# "LITTLE ICE AGE" RESEARCH: A PERSPECTIVE FROM ICELAND

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**Abstract.** The development during the nineteenth and twentieth centuries of the sciences of meteorology and climatology and their subdisciplines has made possible an ever-increasing understanding of the climate of the past. In particular, the refinement of palaeoclimatic proxy data has meant that the climate of the past thousand years has begun to be extensively studied. In the context of this research, it has often been suggested that a warm epoch occurred in much of northern Europe, the north Atlantic, and other parts of the world, from around the ninth through the fourteenth centuries, and that this was followed by a decline in temperatures culminating in a "Little Ice Age" from about 1550 to 1850 (see e.g. Lamb, 1965, 1977; Flohn, 1978). The appelations "Medieval Warm Period" and "Little Ice Age" have entered the literature and are frequently used without clear definition. More recently, however, these terms have come under closer scrutiny (see, e.g. Ogilvie, 1991, 1992; Bradley and Jones, 1992; Mikami, 1992; Briffa and Jones, 1993; Bradley and Jones, 1993; Hughes and Diaz, 1994; Jones et al., 1998; Mann et al., 1999; Crowley and Lowery, 2000). As research continues into climatic fluctuations over the last 1000 to 2000 years, a pattern is emerging which suggests a far more complex picture than early research into the history of climate suggested. In this paper, the origins of the term "Little Ice Age" are considered. Because of the emphasis on the North Atlantic in this volume, the prime focus is on research that has been undertaken in this region, with a perspective on the historiography of historical climatology in Iceland as well as on the twentieth-century climate of Iceland. The phrase "Little Ice Age" has become part of the scientific and popular thinking on the climate of the past thousand years. However, as knowledge of the climate of the Holocene continues to grow, the term now seems to cloud rather than clarify thinking on the climate of the past thousand years. It is hoped that the discussion here will encourage future researchers to focus their thinking on exactly and precisely what is meant when the term "Little Ice Age" is used.

**Key Words**: Climate Variability; Historical Climatology; Iceland; "Little Ice Age"; "Medieval Warm Period"; Sea Ice

## 1. Introduction

The term "Little Ice Age", like the "Medieval Warm Period", is a concept that has entered both the scientific and popular literature. The reality of the "Medieval Warm Period" has been extensively discussed in a special issue of *Climatic Change* edited by Hughes and Diaz (1994). In the introductory article to this issue, they state that this appelation "Medieval Warm Period" has been used to describe the time period from about the "ninth through the fourteenth centuries". This current volume of *Climatic Change* seeks to follow in the footsteps of those researchers by considering what exactly may be meant when the phrase "Little Ice Age" is used, and how useful the term really is. Although the dominant usage has come to mean a general and widespread cold period occurring some time during the past millennium, most commonly from around AD 1500 or 1550 to

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1800 or 1850 (see e.g. Lamb, 1965, 1977; Flohn, 1978; Mikami, 1992) it has often not been defined clearly in the scholarly literature. There are also conflicting opinions as to when and where it may be said to have occurred. In this paper, we seek to elucidate some of the origins of the term and briefly consider prevailing viewpoints, both in the general literature and in this volume.

Prior to the era of modern meteorological data, knowledge of the climate of the past 1000 years comes from a variety of sources, including early instrumental observations, documentary historical evidence, and other high-resolution proxy climate data such as ice cores, marine and lake-core data, dendroclimatological data, phenological data, and glacial records. While we will discuss certain elements of this research, a review of all the relevant literature is clearly beyond the scope of this article. However, in the sections that follow, we outline some of the research that has been undertaken in the North Atlantic and northern European sectors, and also consider a wider perspective. In the context of this special issue of *Climatic Change* with a main focus on the climate of the North Atlantic, particularly Iceland, we also feel it to be appropriate to offer a discussion on what may be termed "the historiography of climate" in Iceland. Much pertinent research has been done on climate history in Iceland, but most of this is not generally well known outside that country. Finally, in the concluding discussion, we volunteer our own perspective.

## 2. Origins and Use of the Term "Little Ice Age"

The term "Little Ice Age" naturally has its origin as a reflection of a larger "Ice Age" (or "Ice Ages") when ice sheets advanced, and cold climatic regimes prevailed, before the current Holocene or "recent" period of the last 10,000 years or so. We may speculate that, as climatologists and palaeoclimatologists in the early and middle part of the twentieth century concentrated on unravelling the details of the climate of the recent past, it was tempting to compare what they perceived to be an interesting phenomenon with a similar episode (albeit of greater magnitude) in the past.

A detailed discussion on the origins and uses of the term the "Little Ice Age" may be found in the seminal work on the topic (J. M. Grove, 1988). However, it is of interest here to mention briefly some of the early uses of the concept. The term "Little Ice Age" appears to have been first introduced into the literature by Matthes, although his definition was very different from that which has passed into general usage. As Chairman of a committee on glacier fluctuations, he stated: '...accordingly it may well be said that we are living in an epoch of renewed but moderate glaciation - a "little ice-age" that already has lasted about 4000 years' (Matthes et al., 1939 p. 520). The subsequent entry of the term into common usage (and with the specific sense of referring to some variant of the period from somewhere around AD 1550 to 1850) may be attributed largely to researchers such as Lamb and Flohn. It is also of interest to note that Manley, another pioneer in the field, did not favour the term. In 1974, in one of his classic papers on the Central England temperature record, he wrote: 'We need to know more...about the onset and progress of what some have been inclined to call, not very satisfactorily, the Little Ice Age...' (Manley, 1974, p. 403). For further early discussions of "post-glacial climatic change" see also Hoyle et al., 1949.

Three main viewpoints on the definition of the nature of the term may be mentioned. Perhaps best-known is the view which equates the "Little Ice Age" with a time period during which temperatures were relatively cold. This is expressed succinctly by Lamb, who states: 'The period we are discussing has been dubbed "The Little Ice Age" because not only in Europe but in most parts of the world the extent of snow and ice on land and sea seems to have attained a maximum as great as, or in most cases, greater than, at any time since the last major ice age' (Lamb, 1977, pp. 461-462). A second viewpoint is presented by J. M. Grove. She states: 'The term "Little Ice Age" does not refer directly to climate but to the most recent period during which glaciers extended globally and remained enlarged...' (J. M. Grove, this volume). Elsewhere she states clearly that the term "Little Ice Age" should refer specifically and only to glaciation, not temperature (J. M. Grove, 1988, p. 3). A third view argues that there was, in fact, no "Little Ice Age" at all in the commonly accepted sense. This is stated most forcefully by Landsberg: '...it is a misnomer because *continental* (his italics) glaciation did not increase nor was there any sustained low global temperature...It would be far better to expurgate the scientifically misleading (even if journalistically appealing) term "Little Ice Age", because of the fact that the interval so designated was not uniformly cold in space or time' (Landsberg, 1985, p. 62).

As regards the time period covered, as Landsberg also noted, 'The literature is not even consistent about what interval is designated as the "Little Ice Age": for example, 1550-1700, eighteenth and nineteenth centuries, 1550-1850, fifteenth through nineteenth centuries' (Landsberg, 1985, footnote to p. 62). However, what may be called the orthodox or the classical viewpoint approximates closely to Flohn's suggestion: '...the cold period, often known as the Little Ice Age, which followed and reached its climax in various parts of Europe at different times between about A.D. 1550 and 1850' (Flohn and Fantechi, 1984). In many of Lamb's works his dates approximate roughly to this time, with minor variations, for example, 'the cold Little Ice Age climate of about 1550 to 1800' (1977, p. 104) and 'It is reasonable to regard the time from about 1550 to 1700 as the main phase for most parts of the world...' (1977, p. 463). Another approach suggests that the "Little Ice Age" began much earlier and extended later. Indeed, Lamb (1977, p. 449) discusses the 'climatic worsening (*Klima-Verschlechterung*) of the late Middle Ages' (AD 1200-1400) and, further: 'The course of the climatic deterioration over five centuries from AD 1200 can quite well be traced...' (Lamb, 1977, p. 451). J. M. Grove states that: 'The "Little Ice Age" was well under way during the thirteenth and fourteenth centuries' (Grove, this volume). It is interesting to note that, with this definition, the start of the "Little Ice Age" encroaches quite significantly on the "Medieval Warm Period" time period of the 'ninth through the fourteenth centuries' as discussed by Hughes and Diaz (1994).

Although the "Little Ice Age", both in the Matthesian and Lambian sense, is a mid-twentieth century construction, discussion on climatic changes in the North Atlantic region during historical time had already started by the early nineteenth century. An example of this is the survey given in 1824 by the Swedish scholar and diplomat, Ehrenheim, on the variability of climate. This discusses both "modern" (i.e. late-eighteenth, early-nineteenth century) variations as well as historical ones. There is no definite conclusion in the work, but he notes that severe winters with heavy ice conditions, both in Scandinavia, and elsewhere in Europe, seem to be getting progressively fewer since the late Middle Ages. He also suggested that the summers have at the same time become cooler, although the more "recent" development is complex, as there is evidence for a cooling in Scandinavia during instrumental measurement time (i.e. from the beginning of the instrumental records in the eighteenth century to his time of writing in the third decade of the nineteenth century). For Ehrenheim, the crux of the matter is variability. According to his ideas, the occurrence of a cold period indicates that a warm period is imminent, or in progress elsewhere. By stretching the point, one can find both a "Little Ice Age" of sorts and a "Medieval Warm Period" within his system, but these do not occur at the same time everywhere. In more modern terminology, Ehrenheim is emphasizing "continentality" as the important variable of climate.

By the end of the nineteenth century, other climatologists were already debating the decreased continentality of the European climate during the preceding nineteenth century and the increased maritime influence (Ekholm, 1899). Enhanced continentality eventually became an important attribute of the "Little Ice Age" (Schove, in Hoyle et al., 1949) and, more recently, by e.g., Jönsson and Holmqvist (1995). Lately, perceived changes in the continental and maritime condition, and the evolution towards a more maritime climate, include the North Atlantic/Arctic Oscillation (NAO/AO) as a player in the "Little Ice Age" drama (Barlow, this volume, and references cited therein).

## 3. Current Issues and Perspectives

### 3.1. INTRODUCTION

Most current researchers would probably agree that a perceived end to the "Little Ice Age" in the latter part of the nineteenth, or early part of the twentieth century, is uncontroversial. The reasons for this are at least twofold. One is that there are many more climate data available for this period than for earlier periods, and it is therefore, relatively speaking, easier to determine the nature of climatic change around this time. Another is the perspective afforded by the increase in global temperatures. Since the late nineteenth century, the Earth has warmed by about 0.6°C (see, e.g., Jones, et al., 1999). At least part of this warming has been attributed to human activities, specifically, the emissions of carbon dioxide and other trace gases. The Intergovernmental Panel on Climate Change (IPCC) states: 'The balance of evidence suggests a discernible human influence on global climate' (Houghton et al., 1996, p. 4). Another perspective is presented by Kreutz et al., (1997), however. From their measurements on sea-salt deposition in ice cores from both Antarctica and Greenland they suggest that if an onset of the "Little Ice Age" can be characterised by the increase in deposition about AD 1400 these conditions are still persisting, and they conclude that '...in terms of polar atmospheric circulation, we suggest it is possible that conditions common during the LIA, may have persisted into the 20th century and may still persist' (Kreutz et al., 1997, p. 1296).

Outside the immediate climate history community, the "Little Ice Age" is generally perceived as a disastrous event that occurred suddenly, at a certain time in the past. However, specialists have always been aware of the difficulty of defining exactly the onset of the "Little Ice Age" and, as stated above, even a cursory glance at the literature reveals that many dates within a 400 year period (1200–1600) are mentioned either as the onset of the "Little Ice Age" or some manifestation of it. It even seems that every climate related change during this particular period, gradual or not, is tied to the "Little Ice Age". Thus the term has become a self re-enforcing one. The recent proliferation of detailed proxy records will in the coming years undoubtedly elucidate the "onset problem" and favour a more focused discussion. This new era is already evident in the literature e.g., in Briffa (2000), Mann et al. (1999) and Kreutz et al. (1997).

