökull, Heinabergsjökull, possibly Fláajökull, and outlets of Öræfajökull, to have reached their LIA maxima between the late eighteenth and early nineteenth centuries (Bradwell 2001a, 2004; McKinzey and others 2004, in press). Additionally, ethnographic and historical evidence implies that a threshold of landscape stability was crossed during the late eighteenth century, and glaciers underwent a period of major expansion and advance. Jökulhlaups caused by an expanded Heinabergsjökull are documented for the first time during this period (þórarinsson 1943). Despite moderate volcanic activity emanating from the Vatnajökull system during the second half of the eighteenth century (Larsen and others 1998) and the massive Laki eruption in AD 1783, tephra from these sources do not appear within the county. However, tephra relating to the Katla eruption in 1755 appears within Austur-Skaftafellssýsla soils (McKinzey and others, in press).

AD 1800–1850

This period encompasses the beginning of the Icelandic instrumental climate record, and the Stykkishólmur series shows that temperatures were extremely variable throughout the first half of the nineteenth century, which peaked ~1°C above the AD 1823–1999 average ~1830. The dendrochronologic record across northern Europe also records extremely rapid change from a very cold period at AD 1810–20 (–1°C departure from the AD 1961–90 mean) to a warmer spell slightly above the long-term average ~AD 1830 (Briffa and others 2002). The Icelandic sea-ice index also indicates variability and trends towards a minimum by the middle of the nineteenth century (Bergþórsson 1969). This evidence is supported by the NAO index, which fluctuated throughout the period, with the only significant negative phase occurring ~AD 1830 (Cook and others 2002). The ethnographic and historical record implies that landscape instability reached extreme levels and was related to the variability in climate. Glaciers underwent significant retreat during the first part of the nineteenth century, releasing increased volumes of meltwater onto the sandur, then seemed to have experienced a short-lived climatic equilibrium as they fluctuated around their reduced extents for some time. Volcanic frequency from the Vatnajökull system was low during the period (Larsen and others 1998).

AD 1850–1900

The Stykkishólmur and Teigarhorn series show that temperatures were below the long-term means throughout the entire second half of the nineteenth century and reached their maximum departure during the early 1870s (Stykkishólmur) and ~AD 1880 and 1890 (Teigarhorn). Precipitation varied according to both series, although the Stykkishólmur record shows generally dry conditions, especially during ~AD 1880–82, and the Teigarhorn record displays wet years during the 1880s. Northern Europe as a whole also experienced a prolonged cool spell (–0.5°C below the AD 1961–90 mean) between ~AD 1860 and 1890 (Briffa and others 2002). Sea-ice incidence around Iceland was variable and peaked during the 1860s and 1880s (Bergþórsson 1969). The NAO index also characterizes variability throughout the period, although negative indices of shorter duration and lesser magnitude compared to the 1780s negative phase occurred during the 1870s (Cook and others 2002). A rapid transition to a prolonged positive NAO phase occurred during the 1880s. An increase in storminess during the late nineteenth century is also apparent in the NA^+ records from the GISP2 ice-core (Dawson and others 2002) and marine sedimentation records (for example, Hass 1996) across the North Atlantic, which corroborates the NAO record. Ethnographic and historical evidence implies a peak in landscape instability between the 1870s and ~AD 1894 related to another major advance at Breiðamerkurjökull (LIA maximum), Lambatungnajökull, Skálafellsjökull, Heinabergsjökull, and Fláajökull. The Stykkishólmur and Teigarhorn time series were analysed using the cumulative deviation from the long-term mean (Bell 1981) and reveal a rapid turning point in Icelandic climate to warmer and wetter conditions ~AD 1920 (Figs 3, 4), although widespread and significant glacier retreat was underway by the late nineteenth century. As a consequence of glacier thinning and related weakening of ice impounding ice-marginal lakes, jökulhlaups became a significant hazard to life and livelihood in Austur-Skaftafellssýsla. Previously prominent farms were abandoned as a result of jökulhlaup destruction to homesteads and grazing land. Eruption frequency from the Vatnajökull system again increased, and tephra from the Grímsvötn eruption in AD 1873 is found throughout the county as a layer ~1 cm thick (McKinzey and others, in press). However, this eruption seemed to have had little impact on human welfare, as farmers do not mention the fallout to have had any serious consequences.

