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The 'Little Ice Age' in the Southern Hemisphere in the context of the last 3000 years: peat-based proxy-climate data from Tierra del Fuego

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Complete List of Authors:	Chambers, Frank; University of Gloucestershire, Centre for Environmental Change and Quaternary Research, School of Natural and Social Sciences Brain, Sally; University of Gloucestershire, Centre for Environmental Change and Quaternary Research, School of Natural and Social Sciences Mauquoy, Dmitri; University of Aberdeen, School of Geosciences McCarroll, Julia; University of Gloucestershire, Centre for Environmental Change and Quaternary Research, School of Natural and Social Sciences Daley, Tim; University of Plymouth, Institute for Sustainability Solutions Research
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The 'Little Ice Age' in the Southern Hemisphere in the context of the last 3000 years: peat-based proxy-climate data from Tierra del Fuego

Frank M. Chambers[1], Sally A. Brain[1], Dmitri Mauquoy[2], Julia McCarroll[1] and Tim Daley[3]

[1]Centre for Environmental Change and Quaternary Research, School of Natural and Social Sciences, University of Gloucestershire, Francis Close Hall, Swindon Rd, Cheltenham GL50 4AZ, United Kingdom

[2] School of Geosciences, University of Aberdeen, Elphinstone Road, Aberdeen AB24 3UF, United Kingdom

[3]Institute for Sustainability Solutions Research, A522, Portland Square, Plymouth University, Drake Circus, Plymouth PL4 8AA, United Kingdom

Abstract

The so-called ‘Little Ice Age’ (LIA) of *c*. the 15th to 19th centuries AD is well-attested from much of Europe and from some other parts of the Northern Hemisphere. It has been attributed to solar forcing, associated with reduced solar activity, notably during the Spörer, Maunder and Dalton solar minima, although other causes have also been proposed and feature strongly in recent papers. Detection of the LIA in some proxy-climate records from the Southern Hemisphere is less clear, leading to suggestions that the LIA was perhaps not a global phenomenon. Resolving this issue requires more data from the Southern Hemisphere. We present proxy-climate data (plant macrofossils; peat humification) covering the past three millennia from an ombrotrophic mire (peat bog) in Tierra del Fuego, southern South America, but focus our discussion on the period traditionally associated with the LIA. During parts of this time the mire surface was apparently relatively dry compared with much of its 3000-year record. It was reported earlier that a particularly dry episode in the mire coincided with the 2800 cal. BP ‘solar’ event (since identified as a Grand Solar Minimum), which was attributed to solar-driven changes in atmospheric circulation, and more specifically to a shift in position of the Westerlies. Parts of the LIA record show a similar shift to dryness, and we invoke a similar cause. The shifts to and from dry episodes are abrupt. These new data support the concept of a global LIA, and for at least the intense dry episodes might reinforce the claim for solar forcing of parts of the LIA climate.

Keywords: Little Ice Age; proxy-climate data; Tierra del Fuego; solar forcing; peat humification; *Sphagnum*

Introduction

While the timing of its onset varies both geographically and between archives, the so-called ‘Little Ice Age’ (LIA) from the 15th to 19th centuries AD has long been characterised in Europe as a period of advancing glaciers (Le Roi Ladurie, 1971), relatively cold winters (Grove, 1988) and, at times, failing harvests (Lamb, 1995). Often characterised as having intensely cold winters in Northwest Europe under anticyclonic conditions, the late autumn/winter weather in the LIA was much more varied than this and included a particularly severe storm event in England in late November AD 1703, classically reported by Defoe (1704).

With glaciers in Southern Norway reaching their maximum Holocene extent variously from the early 18th to the late 19th Century AD (Nesje, 2009), the LIA has long been regarded in Europe as the most severe prolonged downturn in climate warmth since the Late-glacial. However, it was not as deep as the centennial-scale downturn of the so-called 8.2 ka event of the early Holocene, which is now regarded as the most severe climate shift in the post-glacial (Kobashi et al., 2007; Daley et al., 2011). A pronounced putative global climate shift *c.* 2800 cal. BP (van Geel et al., 1996; Chambers et al., 2007) and a decade of relative coolness in the AD 540s, recorded especially in Europe but also elsewhere (Baillie 2001), are other candidates for the second-most severe downturn since the Late-glacial. In those instances, the inferred climate changes are abrupt, but short-lived. By contrast, the LIA is of much longer duration than any other inferred reduction in climate warmth during the Holocene, although the climate within the LIA was variable and was not uniformly colder, either temporally or geographically.

While proxy-climate data from individual sites show that the period from *c.* AD 1420 to *c.* AD 1850 was not cold continuously, it can be viewed as a multi-centennial period in which temperatures in the Northern Hemisphere were on average some 0.8°C lower than the 1961–90 reference period (Bradley and Jones, 1993; Mann et al., 1998; Mann, 2002), although some archival datasets imply far greater temperature reductions in specific locations (e.g. in northern Norway: Lauritzen and Lundberg, 1999). More recent examination of tree-ring data over the last millennium in northern Scandinavia by Esper et al. (2012) suggests some reappraisal of the magnitude of temperature changes is required.