## 3.2. DATA SETS AND APPROACHES

### 3.2.1. *Paleoclimatic Data Sets*

Different locations in the Atlantic Arctic region are represented by different proxy climate indicators as not all areas possess the same type of records. Thus, for example, long ice-core records (of e.g., stable isotopes, dust, chemical composition) are available from a number of sites in Greenland (see, e.g., Dansgaard, 1964; Dansgaard et al., 1975; Johnsen et al., 1989; Mayewski et al., 1993; Barlow, 1994, this volume; White et al., 1997; Kreutz et al., 1997). Accumulation has also been studied in the ice cores (e.g. Friedman et al., 1995; Cuffey and Clow, 1997). Iceland is well known for its excellent historical and early instrumental records (Ogilvie, 1991, 1992; Jónsson and Garðarsson, this volume). Historical and early instrumental records are also found in Scandinavia (see e.g. Jönsson, 1998; Selsing, 1998; Moberg and Bergström, 1997). Dahl-Jensen et al. (1998) report on temperatures in the Greenland boreholes. Huang et al. (2000) give a survey of borehole temperatures around the world, but only a few originate in the North Atlantic region. Long tree-ring series are available from a number of sites in Scandinavia, and also North America (Bartholin and Karlén, 1983; Briffa et al., 1990, 1992; Briffa and Jones, 1994; Jacoby et al., 1999; Briffa, 2000). Glacier variations have been documented by, for example, Karlén, 1982; J. M. Grove, 1988, this volume; Grove and Switzur, 1994; Guðmundsson, 1997; Geirsdóttir et al., 2000). Marine data from *foraminifera* and sediment cores give valuable proxy climate information for the past 1000 to 2000 years, and may also act as a proxy sea-ice indicator when these data are lacking (Jennings and Weiner, 1996; Jennings et al., this volume). Lake-core records are available from, for example, Iceland (see, e.g., Doner, 1999; Harðardóttir et al., in press) and Baffin (Doner and Overpeck, 1995; Hughen et al., 2000). Syntheses of a selected number of different proxy records have been made by, for example, Lamb (1977); Williams and Wigley (1983); Bradley and Jones (1993); Briffa and Jones (1993); Overpeck et al. (1997); Jones et al. (1998); Mann et al. (1998, 1999) and Crowley (2000). Drawing on some of the above-mentioned research, a few of the varying viewpoints regarding the climate of the last millennium are outlined below.

### 3.2.2. *Recent "Little Ice Age" perspectives*

As mentioned above, the most commonly stated orthodoxy regarding the time frame of the "Little Ice Age" has been to confine it to some time from around AD 1550 to 1850. An early attempt to rigorously analyse palaeoclimatic data sets noted: '...the "Little Ice Age" of the last few centuries, a "Medieval Warm Period" around the 12th century AD., and an earlier cold period some time between the 8th and 10th centuries' (Williams and Wigley, 1983). Recent research seems to be finding less and less evidence for the concept of the "Medieval Warm Period" (see e.g., Hughes and Diaz, 1994; Ogilvie and Farmer, 1997. However, see also Dahl-Jensen et al., 1998; Pfister et al., 1998). Thus, for example, Jones et al., (1998, p. 464) state: '...we can only concur with Hughes and Diaz (1994) that there is little evidence for the "Medieval Warm Period"...'. In the composite northern latitude tree-ring data series for the last two millenia (Briffa, 2000) one might use the label "Medieval Warm Period" for a temperature maximum that is evident during c. 980 to ca. 1100. It is very doubtful, however, if such a short period fits the idea of that concept. The general perception of the "Little Ice Age" concept is also challenged by Briffa's tree-ring dataset, as the post-1200 period is composed of both cold and warm periods, and definite intervals of multi-century deviation are difficult to find. The longest lasting negative deviations during the last two millennia as suggested by Briffa's data set is in the thirteenth and early fourteenth centuries (the "Medieval Cold Period") and the coldest years in the series seem to occur during ca. 534 to ca. 550.

In 1998, Jones et al., concluded that there is clear evidence for: '...cooler centuries between 1500 and 1900, particularly the seventeenth and nineteenth centuries which are indicative of a two phase "Little Ice Age"...' (1998, p. 469). However, a wider perspective is also noted: 'The new series...are challenging the concepts embodied in the terms "Medieval Warm Period" and "Little Ice Age" (Jones et al., 2001).

Based on analyses of a variety of palaeoclimatic data, a further interpretation of the temperature changes during the last 1000 years is put forward in Mann et al. (1999). The changes are interpreted as a cooling trend (0.028°K per century) during the whole period, with an abrubt end about 100 years ago. It is suggested that 'this cooling is possibly related to astronomical forcing' (Mann et al., 1999, p. 762). The late eleventh, late twelfth and late fourteenth centuries rival *mean* (their italics) twentieth century temperature levels. In this view, an indistinct starting time of the "Little Ice Age" is not a problem; it does not start, it creeps upon us. They suggest further that '...cooling following the fourteenth century could be viewed as the initial onset of the Little Ice Age *sensu lato*' (Mann et al., 1999, p. 762). The paper by Crowley (2000) challenges the idea of relating the AD 1000 to 1800 cooling to "astronomical forcing". Instead, the low-frequency variability of temperature during the last millennium is in large part attributed to volcanic forcing, changes in solar irradiance and greenhouse gas variability. Working with the GISP2 and GRIP ice-core records, Barlow (1994, this volume) found that the isotopic signals do not support the concept of a centuries-long low temperature time period representative of the so-called "Little Ice Age", and suggests that the climate record was rather variable in the 1500s and 1600s (GISP2 and GRIP records) and into the 1700s (GISP2). On a century time scale the lowest temperature time period during the last 1000 years may have been the 1300s (Dansgaard, et al., 1975: Barlow et al., 1997; Barlow, this volume).

In addition to the uncontroversial fact that glaciers advanced and retreated during the last millennium, analysis of borehole temperatures from bedrock and ice sheets present the most forceful 'evidence' for a cooler period preceding the twentieth century. The idea of using subtle variations in bedrock temperature gradients as manifested in boreholes in order to make inferences about climate history has existed for some time, at least since the 1920s (see e.g., references in Beck, 1992). The use of the method for detecting specifically the "Little Ice Age"and a preceding "Little Climatic Optimum" (i.e. a "Medieval Warm Period") was compellingly introduced by Cermák (1971). A brief history of the subject and more recent developments are given by Beck (1992) and by Beltrami and Mareschal (1995). Recently Huang et al. (2000) have analyzed 616 borehole profiles from all continents except Antarctica. Almost 80 per cent of these 'show a net warming over the past five centuries' (p. 757) and they suggest that the cumulative temperature change during the last 500 years exceeds 'recent estimates from conventional climate proxies' (p.756). The borehole approach has also been used for analysis of past Greenland ice surface temperatures (Clow et al., 1996; Cuffey and Clow, 1997; Dahl-Jensen, et al., 1998). Dahl-Jensen et al. (1998) resolve a "Little Ice Age" (their own label) with two distinct minima (at 1550 and 1850) and a preceding period of warmer temperatures as well.

The problems regarding the use of borehole temperatures for estimation of ground surface temperature history have been discussed in detail in the literature (see e.g. Beck, 1992; Clow, 1992; Beltrami and Mareschal, 1995; Huang et al., 1996). Clow et al. (1996) discuss the particular problems encountered in both the measurement and interpretation of ice-core borehole temperatures. A discussion of most of these problems is out of the scope of this paper, as are the differences between results obtained by the miscellaneous analysis methods.

Cermák (1971) already stresses the 'uncertain relation between surface ground temperature and the mean air temperature' and considers this a 'great obstacle' that 'requires a quantitative assessment' (Cermák, 1971, p. 17). Later studies support this cautionary point of view and show how changes in land use (deforestation, agriculture) can have a significant influence on the local ground surface temperature histories that diverge greatly from the mean air temperature changes. Here it suffices to mention the study by Skinner and Majorowicz (1999), for northwestern America, and Sebagenzi et al. (1992) for Zaire in Africa. The detailed Skinner-Majorowicz study reveals large ground surface temperature changes, independent of climatic change, at the time of deforestation, and conversion of prairie grassland to an agricultural area. The Sebagenzi et al., paper regarding Zaire is interesting in our context because the large warming that is detected (3-4°C) is almost exclusively attributed to deforestation and other surface changes. Climate changes are deemed to be 'a smaller term which could not be resolved by analyses of the available data' (p. 216). It is thus important that boreholes for a climate analysis are carefully selected and that surface ground temperature changes are not automatically attributed to climate change.

The temporal resolution of the borehole temperature deteriorates very rapidly backwards in time as a consequence of the heat diffusion process. Information about surface temperature variations slowly diffuses downwards, but at the same time the amplitude of the variations attenuates. Shen et al. (1996) apply two different analysis methods at three different measurement noise levels on two synthetic 1000-year-long data series (years 1000 to 2000 in their notation). One of these is a saw-tooth signal with an amplitude of 2°C and a period of 400 years, the other a single ramp signal starting at 1800, with a 3°C increase in temperature until 2000. At realistic noise levels (10m°K) analysis of the two very different histories render a strikingly similar result before 1800 (pp. 51 and 52).

There is a qualitative difference between the ice-core borehole data and data recovered from bedrock boreholes. In the case of the ice, the ice itself "propagates" downwards to greater depths as snow accumulates on top of it. It thus carries information about its original temperature downwards. At the same time, the ice continuously exchanges heat with the layers above and below by diffusion. The diffusion gradually smears out the original gradients (Clow et al., 1996). Eventually, at greater depths, the geothermal gradient also dominates the ice holes, just as in the bedrock ones (clearly seen in Dahl-Jensen et al., 1998, p. 269). The difference in the amplitude of the temperature variations between the

Dye and Grip core holes (Dahl-Jensen et al., 1998) is of some concern. One should also note that the past temperature estimates made by the ice-borehole temperature measurements are independent of the now "traditional" stable isotope methods.

It is very difficult to doubt the borehole records as indicators of real, albeit not fully scaled, temperature changes, but it is easy for the non-specialist to overlook the importance of resolution. There is a problem of presentation, as the resolution of one end of a bore hole time plot is much better than at the other. This gives the decidedly incorrect impression that the variability in the past was much smaller than near the present. Drawing progressively wider uncertainty (or standard error) envelopes towards the past is not appropriate either, as the early entries are multi-century values and are not very uncertain in the technical sense of the word. A possible solution would be to restrict the plot to a few points, progressively more sparse towards the past, not connected by a continuous line.

Although the borehole data present convincing evidence of a warming of the northern and mid-latitude continents during the last 200 years or so, care must be taken in the interpretation of its association with mean air temperature changes. The tropical data show that other explanations can at least in some cases also be valid. This is especially the case in areas subject to large changes in land use during the last 200 years.