Life in the seventeenth through nineteenth centuries

The availability and quality of summer grazing and winter fodder are key factors in determining the number and productivity of domestic animals in the North Atlantic. Throughout the last few centuries, sheep-grazing has been the dominant land-use strategy (Statistics Iceland

Table 3. Critical periods apparent in census data throughout Skaftafellssýsla, AD 1695–1901. *Most of the data were not divided into Austur- and Vestur- Skaftafellssýsla until the late nineteenth century. Thus, to maintain consistency, data are only used from the entire region as a whole. †Land holdings were subdivided in the original census data. Subdivisions have been added together to show overall change.

Period (years AD)	Change in livestock numbers	% change	Population change*	% change	Change in number of land holdings†	% change
1770–1801			–267	–10		
1783–1784	–12,473 (sheep)	–95				
	–873 (cattle)	–48				
	–1717 (horses)	–76				
1785–1795					–266	–53
1801–1802	–4973 (sheep)	–37				
1809–1810	–3990 (sheep)	–24				
1816–1817	–5408 (sheep)	–31				
1835–1836	–8953 (sheep)	–41				
1835–1840			–235	–7		
1858–1859	–3461 (sheep)	–15				
1861–1872					–288	–54
1881–1882	–12,693 (sheep)	–37				
1880–1890			–299	–9		