In Europe and North America, a wide range of proxy-climate methods has been used to infer the climate over the LIA. Detection of the LIA elsewhere has been patchy. Mann (2002) reviewed some of this evidence, which was largely terrestrially based, and noted rather subdued cooler overall temperatures in eastern China, more pronounced cooling for a time in the tropical Andes and evidence of glacial advances in New Zealand, but that there were large regional variations (Jones and Mann, 2004). Indeed, subsequently, Schaeffer et al. (2009) reported glacier fluctuations in New Zealand that are not fully in accord with those in the Northern Hemisphere.

Whether the LIA can be regarded as a ‘global’ event has been disputed (compare, for example, views expressed in Jones et al., 2009; Rhodes et al., 2012). Part of the reason for caution is the paucity of LIA proxy-climate records from southern latitudes, which contrasts with the far greater concentration of proxy-climate studies of the LIA in the Northern Hemisphere. This is attributable in part to the large expanse of ocean compared with land in the Southern Hemisphere (SH), which restricts the availability of suitable SH terrestrial sites to provide land-based records. However, new data from the Antarctic Peninsula suggest the period of lowest ice melt and coolest temperatures in the last millennium was *c.* AD 1410 and 1460, “when mean temperature was 1.6°C lower than that of 1981–2000” (Abram et al., 2013, p. 404). Ocean-margin ice-core records point to significant LIA climate changes in the SH, averaging 1.6 ±1.4 °C cooler than during the last 150 years (Rhodes et al., 2012); these authors emphasise that other SH proxy-climate records are required to enrich the LIA database.

The depth, geographical extent and duration of the LIA has a bearing on expectations of future climate, because both the trajectory of recent climate changes and computer projections for future climate are made against a background of the proxy-climate of the past millennium (Mann et al., 1998; Mann, 2007) or past two millennia (e.g. Mann et al., 1999; 2008; IPCC, 2013), in which both the Medieval Climate Anomaly and LIA feature—more prominently in some reconstructions than in others (Mann et al., 2009; cf. Esper et al., 2012). The importance of being able to reconstruct climates of past recent millennia was stressed by McCarroll (2010, p. 1661), who stated: “The wider the range of climate parameters that can be reconstructed, and the wider the range of locations, the more constraint will be provided”.

Here, in this Research Report, we present proxy-climate data from a peat bog in Tierra del Fuego, southern South America, for the last 3000 years. The methods used to derive a proxy-climate record from this southerly site are identical to those that have been used widely in northern and central Europe and in parts of North America (Chambers et al., 2012) and for which a set of field and laboratory protocols has been established (De Vleeschouwer et al., 2010a). We focus our discussion on the period of time commonly associated with the LIA, and draw comparisons within the 3000-yr record, including a previously reported, particularly intense but short-lived climate shift in that record, dated to *c.* 2800 cal. BP (Chambers et al., 2007), which corresponded in time with one of opposite direction, reported from Europe (van Geel and Renssen, 1998). Our proxy-climate record is based largely on bog surface wetness (*sensu* Barber et al., 1994), rather than temperature. Although there may be a temperature component in the data, this is unlikely to be a major component at such southerly cool latitudes; indeed, on the basis of changes within the period of meteorological records it seems more likely that precipitation changes in response to variation in the Westerlies would have the strongest influence on bog surface wetness (Daley et al., 2012).

Our data can be seen in the context of claims made recently by Moreno et al. (2014, p.1) based on stratigraphic data from a lake in southwest Patagonia that there is "in-phase inter-hemispheric coupling of palaeoclimate over the last 3000 years through atmospheric teleconnections".

Study Site and Field Methods

The field location for analyses reported here is a *Sphagnum*-dominated raised mire, located *c.* 6 km north-east of Ushuaia, in the broad Andorra valley (Fig. 1), Southern Argentina. Details of the mire vegetation are provided in Mauquoy et al. (2004), in which results of pollen analysis on a separate core of peat were reported. The two-metre core of peat (labelled AND-2) for the present study was extracted later by DM using a series of 10×10×50 cm stainless steel boxes, hammered into a cleaned peat face exposed during the creation of ditches for peatland harvesting (De Vleeschouwer et al., 2010b), and sub-sampled into 1 cm slices, which were bagged and transported back to the UK, for laboratory analysis.

Laboratory Methods

Two standard methods were used for producing a proxy-climate record from peats: plant macrofossil analysis (Mauquoy et al., 2010), conducted by DM in Uppsala, and determination of peat humification (Blackford and Chambers, 1993), the latter method modified (as in Chambers et al., 2011) and conducted by SB at Cheltenham. Radiocarbon dates for the core were requested by FMC from the Natural Environment Research Council, UK, in two submissions: a rangefinder series that focused on major shifts in the peat humification data, followed by groups of samples that amplified the original rangefinder data (see Table 1), to facilitate possible wiggle-matching (van Geel and Mook, 1989; Piotrowska et al., 2011). With one exception (an Ericales macrofossil, close to the base of the core), all dates were carried out on *Sphagnum* leaf macrofossils, separated assiduously from the peat by SB, following the methods used in the Northern Hemisphere ACCROTELM project (Chambers, 2006). An attempt to date the upper part of the core by ^{210}Pb was unsuccessful, probably owing to low radon source in this region.

