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The Fimbulwinter myth in the context of Nordic tree-ring climate proxy data

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The Fimbulwinter myth in the context of Nordic tree-ring climate proxy data

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Abstract

High-magnitude late Holocene volcanic eruptions contributed to the climate-related hardships of past societies. It has been theorised that memories of one of the volcanic events and its terrible consequences are recorded in the Old Norse traditions of the Fimbulwinter and Ragnarök (possibly also in the Old Kalevala). This Fimbulwinter theory suggests that the eruption (or double-eruption) responsible for the calamity was the one that caused the AD 536 dust veil and led to strong reductions in incoming sunlight and summer temperatures especially over the next decade. The theory is explored here with tree-ring records from Sweden, Finland, Norway and Denmark, historical data on dust veils, ice core evidence for major volcanic eruptions, and North Atlantic proxy records. Very low summer temperatures and reduced irradiance are evident across the study region over the duration of the AD 536/540s event. Alternative cold events (656-655 BC, 420-419 BC, 42-41 BC, AD 800-801 and AD 1127-1128) were less prominent than the AD 536/540s event. A cold event in AD 1601 serves as an interesting counterpart for the prehistoric events as it occurred, akin to the 536/540s event, at the height of the North Atlantic pulses of drift ice. This suggests that the coupled sea ice-ocean mechanism needed to deepen the anomaly is sensitive to the initial climate state and emphasises the importance of longue durée structures when reconstructing the human past. Overall, the AD 536/540s event appears a climate-related natural catastrophe to be remembered by following generations, which accords with the Fimbulwinter theory.

Key words: Fimbulwinter, Ragnarök, AD 536 event, Dark Ages Cold Period, Little Ice Age, Migration Period crises, palaeoclimatology, dendrochronology

Introduction

The climatic downturns of the first millennium AD have long intrigued scholars from various disciplines. Central to this topic and serving as the cornerstone of the discussions is the AD 536 dust veil (Stothers and Rampino,1983; Stothers,1984, 2002; Baillie,1994), which, according to Mediterranean textual sources dimmed the sun for an 18-month period from March AD 536 until June AD 537, with a coinciding famine devastating “the whole world” (Stathakopoulos, 2003; Arjava, 2005). The likely cause was a Northern Hemisphere/North American eruption, dated to AD 535 or early 536 by means of Greenland ice-core geochemistry (Sigl et al., 2015). Reductions in solar radiation reaching Earth’s surface and in summer temperatures are indeed observed for one to two years after major volcanic eruptions (Robock, 2000). The aftermath of the AD 536 dust veil was extended, however, with another major (tropical) eruption in AD 539/540, identified from Greenland and Antarctica ice cores (Sigl et al., 2015). In climate simulations, decadal-scale Northern

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Hemisphere (NH) extra-tropical radiative forcing from the 536/540 CE double-eruption exceeds any other period over the last 1200 years (Toohey et al., 2016). Moreover, tree-ring data indicate that the summers in the Northern Hemisphere were colder than normal in these years (Stoffel et al., 2015; Büntgen et al., 2021; Helama, 2023).

A northern connection bridging the Late Antique texts and Old Norse literature, Prose Edda, especially the Fimbulwinter myth, describing the mighty winter predating the destruction of all the worlds according to Norse mythology, was initiated by Axboe (1999), based on his studies of precious golden objects as sacrificial investments during the crisis. Gräslund (2008) and Gräslund and Price (2012) went on to argue that the Fimbulwinter myth could in fact narrate the atmospheric effects of the AD 536/540s event, thus forming a counterpart to Mediterranean documentary sources. Parallels in the Finnish national epic Kalevala with eloquent verses describing darkened skies were later highlighted by Price and Gräslund (2015). Importantly, the same authors provided a wider archaeological context for the period, the Scandinavian ”Migration Period Crisis” (AD ~400-550), with changes in the archaeological settlement histories of Scandinavia, to augment their interpretation of calamities becoming mythologised in the Norse account. On these grounds, the Fimbulwinter theory has stimulated a great deal of research in archaeological and natural science (see reviews in Gundersen, 2019; Gjerpe, 2012; Arthur et al., 2024; Anagnostou et al., 2025) and the period discussed under the theory now encompasses not only the AD 536 dust veil but a more extended timeframe of ±150 years or so around that event.

This paper’s main objective is to examine the Fimbulwinter theory in the light of Nordic tree-ring records and climate reconstructions, identifying circumstances that may

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correspond to those encountered in the Prose Edda and Kalevala verses, as no such topical account exists in the literature. Whether or not these conditions really concern to the AD 536/540s event remains unclear. As Gräslund and Price (2012) note, Prose Edda represents an early thirteenth-century text but of much earlier oral tradition. Kalevala represents oral tradition collected during the early eighteenth century. Like the Norse material, some elements of Kalevala appear to be derived from the Iron Age but may also incorporate later tales (Price and Gräslund, 2015). Despite the complex nature of oral-to-written transmission (Quinn, 2000; Mundal, 2016), Gräslund and Price (2012) suggest that these texts may be of mid-sixth century AD origin.

This comparison was extended to documentary data on other historical dust veil events from Mediterranean sources (Stothers, 2002) and ice core data indicative of volcanic forcing and eruption dates (Sigl et al., 2015, 2022; McConnell et al., 2020). Moreover, the region is located downwind of the North Atlantic, which links local atmospheric conditions to large-scale hemispheric and global circulation variability (Helama et al., 2009, 2021), for which reason the tree-ring data were also collated with a set of records attributable to long-term processes in the North Atlantic circulation patterns (Bond et al., 2001; Bianchi and McCave,, 1999; Lapointe et al., 2020). A timeframe of the last 3,000 years was selected as the era of agriculture (Widgren and Pedersen, 2011; Lahtinen and Rowley-Conwy, 2013), a subsistence system proposed as central in mediating the climatic effects on society and thus a key for transforming the myth into a scientific hypothesis.

Edda and Kalevala

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Gräslund and Price (2012) excerpt a description of Fimbulwinter from translated (Faulkes, 1987) sources of Norse mythology as follows:

"First of all that a winter will come called Fimbulwinter. Then snow will drift from all directions. There will then be great frosts and keen winds. The sun will do no good. There will be three of these winters together and no summer between."

The passage describes the disturbed weather in surprising detail, with accumulating snowdrifts, harsh weather, a reduction in incoming sunlight (irradiance), and, as Gräslund and Price (2012) also emphasise, at least two years without a summer. Clearly, the weather is described in a way that indicates no similar event since time immemorial. Price and Gräslund (2015) highlight an interesting parallel from the translated Old Kalevala (Magoun, 1969) when the Mistress of the Northern Land has captured both the sun and moon:

"Now the night was perpetual,
long, dark as pitch, a deep place unreached by the sun.
It was night for five years, no sun for six years,
no moon for eight years"

Surprisingly, the English translation has lost the following two lines, included in the original Finnish Old Kalevala (Lönnrot 1835), that extend the event by two years with the following celestial description:

"nine without the Great Bear,

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a full ten with no stars."[1]

Interestingly, the passage suggests a much longer period of solar dimming than Edda, from five to ten years, including a gradual recovery.

In comparison, existing tree-ring evidence from Sweden, Finland, Norway, and Denmark demonstrates deteriorated tree growth in AD 536 and over the following decade (Figure 1) (see supplementary information for methods). Frost rings in AD 536 are observed in Finland (Figure 1b–d), indicating very low temperatures at the height of the growing season. Growth curtailments and cold summer temperatures (<12 °C) in AD 536 continued, especially during the AD 539-545 period (Figure 1e–k). Relevant for this analysis, stable carbon isotopes ($\delta^{13}C$) from tree rings indicate a sharp drop in irradiance in AD 536 and, consistent with the temperatures, a longer period of markedly low irradiance for the AD 541-544 period (Figure 1l). The volcanic forcing from the double-eruption is demonstrated by increased stratospheric aerosol optical depth over the intervals, with the highest values being observed in AD 536 and AD 541 (Figure 1m).