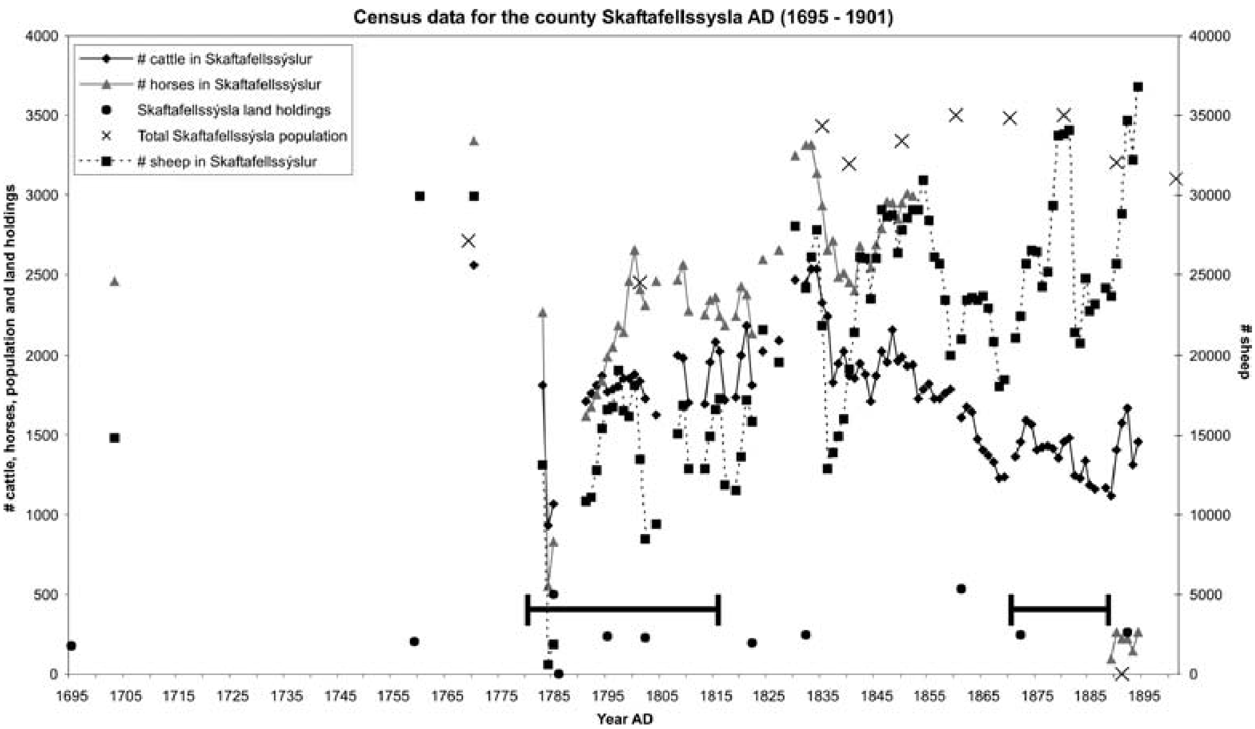

Fig. 6. Collated census data for the county of Skaftafellssýsla (both Vestur- and Austur-) for the years AD 1695–1901. Black bars denote periods of major glacial advance. Data obtained from Statistics Iceland (1997).

1997), and, although other livestock numbers sometimes declined, sheep numbers in Austur-Skaftafellssýsla varied the most during the LIA probably due to losses of grazing land and culling in times of hunger (Table 3; Fig. 6). Mild conditions that preceded the LIA may have induced a misleading sense of security for traditional farming practices, which meant that grazing regimes previously used for generations may have been poorly suited to LIA climatic extremes (Simpson and others 2001). Climatic changes, particularly during the spring and autumn, would have significantly impacted the length of the growing season and dictated grazing pressure (Kirkbride and Dugmore 2005). A number of different strategies were possible to help cope during periods of unpredictable climate, such as manuring to enhance soil fertility, although others, such as exploitation of marine resources, may have been crucially dependent on the wider socio-political situation. Although the local community perceives climatic variability as difficult to manage, it is the times of prolonged extremes that most severely restrict their efforts to farm and survive effectively.

Decreased mean annual temperatures, such as during the end of the eighteenth and nineteenth centuries, reduced grass growth and potential grazing area. An approximate 1°C decline in mean annual temperature may initiate a 10–20% decrease in the grazing viability of rangelands (Haraldsson and Ólafsdóttir 2003) and reduce livestock carrying capacity by 30% (Bergþórsson 1985). Recent reconstructions of glacier equilibrium line altitude at Sólheimajökull (an outlet of the Mýrdalsjökull ice cap) indicate that the overall cold peak between the 1780s and 1790s corresponded to a temperature decrease of 1.6°C compared to the 1960–90 mean (Mackintosh and others 2002). Therefore, grazing potential and livestock carrying capacity may have been reduced by ~15–30% and ~45%, respectively, during the late eighteenth century, and this change is apparent in the census data (Table 3). Recent vegetation simulations suggest that the reduction of biological activity may have even been as high as 40% (Rannveig Ólafsdóttir, unpublished data).

Among other factors, climatic deterioration during the LIA is known to have been associated with farm abandonment throughout Iceland. In the eastern fjords, farms located farthest inland and at highest elevations were the first to be abandoned, as conditions became increasingly harsh and access to wider resources from the lowlands was potentially diminished (Sveinbjarnardóttir 1992). As temperatures decline during cold periods, increased cryogenic (freeze–thaw) processes at higher elevations disturb vegetation and expose topsoil that is then susceptible to erosion. Highland solifluction is known to have increased during the LIA (Kirkbride and Dugmore 2005). This effect is eventually transmitted downslope if the period is prolonged and of severe duration (Ólafsdóttir and Guðmundsson 2002; Haraldsson and Ólafsdóttir 2003). Scars from these cryogenic processes are still visible in lowland sites around Skálafellsjökull and Heinabergsjökull (McKinzey and others 2004b). Likewise, glacier advances during the LIA period intermittently decreased the area of potentially usable farmland across Austur-Skaftafellssýsla. However, by the late nineteenth century, when climate was generally more mild and glaciers undergoing retreat, in addition to fewer epidemics and increasing trade routes, isolated land formerly underused for grazing and habitation in eastern and southeastern districts, such as Víðidalur, had been resettled (Sveinbjarnardóttir 1992).