Initial deposition-rate curves were produced using a precursor of the 'Bacon' method of Blaauw and Christen (2011); limitations of this method for extrapolation when the basal age is unknown were exposed by initial lack of dating control beyond the base of the core, and so further samples were dated close to the base, to anchor the basal age by wiggle-matching. Dated samples in this basal-age wiggle match fitted the calibration curve very closely (Fig. 2; see also Fig. 3 in Chambers et al., 2007), and so permitted precise and accurate dating of the base of the sequence. The closely-spaced sets of radiocarbon dated samples at intervals along the core have ensured precision and accuracy in dating the proxy-climate records, except in the uppermost layers, for which the sampling date provides a topmost dating-anchor point.

Results

Proxy-climate data for the past 3000 years are presented in a composite diagram (Fig. 3), showing peat humification (expressed inversely as percentage light transmission) and the proportions of *Sphagnum* leaves and *Empetrum*/Ericaceae roots in plant macrofossils recorded from the mire.

These data show that for most of the past 3000 years the principal peat former has been *Sphagnum*, normally with over 70% and typically 75–95% of plant macrofossils being *Sphagnum* remains. Overwhelmingly, the dominant species has been *S. magellanicum*, with some 80 to 100% of the *Sphagnum* leaves attributable to this species. Owing to this dominance, it was not necessary to apply k-value corrections to the humification data (cf. Hughes et al., 2012). While original above-ground macrofossils (e.g. *Sphagnum* leaves) and below-surface remains (e.g. *Empetrum*/Ericaceae roots) in the same horizon may not be exactly contemporaneous, the latter are relatively shallow-rooted in ombrotrophic peats.

There are notable exceptions to the *Sphagnum* dominance: (i) a short-lived but pronounced episode *c.* 2800 cal. BP, in which *Sphagnum* leaves are below 30% of plant macrofossils, while *Empetrum*/Ericaceae macrofossils were more abundant at >50%; (ii) a short-lived episode *c.* 750 cal. BP (*c.* cal. AD 1200) in which total *Sphagnum* remains dip below 70%; and (iii) a longer period towards the top the core, estimated between 275 cal. BP and 200 cal. BP (i.e., cal. AD 1675 to cal. AD 1750) in which *Sphagnum* remains are below 50%, within which they twice dip below 10%, and over which *Empetrum*/Ericaceae remains are generally higher than for most of the time period covered by the core. In each of these low points in the *Sphagnum* curve, the light transmission data also dip.

Peat humification data from peat bogs often show an overall trend from higher humification values (i.e., lower light transmission) at the base to lower humification (or higher light transmission) towards the surface. Part of the reason for this is undecayed plant material in the upper peat layer (acrotelm), but the overall trend relates to continued slow decomposition over time in the catotelm below (Clymo 1984). Removal of that overall trend (Fig. 4) by linear regression reveals the low points in the light transmission curve, to be *c.* 2800 cal. BP, 1735–1710 cal BP, *c.* 950 cal. BP, *c.* 490 cal. BP and from 250–180 cal. BP. These are equivalent to *c.* 850 cal. BC, *c.* cal. AD 215–240, *c.* cal. AD 1000, *c.* cal. AD 1460 and *c.* cal. AD 1700–1770.

The ages cited above are based on the new calibration curve (Fig. 2) using the Bacon method of Blaauw and Christen (2011), with the estimated ages then rounded to the nearest 5 years.

Interpretation and Discussion

Plant Macrofossils

The overall plant macrofossil record for the past 3000 years, shown in Fig. 3, indicates a mire dominated by *Sphagnum magellanicum* for most this period, but with some short interludes in which the mire has increased proportions of *Empetrum*/Ericaceae when *Sphagnum* is less abundant. This general dominance of *S. magellanicum* for millennia is reminiscent of northwest European bogs in which *S. imbricatum* (syn. *S. austinii*) has overwhelming dominance as the major peat former. Interestingly, in parts of Northwest Europe, notably in Britain, *S. imbricatum* becomes extinct at many sites during the last millennium, possibly related to airborne eutrophication (McClymont et al., 2008); at many sites it is replaced by *S. magellanicum*, apparently occupying the same ecological niche, leading to its record being interpreted as having the same climate-indicator value in data analysis, with the data from the two species amalgamated (Barber et al., 1994). As *S. imbricatum* is a Northern Hemisphere species, it is not native to Patagonia. No major moss species change took place in this core, and so no species amalgamation has been necessary for interpreting the *Sphagnum* record.