### 3.2.3. *Changing viewpoints*

Advances in the study of palaeoclimatic proxy records have led to increased questioning regarding the accepted wisdom of the reality of the "Little Ice Age" and its companion, the "Medieval Warm Period". Thus, as gaps in the knowledge of the past thousand years (and further back in time) are increasingly filled, it has become clear that there is considerable spatial variability (Hughes and Diaz, 1994; Mann et al., 1999) and that percieved cold periods are invariably punctuated by milder episodes and vice versa (Ogilvie, 1992; Ogilvie and Farmer, 1997; Mann et al., 1999). A further perspective is noted by Jones et al. (1998). This latter paper focuses on the coherence of proxy data series used for temperature reconstructions. Little coherence is found between the proxies on the 30-50 year timescale. This result is also valid for those that are geographically quite close and 'there does not appear to be anything approaching a pattern of coherent near-global temperature change implied by the results' (p. 467). There are some strong teleconnections in the 0.03 cpy (cycles pr. year, 33-year period), but these are seriously degraded by a small frequency change down to 0.02 cpy (50-year period). Individual data series can thus not be expected to reveal anything about the structure, onset, or an end of a hemispheric (or global) "Little Ice Age". Jones et al. (1999) conclude that there is evidence that the seventeenth century was the coldest of the period since 1400, being 'on the average only 0.5° – 0.8°C below the 1961-1990 base' (p. 190). Also, as Overpeck et al. (1997) have noted in a recent paper on the Arctic climate of the past four centuries: 'interannual to century-scale Arctic climate variability is the norm' (p. 1254). Kreutz et al. (1997) sum up much current research: 'Although it was a globally distributed event, the LIA was not a 500-year period of global cooling. High-resolution tree-ring records from several areas have suggested that although there is substantial decadal-scale variability related to temperature changes over the last 2000 years, no distinct LIA signal is recorded. Indeed it is possible that the LIA was not simply a cooling everywhere but instead a period of both warm and cold anomalies that varied in importance geographically' (p. 1294).

## 4. The Historiography of Climate in Iceland

### 4.1. INTRODUCTION

Perhaps because Icelanders have long been aware of living near the climatic margin for an economy based on animal husbandry and agriculture (Ogilvie, 2000), their records of meteorological events tend to be full and varied and extend far into the past. In particular, historical records exist of the incidence of sea ice off the coasts of Iceland. Although many early writers commented on the weather and climate, and specifically on the sea ice, our discussion will focus on the principal research done in this area . This includes work by: Hannes Finnsson (first published 1796, see the 1970 edition of his work); Þorvaldur Thoroddsen (1892-1904, 1908-1922, 1914, 1916-1917); Jón Eyþórsson (1926, 1949, 1950, 1965, 1966); Lauge Koch (1945); Sigurður Thórarinsson (1956a b, 1974) and Páll Bergþórsson (1967, 1969a b, 1985). As a comprehensive survey of research into historical climatology in Iceland has not been published previously (however, see Ogilvie, 1982) it is appropriate to include it here as a context for our general discussion of research on the climate of the past millennium.

In this discussion of historical climate in Iceland, three separate viewpoints regarding climatic change will be alluded to. One may be termed the "uniformitarian" view. As this implies, it suggests a fairly constant climate, with no variation to speak of. A second may be called the "deterioration" view. This involves a transition from a relatively favourable early climate to an unfavourable later climate. This has several variants. A third may be termed the "relative" view. This emphasises that climate is constantly changing, and suggests that, even if there were relatively long cold or warm time periods they nevertheless encompass much annual-to-decadal variability.

Specific research on past climate may be said to have begun in Iceland with the publication in the late-eighteenth century of a scholarly treatise on the effects of dearth years and severe seasons. This work, *Mannfækkun af Hallærum á Íslandi*, ("Loss of Life as a Result of Dearth Years") by Hannes Finnsson was first compiled in 1793, and subsequently published in 1796 and 1970. (The edition from 1970 is used here). Finnsson defined a dearth year as one in which there was famine and deaths from hunger all over the country. He does not consider the possibility that the climate may have varied during the period of his survey (from early medieval times to the late-eighteenth century) but he does broach the subject of whether dearth years have increased or decreased. He suggests that it is difficult to make comparisons between the number of deaths from famine in the eighteenth century and earlier times because of the lack of data for the earlier period (a notably modern perspective). However, he suggests that there were fewer dearth years before AD 1280 than after, and that the main reason for this was that trade was more favourable for Iceland then. Finnsson's work is of great value and interest; it is one of the earliest attempts to investigate past climate and climate-society interactions written in Iceland, or anywhere else, and is a most scholarly and well-written work. Although he did include some works which more recent research has shown to be unreliable (Vilmundarson, 1969, 1972; Ogilvie, 1984) his careful attention to the documentation of his sources, for example, is in the best tradition of rigorous scholarship.

Other minor works on the general subject of the effects of severe seasons continued to be written in the nineteenth century. However, these are of little interest here. They consist mainly of lists of severe years, with little or no discussion, and most of them are no more than extracts from Finnsson's work. There were no new developments in the field in Iceland until the early decades of the twentieth century, when the concept of a changing climate, and the consequences of this for societies, was first suggested and subsequently discussed.

## 4.2. THE WORK OF ÞORVALDUR THORODDSEN

The major author on the past climate of Iceland is arguably Þorvaldur Thoroddsen (1855-1921). His photograph is shown in Figure 1. Thoroddsen's primary works on the subject of climate are the compilation *Árferði á Íslandi í þúsund ár* ('The Climate of Iceland Through one Thousand Years'), published in the same volume as the monograph, *Hafís við strendur Íslands* ('Sea Ice off Iceland's Coasts') in 1916-17. These works are in Icelandic and have never been translated into any other language. (Quotations from these given below have been translated by the authors.) Thoroddsen's compilations bring together much information on many different kinds of weather phenomena, from the time when Iceland was first settled in the late ninth century, to the early 1900s. They have been extensively used by researchers interested in the past climate of Iceland.

It is clear from his published work, that Thoroddsen adhered to the view that the climate of Iceland did not change markedly from Iceland's settlement to the time when he was writing at the end of the nineteenth and beginning of the twentieth centuries (Thoroddsen, 1914, 1916-17). He suggested that changes in the fortunes of the population were more related to the unwillingness of the inhabitants to admit to the facts of natural variability and their failure to behave accordingly, rather than being caused by long, protracted periods of hostile weather. As noted above, this is the "uniformitarian" view of climatic change.


*Figure 1.* Þorvaldur Thoroddsen (1855-1921). From Thoroddsen (1922-1923).

> Everything regarding weather and climate is everywhere very irregular, fickle and unstable...In all ages average and good years have been much more numerous than the bad. But it is a depressing truth that most common men, in spite of centuries of penance, seem unable to learn foresight and prudence (Thoroddsen, 1916-17, p. 350).

However, almost at the end of his commentary, after a discussion of the shortage of data prior to AD 1600, there is possibly an indication of a new perspective:

> The last three centuries can in all likelihood be compared and a close scrutiny reveals that the difference is not large. But it is quite certain that the climatic conditions of the nineteenth century, in spite of periods of hardships, have been considerably better than the conditions of the seventeenth and the eighteenth centuries (Thoroddsen, 1916-17, p. 354).

In view of the effort that Thoroddsen put into the compiling of *Árferði á Íslandi,* and the fact that it has been used so extensively by later authors on climatic variations in Iceland, it is ironic that he was convinced that the climate of Iceland had not changed significantly in the past. This he states categorically:

> It can be said with certainty that since Iceland was settled no significant changes in the climate or weather have occurred. Sagas and annals show quite clearly that good and bad years, in the past as now, have alternated with long and short intervals. Then, as now, the sea ice came to the coasts, the glaciers were the same, the desert areas the same and the vegetation the same (Thoroddsen, 1908-1922, Vol. II, p. 371).

However, it seems that it is possibly the definition of "climatic change" that is at issue here for he is ready to concede that '...good and bad years...have alternated with long and short intervals'. Another interesting point is that it has been suggested that, during the early centuries of settlement, the comparatively favourable climate of Iceland was similar to that of the early twentieth century. Presuming this to be true, Thoroddsen's remark that 'the climatic conditions have, on the whole, been the same (during the settlement period) as during the present (1914, p. 205) would be correct at least as far as this particular period was concerned.

## 4.3. A VICTORY FOR THE UNIFORMITARIANS?

In the early years of the twentieth century, Thoroddsen entered a heated debate on the climate of medieval Scandindavia. In 1913, the Swedish oceanographer, Otto Pettersson, published a paper entitled *Klimatförändringar i historisk och förhistorisk tid* (Pettersson, 1913). This was published in English the following year as 'Climatic Variations in Historic and Prehistoric time' (Pettersson, 1914). Here Pettersson asserted that not only does climate vary with time, but also that an economic decline in the late Middle Ages in northwestern Europe (especially Scandinavia) coincided with a period of severe climate and that this was an important causal factor for the decline. This corresponds to the "deterioration" viewpoint mentioned above. As Pettersson puts it:

> All these (climatic) events are recorded in ancient chronicles which also depict the social and economic state of the comunities, which were greatly influenced by these violent climatic variations and their consequences: famine and disease (Pettersson, 1914).

Pettersson noted that the first inhabitants of Iceland were able to cultivate grain and that this later became impossible. He also concluded that from the thirteenth century onwards, Iceland began to be blocked by drift ice and that the amount and duration of the ice was far greater than at the present time (i.e. 1914). From these observations he sought to refute the belief held by '...most geographers of our time' who 'take it for granted that the climate of Iceland has not altered in historic time' (Pettersson, 1914).

In contrast to many early (and some later) writers on climatic change, Pettersson suggested a physical explanation for the changes; a tidal theory (Pettersson, 1914). According to this view, climatic changes are driven by an 1800-year variation in the tidal forces of the moon and sun. At the tidal maxima the oceanic circulation is more vigorous, and the climate of the North Atlantic region gets colder. The Pettersson theory was later heavily critisised by Nansen (1925) as being full of inconsistencies and lack of oceanographic rigor. However, the 1800-year cycle has recently been revived (Keeling and Whorf, 2000) as a possible cause of changes evident in deep sea cores in the North Atlantic region (Bond et al., 1997). Whether this development will rehabilitate Pettersson's viewpoint remains to be seen.

As suggested above, Thoroddsen was probably one of the geographers criticised by Pettersson. However, he did believe that the climate, whether it varied or not, was of great importance for the people of Iceland. He wrote, for example:

> The sea ice...has been the most important causal factor in the dearth-years, price-rises and famines, and has done more harm to the Icelandic population than all the volcanic eruptions and earthquakes (Thoroddsen, 1914, p. 205).

In 1915, a Norwegian historian, Edvard Bull, entered the debate. He agreed with Pettersson that the climate had changed. In order to try and prove this, he listed a number of severe years within the period 1291 to 1392, and claimed that this period stood out as having a far more unfavourable climate than the periods immediately preceding or following it. Bull also called for a more precise analysis, and suggested that the most important question in the debate was not whether the Icelandic climate in early medieval times was essentially more favourable than that of the present day (c. 1915), but whether a definite climatic decline could be observed at a particular time. He went on to comment that a response to this change, and therefore its importance historically, depended not only on the magnitude of the change, but also on how quickly it occurred, and on the country's distance from the limit for successful settlement.

Bull must have been the first to suggest that because of Iceland's marginal location, only minor climatic variations needed to occur in order to make conditions difficult for the inhabitants, and that climate must therefore be of great importance for the history of such a country. He also raised another extremely important point: the need to use accurate and reliable sources for the reconstruction of climate (see e.g., Bell and Ogilvie, 1978). He pointed out that many of the sources used by Thoroddsen did not come into this category (Bull, 1915).

The debate on climate change in the early part of the twentieth century in fact interested a number of Scandinavian researchers (see e.g. Hildebrandsson, 1915; Norlind, 1915). It is not possible to mention all of these; however, it is of interest to note the research done by the Dane, Speerschneider. His main work was *Isforholdene i de Danske Farvande i ældre og nyere Tid, Aarene 690-1860* ('The State of the Ice in Danish Waters in Former and Present Times, AD 690 to 1860'). He was writing around the same time as Thoroddsen, Pettersson and Bull, and was another devotee of the "uniformitarian" viewpoint. In particular, he challenged the notion of changes in ice severity (at least around Denmark). In the English summary to his above-mentioned work (Speerschneider, 1915, p. 141) he categorically stated: 'There is no reason to believe in any marked difference in the amount of ice in Danish waters during the winters of former periods and of the present day'.