Critically, the effectiveness of socially constructed buffering strategies during the LIA became paramount during times of climatic and environmental stress in southeast Iceland. Humans were at most risk from starvation when strategies failed, possibly triggered by cold summers when food stores had dwindled and people became dependent on new pasturage to revive milk production. Animals were culled to alleviate malnutrition and disease during prolonged years of hunger following the Laki eruption in AD 1783, as well as during AD 1802–05 and during the 1880s (Table 3; Vasey 2001; Grove 2004). However, food shortages were generally lower by the second half of the nineteenth century due to the availability of new technologies, increasing imports or sowing of recently introduced crops like potatoes. Thus, buffering mechanisms and coping strategies had significantly changed towards the end of the LIA period. Additionally, the possibility of emigration to North America during ~AD 1890 also provided another means of coping during times of hunger (Vasey 2001).

Climate change is also intertwined with the development of social, economic, and political structures between the seventeenth and nineteenth centuries. For example, political power, land ownership, farm size, livestock mixes, trade policies, and the relative advantages they could be used to promote, acted to gather wealth into the hands of an elite. This tendency seems to have been exacerbated when interplayed with climatic deterioration. Thus, increased pressure was put on the less economically independent and tenant farmers, and powers of the elite were extended. However, wealthier farms and their holdings created a critical buffer (for example, replacement livestock and dairy produce) to those less fortunate during short-term resource crises. If the crises persisted, the more likely it became that the recipients lost their economic independence, thus causing the wider pattern of landholdings to change, such as during the end of the eighteenth and mid-nineteenth centuries (Table 3; Fig. 6). Overall, a local economy was created that involved tenant farmers becoming increasingly reliant upon a few major households. Initially, 'bad seasons' would have first impoverished lower- and middle-ranking farmers and their social mechanisms to cope, whereas successive 'bad years' during the LIA would have elevated the economic and political status of a few major farms and church holdings and, combined with potentially deliberate strategies of the elite, reduced the levels of the most vulnerable tenant farmers and paupers (McGovern 1994; Vasey 2001). However, even large, long-established farms, such as Breiðá and Fjall, eventually succumbed to LIA glacier expansion, whilst others, like Fell and Haukafell, were moved to safer ground that ensured preservation of economy.

Overall, LIA climatic deterioration increased pressure on the peoples of southeast Iceland, primarily through its impact on the land, either by reducing its extent or its productivity. Temperature decreases in particular acted to reduce the length of the growing season, and thus significantly increased the pressure on vegetation growing in marginal areas (Ólafsdóttir and others 2001). By the end of the LIA, the landscape in southeast Iceland can be perceived as being both reduced in area and 'exhausted,' in that formerly viable areas for grazing and hay production had either been directly eroded by changes in the glaciers and rivers themselves (jökulhlaups distinguished as the most threatening physical hazard), or had been inadvertently degraded due to increasing pressure on limited farming resources that promoted soil erosion and loss of natural capital. From the scientific point of view, environmental variability is usually discussed from a negative standpoint, that is, that all changes are detrimental to human beings. Yet, from a positive perspective, people survive despite the hardships. Even during the most extreme years during the LIA, concurrent cultural and socio-economic trends ensured that people living in Austur-Skaftafellssýsla survived with little loss of human life (Table 3). Moreover, they were able to build a successful society.

The LIA maximum in southeast Iceland: coherence or disparity?

According to implications regarding landscape stability derived from the ethnographic survey, the timing of the LIA maximum in southeast Iceland appears to have occurred at the end of the nineteenth century (Table 2). This is not an issue of data quality, as respondents provided as much detailed and relevant information regarding environmental and climatic changes from the eighteenth as from the nineteenth centuries. Therefore, it seems that the landscape in southeast Iceland retains environmental 'memory' of cumulative impacts. Past climate is recorded in the landscape as a record of accumulated physical effects to a greater or lesser extent. For example, the landscape in southeast Iceland did not have enough time to 'recover' from severe environmental stress, in terms of climate and glaciological response, that occurred during the late eighteenth–early nineteenth centuries before it had to 'cope' with another pulse of extreme climatic variability during the latter half of the nineteenth century. This suggests that landscape or environmental responses in an already marginal location, such as Austur-Skaftafellssýsla, are in the order of decades to centuries. Thus, the sum total of environmental impact accumulated during the previous ~100 years caused the landscape to reach a threshold of 'extreme instability' during the waning stages of the LIA and explains the emphasis of cultural memory and oral history on changes that occurred during that time.

