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The Little Ice Age

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Introduction

The so-called Little Ice Age of the 15th to 19th Centuries is a fascinating period of time, for many reasons. Extensive reading of the literature on the topic can reveal the following: (1) in many (but not all) proxy-climate reconstructions, it is shown as having a fast and strong onset (O'Brien et al., 1995), exceeded in the Holocene perhaps only by the 8.2ka event (Mayewski et al., 2004); (2) it includes evidence for glacier re-advance—in northern Europe, particularly, to positions not otherwise (or seldom) reached within the Mid–Late Holocene (Matthews and Shakesby, 1984; McCarroll, 1991); (3) it follows the Medieval Climate Anomaly and precedes the period of recent 'Global Warming', and therefore it post-dates the Medieval Solar Maximum, encompasses up to three solar minima (Spörer, Maunder and Dalton) (Grove 1988), and precedes the 'Contemporary' (viz. Late-20th Century) Solar Maximum (Hoyt and Schatten, 1997; Pan and Yau, 2002); (4) there are multiple hypotheses as to the cause of its onset (cf. Miller et al., 2012), although it is widely considered that reduced solar activity is the cause of at least its most intense phases (cf. Mauquoy et al., 2002); (5) there are differing views as to the magnitude of the depression of global temperature (e.g. IPCC, 1995, Fig. 3.20; Mann, 2002; Soon and Baliunas, 2003; IPCC, 2013; Figs. 5.7, 5.8); indeed (6) comparison of individual reconstructions of Northern Hemisphere temperatures with the Intergovernmental Panel on Climate Change's earlier somewhat muted successive summary curves shows considerable difference (compare IPCC, 2001: Figs 2.20, 2.21; IPCC, 2007: Fig. 6.10, also Box 6.4, Fig 1); (7) it had previously been thought that its expression was *not* influenced by human activity, whereas the 'plague' claim in the 'early anthropogenic' hypothesis of Ruddiman (2003) implies otherwise; (8) it largely precedes what some have viewed and attempted to define as a new epoch, representing evidence of widespread human influence on global systems: the so-called Anthropocene (Crutzen and Stoermer, 2000; Zalasiewicz et al., 2015)); (9) its effects upon some human societies appear to have been profound in particular regions of the world, notably in Greenland (Ribeiro et al., 2012), Norway (Lamb, 1995) and the Alps (Le Roy Ladurie, 1971); and yet (11) its very existence as a coherent, globally climatically defined period has been questioned (compare Mann et al., 1999 with Goosse et al. 2005); although (12) recent work implies an in-phase relationship between the Southern and Northern Hemispheres (Simms et al., 2012; Chambers et al., 2014).

The Little Ice Age is a period for which, at the start, documentary and observational information is relatively sparse and localised, but by the close there is increasing availability of documentary, observational and direct instrumental meteorological records from many parts (though not all) of the globe.

From a scientific and cultural viewpoint, the Little Ice Age is of particular interest because, temporally, it sits between the so-called Medieval Climate Anomaly and the contemporary 'Anthropocene'; it includes the commencement both of continuous instrumental meteorological records and of reliable scientific observation and recording of sunspots; and (in its later part) encompasses the initial period of industrialization in parts of the northern hemisphere, with a concomitant commencement of a sustained increase in emissions of carbon dioxide and methane to atmosphere.

Selected papers

It is entirely appropriate that *The Holocene* journal, which focuses on recent environmental change, has published a large number of papers that either focus on or refer specifically to the Little Ice Age. In this virtual issue, a selection has been made that demonstrates geographical spread, a diversity of proxy-climate archives, and a range of techniques that can be used to extract a climate signal from these archives.

This selection of papers includes proxy-climate data from five continents: North America, from Alaska (Wiles et al., 1999), Canada (Johnston et al., 2010); South America, from Chile (Araneda et al. 2009), Argentina (Chambers et al., 2014); Europe, from Britain (Harrison et al., 2014) and Spain (Garcia-Ruiz et al., 2014); Asia, from China (Chen et al., 2005; Liu et al., 2011); Australasia, from New Zealand (Winkler, 2004); and the ocean, from the Alboran Sea (Nieto-Moreno et al., 2013)

It includes proxy-climate data from a range of archives: aeolian sand (Liu et al., 2011); documentary sources (Araneda et al., 2009); lake (Chen et al., 2005; Johnston et al., 2010); marine records (Nieto-Moreno et al., 2013); mire (Chambers et al., 2014); tree-rings (Wiles et al., 1999). It deals with LIA temperatures (Nesje and Dahl, 2003); hydrology (Nesje and Dahl, 2003; Johnston et al., 2010; Liu et al, 2011; Nieto-Moreno et al., 2013; Chambers et al., 2014); glacier activity (Wiles et al., 1999; Winkler, 2004; Araneda et al. 2009; Garcia-Ruiz et al., 2014; Harrison et al., 2014); and with inter-hemispheric comparison (Chambers et a l., 2014).

Proxy-climate evidence is provided from analysis of plant macrofossils and peat humification (Chambers et a l., 2014), dendroclimatology (Wiles et al., 1999), lake-sediment chemistry (Chen et al., 2005) and marine sediments (Nieto-Moreno et al., 2013); lake-level variation is derived from palaeolimnology and geophysical analyses (Johnston et al., 2010); glacier limits are reconstructed from geomorphology (Garcia-Ruiz et al., 2014), tree-ring data (Wiles et al., 1999), lichenometry (Winkler, 2004) and inferred from documentary records (Araneda et al. 2009) and glacier modelling (Harrison et al., 2014).