Collectively, these data indicate that the anomalous conditions in temperature and sunlight not only in AD 536 but over the AD 540s are required to mirror the multi-annual duration of the event, which Edda and Old Kalevala both convey. This interpretation would extend the length of the event to ~5-10 years, akin to that found from the Old Kalevala. Such an extension would not even be at odds with the Fimbulwinter of Edda, where the number of years without a summer may not be limited to two, as Gräslund and Price (2012) construe. It is notable that the presence of the extension in multiple proxy types supports a direct

[1] Translation of the two lines by the corresponding author of this paper.

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climatic interpretation instead of legacy effects (Zweifel and Sterck, 2018) in explaining the AD 540s anomaly.

The AD 536 dust veil – the only candidate for Fimbulwinter?

Despite the degree of similarity between the textual and natural-scientific descriptions, an essential question remains concerning whether the mid-sixth-century AD dust veil represents the only possible event behind the Fimbulwinter myth (Gjerpe, 2021). A comparison of cold events, expressed as negative departures from the mean record of Swedish and Finnish tree-ring chronologies over the last 3,000 years, reveals that the 536/540s event was not the only strongly negative anomaly (Figure 2). However, when the examination of similarly strong events is limited to a period before the thirteenth centuries AD (when the Edda was textualised), the number of candidate events challenging the strength of the 536/540s event is much reduced.

Interestingly, the strongest anomalies in the BC era are mainly observed as two-year cold events (Figure 2a). The one in 874 BC and another in and around 330 BC have been noted in Fennoscandian tree-ring literature (Eronen, 2002; Grudd et al., 2002; Helama et al., 2013; Jones et al., 2013) but cannot be associated with any volcanic signals, whereas those in 656 BC and 420 BC can be tentatively linked to stratospheric aerosol optical depth anomalies dated to 661 BC and 429-428 BC (see Figure 2d–f). The absolute age uncertainties in the ice cores, which are suggestively better than ±5–15 years over the earlier anomaly, may permit such a connection. However, the uncertainties better than ±1–5 years over the last 2500 years may not in any case favour the fifth-century BC connection (Sigl et al., 2022).

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Historically documented dust veils observed in 44 BC, AD 536 and AD 797 (Stothers, 2002) coincide with two-year and five-year cold events (Figure 2a–b). Regarding the cold event starting in 42 BC, one of the largest volcanic eruptions of the last 2,500 years is known to have started in early 43 BC, with elevated volcanic fallout lasting more than two years (McConnell et al., 2020). Low summer temperatures, reconstructed previously by Luterbacher et al. (2016) for the duration of the eruption, have been linked with crop failures, famine, and disease, exacerbating social unrest throughout the Mediterranean region (McConnell et al., 2020). However, the cold event in AD 800-804 postdates the AD 797 dust veil in the Mediterranean (Stothers, 2002) by three years, in any case coinciding with a Northern Hemisphere eruption in AD 800 (Sigl et al., 2015). Collectively, the stratospheric aerosol optical depth increased in both AD 798 and 803 (Sigl et al., 2022).

Among the remaining tree-ring anomalies, the cold event in AD 1127 can be compared with ice-core evidence for a tropical eruption in AD 1127 (Sigl et al., 2015). This is not the case with an earlier cold event in AD 336, for which no counterpart in the volcanic record has been found (Sigl et al., 2015, 2022) (Figure 2).

There were many cold events during the Little Ice Age (Figure 2a), potentially reflecting the effects of volcanic activity increasing over the same period (AD ~1250-1850) and likewise cooling the Northern Hemishere summer climate (Wanner et al., 2008, 2011). While this interval postdates the textualisation of the Edda, the cold event starting in AD 1601 compares in strength with the AD 536/540s event. This observation holds for the two-year, five-year and ten-year events (Figure 2a–c). Following the eruption of Huaynaputina in Peru in AD 1600 (Briffa et al., 1998), existing documents indicate exceptionally bad

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harvests in AD 1601 in Denmark and Norway, and for AD 1601-1603 in southeastern-to-western/central Sweden (Utterström 1955; Dybdahl, 2012; Dribe et al., 2015). In Finland, AD 1601 is known as the ”great straw year” (the amount of harvested grain was in some cases less than that sown) and was likewise followed by several poor crop years (Figure S2) (Holopainen and Helama, 2009), which resulted in the authorities deciding not to collect grain tithes in many provinces (Huhtamaa and Helama, 2017). As a result, approximately 13 per cent of the farms in Finland could be classified as deserted at the end of the 1610s (Sundquist, 1931). The sun was obscured in Norway and Sweden in AD 1601 (Kalela-Brundin, 1997) but tree-ring $\delta^{13}C$ data from northern Sweden (Loader et al., 2013) do not indicate any marked drop in irradiance around that date (Figure S3). Overall, the AD 1610s data may set a yardstick for the AD 536/540s event demonstrating the extent of agriculture-related calamities attributable to volcanic forcing.

A context of slow changes: longue durée

The essential point from the Fimbulwinter theory is that the AD 536/540s event may provide the ”Migration Period Crisis” with a climatic/environmental context, for the perturbed climate during the event would serve as a forewarning of the Ragnarök, the destruction of all the worlds and their inhabitants. Gräslund and Price (2012) and Price and Gräslund (2015) illustrate a possible reflection of such a process through the dramatic sixth-century AD decline in the number of excavated settlements in eastern central Sweden (Figure 3a), constituting the greatest change in settlement patterns in Sweden for 6,000 years. Somewhat optimistically, they also cite consistent results “over the rest of Scandinavia for which we have data”, suggesting that the populations of Scandinavia may have been halved in the middle of the century.

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However, placing the population history in this context has been contested, for the decline had actually begun as early as the third century AD, a view several archaeologists emphasise (Näsman, 2012; Moreland, 2018; Gundersen, 2019). The AD 536/540s event must therefore also be studied in a longer time perspective (Gjerpe, 2021). Relevant for this discussion, the Dark Ages Cold Period (DACP; AD ~250-800) has been determined in the palaeoclimate literature with a cool and disturbed climate over the Northern Hemisphere (Lamb, 1995; Ljungqvist, 2010; Wanner et al., 2011; Helama et al., 2017a, 2017b; Riechelmann and Gouw-Bouman, 2019). The palaeoclimatic DACP thus encompasses the Migration Period, providing a particularly meaningful context for the AD 536/540s event.

Indeed, the early part of the DACP overlaps with the long-term settlement decline from the third century AD. Consistent with this view, latewood-based temperature records from Sweden and Finland show that long-term cooling started several centuries before the AD 536/540s event (Figure 3b–c). It is essential to note that parallel trends coeval to the putative population decline can also be observed in the North Atlantic proxy records, indicated by colder sea surface temperatures, the slowing of the deep-ocean flow of thermohaline circulation, and the intensified pulse of drift ice on subpolar North Atlantic waters (Figure 3d–f). It is noteworthy that the concept of Late Antique Little Ice Age (AD 536-660) (Büntgen et al., 2016) that fully overlaps with DACP cannot explain the climatic downturn that started before AD 536 and remains unconnected with North Atlantic climate history before that date (Helama et al., 2017a, 2021).

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Moreover, the DACP has been commonly juxtaposed (e.g. Berglund, 2003; Helama et al., 2017a; Spencer et al., 2025) with the North Atlantic drift-ice pulse number 1 at about 1,400 years ago (Figure 3g) and is therefore viewed in a palaeoceanographic context of similar events representing a continuum of solar-forced variability through the Holocene global-scale climates (Bond et al., 1997, 2001). Making the juxtaposition here places the AD 536/540s event at the height of the drift-ice pulse number 1 (Figure 3g). Intriguingly, a similar observation is evident for the drift-ice pulse number zero, correlated with the Little Ice Age (Bond et al., 1999) thus positioning the AD 1601 event in the high phase of that pulse (Figure 3g).