However, if the entire range of scientific and ethnographic evidence is included, then coherence exists across all of the sources of data, and the timing of the LIA maximum shifts to the late eighteenth–early nineteenth centuries (Table 2). Residents in Austur-Skaftafellssýsla displayed an exceptional understanding of the scientific literature and previous research in their region, and most acknowledged that glacier expansion during the late nineteenth century might not have been quite as extensive as ~100 years previous. Hierarchical classification of data sources may lead to the misunderstanding of environmental change (Crumley 1994), such as the confusion regarding the timing of the LIA glacier maximum in southeast Iceland. This has apparently resulted from the misinterpretation of historical information retold in Þórarinsson's (1943) compendium regarding fluctuations of Vatnajökull glaciers. Þórarinsson (1943) implied that the spatial extent of both the late eighteenth to early nineteenth century and late nineteenth century advances were similar in most places, thus raising the question whether or not the true LIA maximum limit in many areas of southeast Iceland is identifiable. Information derived from the current ethnographic survey and local literature sources supports Þórarinsson's (1943) conclusion, although it also indicates that the earlier period of glacier advance pertained to the maximum LIA glacier limit. Moreover, it highlights the importance of local knowledge and careful assessment of all types of data when reconstructing former glacier limits.

Conclusions

The people of southeast Iceland have developed strategies to contend with both climatic variability and accumulated climate change as expressed through glacier fluctuations throughout their history. This study has highlighted the value of ethnographic research in combination with field science when exploring the human dimension of extreme environmental variability, such as during the seventeenth–nineteenth centuries. Despite recent arguments regarding the validity of the LIA term (for example, Jones and Mann 2004), it is crucial that we do not forget that this period had real and significant impacts on everyday life for those having to live through it, especially in places like Iceland. Global compilations of data may show little significant temperature change throughout the LIA period, but glacier and associated environmental changes were a reality that the people of Austur-Skaftafellssýsla had to manage. Furthermore, the perceptions, memories, and histories of local people living in sensitive environments like Austur-Skaftafellssýsla provide a rich and critically underused resource for the numerous scientific investigations that draw conclusions about the timing of the LIA maximum in Iceland. An exploration in the coherence of data from many sources, both from the scientific record and the ethnographic point of view, has shown that the more varied and integrated the sources of information, the more complete the understanding and reconstructions of past change.

Therefore, the main conclusions from this study are:

1. LIA climatic deterioration significantly increased the pressure on vegetation growing in marginal areas, which affected grazing capacity, and, thus, farming viability, hence causing stress to farmers living in Austur-Skaftafellssýsla;
2. However, it was the interplay of climate with concurrent cultural, social, and economic factors through the past few centuries which determined the strategies that ensured effective survival and preservation of economy among the local community;
3. Landscape in southeast Iceland retains environmental 'memory,' which reached a critical instability threshold during the late nineteenth century and explains the emphasis of cultural memory and oral history on changes that occurred during that time;
4. An holistic approach that integrates all sources of information relevant to the impact and magnitude

of LIA changes shows coherence in the different trajectories of perception and indicates that the LIA maximum in southeast Iceland occurred during the late eighteenth–early nineteenth centuries.

Acknowledgements

We are grateful to the Institute of Geography at the University of Edinburgh, the Mackay Fund, the Quaternary Research Association, and the Leverhulme Trust for funding this research. We thank the Hornafjörður Municipality, Guðný Svarvarsdóttir and the Hornafjörður Library staff, Nina Sigurjónsdóttir, Flatey Farm, and Skálafell Farm. Finally, we are indebted to the residents of Austur-Skaftafellssýsla for their interest in this research — without their participation and kindness, this research could not have taken place. KMM is especially grateful for the wisdom and friendship of the people of Austur-Skaftafellssýsla which made this work a very rewarding experience.