In the early 1920s, the Norwegian scientist and explorer, Fridtjof Nansen, took up the debate. He was well acquainted with medieval Scandinavian literature, in particular with what may be termed early geographical texts (see e.g., Ogilvie, 1991). One of these may be mentioned here. This is the *Konungs skuggsjá* ('The King's Mirror') believed to have been written in Norway around 1250 (Anonymous, 1917; Ogilvie, 1988). In this work, ice conditions around Greenland are described very clearly and accurately (see e.g. Lehn and Schroeder, 1979). Nansen was also very familiar with the ice conditions in polar waters due to his extensive travels in these regions. Because of his knowledge of the early texts such as 'The King's Mirror' (which to him seemed to describe the ice conditions as they were in his own day) and his own experiences as an explorer, Nansen found it it difficult to see where the idea of a milder climate in medieval times had originated. He therefore speculated that this concept was due to a misunderstanding caused by the names of the two Norse settlements in Greenland, *Eystribyggð*, the "Eastern Settlement" and *Vestribyggð*, the "Western Settlement". (In reality, both settlements were located in southwest Greenland, with the "Western Settlement" having the more northerly location.) It was thought (Nansen assures us) that the "East" component in the name *Eystribyggð* referred to the geographical area east of Cape Farewell. This area is now infested with sea ice in almost every year, but, according to this argument, could not have been during the Norse settlement period. *Ergo*, the climate must have been milder during that time. However, (Nansen continues) as the Eastern Settlement is really on the western side of southern Greenland, and as the climate there is now (for Nansen "now" is the early twentieth century) capable of supporting both cattle raising, and some cereal growing, there is, according to him, no need to invoke a complicating deterioration theory for this region. In a similar manner, Nansen also opposed the idea of a late medieval deterioration of the climate of Scandinavia and the Baltic (Nansen, 1925) and thus must be seen as siding with the uniformitarians.

The discussion was soon carried further. The first formally trained Icelandic meteorologist, Jón Eyþórsson, published a paper in 1926 with the title *Um loftslagsbreytingar* ("On Climatic Change"). In it he neatly summarizes the then recent debate and tends to agree with the conclusions of Thoroddsen and Nansen. The main emphasis of the paper is, however, a systematic refutation of the existence of what later became known as the "Medieval Warm Period" and its alleged benefit for the colonisation of Greenland.

The conclusions of Nansen and Eyþórsson were firmly based on the meteorological and oceanographical knowledge of the time. As noted above, one of their main arguments was that reliable medieval sources described ice and oceanographic conditions exactly as they are today. This conclusion is still difficult to dismiss. Regarding "land-based" arguments for a warm medieval period, they allude to human-induced environmental degradation complicated by socio-economic developments as the major forcing factor, rather than climate. They also emphasise the error of assigning a weight to the medieval *Sagas of Icelanders* as a reliable source of climate data (see Ogilvie, 1991). Both authors do confess to a belief in the reality of a climatic optimum in the early part of the Holocene, and they look to the sun or to orbital changes as the ultimate agents of climatic variability on all timescales. At the same time, they entirely dismiss the moon-sun tidal cyclicity theories of Pettersson. It is often forgotten that the main cyclic orbital changes had been calculated, and their influence on climate were already being vigorously debated in the nineteenth century. A useful overview of pre-Milankovitch knowledge on orbital changes and climate is given by Ekholm (1899, p. 381ff.).

Nansen and Eyþórsson thus found Thoroddsen's uniformitarian view the more rational one, and their long and well-argued papers could possibly have been the final blow to the "deteriorarians" if the climate itself had not intervened, so to speak. The warming that had started before the turn of the century accelerated in the 1920s, and by 1950, the reality of large climatic fluctuations between colder and warmer periods was no longer open to dispute.

## 4.4. A CHANGE OF CLIMATE

That a considerable warming was in progress had, in fact, become evident before 1940 (Callendar, 1938). Lauge Koch, the Danish geologist, and author of the major work on the Arctic sea ice, *The East Greenland Ice*, published in 1945, put forward the interesting idea that Thoroddsen's adherence to the view that climate does not change may have been partly due to the climatic regime that prevailed during his lifetime.

> Thoroddsen wrote his first survey of the ice conditions in Iceland immediately after the two heavy ice years 1881 and 1882. The only period with a mild climate to which he gave attention was the fourteen-year period 1840 to 1854. In 1916 to 1917 he treated the Icelandic ice conditions for the last time. In the intermediate years an amelioration of the climate did not occur until after Thoroddsen's death and consequently he never himself experienced a real and protracted amelioration of the climate like that known from the last two decades. (Here Koch means the 1920s and 1930s.) Koch (1945, pp. 210-211).

In his later papers (1949, 1950) Eyþórsson admitted that there had been some shift in the climate during the preceding thirty years. As the founder of the "Icelandic Glaciological Society" he was very well aware of the rapid recession of most of the Icelandic glaciers, and he began his 1950 paper with the statement that: 'Every middle aged and old person, living his life in Iceland, agrees that there is less snow in the winter now and that the climate is milder than it was before the turn of the century and in the beginning of the present one' (p. 67). (See also Thórarinsson, 1943). At the end of the paper, Eyþórsson cautiously states: 'We do not know if this temperature increase will continue or decline. An additional warming is very unlikely and during the last 10 years the temperature seems to have stagnated or even started on a downward route' (p. 84).

With fifty years of hindsight, it is interesting now to be able to confirm that Eyþórsson was certainly correct in his view of the climate of the first half of the twentieth century. The twentieth-century maximum warming was already then a thing of the past, but the temperature did not revert to pre-1925 levels until 1965. In one of his last papers on climate (1965) we witness a partial withdrawal of the earlier view on the "stationarity" of the Icelandic climate of historical times:

> As my experience and research on climate, sea ice and glaciers has grown, the more convinced I become, that the period 1600-1900 (or 1920) was a distinctively cold and hard one and therefore can from our point of vantage

be labelled "The Lesser Ice Age" or "The Final Ice Age" (Eyþórsson, 1965, p. 6).

Eyþórsson's final text on climate history is a short commentary on a list of mild winters compiled from Thoroddsen's work of 1916-1917 (Eyþórsson, 1966). It is tempting to view this choice of subject as an allusion to the possibility of "hidden" warm periods spanning many decades. After all, the most recent warm period (prior to 1966) only lasted 40 years.

As late as the 1950s, the Icelandic geologist, Sigurður Thórarinsson, found it necessary to point out that the debate on medieval climate had gone on so long that, during the time that had elapsed, the object of comparison, the climate of the present day, had changed to a large extent (Thórarinsson, 1956a). It seems that, by 1960, there was a general agreement on the overall shape of a curve showing temperature conditions in Iceland since settlement in the late ninth century. According to this view, it was generally warm until the thirteenth century. Then the cold set in, and lasted to 1920, with some amelioration in the fifteenth and sixteenth centuries. The cold period around 1300 is fairly well documented in written sources (see Ogilvie, 1991). Palaeoglaciological work (see e.g., Guðmundsson, 1997) also indicates major glacial advances at approximately that time. However, does this indicate that the "Little Ice Age" started as early as AD 1250 in Iceland? Was this late medieval cold period a part of so-called "Little Ice Age" 'proper'?

Questions concerning the actual rather than relative temperature changes had not been answered either. However, in a series of papers written before 1970, Páll Bergþórsson sought to address these (Bergþórsson, 1967, 1969a b). His effort was mainly concentrated on two issues: i) the determination of the actual temperature range since the settlement and; ii) the effect of temperature changes on agriculture and economy (Bergþórsson, 1985). His approach to the temperature determination is described in a paper published in English in 1969 (Bergþórsson, 1969a). Here he draws attention to the issue of a diffuse beginning of a "Little Ice Age" versus an abrupt end. In an Icelandic version of the same paper he is more explicit: 'It is thus most likely that a nearly continuous cold period stretched from the late twelfth century until the early present century' (Bergþórsson, 1969b, p. 343).

Central to Bergþórsson's approach, is a comparison of temperatures as measured at two Icelandic stations (Stykkishólmur at the west coast, from 1845 to 1969, and Teigarhorn at the east coast, from 1874 to 1969) and the sea-ice incidence during the same period. During the first part of this period (1846 to 1919) Bergþórsson finds a good correlation (-0.69) between the annual temperatures and sea ice. During the latter part (1920 to 1969) the correlation is not as good (-0.39). He then assumes that the first mentioned relationship is valid during the period 1591 to 1845 with the *ad hoc* premise that prior to 1780 "light ice" months are under-reported and 'that one has to increase the apparent incidence of ice'

(1969a, p. 94). He also asserts that due to the better reporting of ice after the Icelandic Meteorological Office was established in 1920, it 'was therefore inevitable to reduce the observed ice amount of the last decades considerably' (p. 95). Although Bergþórsson is probably qualitatively correct regarding an under-reporting of "light ice" during the seventeenth and early-eighteenth centuries, the quantification of this problem is open ended. As he himself concedes 'it must also be admitted that this fact reduces considerably the confidence of these ice records' (p. 95). For the pre-sixteenth century estimation, Bergþórsson relied on a count of "severe years" made first by Finnsson (1796, 1970) and then by Thoroddssen (1916-1917). This he correlates with the sea-ice incidence (r=0.69) during the 1591 to 1940 period. Very cold years were not always heavy ice-years, but the correlation is fairly high, and therefore Bergþórsson's assumption is probably justified.

By the method outlined above, Bergþórsson estimated 30-year temperature running means in Iceland (Stykkishólmur and Teigarhorn average) as ranging from 4.5°C in the early tenth and twelfth centuries, down to slightly below 3.0°C at the end of the thirteenth century, and in the late-eighteenth and late-nineteenth centuries. The corresponding 1931-1960 average of these stations is 4.3°C, and the 1961-1990 mean 3.6°C. According to Bergþórsson, the temperature depression of the "Little Ice Age" is thus about 0.5°C compared to the present values. However, this is about 1.2°C relative to the 1931-1960 average.

The graphs from the Bergþórsson (1969a) paper have been widely quoted, most recently in, for example, Broecker et al. (1999) and Crowley and Lowery (2000). It is disconcerting that researchers who have used Bergþórsson's ice index tend to ignore the caveats that Bergþórsson himself recognises.

## 4.5. HISTORICAL SOURCES, SEA ICE AND CLIMATE

The history of the uses of the term "Little Ice Age" has, like most histories, many strands. One is how it has been defined by previous researchers, another is how accurate they were in their conclusions. Just as a detailed survey of the former is beyond the scope of this article, so is any detailed analysis of the latter. However, a few points may be made here. Many of the early discussions on the "Little Ice Age" were based on historical records. Examples are the work by Lamb, Flohn, and, indeed, the Icelanders we have been discussing, from Finnsson and Thoroddsen onwards. One flaw in many early reconstructions is the failure to carefully analyse the historical sources in order to ensure their reliability. This has been pointed out by comparatively recent research (see e. g. Bell and Ogilvie, 1978). However, it was also emphasised by Bull (see above) and by Lauge Koch.

Koch's reconstruction of past ice incidence is largely based on the compilation by Thoroddsen, described above, particularly the section on sea ice. However, Koch is critical of some of Thoroddsen's methods. For example, Koch points out that Thoroddsen frequently assumed the presence of sea ice not only on the basis of direct descriptions of ice but also on indirect evidence and this was 'sometimes on a very vague basis'. As an example, Koch refers to the report that 35 ships were lost in 1118. Thoroddsen suggests that, in all likelihood, these ships were crushed by sea ice. As Koch puts it, 'this does not seem very convincing' Koch, (1945, pp. 204-205).

Koch also gives an extensive review of the literature on the past climate of Iceland, including the papers described above by Eyþórsson, Pettersson and Bull, and shows himself to be aware of many of the problems involved in using documentary sources in the reconstructions of past climate, or sea-ice incidence. For example, he postulates an argument by Nansen that records of ice incidence only reflect the number of the ice records in the literature, not the quantity of ice. As Koch points out, according to this argument the amount of ice recorded would apparently increase as records became fuller. This is not always the case, however, and Koch notes the great variations in ice conditions from about 1780 onwards, when records of ice had become more or less complete (Koch, 1945, p. 248).