Summaries of the individual papers

In the most recently published of the selections, Chambers et al. (2014) compare proxy-climate records from a mire in Tierra del Fuego with those derived using identical methods in continental north-central Europe, and find that the hydrological response of the South American mire in the most extreme phases of the Little Ice Age is similar to that at 2800 cal. BP when the mire became unusually dry—an opposite response to that recorded from Europe. The timing of the dry phases in South America appears to match that of the most extreme phases of the LIA in Europe, and is attributed to equatorward movement of moisture-bearing winds, possibly caused by reduced solar activity.

Garcia-Ruiz et al. (2014) investigated Holocene and 'Little Ice Age' glacial activity in the Marboré Cirque in the Central Spanish Pyrenees. They detected two separate glacial pulses within the LIA, the first probably being in the Maunder Minimum (late 17th or early 18th century), whereas the second took place between AD 1790 and 1830 (close to the Dalton Minimum); these pulses followed melting during the Medieval Climate Anomaly, and the two were separated by a glacial retreat.

Harrison et al. (2014) used a glacier-climate model, fuelled by data from local weather stations, to argue that the *last* glacier ice in Cairngorm, Scotland was in the LIA, and not over ten thousand years earlier in the Younger Dryas, as hitherto widely assumed. Evidence from boulder moraines is adduced in support of the contention. It is argued that the last glacier ice that existed elsewhere in upland Britain may also relate to the LIA.

Nieto-Moreno et al. (2013) analysed two deep-sea marine cores from the Mediterranean to investigate the time period from the Medieval Climate Anomaly, through the LIA and up to the late 20th Century. While inferred dry periods characterised the MCA and late 20th century, the LIA presented as a more humid phase, but "developed as a sequence of successive short and abrupt dry–humid phase alternation" (Nieto-Moreno et al., 2013: 1227).

Liu et al. (2011) analysed carbon isotopes from plant leaves in a 10.5 m aeolian section in northwestern China, finding large negative isotope excursions during the LIA, implying a wetter climate. This is interpreted as indicating regional hydrological changes associated with "possible changes in the trajectory or strength of the westerlies and/or the orographic effect in this region" (Liu et al., 2011: 409).

Johnston et al. (2010) examined a barrier-beach complex using multi-proxy palaeolimnological analyses combined with geophysical examination using ground-penetrating radar to investigate the former lake levels of Lake Athabasca, Canada. Interpretation of the data suggested that the lake level was, on average, some 2.3 m higher than present during the LIA, implying that the surrounding landscape of the Peace-Athabasca delta had, until recently, been flooded frequently.

Araneda et al. (2009) used documentary sources, including written records, maps, photographs and iconography to reconstruct the limits of the Cipreses Glacier, Chile. The authors infer that the last advance of the glacier in the LIA was c. AD 1842, and was in retreat from AD 1858 and subsequently. These data are compared with evidence from the San Rafael glacier, which reached its most recent maximum extent between AD 1857 and 1875. The 30-year discrepancy between the responses of the two glaciers is attributed to temperature and precipitation changes thought mainly associated with fluctuations in the Westerlies.

Chen et al. (2005) used principal components analysis on 21 elements in their examination of the sediment chemistry of Lake Erhai, southwest China, and found three controlling factors: (1) physical erosion in the catchment; (2) autochthonous precipitation of calcite; (3) early digenesis in sediment. The LIA was characterised by low factor (3) and high (1), implying a cool-wet climate from AD 1550 to 1890, which the authors linked to the timing of the LIA in Europe; this contrasted with high factor

(3) and low (1) around Lake Erhai from AD 1340–1550 and AD 1890–1950, implying warm-dry episodes.

Winkler (2004) used lichenometric dating of moraines of four glaciers in the Mt Cook National Park, New Zealand, to detect the maximum extent of glaciers in the LIA, which was revealed as c. AD 1725–1740. Subsequent retreat of the four glaciers has been followed by readvances in the late 19th and early 20th centuries, and one of the glaciers (Tasman) has since reached its 18th century LIA maximum.

Nesje and Dahl (2003) challenged the simplistic view that the LIA was primarily about temperature changes by presenting data from southern Norway to show that rapid glacier advance there in the early 18th century was mainly a result of increased winter precipitation in mild, wet winters and not just lower summer temperatures. They compared LIA glacier fluctuations in southern Norway with those of the European Alps, and suggested that asynchronous 'Little Ice Age' maxima between the two regions may be related to trends in the North Atlantic Oscillation dipole pattern.

Wiles et al. (1999) conducted tree-ring studies on 13 glacier forefields in western Prince Edward Sound, Alaska. Cross-dated sequences from eight sites indicated synchronous glacial advances (on decadal timescales) in the early LIA of late 12th to 13th centuries), and again in the mid-LIA of the 17th to early 18th centuries, while 9 sites suggested a further advance in the late 19th century. The data compared well with studies of other glaciers in the region, allowing the structure of LIA glacier fluctuations to be discerned.

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