Discussion and concluding remarks

This examination had both expected and unexpected outcomes. Although it may be impossible definitively to prove a connection between the Fimbulwinter myth and any climatic event recorded in climate proxy data, it is indeed possible to evaluate whether natural-scientific data are supportive or unsupportive of the theory. Overall, the AD 536/540s event is characterised by very low summer temperatures and reduced irradiance across the study region and period, providing plausible support for the Fimbulwinter theory entailing an unforeseen climate-related natural catastrophe (Gräslund and Price, 2012; Price and Gräslund, 2015).

While the data demonstrate alternative two-year cold events that can be associated with historical dust veils and/or ice core signals of volcanic eruptions dating from times before the Edda was written down (656-655 BC, 420-419 BC, 42-41 BC, AD 800-801, and AD 1127-1128), extreme conditions seem more evident for the AD 536/540s event, especially

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when the examination is extended to five-year and ten-year events. The emphasis on the longer events directs attention to the Old Kalevala with its verse descriptions of similar atmospheric occurrences. These results not only confirm the severity of the AD 536/540s event but provide its multi-dimensional characterisation within natural science and mythologised contexts.

Interestingly, multiple lines of evidence suggest that the AD 1601 event provides a more recent counterpart for the AD 536/540s event. This would make the Fimbulwinter myth less mythic for us, perhaps, and the AD 536/540s event less enigmatic for research, as much natural-scientific and historical data exist across the region for the early AD 1600s, thus becoming available for building analogues to interpret the mid-sixth-century hardships.

While this is not to suggest that the prehistoric and historical agricultural systems were similar in all respects, the suggested halving of the populations of Scandinavia by the AD 550s (Gräslund and Price, 2012) would appear an overestimate. Nor should starvation due to crop failures be underestimated, as the historical analogues from the early seventeenth century AD subsistence crises indicate.

Furthermore, placing the AD 536/540s and AD 1601 events in the context of slow palaeoclimatic/palaeoceanographic changes hints at their unique timing at the heights of the North Atlantic pulses of drift ice. First, the coupled sea ice-ocean mechanism may be sensitive to the initial climate state (Zhong et al., 2011). Such a setting suggests that pre- and coexisting influences from long-term cooling trends paved the way for the abrupt volcanic events (Helama et al., 2021) which, secondly, may induce a deepening of anomalies through feedback mechanisms (Brönnimann et al., 2019; van Dijk et al., 2022,

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2024). The setting could also be behind the relatively weak 42 BC event, which may not have been similarly preconditioned by the palaeoceanographic circumstances.

It is evident that these signals of different scale are superimposed within the palaeoclimatic archive, and it seems important to combine their diversity instead of examining just one type of forcing factor (e.g. volcanism) when working towards the synthesis of climatic data and analysing their effects on human populations and actions. The results also demonstrate the unification of historical and natural-scientific scales in the framework involving very long-term changes, longue durée structures (Braudel, 2009; Lee, 2018), and the need for such unification when reconstructing the human past (Izdebski et al., 2024) and, relevant for this paper, when theorising the Fimbulwinter myth. The longue durée remains invisible to contemporaries but can be revealed as geological processes, as shown here, evolving through deep time with Earth’s changing climate.

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Data availability

Sources of the data used in this paper are detailed in Table S1.

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FIGURE CAPTIONS

Figure 1. Fennoscandian map showing the study area and the tree-ring sites in northern Norway (N), northern Sweden (Torneträsk region (T)), northern Finland (F), central Sweden (Jämtland (J)), northern Sweden (Torneträsk (T)), and Denmark (D) (a). The frost ring in AD 536 in samples N3-1 (b), NK2-6 (c) and K8-99 (d) from northern Finland portray under-lignified deformed tracheids (Helama et al., 2019). Tree-ring width (TRW) records sensitive to summer (June to August, JJA) temperatures produced from northern Norway (Kirchhefer, 2005) (e), northern Finland (Helama et al., 2010) (f), northern Sweden (Grudd et al., 2002) (g), and central Sweden (Gunnarson, 2008) (h). Summer (JJA) temperature reconstructions from latewood maximum densities (MXD) combine the northern Swedish and Finnish materials (Matskovsky and Helama, 2014) (i) and from minimum blue channel light intensities (BI) representing northern Finland (Helama et al., 2022) (j). The tree-ring width (TRW) record is from Denmark (Larsen et al., 2024) (k). Summer irradiance (June to July; JJ) is reconstructed from tree-ring stable carbon isotopes ($\delta^{13}C$) for northern Finland (Helama et al., 2018), with open circles representing the strongest five-year anomaly (l). Stratospheric aerosol optical depth (SAOD) is reconstructed from volcanic stratospheric sulphur injection estimates obtained from Greenland and Antarctica ice-core data (Sigl et al., 2022), shown here for the summer (June to August (JJA)) months and Scandinavian latitudes (70-55˚N) (l). The vertical dashed line denotes AD 536, and the shading the AD 539-548 period, with common indications of low temperatures and irradiance. See Table S1 for data characterisation.

Figure 2. Tree-ring and ice core data over the last three millennia. Cold events are shown as negative anomalies calculated from the mean record of tree-ring data representing

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central and northern Swedish and Finnish sites (Grudd et al., 2002; Gunnarson, 2008; Helama et al., 2010, 2022; Matskovsky and Helama, 2014) expressed as z-scores with two-year (a), five-year (b) and ten-year (c) running means. Stratospheric aerosol optical depth (SAOD) is reconstructed from volcanic stratospheric sulphur injection estimates obtained from Greenland and Antarctica ice-core data until AD 1900 (Sigl et al., 2022), shown for the summer (June to August) months and Scandinavian latitudes (70-55 °N) (d). The mean record of the abovementioned central and northern Swedish and Finnish tree-ring chronologies over the intervals have a peculiar agreement with ice-core data (e). SAOD and volcanic fallout is expressed as non-sea-salt sulphur (nssS) concentration of NGRIP2 ice core for the summer months (McConnell et al., 2020) (f). Tree-ring dates are denoted by downward arrowheads indicate dust veils from Mediterranean sources (44 BC, AD 536 and AD 797) (Stothers 2002) with agreement with cold events as discussed in the text. The vertical dashed lines denote agreements between tree-ring based cold events and high values of SOAD/nssS. Tree-ring dates are indicated by the first year of the cold event. The variance of the mean record was stabilised using the methods of Osborn et al. (1997). The BC/AD timeline (1000 BC to AD 1900) does not have ”year zero”. See Table S1 for data characterisation, Figure S1 and Table S2 for the mean tree-ring record and Table S3 for the numerical values of the cold events.

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Figure 3. Long-term changes. The number of excavated prehistoric settlements (n) in eastern central Sweden (digitised from Gräslund and Price (2012)) (a). Latewood maximum density (MXD) record combining the northern Swedish and Finnish materials (Matskovsky and Helama 2014) available since 8 BC (b). The minimum blue channel light intensity (BI) is record from northern Finland (Helama et al., 2022) (c). Reconstructed North Atlantic summer (June to August) sea-surface temperatures (0°–70°N) are inferred

from titanium counts of an annually laminated sedimentary archive from High-Arctic Canada (Lapointe et al., 2020) (d). North Atlantic sedimentary records of mean sortable silt grain size (10-63 μm) as a deep-ocean flow speed proxy (Bianchi and McCave, 1999) reflect flow changes in the Iceland-Scotland Overflow Water which is an important component of the thermohaline circulation (e) and percentages of lithic grains as a measure of ice-rafted debris (Bond et al., 2001) reflecting advections of ice-bearing surface waters from polar sea regions (f), both constrained by calibrated ^{14}C dates. The North Atlantic pulses of drift ice, using the same proxy data as above, are filtered to demonstrate millennial (1000–2000 year) timescales, previously numbered from 8 to 0 (Bond et al., 2001; Wanner et al., 2011). Pulses numbers 1 and 0 are correlate with the Dark Ages Cold Period (DACP) and Little Ice Age, within which periods the vertical dotted lines denote the AD 536/540s and AD 1601 events (g). The timeframes of the DACP (AD ~250–800) and the ”Migration Period” (AD ~400–550) are illustrated as areas of light and dark shading, respectively. The vertical dashed lines (a–f) denote agreements between tree-ring-based cold events and ice core volcanic signals as discussed in the text. The BC/AD timeline (1000 BC to AD 1900) does not have ”year zero”. See Table S1 for data characterisation and Figure S2 for annually resolved tree-ring records.