The longest period in which the proportion of *Sphagnum* is lower, while *Empetrum*/Ericaceae remains are more abundant, though not as prominent as *c.* 2800 cal. BP, is that between *c.* cal. 275 and *c.* cal. 200 cal. BP (i.e., *c.* cal. AD 1675 to 1750). This period can therefore be regarded as a significant deviation from an overwhelming dominance by *Sphagnum magellanicum* during most of the past three millennia.

Peat Humification

There is generally close agreement in direction, if not in magnitude, between the plant macrofossil record of a generally wet site (indicated by high percentages of *Sphagnum* remains) interrupted by short, dry episodes (shown by lower *Sphagnum* values and increased representation of *Empetrum*/Ericaceae remains), and the light transmission data, which indicate a mainly wet bog surface (shown by values >40%) interposed by drier episodes (when values dip below 40%). The most extreme dry episode is short-lived, at *c.* 2800 cal. BP (reported by Chambers et al., 2007). A short dry episode is suggested subsequently at *c.* cal. AD 1460, while a longer dry episode is indicated *c.* cal. AD 1700–1770.

Combining the proxy-climate records

When the two proxy-climate records are combined, there is evidence mainly from a pronounced low in the light transmission curve for a dry episode at *c.* cal. AD 1460, while a combination of plant macrofossil and light transmission values suggests a particularly dry episode from *c.* cal. AD 1675 to *c.* cal. AD 1770, These data compare with those from Rhodes et al. (2012, p. 1223), who inferred from a coastal ice-core record in the Ross Sea, Antarctica, that there were “three 12–30 yr intervals of cooler temperatures” within the LIA, centred on AD 1690, 1770 and 1840. The time-period *c.* cal. AD 1675–1770 encompasses two of those three intervals, and noticeably has a somewhat less dry period in between. The overall time-period corresponds with the most severe climatic episodes within the LIA in terms of cold climate in Northwest Europe, matched only by the early 15th Century (Lamb, 1995).

Relationship to Solar Activity?

Short-term climate changes in the Holocene have been attributed to volcanism (Robock, 2000), changes in solar activity (Beer and van Geel, 2008) or other extra-terrestrial causes (Baillie 2007), whereas the Little Ice Age has in the past been attributed to reduced solar activity (Grove, 1988), notably around the Maunder (Eddy, 1976) and Dalton minima. However, other factors, including volcanism (Robock, 2000) and ocean circulation, are claimed to play a part (Mann 2002), while its onset has recently been claimed to be caused by four, large, sulphur-rich explosive eruptions in a 50-year period, and its continuance to be sustained by sea ice/ocean feedback “during a hemispheric insolation minimum” (Miller et al. 2012, p. 1), rather than requiring a reduction in solar activity. In contrast, Hunt (2006, p. 677) used only internal forcing in the CSIRO mark 2 coupled global climate model and concluded that both the ‘Medieval Warm Period’ (i.e. the MCA) and LIA could not be explained by natural (i.e., internal) processes, and that “external forcing must be involved”. This conclusion was earlier exemplified by Mauquoy et al. (2002; 2008), who used proxy-climate techniques on mires in Denmark and northern England, and identified solar-forcing signals during the Little Ice Age

It is notable that the dry episode we infer from the Valle de Andorra mire at *c.* cal. AD 1460 is between a putative start of the LIA at AD 1420, according to Lamb (1995), and the lowest point in the solar-activity Spörer Minimum (at AD 1490), while the dry episode of *c.* cal. AD 1675–1770 is very close to the Maunder Minimum of AD 1645 to AD 1715. Indeed, the period *c.* cal. AD 1675–1770 presents as the driest in this mire record since the inferred solar-driven ‘global’ climate change *c.* 2800 cal. BP (Chambers et al., 2007; see also van Geel et al., 1996).

Suck-in and Smear

The deposition-rate curve from this site (Fig.2) contains some of the best examples of wiggle-matched dates from peat sequences, but this tight chronology only serves to emphasise the lesser chronological control in recent centuries. Baillie (1991) cautioned archaeologists about the dangers of both ‘suck-in’—in which unrelated events, apparently closely dated in time, might be interpreted falsely as presenting evidence for a single event)—and ‘smear’, in which the dating of a single event at different sites may cover a wide dating range, owing to inaccuracy and/or imprecision in dating techniques. Interpretations made in the present study are subject to that cautionary advice. For example, although the dry period from *c.* AD 1675–1770 is close both in time and duration to that of the Maunder Minimum (AD 1645–1715), limitations of the method preclude more precise dating of the mire data, because the dating of the peat that accumulated during recent centuries is compromised by the acknowledged 'fuzziness' of the calibration (see Fig. 2) and the failure of ^{210}Pb dating at this site. Indeed, it is unfortunate that some other methods to help date the top of the core, which can be used in Europe (van der Plicht et al., 2013), could not be applied here. Nevertheless, the closeness of fit of the driest episodes in the mire with cold episodes noted elsewhere and with solar minima, is striking, even allowing for imprecision in calibrated ages (and therefore possible inaccuracy in dating) in this part of the core.