References

Bell, B. 1981. Analysis of viticultural data by cumulative deviation. In: Rotberg, R.I., and T.K. Rabb (editors). *Climate and history*. Princeton, NJ: Princeton University Press: 271–278.

Benediktsson, G. 1977. *Í flaumi lífsins fljóta. Bernsku- og æskuminningar*. Reykjavík: Örn og Örlygur.

Bergþórsson, P. 1969. An estimate of drift ice and temperature in Iceland in 1000 years. *Jökull* 19: 94–101.

Bergþórsson, P. 1985. Sensitivity of Icelandic agriculture to climatic variations. *Climatic Change* 7: 111–127.

Björnsson, H. 1979. Glaciers in Iceland. *Jökull* 29: 74–80.

Björnsson, H. 1998. Frá Breiðumörk til jökulsands: mótun lands í þúsund ár [From Breiðamörk to glacier sands: geomorphology in thousand years]. In: Arnason, G.S. (editor). *Kvískerjabók*. Hornafjörður: Sýslusafn Austur-Skaftafellssýslu: 164–176.

Bradwell, T. 2001a. Glacier fluctuations, lichenometry and climate change in Iceland. Unpublished PhD thesis. Edinburgh: Department of Geography, University of Edinburgh.

Bradwell, T. 2001b. A new lichenometric dating curve for southeast Iceland. *Geografiska Annaler* 83A: 91–101.

Bradwell, T. 2004. Lichenometric dating in southeast Iceland: the size-frequency approach. *Geografiska Annaler* 86: 31–42.

Briffa, K.R., T.J. Osborn, F.H. Schweingruber, P.D. Jones, S.G. Shiyatov, and E.A. Vaganov. 2002. Tree-ring width and density data around the Northern Hemisphere; part 1: local and regional climate signals. *The Holocene* 12: 737–757.

Cook, E.R., R.D. D'Arrigo, and M.E. Mann. 2002. A well-verified, multiproxy reconstruction of the winter North Atlantic Oscillation Index since AD 1400. *Journal of Climate 15*: 1754–1764.

Crumley, C.L. 1994. Historical ecology: a multidimensional ecological orientation. In: Crumley, C.L. (editor). *Historical ecology: cultural knowledge and changing landscapes*. Santa Fe: School of American Research Press: 1–16.

Dabski, M. 2002. Dating of the Fláajokull moraine ridges SE Iceland: comparison of the glaciological, cartographic and lichenometrical data. *Jökull* 51: 17–24.

Dawson, A.G., K. Hickey, T. Holt, L. Elliott, S. Dawson, I.D.L. Foster, P. Wadhams, I. Jonsdóttir, J. Wilkinson, J. McKenna, N.R. Davis, and D.E. Smith. 2002. Complex North Atlantic Oscillation (NAO) Index signals of historic North Atlantic storm-track changes. *The Holocene* 12: 363–369.

Evans, D.J.A., S. Archer, and D.J.H. Wilson. 1999. A comparison of the lichenometric and Schmidt hammer dating techniques based on data from the proglacial areas of some Icelandic glaciers. *Quaternary Science Reviews* 18: 13–41.

Eyþórsson, J. 1952. þættir úr sögu Breiðár [Brief history of Breiðá]. *Jökull* 5: 17–20.

Gadde, N.O. 1983. *Íslandsferð sumarið 1857, úr minnisblöðum og bréfum frá Nils Ohlsson Gadde*. [*A trip to Iceland, in the summer 1857, from memory notes and letters from Nils Ohlsson Gadde*]. Reykjavík: Hörpuútgáfan.

Geirsson, þ. 1995. *Gamla hugljúfa sveit, II, af mönnum og málefnum í Austur-Skaftafellssýslu* [*Old loved district II, stories of men and issues in Austur-Skaftafellssýsla*]. Reýdará í Lóni: þorsteinn Geirsson.