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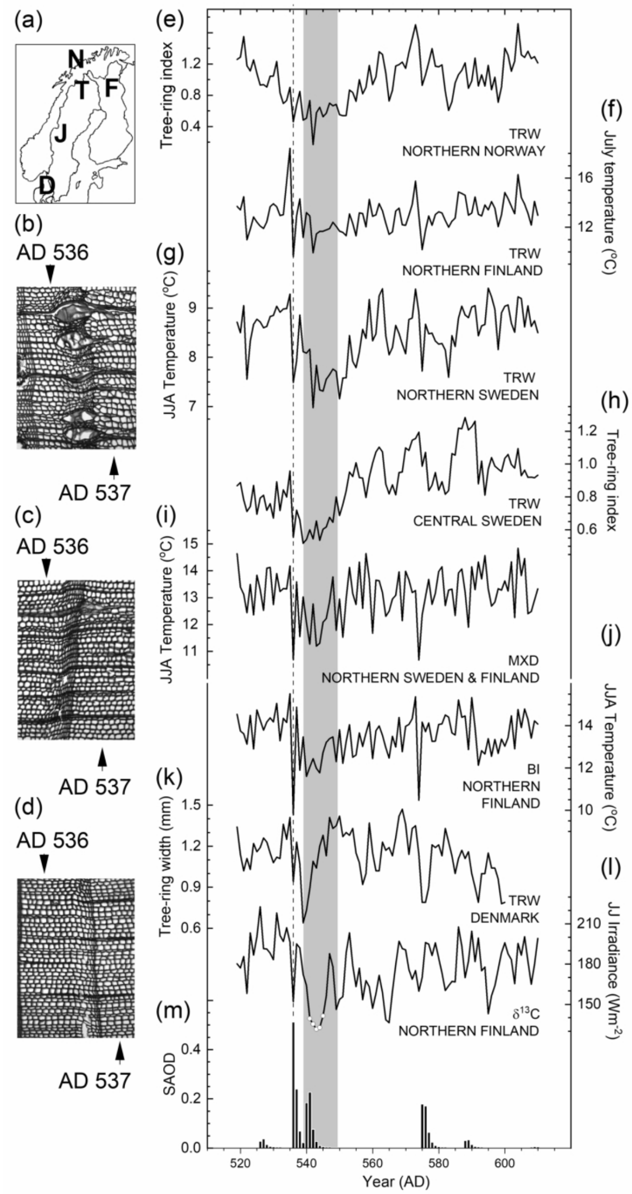

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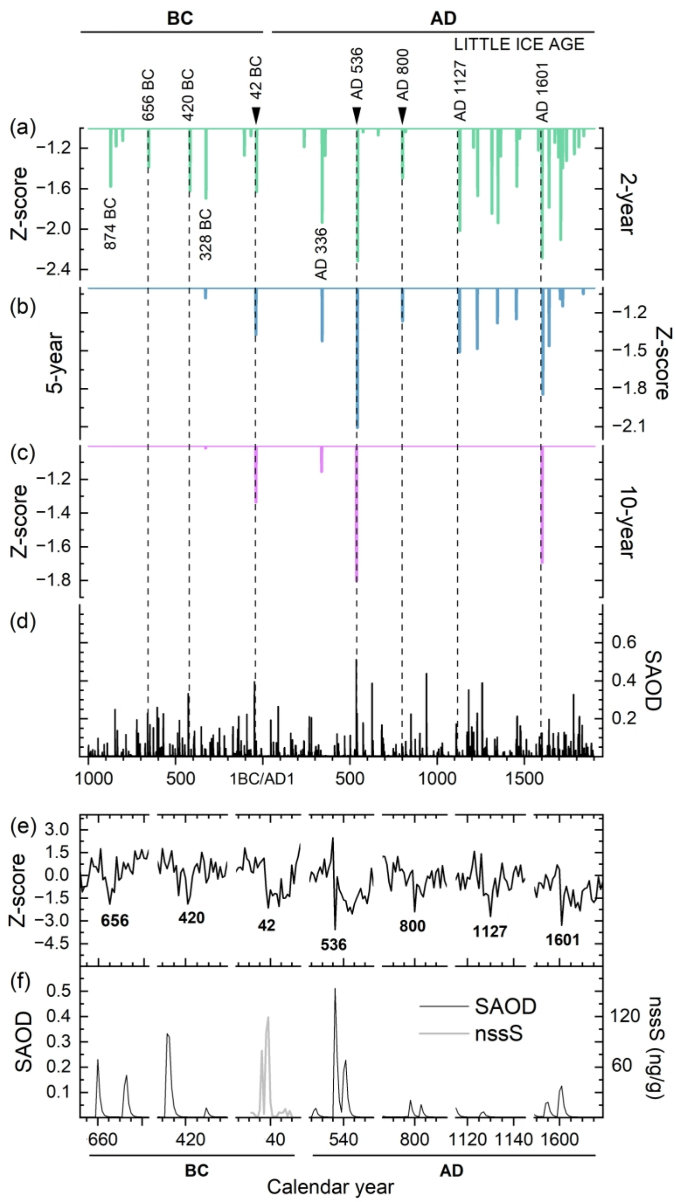

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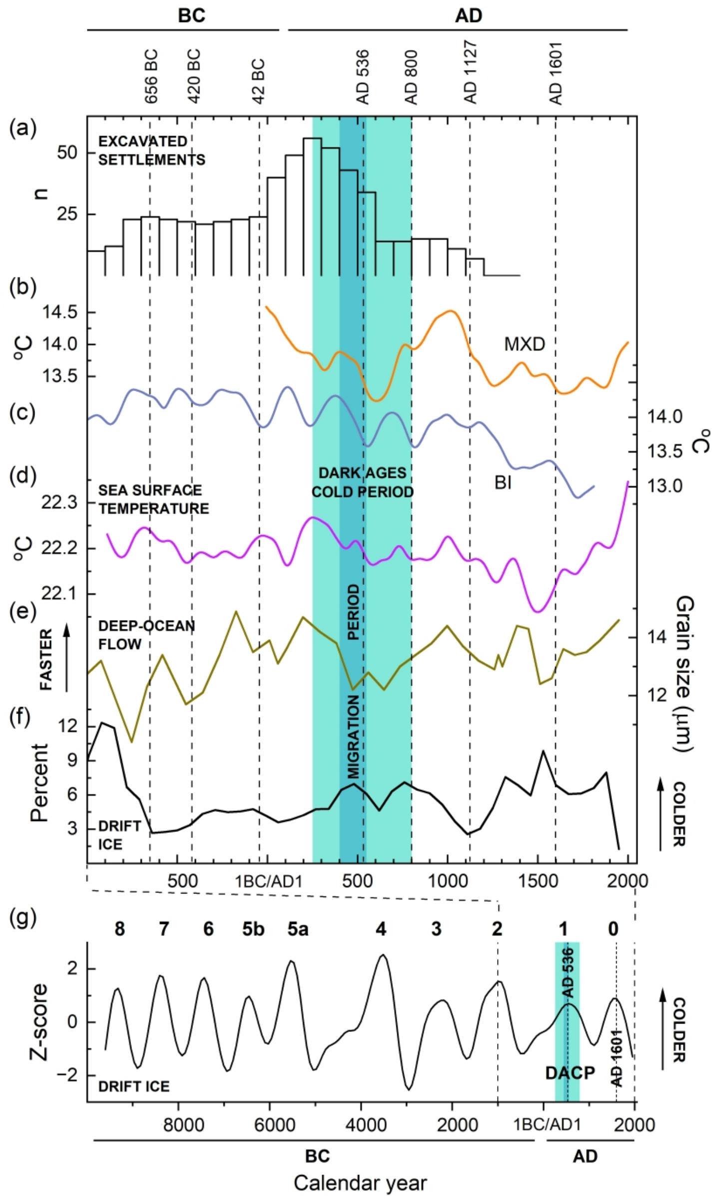