As stated, in more recent times, temperature and ice incidence for Iceland during the period AD 940 to 1969 have been estimated (see above) by Páll Bergþórsson. He also based his analyses on the work of Thorodssen. When considering sea-ice history the issue comes up again as to how the ice is estimated when descriptions are oblique or lacking. It has been suggested that the absence of ice cannot simply be assumed during times when there is little evidence due to lack of data (Vilmundarson, 1969, 1972; Ogilvie, 1984, 1992). As Koch also pointed out (see above) Thoroddsen frequently assumed the presence of ice on rather flimsy evidence. However, it may not be appropriate to assume the presence of ice on indirect evidence. In discussing this issue, Bergþórsson gives an example. He says that in 1758 'the annals tell us there was no drift ice at the coast, and that this had hardly occurred in memorable time' and that 'even if no ice is mentioned in the annals for 1751, 1752 and 1753, it is therefore not justifiable to consider them ice-free' (1969a, p. 94). Upon examining the sources more closely, this assumption would seem to be incorrect. Firstly, the phrase upon which the evidence for ice in the years mentioned hinges, 'this had hardly occurred in memorable time', is a sort of stock-phrase used frequently in sources such as the annals, and it is questionable how much reliance may be placed upon it. Secondly, if we look closely at the sources for the other years: in fact sea ice was recorded in 1751. In a contemporary source, *Höskuldstaðaannáll*, it is stated: 'Ice came in at góa (c. third week in February) and filled up all of Húnafjord...The ice lay for a long time' (*Annálar* IV, p. 490). However, sea ice was not recorded for 1752, 1753, 1754 or 1755. The description of ice given in Thoroddsen (1916-17, p. 156) for 1755 is an error for 1756. That there should not be ice seems surprising in view of the cold weather described during these years, but it seems too much of a coincidence that none of the reliable contemporary sources consulted for these years record ice. A further discussion of ice conditions during 1755 and 1756 may be found in Ogilvie (1984) and also in Vilmundarson (1969, 1972) in reference to an unpublished paper (Ólafsson, 1967) on the severe years 1751-1757, in which the compounded errors regarding 1755 are pointed out.

What is most striking, however, is not Thoroddsen's omission of sources but the fact that he consulted as many as he did. That many of these sources (most of the later annals, for example) were in difficult-to-read manuscript form, makes Thoroddsen's work even more laudable; it is unfortunate that he was unable to benefit from the critical work done by the editors of the annals when these works were later published. In the final instance, Thoroddsen's compilation must be valued for the pioneering work that it is.

The importance of carefully analysing historical sources may also be seen in regard to a much broader issue than the accuracy of an account for one particular year. Lamb (and others) have concluded that the old sailing route to Greenland had been abandoned by about AD 1342 because of increasing sea ice, and hence, it has been inferred that the "Little Ice Age" in the North Atlantic set in around this time (Lamb, 1977, p. 6). The source for this description of a changed sailing route is a work entitled *Grænlandslýsing Ívars Bárðarsonar* ('The Description of Greenland according to Ívar Bárðarson'). This is a problematic source (Ogilvie, 1998) and, although the greater part of the work may well be reliable, the mention of sea ice is almost certainly not part of the original account, but a later interpolation. It is not known when the insert on sea ice was written or, indeed, if it is accurate. The information from this difficult source has passed further to other researchers, creating, almost single-handedly, an early "Little Ice Age" in the North Atlantic. Thus, Porter (1981, p. 99) referring to the suggestion of Dansgaard et al. (1975) that a 'comparatively cold Little Ice Age' began in the twelfth century at the site of the Crête ice core, continues: 'At about that time sea ice began to expand around Greenland, and its southern limit moved southward, possibly forcing abandonment of traditional sailing routes between Iceland and the Norse colonies in Greenland...The Little Ice Age may therefore have begun at least two to three centuries earlier in the North Atlantic than is generally inferred'. Of course, Porter's discussion is here lifted out of context, and it should be noted that he does also discuss other evidence, such as glacial advances. That other, reliable, sources regarding sea-ice conditions in the fourteenth century may exist is a separate issue (Ogilvie, 1991, 1998).

## 4.6. CURRENT RESEARCH ON THE PAST CLIMATE OF ICELAND

The very name of "Iceland" conjures up a country living in a permanent ice age - whether minor or major. However, Iceland's climate history over the past 1000 years is notable for its great variability. As research into historical and early instrumental records continues, this history has been increasingly refined. As stated above, in his work, *The East Greenland Ice*, Lauge Koch presented a record of sea-ice variations back to c. AD 865. Comparing the curves that he produced to 'lowlands and mountain chains', Koch concluded that: 'a lowland occurred in the saga time, a low mountain chain from 1200-1400, and from 1600-1900 actual alps' (Koch, 1945, p. 260). This is similar to the broad conclusions of Eyþórsson, mentioned above. However, as our knowledge of the past climate of Iceland has increased, the complexity of the situation has become more evident, and this picture is no longer valid. Perhaps the most striking aspect of the climatic history of Iceland is the great variability that may be seen. (However, see the discussion below on the topic of variability). Documentary and early instrumental climate data for Iceland also highlight some interesting anomalies. Current knowledge regarding the past climate of Iceland to ca. AD 1900 is outlined briefly below.

Documentary historical climate records exist for Iceland from medieval times, but they do not become prolific until the seventeenth century. Research on these records has been undertaken in recent years by, for example: Ogilvie (1982; 1984; 1991; 1992; 1993; 1996); Jónsson (1998); Guðmundsson (1997); Kristjánsdóttir, 1998; Jónsson and Garðarsson (this volume). Although it has frequently been assumed that the climate of Iceland was relatively favourable during settlement times and shortly thereafter (from c. AD 871 onwards) there are no contemporary documentary sources for this early period. However, other types of proxy evidence do suggest that the climate of that time may have been similar to the warmest part of the twentieth century in Iceland (see, e.g., Bergþórsson, 1997, p. 175-177; Ogilvie, et al., 2000). It is also possible to draw inferences on the climate of the time from our knowledge of the glacial record in Iceland. Of particular interest in this regard, is the siting of farms, prosperous in settlement times, in areas which were later rendered uninhabitable by encroaching glaciers (Ogilvie, 1984, p. 140). However, relatively cold periods are suggested during ca. 1180 to 1210, and again during the 1280s and 1290s. The fourteenth century was extremely variable. Some evidence exists for a mild climate between 1430 and 1560 (Ogilvie, 1991). (See Figure 2 for a visual presentation of these data). Furthermore, for much of this latter period, documentary sources are lacking. For the last part of the sixteenth century, sources indicate a comparatively harsh climate, extending, with some variability, to around 1630, when a particularly severe period seems to have prevailed until around 1640. Relatively mild conditions then lasted to around 1680. The late-sevententh century was severe. The early decades of the 1700s were mild in contrast to the very cold 1690s, 1740s and 1750s. The 1760s and 1770s show a return to a milder regime. The 1780s are likely to have been the coldest decade of the century, with the harsh conditions compounded by volcanic activity (Ogilvie, 1986). The 1810s, 1830s, 1860s and 1880s were also comparatively cold. Temperatures appear to have been fairly mild in the middle of the nineteenth century, but colder in the latter part (Ogilvie, 1992; Jónsson and Garðarson, this volume).

As initially noted by Bergþórsson (1969a b) the Arctic sea ice is another important climate proxy indicator (see Figures 2 and 3a b). The few documentary

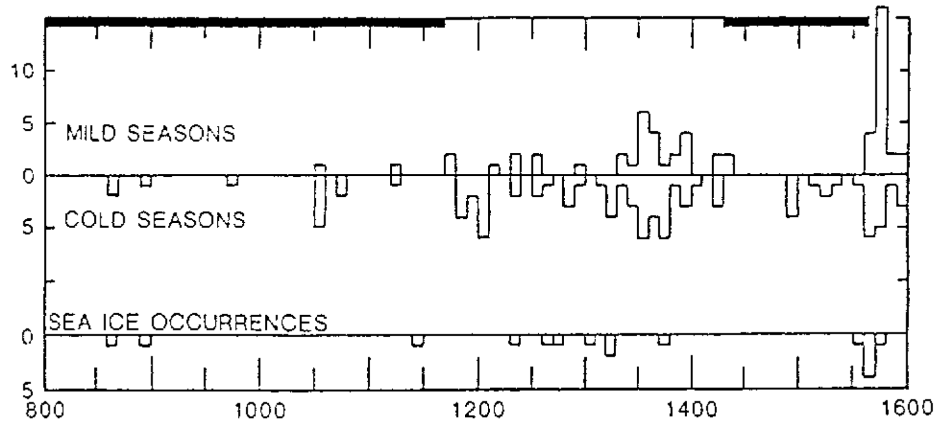



*Figure 2.* Mild and cold seasons in Iceland c. AD 865 to 1598, showing the number of cold or mild seasons per decade. Occurrences of sea ice are also shown; specifically, the number of years per decade in which sea ice was mentioned. The few instances of sea ice recorded at this time, undoubtedly reflect poor data coverage rather than lack of ice. The heavy lines at the top of the diagram indicate periods of very poor data (from Ogilvie, 1991).

descriptions of sea ice that are available before AD 1600 are shown in Figure 2. As may be seen, severe ice-years are documented in 1145, 1233, 1261, 1275, 1306, 1320, 1321, 1374, and then not until 1552, 1564, 1566, 1567, 1568 and 1572. The lack of descriptions of sea ice for much of this time frame must be due largely to the paucity of data, particularly in the period ca. 1430 to ca. 1560. The occurrence of severe sea-ice years in the 1590s is also implied by the sources (Ogilvie, 1991). From AD 1600, the sea-ice data are sufficient to be able to construct indices (see Figure 3a b). While sea ice was extensive in the early years of the seventeenth century, the years 1640 to 1680 seem to have been relatively ice free. No sea ice at all was reported during the 1650s. This coincides with the period when the documentary evidence suggests that mainly mild temperatures predominated. This mild period is in contrast to the marked coldness of the mid seventeenth century in Europe. The decades with most ice present during the last 500

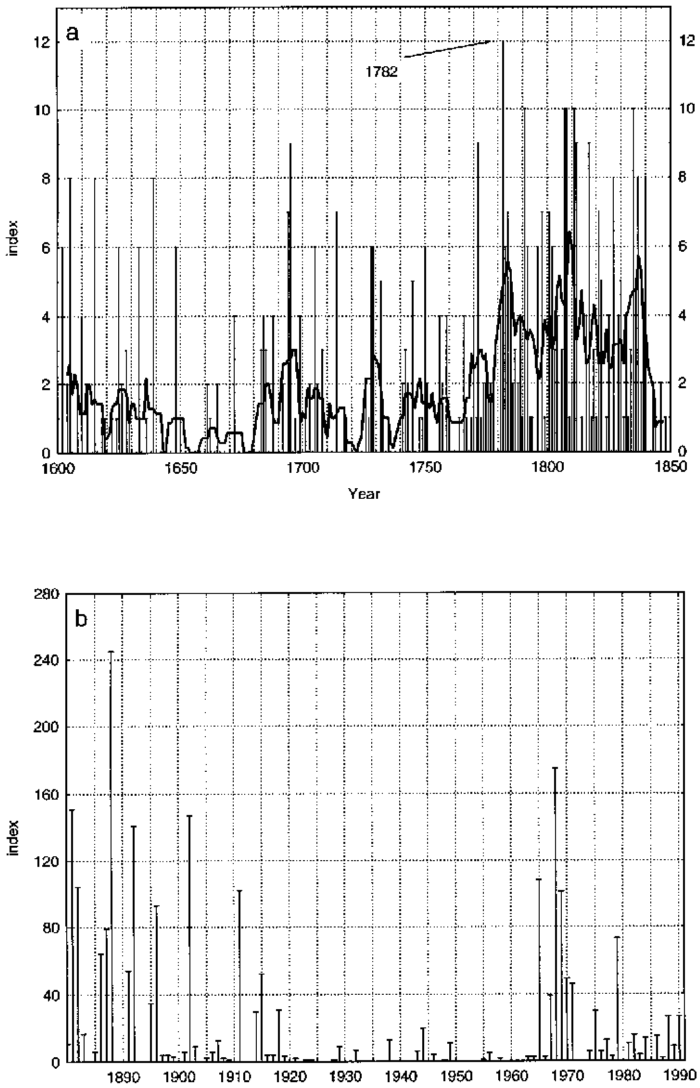



*Figure 3 (a)* Sea-ice index for Iceland AD 1601-1850 based on contemporary documentary sources (discussed in Ogilvie, 1992). The data are shown as individual years and also as 7-year running means. The occurrence of sea ice off the north, northwest, east and south coasts has here been quantified in order to provide an index reflecting both geographical extent and duration. (It may be noted, however, that sea ice rarely reaches the south coast; and, due to the prevailing ocean currents, virtually never occurs off the western coasts.) One "sea-ice point" was awarded for each of the above 4 regions which reported the presence of ice in any given year. A further point was accrued for each season in which ice was reported. Sea ice occurs off Iceland mainly during winter, spring and summer. Autumn ice is rare. The period 1851-1879 is in preparation. *(b)* The Koch ice-index 1881–1990. The figure is based on a table in Wallevik and Sigurjónsson (1998, p. 7–9, see also Koch, 1945). The index is a function of the "residence time" of sea ice near the coast, and a measure of the length of the coast affected each year. Due to much more intensive observations after 1965 some inhomogeneity is to be expected in the series. The "Ice Years" of the late 1960s are outstanding and the difference between the first 3 decades in the figure and the following 5 is clearly seen.