Relationship to previous work

In previous work at the Valle de Andorra bog, using climate proxies on a separate peat core, Mauquoy et al. (2004) did not find clear evidence for the LIA. However, this was under a prevailing mindset that expected the mire to respond in the same way as those in Northwest Europe—to show evidence of cooler, wetter conditions—and these were not evident. In this more recent detailed work, the opposite tendency is shown for the LIA. Mauquoy et al. (2004) identified two notably wet periods: from *c.* AD 1030–1100 and from *c.* AD 1800 to *c.* AD 1930. It is interesting to note that the former is close to the peak warmth of the Medieval Climate Anomaly (a time-period associated in Europe with warmer drier conditions and a relatively ice-free North Atlantic: Lamb, 1995), while the latter encompasses the global temperature recovery from the Little Ice Age and the warming trend in the early 20th Century (cf. Folland et al., 2002). Taken at face value, these data might imply that when conditions In Northwest Europe, and arguably also globally, become noticeably warmer, conditions in this South American mire become wetter. This is the counterpoint to the drier-than-normal episodes recorded in the present study during the LIA and from this same core at 2800 cal. BP. Even so, the same cautionary remarks concerning 'suck-in' must apply here, and this *post hoc* interpretation did not feature in the 2004 paper.

Large-scale controls on the Patagonian climate have been explored recently using results from a 30-yr numerical simulation: Garreaud et al. (2013, p. 215) conclude that variation in zonal winds account for much of the rainfall variability in Patagonia "at synoptic and interannual timescales" and note somewhat opposite responses to the west of the Andes (recent drying trend) compared with the southern tip (modest increase). In general a West–East contrast was noted, with a positive/negative correlation between the 850-hPa zonal wind speed and monthly precipitation for sites located to the west/east of the Andes ridge. It is difficult to relate their findings to our interpretations above, because their data covered only a limited time period; it also would be necessary to decide into which of two regions the mire falls. Geographically it is East for direct precipitation; but in terms of original moisture source for the river in the valley, then arguably it could be West, because it originates there from glaciers and snowpacks. Hypothetically, during times of stronger Westerlies, and so with a more pronounced föhn effect, there could be more snow melt, causing a higher river discharge, which in turn could impede efflux from the mire; so, local water tables rise and appear to give a 'West' response. However, the overall scale of change suggested in the 3000-yr Andorra bog record is greater than encompassed in that 30-yr simulation, while the abrupt episodes of LIA dryness are pervasive for at least a few decades. This implies a more significant mechanism for parts of the LIA than minor variations in strength of the Westerlies, such as for example a major shift in their geographical position (cf. Moreno et al., 2009).

Varma et al. (2011) suggest that during times of reduced solar forcing (as for example, during parts of the LIA), the Westerlies moved north; whereas, during times of higher solar activity (for example, Medieval Climate Anomaly; late 20th Century), the westerly belt was more southerly. This contrasts with an earlier view of Moy et al. (2008), who suggested a poleward shift of the Westerlies during the

LIA, based on data from a lake site in Chile. Also to the west of the Andes, from Lake Puyehue in Chile, Bertrand et al. (2006) report a humid period from AD 1490–1700, which they interpret as coinciding with the LIA; whereas, our record, well to the southeast of the Andes, suggests dryness in the latter part of that period. Note that the dating does not coincide exactly, because after AD 1770, Bertrand et al. (2006) report (in the west) a drying trend; our record shows that a putative countervailing wetter period (to the east) did not start until after *c.* cal. AD 1770. Our data are, however, seemingly in accord with Neukom et al. (2010) whose reconstructions show dry summers for the 17th century in southern South America, compared with those for the mid-late 20th century, which are noticeably wetter. They have only sparse data points for southernmost South America, whereas our reconstructions extend the evidence for (late) 17th Century dryness, further south into Tierra del Fuego. Daley et al. (2012) noted that Ushuaia (see Fig. 1) has in recent decades been getting wetter over the instrumental period in response to intensification and southward movement of the Westerlies. In that context, it may be hypothesized that a LIA drying of the surface of the Andorra bog is not inconsistent with the Westerlies moving northward, which itself would be consistent with the notion of reduced Hadley cell circulation that would be expected with reduced solar activity.

Limitations to the proxy-climate measures

We used two proxy-climate measures, rather than a single method, on this core. However, the measures are not completely independent, because there may be a species effect in humification data (Chambers et al., 1997; Yeloff and Mauquoy, 2006). The peat-humification technique has also been criticised for not fully capturing decay processes (Hansson et al., 2013). In a limited comparative study of methods to assess peat decay at a single site in Europe by Biester et al. (2014), techniques other than the colorimetric technique could be considered to have performed better; several of these other methods have been used in three pristine mires elsewhere in Patagonia (Broder et al., 2012). Nevertheless, the datasets reported here indicate that the greatest inferred climatic deviations fit well with climate excursions elsewhere, even though it is assumed that the principal change in the mire relates to bog surface wetness, rather than to temperature. Further work might be directed to investigating deuterium excess, as suggested in Daley et al. (2012), which could help to show whether shifting Westerlies were indeed the mechanism for inferred changes in bog surface wetness at this site.