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The Fimbulwinter myth in the context of Nordic tree-ring climate proxy data

Supplementary Items

Methods. Description of data analyses

Figure S1. Millennia-long tree-ring records
Figure S2. Grain-figure data from southwest Finland
Figure S3. Reconstruction of Bright sunshine hours

Table S1. Characterisation of tree-ring data
Table S2. Data for the mean tree-ring record
Table S3. List of cold events shown in Figure 2

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Methods. Description of data analyses: timeseries of tree-ring chronologies and climate reconstructions were acquired from the sources itemised in Table S1. These data had been prepared using the methods described in the original papers (Grudd et al., 2002; Kirchhefer, 2005; Gunnarson, 2008; Helama et al., 2010, 2018, 2022; Matskovsky and Helama, 2014; Larsen et al., 2024) (Fig. 1) and no further analyses such as tree-ring standardization or calibration with instrumental climate data were carried out in the present study. Cold events over the last three millennia were adopted as negative anomalies in the longest timeseries (Grudd et al., 2002; Gunnarson, 2008; Helama et al., 2010, 2022; Matskovsky and Helama, 2014). The timeseries were transformed into z-scores to have a mean of zero and standard deviation of one. This period was not covered by all the records, for which reason the variance of the mean record was stabilised using the methods of Osborn et al. (1997). The mean record is presented in Table S2. Two-year, five-year and ten-year (non-overlapping) running means were calculated from the data to determine the most anomalous cold events over the last three thousand years. The cold events are listed in Table S3. Moreover, the coincidence of the cold events was evaluated with volcanic sulphur injection estimates from Greenland and Antarctica ice-core data (McConnell et al., 2020; Sigl et al., 2022) and with documentary evidence of dust veils from Mediterranean sources (Stothers 2002) (Figure 2). Further, the high-resolution temperature records (Matskovsky and Helama 2014; Lapointe et al., 2020; Helama et al., 2022) were filtered with a 200-year spline with a 50% cut-off. The filtered records were compared with a number of excavated prehistoric settlements (Gräslund and Price, 2012) and North Atlantic proxy records (Bianchi and McCave, 1999; Bond et al., 2001). The record of Bond et al. (2001) was further filtered to demonstrate millennial timescales, represented here by the difference between 1000-year and 2000-year splines (Figure 3).

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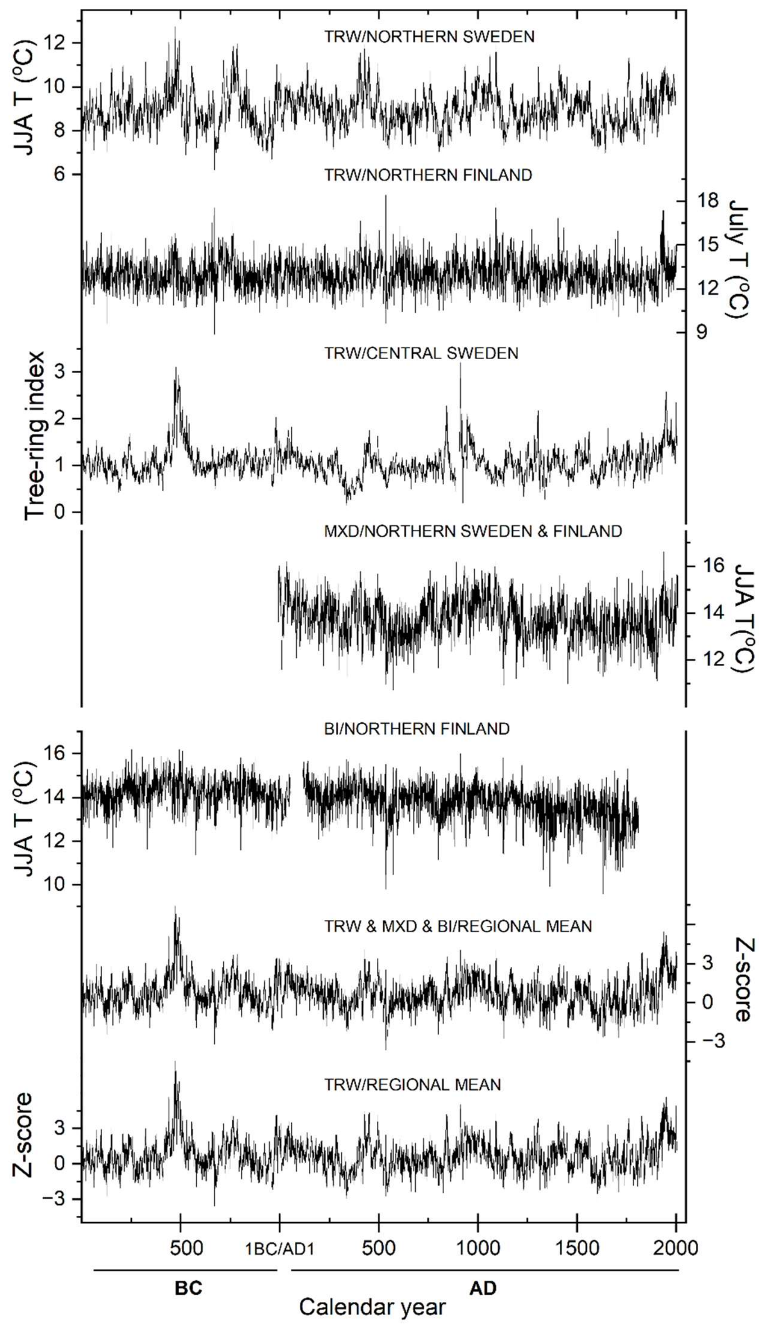

Figure S1. Millennia-long tree-ring records and summer (June through August; JJA) temperature reconstructions. Tree-ring width (TRW) records from northern Sweden (Grudd et al., 2002), northern Finland (Helama et al., 2010), central Sweden (Gunnarson, 2008), latewood maximum density (MXD) record northern Swedish and Finnish materials (Matskovsky and Helama, 2014), and minimum blue channel light intensity (BI) record from northern Finland (Helama et al., 2022). All the five data were transformed into z-scores using the sixth AD century as a reference period and averaged into a regional mean record of all the proxy records (TRW & MXD & BI) (used in Figure 2 of the main paper) and that of TRW records (used in Figure 3 of the main paper). The variance of the mean records was stabilised using the methods of Osborn et al. (1997).

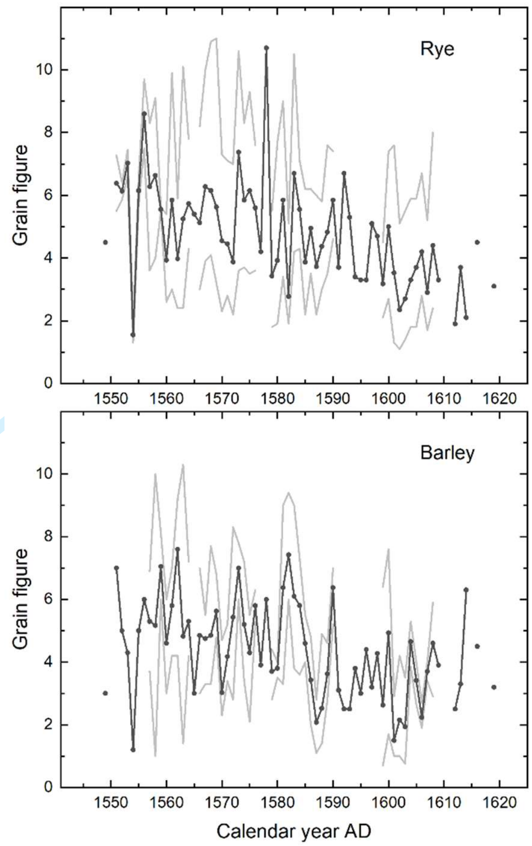

Figure S2. Grain-figure (ratio between sown and harvested grain) data from the Crown estates in southwest Finland for rye and barley (Holopainen and Helama, 2009). The black dots with black line denotes the mean grain figure. The grey lines indicate the maximum and minimum values.