years were probably the 1780s, the 1810s and the 1830s. From 1840 to 1855 there was little ice off the Icelandic coasts. From that time to the end of the century there was frequent ice again, although the incidence does not seem to have been as heavy as in the earlier part of the century. Further clusters of sea-ice years occurred again from ca. 1864 to 1872. The 1880s contained several very severe sea-ice years. Some sea-ice years occurred in the 1890s, but less than in the 1880s. From 1903 onwards sea-ice incidence falls off dramatically. In comparison with the entire period AD 1600 to 1900, sea ice off Iceland has occurred less frequently in the twentieth century (Jónsdóttir and Ogilvie, 1997; Jónsson and Garðarsson, this volume).

## 5. The "Little Ice Age" and the Icelandic Temperature Record

### 5.1. TEMPERATURES IN WESTERN ICELAND 1830-1999

Figure 4 shows the annual temperature in Stykkishólmur in Iceland during the last 170 years, with the thick line representing 10-year running means (for station history see Sigfúsdóttir, 1969). The temperatures during the 1830-1845 period are proxies calculated from measurements made in Reykjavík. Both of the stations were in operation with a similar set of measurements during the 1845-1854 period, which was used as a basis for the calculation (Jónsson, 1989; Jónsson and Garðarsson, this volume).

The period of continuous measurements can be divided into a few sub-periods or episodes. The mid-nineteenth century warm period is clearly seen, ending abruptly in 1859. The next warming did not start until the 1920s, but closer scrutiny of the graph reveals that, after 1892 extremely cold years do not occur, so it is convenient to split the long 1859 to 1925 cold period into two, the first covering 1859 to 1892, and the second from 1893 to 1925. The 1859 to 1892 period is distinguished by large variability not seen in other periods. The coldest years are all characterized by heavy sea ice during the late winter, extending through the spring and into the summer. According to anecdotal evidence, older farmers in the mid-twentieth century reportedly said that by 1893, 'the worst was over' (Sigfúsdóttir, 1969, p. 75). It is worth noting that the two cold periods as defined above, together more or less coincide with the lifetime of Þorvaldur Thoroddsen (1855-1921). The warming in the 1920s started in the winter season, but by 1927 the warm period proper had started. It culminated in the 1930s and 1940s but came to an abrupt end in 1965 when the sea ice returned after being absent for most of the post-1920 period. In Iceland, the period 1965 to 1971 is always referred to as the "IceYears". With the exception of 1979, the ice has only made a few very short visits after 1971, but cool years persisted until the mid-1980s. Later, there has been a slight amelioration.

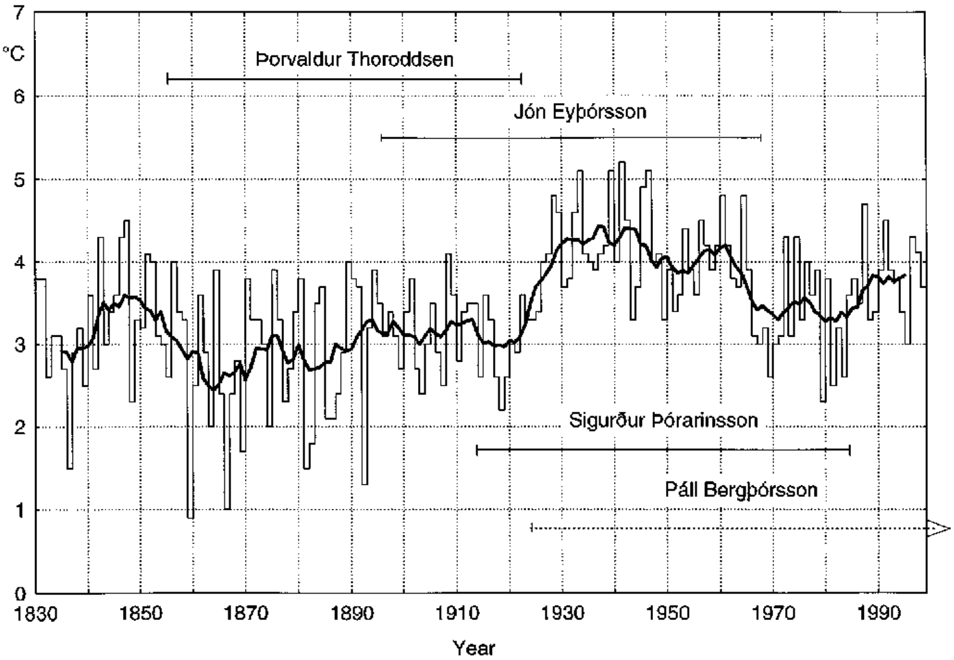



*Figure 4.* The Stykkishólmur temperature series 1830–1999. Individual bars are drawn for every year. The thick line represents the 10-year running means. The thin arrows show the lifelines of 4 eminent Icelandic climate researchers.

The changes in temperature from one period to another are quite abrupt, but there seems to be an underlying trend of about 0.6°C over the period as a whole. The great twentieth-century warm period is well defined in the record. As outlined in section 4 above, it certainly enhanced the image of a cold and dark colonial age, flanked by much more benevolent warm periods of freedom and liberty. The concept was also reinforced greatly by the "discovery" of a similar period in Europe, if not the whole world. After the abrupt cooling of the 1960s, the view back to a well defined "Little Ice Age" in Iceland has not been as clear as before. The warm period lasted about 40 years. It is now natural to question the uniqueness of this interval during historical time in Iceland. If one adheres to the position that all warm periods were both very short and insignificant in Iceland within the alleged "Little Ice Age" period, it seems to imply that temperature variability on the scale of two decades or more was suppressed during this period, compared to the changes of the last century or so. There is no reason to assume that this is the case during any part of the last millennium.

As mentioned above, the year-to-year variability was particularly large during the coldest part of the instrumental temperature record (1859 to 1892). It is worth noting that, if heavy ice years are removed from the record and replaced by "ordinary" cold years, the 1859 to 1892 temperature would have been about the same as it was during the following 1893 to 1925 period. The next two sections focus on sea-ice influence.

## 5.2. ENHANCED YEAR-TO-YEAR VARIABILITY DURING THE COLDEST PERIODS

All the extreme cold "excursions" in the Stykkishólmur temperature record were accompanied by the presence of sea ice and its characteristic temperature anomaly patterns. When the ice is present, instead of being an island, Iceland for a short time period and, in a dramatic manner, becomes more like a promontory of a Greenland-Arctic frozen continent. In an "ordinary" cold winter month the negative anomalies are largest inland, but smaller at the coast, also in the North. When there is heavy sea ice at the coast, the coastal anomalies are also large. The roughly circular (i.e., the shape of the country) anomaly pattern of the ordinary cold winter month is replaced by a large north/south anomaly gradient. The impact of the anomalies that accompany the sea ice is largest in the northern and eastern coastal districts, larger than at Stykkishólmur. It is irrefutable that the sea ice was much more frequent at the coasts of Iceland in the eighteenth and nineteenth centuries than later (see Figure 3a b). Did the sea ice just enhance the effects of the "Little Ice Age" in Iceland, or is there no "Little Ice Age" signal there without the sea ice?

In a "normal" March, the temperature difference between the islands of Vestmannaeyjar off the south coast on the one hand, and Grímsey, a solitary island off the northern coast, on the other, is about 2.5 to 3.0°C. Figure 5 shows a time series plot of this temperature difference (gradient) in March 1878 to 1999. As clearly seen, the late 1960s are highly abnormal. These are the "Ice Years" mentioned above. The break in the time axis signifies a major relocation of the Vestmannaeyjar station in 1921, which involved a change in height above sea level of almost 110 m. A correction, -0.6°C, of the Vestmannaeyjar values prior to the relocation, is applied to the series as plotted. However, a simple comparison of values before and after the break is open to doubt. All the same, it is tempting to interpret the apparent trend throughout the period as a real one. The extreme gradient of March 1881 is not an error. The sea-ice cover was extensive. It is worth pointing out that the next two pre-1921 extreme differences occurred in the heavy ice months of March 1888 and 1902 (see Figure 3b).

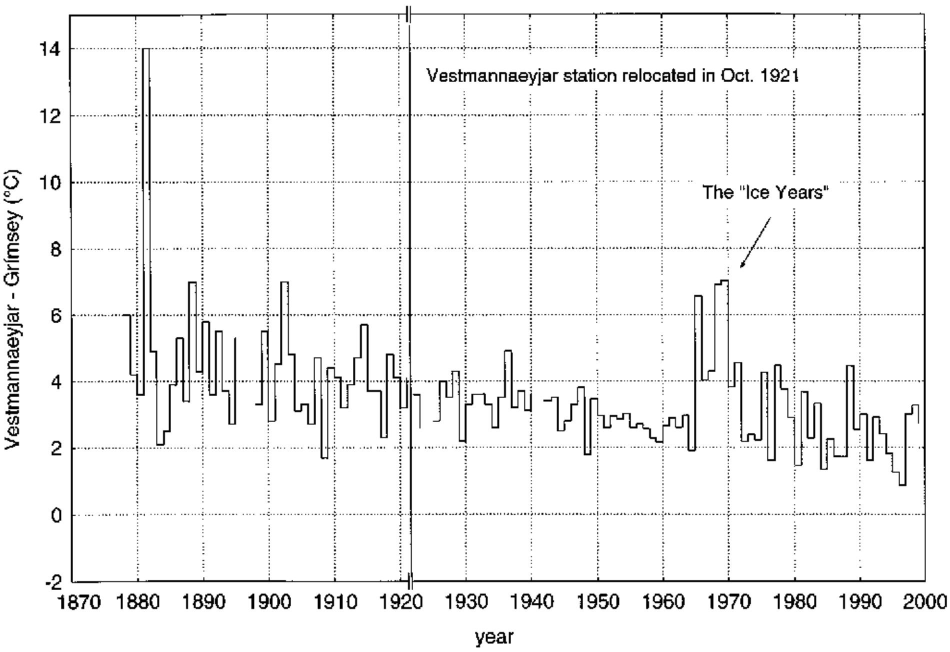



*Figure 5.* Vestmannaeyjar / Grímsey temperature gradient in March, 1878–1999. See text for explanation.