Gellatly, A.F., T.J.H. Chinn, and F. Rothlisberger. 1988. Holocene glacier variations in New Zealand: a review. *Quaternary Science Reviews* 7: 227–242.

Glueck, M.F., and C.W. Stockton. 2001. Reconstruction of the North Atlantic Oscillation 1429–1983. *International Journal of Climatology* 21: 1453–1465.

Grove, J.M. 2004. *Little Ice Ages ancient and modern*. Second edition. London: Routledge.

Guðmundsson, H.J. 1997. A review of the Holocene environmental history of Iceland. *Quaternary Science Reviews* 16: 81–92.

Haraldsson, H.V., and R. Ólafsdóttir. 2003. Simulating vegetation cover dynamics with regards to long-term climatic variations in sub-Arctic landscapes. *Global and Planetary Change* 38: 313–325.

Hass, H.C. 1996. Northern Europe climate variations during the late Holocene: evidence from marine Skagerrak. *Palaeogeography, Palaeoclimatology, Palaeoecology* 123: 121–145.

Henderson, E. 1957. *Ferðabók, frásagnir um ferðalög um þvert og endilangt Ísland árin 1814 og 1815 með vetursetu í Reykjavík*. [*Iceland: or the journal of a residence in that island during the years 1814 and 1815]*. Reykjavík: Snæbjörn Jónsson & Co.

Jones, P.D., and M.E. Mann. 2004. Climate over the past millennia. *Reviews of Geophysics* 42: 1–42.

Jónsson, þ. 1954. *þorleifur í Hólum Ævisaga* [Bibliography]. Reykjavík: Bókaútgáfa Guðjóns Ó. Guðjónssonar.

Karlén, W. 1988. Scandinavian glacial and climatic fluctuations during the Holocene. *Quaternary Science Reviews* 7: 199–209.

Kirkbride, M.P., and A.J. Dugmore. 2001. Can lichenometry be used to date the Little Ice Age glacial maximum in Iceland? *Climatic Change* 48: 151–167.

Kirkbride, M.P., and A.J. Dugmore. 2005. Late Holocene solifluction history reconstructed using tephrochronology. In: Harris, C., and J.B. Murton (editors). *Cryospheric systems: glaciers and permafrost*. London: Geological Society (Special Publication 242): 145–155.

Ladurie, E.LeR. 1971. *Times of feast, times of famine: a history of climate since the year 1000*. London: George Allen & Unwin.

Lamb, H.H. 1977. *Climate: present, past and future*. London: Methuen & Co.

Larsen, G., M.T. Guðmundsson, and H. Björnsson. 1998. Eight centuries of periodic volcanism at the center of the Iceland hotspot revealed by glacier tephrostratigraphy. *Geology* 26: 943–946.

Mackintosh, A.D., A.J. Dugmore, and A.L. Hubbard. 2002. Holocene climatic changes in Iceland: evidence from modeling glacier length fluctuations at Solheimajökull. *Quaternary International* 91: 39–52.

McGovern, T.H. 1994. Management for extinction. In: Crumley, C.L. (editor). *Historical ecology: cultural knowledge and changing landscapes*. Santa Fe: School of American Research Press: 127–154.

McKinzey, K.M., W. Lawson, D. Kelly, and A. Hubbard. 2004a. A revised Little Ice Age chronology of the Franz Josef Glacier, Westland, New Zealand. *Journal of the Royal Society of New Zealand* 34: 381–394.

McKinzey, K.M., J.F. Orwin, and T. Bradwell. 2004b. Re-dating the moraines of Skálafellsjökull and Heinabergsjökull using different lichenometric methods: implications for the timing of their Little Ice Age maxima. *Geografiska Annaler* 86A: 319–335.

McKinzey, K.M., J.F. Orwin, T. Bradwell, and A.J. Dugmore. In press. A revised chronology of key Vatnajökull outlet glaciers during the Little Ice Age. *Annals of Glaciology*.