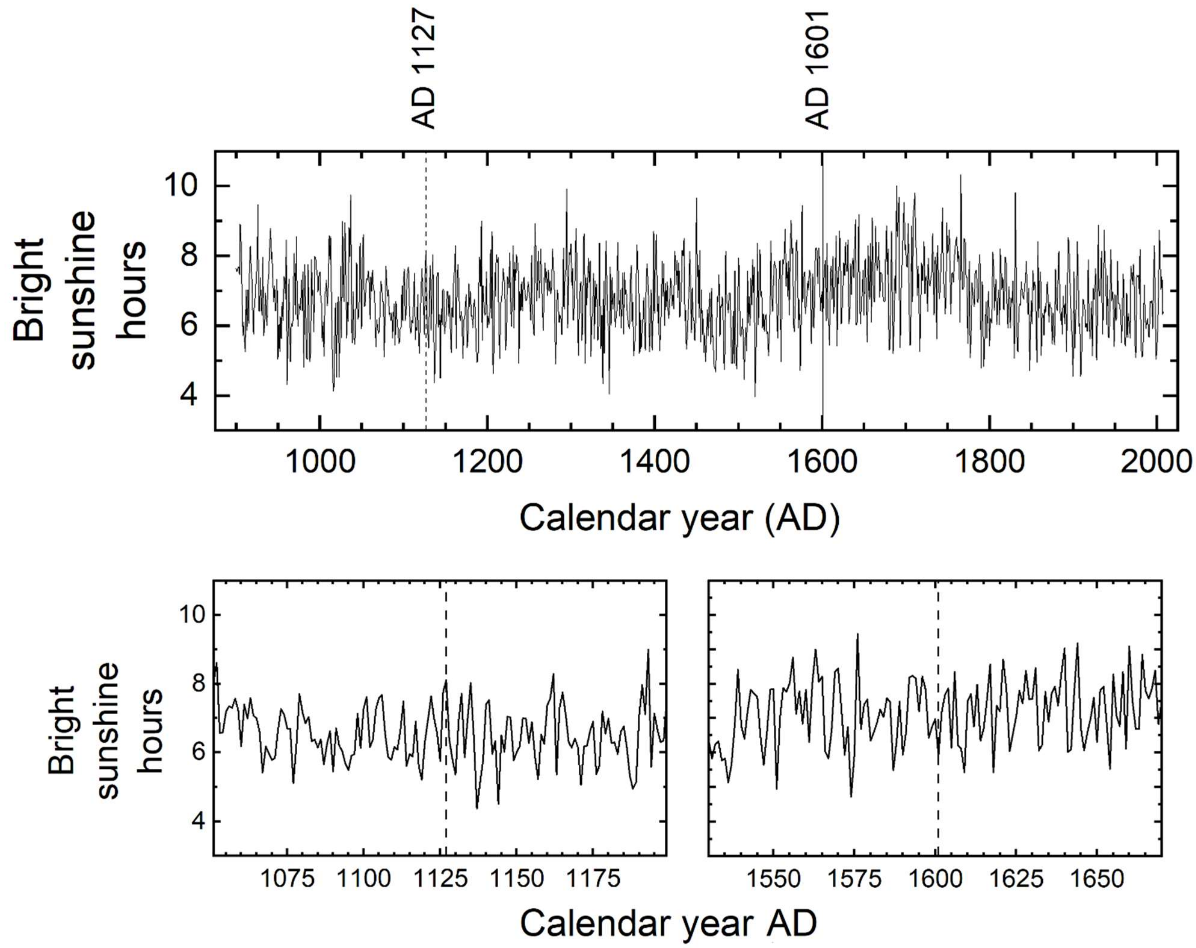

Figure S3. Bright sunshine hours (June-August) reconstructed for northern Sweden from tree-ring $\delta^{13}C$ data (Loader et al., 2013). Vertical dashed lines indicated cold events at AD 1127 and AD 1601. The latter event is of special interest due to weak summertime sunshine observed in Norway and Sweden with descriptions such as "the sun this year [1601] shone as through haze or smoke and without its right shine" (Kalela-Brundin, 1997).

Table S1. Characterisation of tree-ring data. In addition to reference to literature, the data are quantified by the country of sampling sites (SWE = Sweden, NOR = Norway, FIN = Finland, DEN = Denmark), tree species (PISY = *Pinus sylvestris*, QURO = *Quercus robur*), proxy variable (TRW = tree-ring width, MXD = maximum latewood density, BI = minimum blue channel light intensity), and accessibility.

Reference	Country	Species	Proxy	Accessibility
Grudd et al., 2002	SWE	PISY	TRW	https://www.ncei.noaa.gov/pub/data/paleo/treering/measurements/correlation-stats/swed334.txt
Kirchhefer, 2005	NOR	PISY	TRW	Personal communication
Gunnarson, 2008	SWE	PISY	TRW	https://bolin.su.se/data/gunnarson-2017-jamtland
Helama et al., 2010	FIN	PISY	TRW	https://www.ncei.noaa.gov/pub/data/paleo/paleolimnology/arctic/fennoscandia-v2.xls
Matskovsky and Helama, 2014	SWE & FIN	PISY	MXD	https://cp.copernicus.org/articles/10/1473/2014/cp-10-1473-2014-supplement.zip
Helama et al., 2022	FIN	PISY	BI	https://www.ncei.noaa.gov/pub/data/paleo/treering/reconstructions/europe/finland/helama2022/helama2022-temp.txt
Larsen et al., 2024	DEN	QURO	TRW	Personal communication

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Table S2. Tree-ring record representing central and northern Swedish and Finnish sites (Grudd et al., 2002; Gunnarson, 2008; Helama et al., 2010, 2022; Matskovsky and Helama, 2014) expressed as averaged z-scores (multiplied by 100) used to calculate the cold events shown in Figure 2a–c. The timeline contains 'year zero' (that is, years -1 = 2 BC, year 0 = 1 BC, year 1 = AD 1).