## 5.3. VERTICAL STABILITY AND THE "LITTLE ICE AGE"

The vertical stability of the atmosphere over the relatively warm ocean surrounding Iceland is at a minimum during the winter. During severe ice-years the stability at the northern and eastern coasts increases as the ice covers ocean surface areas that are usually open, and operate as heat sources. In this situation, the frequency of cold inversions (in the broad sense of the word) over the affected areas increases. The information exchange beween the near-surface layer and higher levels decreases. The convective activity associated with cold outbreaks over an open ocean diminishes in ice-affected areas, relative to the normal situation. "Normal" circulation/temperature relationships "fail". An example is seen in Figure 6, a scatterplot showing the Vestmanneyjar/Grímsey gradient introduced above, plotted against the difference of the average 500/1000hPa thickness along 70°N and 60°N between 10° and 30°W. (Thickness values from the NCEP dataset; Kalnay et al., 1996). As seen, the larger thickness gradients are usually ac-

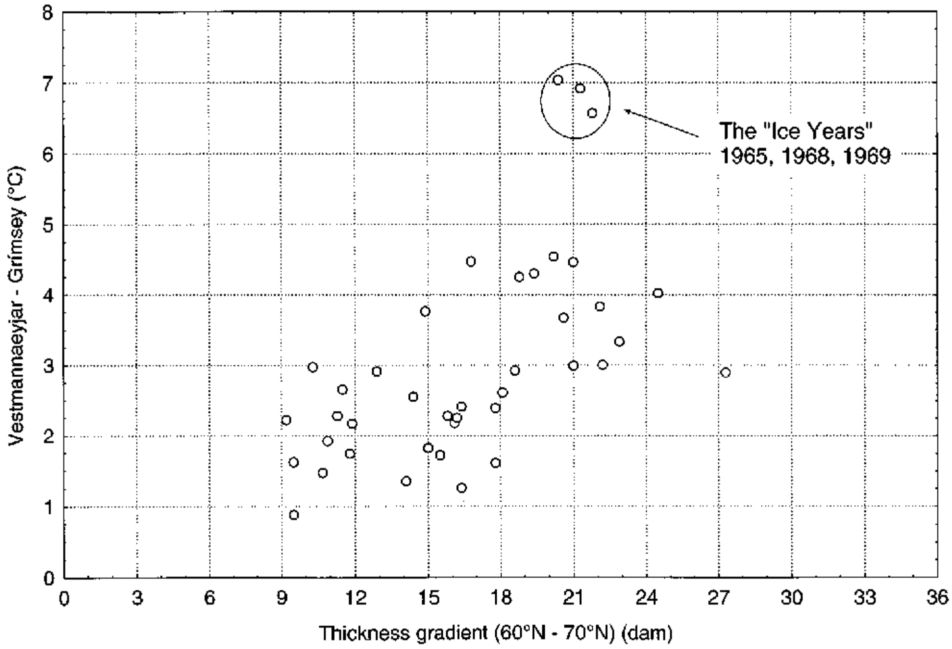



*Figure 6.* Vestmannaeyjar / Grímsey temperature gradient (vertical axis). NCEP 500/1000hPa thickness gradient between 60°N and 70°N averaged over the longitude interval 10°W to 30°W. Time period: 1958–1998. See text for explanation.

companied by a relatively large Vestmannaeyjar/Grímsey gradient. The group far outside the "cloud" consists of the three heavy-ice March months of 1965, 1968 and 1969. The surface gradient is in this case 2-4°C larger than expected during a month with a similar thicknes gradient during an open ocean situation.

This implies that it is not to be expected that the Summit area of Greenland (3000 m a.s.l.) gets the same message about the Icelandic climate during an ice maximum as at a minimum. The presence of the ice thus enhances cold anomalies in the lowest layers of the troposphere relative to the upper ones, at least during the 1960s ice episode. Figure 5 seems to imply that the southern/northern Iceland temperature gradient was influenced in a similar manner during the ice years prior to 1920, and these earlier occurrences were also characterised by the relative intensification of low-level negative temperature anomalies.

It is possible to split cold signals in the Iceland/southern Greenland area into two components. On the one hand, there is a deep tropospheric cooling, involving the whole troposphere down to the surface. On the other, is a low-level (shallow) cold anomaly associated with "anomalous" extensions of the sea ice or low oceanic surface temperatures. It is highly likely that both components are operating. The weight of each component is open to speculation. The sea-ice enhanced negative anomalies present in the Icelandic temperature record seem to indicate that the low-level component is considerable in that particular area. If this is the case, one would expect a smaller "Little Ice Age" signal in the highest level ice cores than at sea level, as the latter experiences both types of cold anomalies, while the former only one. One should also expect a "non-stationarity" of relationships between general tropospheric variables (circulation) and surface temperature records if this two-type-anomaly hypothesis is valid. The hypothesis is probably testable, but in the next few years it is more likely that the evidence will remain circumstantial rather than conclusive. It is appropriate at this point to recall the amplitude difference of the Dye and GRIP borehole temperatures mentioned above (Dahl-Jensen et al., 1998). This difference has not been explained in a satisfactory manner, but it supports the notion of the low-level conceptual model introduced above.

## 6. Perspectives from the Present Volume

The papers in this special issue of *Climatic Change* are drawn from a number of different subject areas within paleoclimatic research. What we have categorized as: "Palaeoclimatic Data Analyses" are the papers by: J. M. Grove; A. T. Grove; Jennings et al.,; Barlow; Buckland and Wagner; and Kirkbride and Dugmore. Papers focusing on "Early Instrumental Observations" are by: Jónsson and Garðarsson; Nordli; and Tarand and Nordli. The paper of Jacobeit et al., comes under the general heading of "Synoptic Climatology". A "Human Dimensions" section is represented by the paper by Vasey. Some of these studies face the question of the meaning of the term "Little Ice Age" directly. Others focus on issues other than a specific definition of the term, and allude to it in varying terms, from clear and precise to oblique.

The paper by J. M. Grove 'The initiation of the "Little Ice Age" In Regions Round the North Atlantic' clearly shows that the late-thirteenth century, and fourteenth-century glacier advances, were of a similar magnitude as later advances that have earlier been used as a definition of the "Little Ice Age" period. She is also quite specific on the definition of the "Little Ice Age" stating: 'The term "Little Ice Age" does not refer directly to climate, but to the most recent period during which glaciers extended globally, and remained enlarged, while their fronts fluctuated about more forward positions'. She also notes that the timing attributed to the "Little Ice Age" 'has varied considerably from author to author, perhaps reflecting real regional differences. However, this lack of agreement could be due in part to the uneven distribution and character of the evidence available, to the dating techniques used, and their resolution, and possibly to differing degrees of effort devoted to unravelling glacial history.' As regards the time frame of the "Little Ice Age", she concludes: 'It is evidently reasonable to view the whole period between the start of expansion in the thirteenth century and the great retreat of the late nineteenth and twentieth centuries as one complex "Little Ice Age", with each century-scale fluctuation itself made up of smaller scale oscillations...'. Furthermore, 'In all the regions around the North Atlantic, physical evidence of pre-sixteenth century glacial advances has been identified...General glacial advances took place in the North Atlantic region in the thirteenth and fourteenth centuries' (J. M. Grove, this volume).

The paper by Barlow 'The Time Period AD 1400-1980 in Central Greenland Ice Cores in Relation to the North Atlantic Sector' considers the Greenland isotope record and the absence of a persistent multi-century signal in the ice cores during the 'traditional' "Little Ice Age" time period. This apparent discrepancy between the signals from Greenland and Europe is mainly attributed to the large weight of the NAO governed Europe/Greenland temperature seesaw in the synoptic climate of the area. The paper shows a fairly good connection with temperature variations in Iceland on one hand, and the Greenland isotope record on the other.

The results of the Jennings et al., paper 'Oceanographic Change and Terrestrial Human Impacts in a Post AD 1400 Sediment Record from the Southwest Iceland Shelf' throws new light on a point that has already been made by Ogilvie (1992). A scrutiny of Icelandic historical sources seems to indicate that the sea ice visited the coasts of Iceland more frequently in the eighteenth than in the seventeenth century and there was indeed a difference between the two centuries. As stated above, the general view has been that the period 1600-1900 was more or less uniformly bad in Iceland, except for a few short and insignificant warm spells. It is of course not unlikely that the increased frequency of sea ice is at least partly a consequence of increased data density. However, the core data analysed by Jennings et al., indeed indicate accelerated environmental degradation at approximately the same time as the apparent sea-ice frequency increased. As the authors clearly point out, however, it is difficult to separate entirely the climatic effect on the environment from the impact of humans. Nevertheless, the potential of shallow shelf cores as a tool in late Holocene research is very clear.

In their paper 'Can Lichenometry be used to Date the "Little Ice Age" Glacial Maximum in Iceland?' Kirkbride and Dugmore question the use of lichenometry as an absolute dating tool. They present evidence for the method's underestimation of the age of late "Little Ice Age" landforms in southern Iceland, and conclude that it is evident that many of the small outlet glaciers there were at their maximum "Little Ice Age" extension in the mid-eighteenth century (or even earlier), rather than a century later. The evidence thus supports the notion of a complicated glaciation history of the last few centuries in Iceland.

The use of ice break-up and other data, cereal growing, and changes in the insect fauna, as proxies for climatic changes, are the subjects of the papers by Tarand and Nordli, Nordli, and Buckland and Wagner, respectively. The paper by

Tarand and Nordli, 'The Tallinn Temperature Series Reconstructed Back Half a Millennium By Use of Proxy Data' deals with the use of three different climate proxies: i) ice break-up in the port of Tallinn as a proxy for mean winter temperature; ii) ice break-up on the rivers in northern Estonia as a proxy for the beginning of spring; and iii) the first day of the rye harvest as a proxy for spring and summer temperatures. On the basis of these, the mean winter temperature could be extended back to AD 1500, and the spring and summer temperature to 1706. From the late-eighteenth century, the records document an overall warming trend in both seasons. In his paper, 'Reconstruction of Nineteenth Century Summer Temperatures in Norway by Proxy Data from Farmers' Diaries', Nordli demonstrates how good records of cereal harvesting can be used for quality checking and adjustment of early instrumental temperature records. 'Huge inhomogeneities of the "classical" Trondheim series were detected' (quotation from the abstract). The potential of using such records for the estimation of temperatures prior to the advent of instrumentation is emphasised. Discussing the period from the early to the late-nineteenth century, Nordli concludes that 'the summer temperature during the last part of the "Little Ice Age" was low compared with the climate in the twentieth century. The use of insect assemblages as a climatic indicator within the "Little Ice Age" time period is discussed in the paper by Buckland and Wagner, 'Is There an Insect Signal for the "Little Ice Age"?' The difficulty of discriminating between "natural" causes and human impact is emphasized by the authors, and they point out that a site that has not been perturbed by human interference throughout the last two millennia has yet to be found. Buckland and Wagner conclude that, in spite of this, 'the downturn in temperature in the late medieval period is likely to have had a 'significant impact upon insect distribution' and that: 'To the question posed as the title to this paper...the answer has to be a guarded, "Yes, probably" '.

Alluvial sedimentation in Mediterranean Europe during the Holocene is the subject of the paper by A. T. Grove, 'The "Little Ice Age" and its Geomorphological Consequences in Mediterranean Europe'. Concurring with J. M. Grove, the author states that: 'The "Little Ice Age" is best defined as being the interval within the second millennium A.D. during which glaciers extended further down their valleys than in the twentieth century.' According to A. T. Grove, much previous research has concluded that rapid sedimentation in river valleys and deltas in medieval and early modern times may be attributed to soil erosion. This erosion, in turn, is the result of human activity, particularly in the form of agricultural expansion and deforestation. However, A. T. Grove argues that: 'climatic extremes, especially a greater frequency of deluges, possibly associated with "Little Ice Age" advances, were more important than is usually recognized.' He thus concludes that the climatic conditions that induced the "Little Ice Age" glacier advances also were responsible for an increase in flooding frequency and sedimentation rate during the same time period. Similar earlier events could explain the formation of the so-called "younger fill" fluvial terraces in the area.