Conclusions

Proxy-climate data from a mire in Tierra del Fuego, Southern Argentina, using the techniques of plant macrofossil analysis and determination of peat humification, show that the main climate changes recorded during the past 3000 years were (i) at 2800 cal. BP and (ii) during parts of the time period conventionally associated with the Little Ice Age. These changes manifest as vegetation changes and changes in peat humification, both indicative of changes in bog surface wetness; they present as significantly drier-than-normal interludes. Although there may well be a temperature component in the records, no temperature-change equivalent can at present be calculated from these data.

The 2800 cal. BP shift is sharp, short-lived, and coincides with a claimed abrupt ‘global’ climate change attributed to a temporary decrease in solar activity during a ‘Grand Solar Minimum’. That drier episode was interpreted by Chambers et al (2007) as indicating a shift in the position of the moisture-bearing Westerlies. Subsequent short-lived climate shifts, of lesser magnitude, seemingly occurred at *c.* cal. AD 215–240 and *c.* cal. AD 1000. Later, a more pronounced short-lived shift occurred *c.* cal. AD 1460, close to the putative claimed start of the LIA, while a twin-peak episode of more comparable magnitude to that of *c.* 2800 cal. BP, lasted from *c.* cal. AD 1675–1770, coinciding with the most severe interludes of the Little Ice Age in Europe. A similar mechanism to the pronounced shift at *c.* 2800 cal. BP might be invoked to explain these shifts to dryness in the last millennium: namely a change in the position of the Westerlies.

While the proximal cause of major changes in bog surface wetness may be shifts in the southerly jet stream, the data from this site suggest (i) that the LIA is recorded in Southern Argentina; (ii) at its peak intensities it is comparable in magnitude to the 2800 cal. BP climate perturbation; (iii) the data support Moreno et al's (2014) claim of "inter-hemispheric [temporal] symmetry"; (iv) these data are not inconsistent with the long-standing interpretation of the more severe multi-decadal episodes within the LIA being associated with decreased solar activity; and (v) that it may be hypothesized that decreased solar activity caused an equatorward shift of the Westerlies, resulting in a drier mire surface at the Andorra bog in Tierra del Fuego *c.* 2800 cal. BP (which while temporally coincident with a major change to wetness recorded in mires in northwest continental Europe is nevertheless an opposite response of the bog-surface here) and again during the more intense phases of the LIA; this hypothesis remains to be tested at other sites.

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Figure captions

Fig. 1 Map to show location of Valle de Andorra mire and Ushuaia, Tierra del Fuego.

Fig. 2. Radiocarbon-calibrated deposition-rate curve for the AND2 core, produced using the Bacon method of Blaauw and Christen (2011), showing groups of samples that assist with 'wiggle-matching' (van Geel and Mook, 1989), resulting in a tight chronology for most of the past 3000 years. Grey-scale plot indicates relative precision of dating; calibration based on SHCal13.

Fig. 3 Percentages of identifiable *Sphagnum* [showing proportion of *S. magellanicum*] leaves and stems, and percentage light transmission through alkali extract of the AND2 core peat [low values indicate dryness; high values indicate wetness] in contiguous 1 cm samples for the past three millennia, plotted against *Empetrum/*Ericaceae roots [indicating relative dryness]. Age estimates derive from SHCal04, to be consistent with data published in Chambers et al. (2007); there are minor differences from SHCal13 used for Fig. 2.

Fig. 4 Detrended peat humification data for the AND2 core, plotted using absorption data, for the past 3000 years (age estimates as per Fig. 3). Note the reverse vertical axis used when plotting these data, so as to create the same visual impression as in Figure 3: deep troughs indicate short-lived dry episodes.

Table Caption

Table 1. Radiocarbon dates for Core AND-2.