Oerlemans, J., B. Anderson, A. Hubbard, P. Huybrechts, T. Johannesson, W.H. Knap, M. Schmeits, A.P. Stroeven, R.S.W. van de Wal, J. Wallinga, and Z. Zuo. 1998. Modeling the response of glaciers to climate warming. *Climate Dynamics* 14: 267–274.

Ogilvie, A.E.J. 1984. The past climate and sea-ice record from Iceland. *Climatic Change* 6: 131–152.

Ogilvie, A.E.J. 1992. Documentary evidence for changes in the climate of Iceland, AD 1500 to 1800. In: Bradley, R.S., and P.D. Jones (editors). *Climate since AD 1500*. London: Routledge: 92–117.

Ólafsdóttir, R., and A.D. Júlíusson. 2000. Farmers' perception of land-cover changes in NE Iceland. *Land Degradation and Development* 11: 439–458.

Ólafsdóttir, R., and H.J. Guðmundsson. 2002. Holocene land degradation and climatic change in northeastern Iceland. *The Holocene* 12: 159–167.

Ólafsdóttir, R., P. Schlyter, and H.V. Haraldsson. 2001. Simulating Icelandic vegetation cover during the Holocene: implications for long-term land degradation. *Geografiska Annaler* 83(A): 203–215.

Ólafsson, E., and B. Pálsson. 1981. *Ferðabók Eggerts Ólafssonar og Bjarna Pálssonar um ferðir þeirra á Íslandi árin 1752–1757* [*The travel book of Eggert Ólafsson and Bjarni Pálsson about their travel around Iceland in the years 1752–1757*]. Reykjavík: Örn og Örlygur.

Pálsson, S. 1983. *Ferðabók* Sveins Pálssonar: Dagbækur og *ritgerðir 1791–1797* [*The travel book of Sveinn Pálsson: diaries and essays 1791–1797*]. Second edition. Reykjavík: Örn og Örlygur.

Simpson, I.A., A.J. Dugmore, A. Thomson, and O. Vésteinsson. 2001. Crossing the thresholds: human ecology and historical patterns of landscape degradation. *Catena* 42: 175–192.

Statistical Bureau of Iceland. 1960. Population census 1703. *Statistics of Iceland II.21*.

Statistics Iceland. 1997. In: Jónsson J., and M.S. Magnússon (editors). *Hagskinna, Sögulegar hagtölur um Ísland* [*Icelandic historical statistics*]. Reykjavík: Hagstofa Íslands.

Sveinbjarnardóttir, G. 1992. *Farm abandonment in medieval and post-medieval Iceland: an interdisciplinary study*. Oxford: Oxbow (Monograph 17).

Sýslulýsingar. 1744–1749. [County description 1744–1749]. Sögurit XXVIII: Sögufélagið. Isafoldarprentsmiðja.

Thoroddsen, þ. 1959. *Ferðabók, Skýrslur um rannsóknir á Íslandi* 1882–1889, *2. útgáfa, III. bindi*: [Travel book, reports about researches in Iceland 1882–1889]. Second edition. Reykjavík: Prentsmiðjan Oddi.

Vasey, D.E. 1996. Population regulation, ecology and political economy in pre-industrial Iceland. *American Ethnologist* 23: 366–392.

Vasey, D.E. 2001. A quantitative assessment of buffers among temperature variations, livestock and the human population of Iceland, 1784 to 1900. *Climatic Change* 48: 243–263.

Watts, W.L. 1962. *Norður yfir Vatnajökul eða um ókunna stigu á Íslandi*. [*Watts' trip to Iceland 1874*]. Reykjavík: Bókfellsútgáfan.

þórarinsson, S. 1943. Vatnajökull: scientific results of the Swedish–Icelandic investigations 1936–37–38. *Geografiska Annaler* 1–2: 1–54.

þórarinsson, S. 1956. *The thousand year struggle against ice and fire*. Reykjavík: Bókaútgáfa Menningarsjóðs.

þórarinsson, S. 1958. The Öraefajökull eruption of 1362. *Acta Naturalia Islandica* 2: 1–99.

þórðarson, þ. 1993. *Í Suðursveit* [*In Suðursveit]*. Reykjavík: Mál og Menning.