Noting that there 'appears to be a link between glacier advances and some types of extreme weather close by in the Mediterranean' he concludes that if climatic variations are responsible then: 'Rarely does it seem necessary to invoke forest clearance, the spread of agriculture, or the abandonment of land to explain the sedimentary features'.

So-called "non-stationarity" is emerging as one of the more acute problems facing climate researchers. It is becoming clear that relationships between climatic variables that have appeared to be both robust and simple in recent decades are not so strong in the long run. The paper of Jacobeit et al., 'Zonal indices for Europe 1780-1995 and running correlations with temperature' focuses on the non-stationarity of the relationship between two zonal indices on the one hand, and the temperature in Europe on the other, during the period 1780 to 1995. A major shift in circulation-temperature relationships is identified for both winter and summer conditions. It is suggested that the period 1850 to 1870 indicates a transition period in which circulation modes change from the "Little Ice Age" to the present climate of Europe. The paper underlines the value of early instrumental records in the analysis of the climate of recent centuries and the quest for its origins.

The paper by Jónsson and Garðarsson concerns 'Early instrumental meteorological observations in Iceland'. A substantial part of these early data has been digitized, and the Icelandic instrumental record is thereby extended back to the 1770s. This article focuses on the available sources rather than a climate analysis; however, the authors note that the eighteenth and nineteenth centuries appear to have been difficult climatically, with lower temperatures and heavier sea-ice incidence than experienced in this area in the twentieth century. Milder periods were found, though. Furthermore, it seems likely that the seasonal variation of temperature was somewhat larger than the present day, and the temperature gradient between southern and northern Iceland during winter was also larger than now. This research provides a solid basis for a further close study and comparison of both documentary and instrumental data from the period around 1770 onwards (Jónsson and Ogilvie, in preparation).

The final paper in this special issue is by Vasey, and focuses on the "human dimensions" aspects of climatic and environmental impacts in Iceland. Entitled 'A quantitative assessment of buffers among temperature variations, livestock, and the human population of Iceland, 1784 to 1900' the paper gives a modern analysis of issues that occupied Hannes Finnsson and other early researchers. Rather than focus purely on potential impacts of climate on the populace, Vasey discusses the buffers that were in place within the food chain to prevent hunger and malnutrition. He concludes that available buffers were, in fact, large, in spite of the marginal nature of the farming economy, and the relative poverty of the inhabitants.

## 7. Conclusions

Knowledge concerning climatic variability during the Holocene is rapidly advancing. As J. M. Grove and others note, it has become clear that the "Little Ice Age" (in its strict "glacial" sense) was not a unique event. Several phases of glacial expansion during the Holocene comparable in scale with those noted during the last millennium have been traced in both the Swiss and Austrian Alps (J. M. Grove, 1996, this volume, and references cited therein). Discussing a broader viewpoint, encompassing also a temperature signal, J. M. Grove's suggestion is reinforced by Kreutz et al., (1997, and references cited therein) who state that it now appears that 'several LIA-type events have occurred throughout the Holocene and that relatively minor forcings may be responsible for these events' (p. 1294). From another type of (marine-based) palaeoclimate proxy, evidence is accumulating for a semi-regular variation in the deposition of debris carried by ice into areas south of the modern ice edge (Bond et al., 1997). The so-called Ice-rafted-debris-cycle (IRD) is typically 1500 years long. It is interesting that this period is close to the Pettersson 1800-year tidal cycle mentioned above (Pettersson, 1914; Keeling and Whorf, 2000). Evidence for the linkage of the IRD to subtleties in the global thermohaline circulation is compelling (Broecker et al., 1999). Bond et al., (1997) suggest that the "Little Ice Age" is 'the most recent cold phase in the series of millennial-scale fluctuations' (p. 1264).

One of the grave difficulties regarding the "Little Ice Age" concept is that it has been (and is being) used to describe not just local, but also regional and hemispheric conditions. On the hemispheric scale, it is evident (see e.g. Jones et al., 1998; Mann et al., 1999; Briffa, 2000; and Crowley, 2000) that the temperature during the centuries preceding the twentieth were slightly lower than earlier in the period. However, there is no consensus on the nature of the cooling; it can be interpreted either as a slow "ramp" cooling or a period consisting of a few steps, each characterized by more uniform conditions. These steps are so small, however, that their significance is easily contested. On the regional scale, the overall picture tends to dissolve in details of variability. Although on this scale, it is possible in many cases to label certain cold periods as the starting dates of a "Little Ice Age", different proxy records tend to support different dates at different places (even at close locations). For these reasons, the tendency to implicate the "Little Ice Age" in any apparent perturbation in a climate or proxy variable during the last millennium, has, in the view of the present authors, been taken to the extreme, not least because it confers a one-dimensional view of climate variability. It is not to be denied that the appellation "Little Ice Age" is an evocative one, far more so certainly than, for example, "Ice rafting debris episode" (see above) and, because of this, if for no other reason, it may well continue to be used.

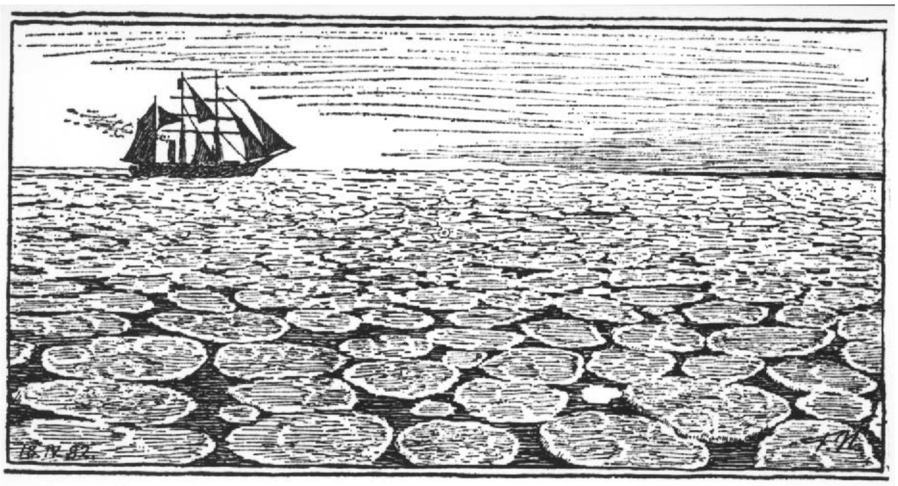
Regarding the North Atlantic region, the greater part of the evidence continues to support the notion that the general climate during ca. 1250 to ca. 1900 was at least slightly colder than the twentieth century overall. Conditions in this part of the world have, as we have seen, considerably contributed to the emergence and maintenance of the "Little Ice Age" concept. As described above, the large early-twentieth century warming greatly facilitated the acceptance of the concept in Iceland as well as in the Nordic region. With this perspective, the "Little Ice Age" had surely ended. However, it could be argued that it then set in again. The intensity of the late-twentieth century cold period in the Iceland/southern Greenland area seems to be generally under-appreciated. Just as the early-twentieth century warm period had the effect of focusing the perception of a "Little Ice Age" in Iceland, the subsequent cold period had the effect of blurring it. As background to this point, it may be noted, that the decadal-scale temperature variability during the instrumental era has been large in Iceland and Greenland. Certainly, the concept of an uninterrupted cold period stretches credibility, as this would imply that the decadal variance was suppressed during this time. However, as mentioned above (section 5.1), the year-to-year variability in Iceland was largest in the coldest part of the instrumental record. This merely serves to underline the need to carefully consider the meaning of "variability" as an attribute of climate (see e.g., Wigley and Raper, 1995).

The recent millennial temperature reconstructions (see e.g., Jones et al., 1998; Mann et al., 1999; Briffa, 2000; and Crowley, 2000) all show a marked warming during the last 150 to 200 years. The evidence for a change in radiative forcing due to accumulation of greenhouse gases is persuasive. The astronomical forcing proposed by Mann et al. (1999); the thermohaline variability suggested by Broecker et al. (1999) and the somewhat more complex model of Crowley do not contradict, but rather complement each other, and, along with the other multi-proxy reconstructions mentioned above, would appear to be ushering in a new era in historical climatology. Nevertheless, there is no room for complacency, as a number of issues still require attention. The most serious of these concerns the association between the instrumental temperature record and the proxy indicators (see e.g. Wigley and Raper, 1995). It is unfortunate that potentially disruptive (in the records) anthropogenic influences (for example, the land-use changes noted by Skinner and Majorewicz, 1999; Crowley, 2000; Mann, 2000; and the indirect fertilization of trees noted in Briffa, 2000) commences at about the same time as systematic temperature measurements. During the last 20 years or so, great effort has been expended on purging similar effects (urban warming, screen changes etc.) from the instrumental temperature record (see Jones et al., 1999, and references cited therein). The proxy world is clearly ripe for an analogous sanitising action. Non-stationarities of relationships suggest that there is a missing piece in the jigsaw (see chapter 5 above). It is also worth noting that when multiproxies on the large scale have been calibrated to instrumentally-measured temperatures, they have, on the whole, mainly been calibrated to rising temperatures; a cooling might show a different response.

The tale of the fall of "uniformitarianism" as outlined in section 4 above is a cautionary one, illustrating as it does how the view on the present tends to influence the perception of the past. At the present moment, a unanimous definition of the "Little Ice Age" remains as elusive as ever. The elegant solution of J. M. Grove (the "Little Ice Age" as an exclusively glacial phenomenon) is no longer a practical option. The term has already escaped its confinement. As a name for a relatively small general hemispheric scale temperature excursion it is marginally acceptable. Used in the plural as in a "Little Ice Age" event (Wigley and Raper, 1995) it may also be acceptable. However, as an indiscriminate label of every cold, dry, wet or stormy period during the last 800 years it is to be avoided. The preference of the present authors would be to see it disappear from use.

It is certainly the case that recent work has brought us closer to a partial solution, namely, finding linkages between, or common causes for, the numerous phenomena that are seen as evidence for a "Little Ice Age". An appropriate strategy for future research is a continuing quest for the discovery of further historical sources as well as the addition and elaboration of new proxy data in the coming years. At the same time, climate researchers should continue to seek to chart the climate of the past thousand years with a fresh approach rather than attempting to fit their findings into the convenient straightjacket of those hackneyed labels, the "Medieval Warm Period" and the "Little Ice Age".

To return, in concluding, to our Icelandic perspective; it may be noted again, that the task of assessing the climate signal in the environmental history of Iceland is particularly problematic. The impact of the settlement of Iceland and subsequent resource depletion easily dwarfs most signals of a climatic origin, except for changes in the glaciers. A discussion of the impact of climate on the population of Iceland has been beyond the scope of this article. However, it is appropriate to recall again the words of Þorvaldur Thoroddsen: 'The sea ice...has done more harm to the Icelandic population than all the volcanic eruptions and earthquakes' (Thoroddsen, 1914, p. 205) and to remember the effects of a sometimes difficult climate on the populace. The picture shown in Figure 7 is a sketch by Fridtjof Nansen made in the year 1882 showing a fine example of "pancake" ice. In Icelandic terminology, although a similar word is used to describe this type of ice formation, a very different term also refers to it as "plates of hunger". In seeking to unravel the meaning of the term "Little Ice Age", the present authors question the use of the term when it is used without precise definition; however, this is not to deny the reality of the numerous oscillations in climate over the past thousand years, or the difficulties often experienced by the Icelandic populace, if not during long "ice ages" but, most certainly, during "ice years".



Íslummur („hungur-diskar"). 18. apríl 1882.

*Figure 7.* "Hunger plates" (pancake ice). A drawing made by Fridtjof Nansen on 18 April, 1882, during his first visit to the Arctic. The drawing is from the book on his travels during the year 1882 (Nansen, 1967).

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