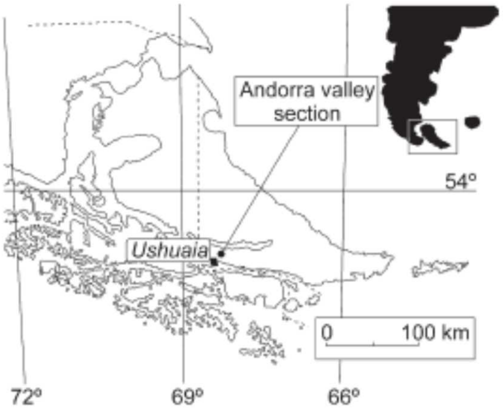


Fig. 1

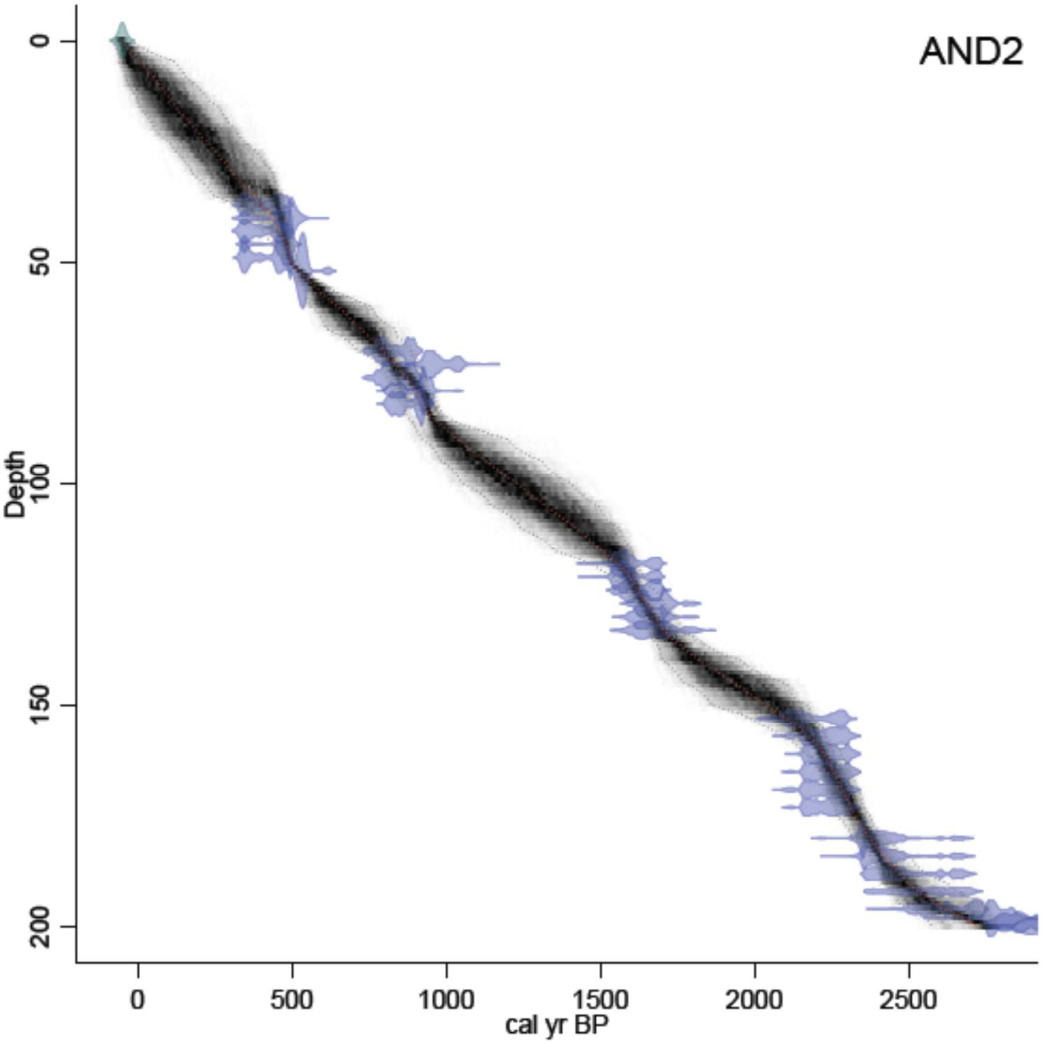


Fig. 2

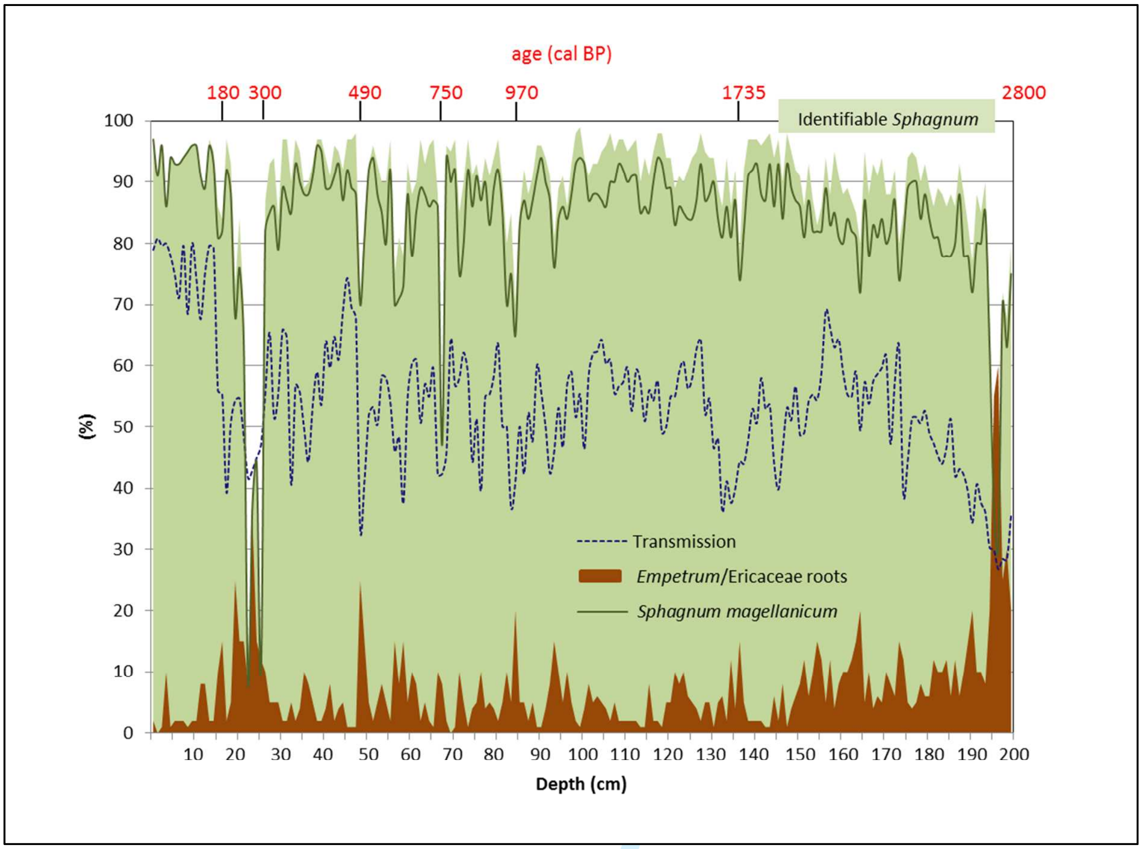
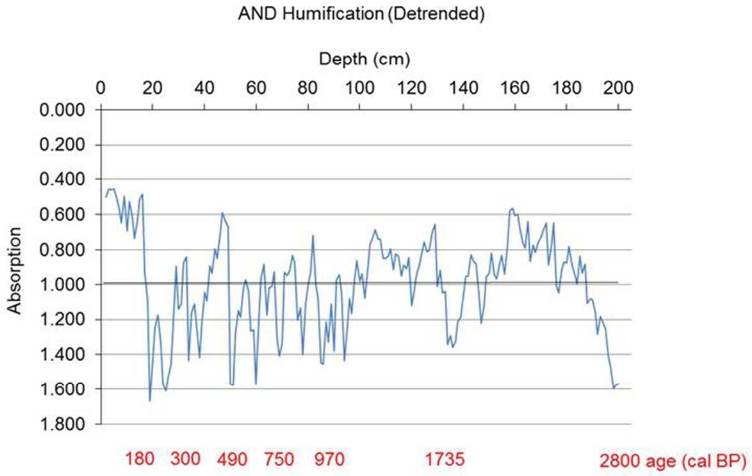

age (cal BP)
180
300
490
750
970
1735
2800
Identifiable *Sphagnum*
100
90
80
70
60
50
40
30
20
10
0
(%)
Transmission
Empetrum/Ericaceae roots
Sphagnum magellanicum
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
Depth (cm)

Fig. 3



Detrended peat humification data for the AND2 core, plotted using absorption data, for the past 3000 years (age estimates as per Fig. 3). Note the reverse vertical axis used when plotting these data, so as to create the same visual impression as in Figure 3: deep troughs indicate short-lived dry episodes.
254x190mm (96 x 96 DPI)

Table 1. Radiocarbon dates for Core AND-2

Sample name	Material	Depth (cm)	Date (^{14}C BP)
SUERC-2468	Sphagnum	37	395±24
AA-54892	Sphagnum	40	468±38
SUERC-2469	Sphagnum	43	394±24