-999		59	123	15	138	30	26	-6	145	-13
-990	-68	-79	-29	-27	64	40	76	29	64	-39
-980	-110	-32	-1	94	-21	90	172	208	78	122
-970	70	13	-39	71	53	100	-75	14	97	14
-960	-2	170	25	120	2	-56	11	-71	-40	58
-950	46	-7	-45	68	77	141	164	100	34	7
-940	31	53	-11	-175	3	-75	-16	68	68	89
-930	143	134	103	150	286	68	149	85	29	-42
-920	29	63	124	89	54	150	52	87	102	163
-910	83	29	47	54	92	78	194	190	62	7
-900	267	135	47	134	107	21	123	-61	35	114
-890	3	-17	-100	-9	-61	-127	-71	10	16	-4
-880	36	-74	-48	-165	-15	17	-76	-239	15	22
-870	-90	-96	80	-46	113	-37	79	97	-89	-40
-860	34	-80	121	125	37	126	128	17	114	150
-850	111	271	202	10	71	67	100	-168	-68	-78
-840	-29	-13	-1	-32	67	104	65	-10	25	-27
-830	77	97	87	49	-52	-77	43	127	9	34
-820	77	52	77	64	41	72	-95	-34	115	-74
-810	-14	19	-153	-48	109	-102	-123	11	-1	-64
-800	-36	-36	-28	-45	9	29	211	222	93	242
-790	166	109	122	175	147	150	16	-10	-11	27
-780	123	137	186	166	143	95	-4	160	93	-8
-770	64	145	65	29	139	23	9	270	189	151
-760	243	135	85	176	138	221	218	140	219	148
-750	129	148	57	161	50	223	177	22	122	36
-740	-12	36	-52	-99	126	-22	22	48	-4	-72
-730	-61	-51	-2	-2	-129	-25	45	39	-108	37
-720	-88	-71	28	10	-22	-66	-126	-28	77	-62
-710	-84	34	-21	-101	37	-27	15	46	87	67
-700	93	-74	47	5	-17	-15	27	119	5	-38
-690	14	-95	23	25	34	34	146	77	70	21
-680	146	221	119	292	185	171	160	75	-40	46
-670	120	-25	38	-108	-73	-71	8	115	58	58
-660	20	175	-28	-11	-89	-189	-87	-112	122	-31
-650	-16	86	42	79	33	9	161	106	114	170
-640	113	109	166	50	0	152	178	21	105	153
-630	39	127	187	93	159	256	159	210	-8	6
-620	106	-7	-19	-10	-4	1	-31	-1	61	84
-610	-40	-26	128	-8	-67	51	11	101	70	13

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-600	15	71	48	117	23	2	14	61	-76	-35
-590	-15	-4	-8	85	121	41	103	203	176	106
-580	195	219	120	35	180	205	99	163	269	153
-570	131	274	29	188	233	166	215	192	322	192
-560	255	498	242	160	252	279	105	66	160	165
-550	247	157	105	221	276	82	153	86	280	283
-540	275	298	166	210	91	305	418	170	598	185
-530	169	720	536	487	426	485	663	363	348	408
-520	141	359	499	566	523	470	416	519	431	349
-510	522	534	521	634	503	493	457	391	244	204
-500	321	336	435	168	158	214	269	174	396	190
-490	337	196	212	195	184	227	175	50	110	103
-480	9	120	55	203	-67	-28	33	15	183	28
-470	229	353	154	186	130	52	62	140	140	-25
-460	44	144	224	109	130	157	46	41	176	225
-450	149	118	145	152	274	310	251	309	288	234
-440	239	77	96	107	185	219	94	166	86	13
-430	177	87	44	95	162	22	64	-133	20	46
-420	-19	-188	-136	-7	54	77	18	152	93	-49
-410	-14	110	22	86	-24	58	-13	-4	89	79
-400	9	66	73	39	-21	-40	118	-28	-76	56
-390	-50	85	28	5	111	16	-35	43	7	-51
-380	-16	28	127	-36	-94	78	16	-23	-113	-18
-370	8	66	40	20	-47	78	63	29	-20	-22
-360	35	90	169	167	118	-2	-40	103	23	-34
-350	17	80	116	-4	2	124	129	100	51	102
-340	251	230	151	153	47	126	103	1	7	247
-330	28	-309	79	-195	-144	57	-150	-85	-37	-184
-320	-48	-79	-95	-78	-61	-24	-39	-46	-22	29
-310	-59	64	166	7	54	83	74	47	125	59
-300	31	48	59	76	101	128	138	-10	160	155
-290	86	136	255	260	200	259	306	221	189	237
-280	181	145	171	-38	7	37	17	-70	91	208
-270	82	185	252	106	209	212	199	149	192	228
-260	109	105	155	49	46	92	148	79	175	84
-250	173	-43	127	154	177	264	267	227	173	213
-240	358	308	264	321	333	355	270	246	235	245
-230	115	57	219	134	99	138	236	74	133	161
-220	237	173	205	251	259	360	299	170	130	240
-210	152	127	157	-16	7	57	-63	32	72	-33
-200	57	149	-9	-54	212	39	-10	-94	-7	-109
-190	24	61	11	-46	57	59	122	92	-6	43
-180	135	101	74	131	150	172	40	27	114	227
-170	143	234	80	41	116	145	9	150	-2	143
-160	96	103	16	148	243	81	192	143	140	116
-150	39	17	96	53	-80	-12	65	57	-67	54
-140	115	159	-43	-20	95	36	-30	-76	222	-40

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-130	30	55	-74	-12	-47	7	101	-25	30	119
-120	109	49	113	1	36	-42	51	-43	-77	-27
-110	-94	-69	29	-147	-107	-3	85	-31	-107	99
-100	72	93	22	-3	0	23	-41	-34	-80	-93
-90	-38	-5	-2	-106	-28	-26	5	10	97	63
-80	115	84	85	136	167	168	87	19	82	95
-70	-43	-116	-100	7	-44	12	-79	-25	10	-34
-60	-35	-108	-58	-34	29	50	55	36	181	110
-50	94	26	17	119	51	80	96	113	-92	-215
-40	-95	-134	-119	-122	-204	-23	-150	-149	-125	-139
-30	68	-55	75	125	208	135	67	269	274	200
-20	182	325	289	225	261	333	-23	228	170	-64
-10	72	115	170	125	210	236	159	330	291	279
0	123	97	196	184	316	115	226	149	-53	-40
10	-116	-14	-13	45	2	21	47	-13	-12	53
20	-10	16	62	133	94	78	98	232	193	116
30	64	181	239	215	209	239	203	298	283	199
40	30	186	192	283	215	216	301	173	137	329
50	206	112	162	144	93	124	97	211	167	279
60	86	161	63	181	218	204	152	98	87	190
70	211	171	96	161	67	148	32	100	192	213
80	27	217	63	83	23	-97	-10	51	209	75
90	158	20	197	150	199	119	112	53	137	224
100	129	-9	15	145	63	60	108	237	129	185
110	138	92	187	170	45	143	206	116	185	108
120	115	64	165	151	52	73	123	104	61	76
130	18	98	228	84	122	103	122	187	142	277
140	186	140	146	219	6	70	46	81	84	81
150	-62	61	-3	19	100	142	55	107	129	148
160	187	207	161	27	77	87	68	106	34	98
170	141	79	85	94	79	-22	20	30	146	112
180	143	74	212	90	65	108	111	-13	109	48
190	167	129	111	12	96	-57	132	30	44	7
200	83	77	39	71	104	60	125	105	4	115
210	215	43	162	66	50	57	70	103	-121	110
220	19	-129	-29	80	2	17	130	-46	-46	186
230	-61	-28	35	-44	2	4	-176	-61	18	49
240	-11	154	135	40	120	95	61	-18	102	37
250	45	-2	179	46	-3	109	141	114	1	126
260	-27	29	149	37	74	-140	175	-57	-57	18
270	-128	15	90	59	-17	11	43	21	0	57
280	99	99	13	164	224	84	157	182	148	97
290	2	163	132	-5	104	96	41	120	140	29
300	-21	-74	-24	-44	-95	-99	-29	-48	-60	22
310	11	-89	8	107	-105	-49	-63	-74	-11	-33
320	2	64	-30	-43	20	-76	-13	-11	16	-130
330	97	6	-32	37	55	-55	-215	-14	42	-223