SUERC-2470	Sphagnum	46	448±20
SUERC-2471	Sphagnum	49	402±18
SUERC-2472	Sphagnum	52	565±24
SUERC-2473	Sphagnum	70	952±22
AA-54893	Sphagnum	73	1101±39
SUERC-2476	Sphagnum	76	961±22
SUERC-2477	Sphagnum	79	1050±25
SUERC-2478	Sphagnum	82	1029±20
SUERC-3033	Sphagnum	85	1131±20
SUERC-2481	Sphagnum	118	1721±25
SUERC-2482	Sphagnum	121	1722±22
SUERC-2483	Sphagnum	124	1747±25
SUERC-2486	Sphagnum	127	1813±22
SUERC-2487	Sphagnum	130	1796±25
AA-54894	Sphagnum	133	1810±38
SUERC-3877	Sphagnum	153	2196±25
SUERC-3878	Sphagnum	157	2236±25
SUERC-3881	Sphagnum	161	2256±19
SUERC-3882	Sphagnum	165	2255±25
SUERC-3883	Sphagnum	169	2238±25
SUERC-3884	Sphagnum	173	2241±21
SUERC-3886	Sphagnum	180	2398±23
SUERC-3887	Sphagnum	184	2418±25
SUERC-3888	Sphagnum	188	2465±21
SUERC-3891	Sphagnum	192	2508±26
SUERC-3892	Sphagnum	196	2577±23
SUERC-5570	Sphagnum	198	2717±30
SUERC-6312	Ericales wood	199	2704±22
SUERC-5573	Sphagnum	199	2805±30
AA-54895	Sphagnum	200	2866±41