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340	-164	-84	-70	-171	-58	-198	-77	-65	5	-8
350	-62	44	-46	-41	-26	-71	-132	-123	-42	15
360	-44	39	-9	59	96	25	0	26	27	3
370	38	33	-121	75	82	52	25	21	98	-68
380	17	-55	-22	-50	42	91	37	-34	63	80
390	117	-32	-4	5	6	42	-40	40	101	142
400	148	231	164	159	180	23	240	225	207	154
410	176	99	49	-81	-104	11	-60	-126	-50	109
420	29	-135	59	125	97	148	113	274	230	340
430	399	209	143	92	214	230	33	159	174	42
440	128	176	209	155	232	192	177	110	166	311
450	297	307	306	307	83	181	154	210	156	-126
460	19	105	-30	61	-53	13	72	-14	17	-13
470	78	-113	69	153	-30	49	82	79	59	25
480	-30	-23	120	177	21	107	129	131	108	129
490	88	164	96	332	260	224	300	151	139	134
500	170	249	169	192	124	10	17	58	91	153
510	183	-1	62	128	58	1	33	75	53	89
520	21	40	-145	-21	-41	22	5	-43	17	55
530	9	108	-11	46	90	247	-357	-9	-94	-125
540	-162	-167	-235	-209	-254	-189	-154	-122	-86	-154
550	-137	-185	-106	46	-67	-92	19	-27	-1	88
560	-71	40	106	65	-71	-122	-62	-29	53	-83
570	20	60	78	183	-107	-101	-1	7	-52	-21
580	13	25	-40	-59	7	-32	154	152	131	-8
590	148	116	-21	6	15	54	30	19	-57	16
600	72	65	86	-43	207	85	95	15	-43	35
610	15	-61	5	101	-29	-59	143	-54	-125	38
620	106	-70	16	107	-31	99	4	-26	-63	-11
630	6	-56	37	82	56	47	56	98	99	78
640	11	151	-8	-1	23	146	15	-48	-67	79
650	-6	-63	99	-45	58	-116	63	83	-5	-41
660	-75	-37	-177	-16	-46	25	91	179	10	-49
670	44	116	44	50	33	65	-57	-49	34	-22
680	63	-28	96	106	110	-169	130	-59	-30	45
690	48	69	-100	-20	33	38	-8	34	-33	68
700	-26	58	33	95	13	10	-6	78	137	-5
710	-27	53	-67	54	94	-14	54	50	62	-45
720	-28	48	35	83	67	204	138	65	76	151
730	118	-9	12	19	107	48	-16	144	-18	45
740	23	-54	36	113	-63	-24	48	151	61	96
750	99	156	4	141	191	184	53	223	182	124
760	164	246	-28	163	130	132	-16	90	178	45
770	-24	191	42	-9	-15	127	-61	107	133	145
780	163	-14	40	-21	31	126	123	72	-46	-102
790	84	24	124	31	41	16	-68	-26	14	33
800	-239	-60	-73	-119	-141	-58	-5	-20	30	-81

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810	21	45	-82	65	-36	-74	50	-70	-90	-118
820	22	-27	-27	8	-160	-11	36	66	16	20
830	123	92	124	163	107	60	121	229	63	304
840	230	237	296	218	222	344	199	52	-12	184
850	189	-28	-46	19	11	113	-2	118	-63	-37
860	39	-68	-110	-16	-36	-129	-25	-23	0	53
870	-24	78	58	36	44	81	129	66	48	83
880	106	-56	17	124	59	90	9	186	86	50
890	138	289	81	52	148	134	68	177	49	226
900	-21	53	-24	-4	77	44	51	-20	94	131
910	235	307	395	179	27	168	111	172	188	278
920	134	15	158	124	97	-17	30	51	214	107
930	206	247	262	222	329	276	231	177	141	221
940	26	54	143	45	41	218	292	269	143	192
950	133	272	88	197	147	184	52	219	23	210
960	192	-65	84	237	189	44	138	150	72	240
970	222	220	358	212	142	211	108	215	242	34
980	70	120	298	153	98	7	211	230	94	16
990	240	113	100	45	223	167	83	282	193	206
1000	244	182	234	160	179	224	257	212	118	65
1010	89	129	93	66	104	4	117	40	139	253
1020	202	168	198	49	166	255	146	242	121	102
1030	253	175	19	139	173	111	136	221	13	100
1040	96	-8	9	95	92	81	9	6	100	89
1050	55	173	210	-63	47	75	102	114	218	133
1060	70	218	292	73	89	103	159	16	18	-13
1070	70	97	21	29	-8	7	78	-34	4	63
1080	21	-24	26	33	54	139	190	87	203	318
1090	78	296	395	249	183	21	-51	161	56	-49
1100	27	39	135	72	151	123	166	45	89	55
1110	-89	42	7	150	61	-28	15	-96	13	-88
1120	-12	-24	51	159	5	-86	141	-133	-119	-132
1130	-271	-100	-19	-141	-25	81	-18	-40	-98	-88
1140	19	60	-8	68	-46	-19	-66	37	60	81
1150	4	67	105	101	8	135	51	110	170	122
1160	170	221	230	188	252	242	172	179	264	155
1170	165	57	137	217	82	225	136	68	123	-16
1180	152	56	-89	99	118	94	-5	86	148	12
1190	60	43	-23	110	-92	-2	32	-73	-71	98
1200	35	-42	-9	42	110	18	-22	-73	-165	35
1210	-87	-12	114	32	75	-99	42	151	83	10
1220	5	181	-26	11	89	34	-152	137	-26	-142
1230	-157	-145	-189	-109	-47	19	-13	44	-103	-18
1240	-47	15	21	-15	44	62	-6	-117	-32	-19
1250	129	75	-56	215	116	144	72	166	69	-62
1260	-32	-27	-46	-101	12	-11	94	45	52	141
1270	125	81	171	60	-28	113	81	-61	-5	-24

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1280	-23	-47	-72	129	35	139	229	119	172	111
1290	27	21	2	52	19	135	-1	-8	175	82
1300	138	202	249	254	236	223	276	186	97	11
1310	45	85	28	-186	-183	66	163	-64	143	61
1320	13	29	39	32	-65	-67	-64	15	-162	23
1330	-173	136	-6	-106	126	-34	-45	-98	-138	13
1340	-13	-29	-40	53	-67	-67	-197	12	-208	-180
1350	-42	39	37	-89	134	39	113	14	-65	40
1360	-13	44	-10	-207	-48	47	186	24	111	2
1370	-59	114	163	30	201	3	15	24	7	118
1380	52	127	49	160	125	-81	138	126	87	-126
1390	21	117	34	-20	0	-31	108	-17	-23	103
1400	-20	10	89	60	163	224	216	114	171	264
1410	160	290	44	157	80	63	38	127	90	149
1420	88	97	-8	-51	184	180	69	86	93	130
1430	21	100	129	165	278	214	136	92	43	63
1440	18	49	98	8	8	64	44	6	73	65
1450	234	138	101	-185	-78	-45	-128	-188	-9	-85
1460	-56	-112	-21	-123	-80	-68	-98	-42	27	-11
1470	104	19	-70	-150	14	-58	-58	-35	-133	10
1480	-24	-13	-52	-130	-48	148	-34	-24	79	63
1490	126	162	156	110	193	41	203	28	70	90
1500	152	169	132	13	83	182	158	91	203	79
1510	46	157	158	168	-17	180	-87	59	133	152
1520	51	80	24	55	-94	4	84	-61	19	-52
1530	-40	15	85	138	93	72	37	142	168	171
1540	73	176	94	21	13	126	112	122	145	18
1550	26	104	47	119	28	96	80	-11	228	155
1560	176	205	154	196	253	163	125	-14	-5	90
1570	-3	-65	8	-8	-116	44	28	-30	-112	12
1580	-153	-91	-40	-15	-73	20	82	-123	-56	-78
1590	-145	-48	-53	-85	6	-27	-99	-24	-2	69
1600	38	-328	-129	-72	-137	-202	-96	-212	-179	-234
1610	-104	-88	-82	-35	-156	-178	-157	-11	-92	-39
1620	-178	21	25	-19	19	-56	86	25	54	174
1630	-38	62	-40	-260	9	-116	-9	-19	-158	-7
1640	140	-252	-105	-98	-125	-151	-39	-149	68	31
1650	5	52	109	21	70	275	110	127	180	51
1660	151	58	6	-57	154	126	26	-88	41	-97
1670	-1	86	-70	-18	-81	-147	-24	-18	2	31
1680	-150	-3	-3	58	101	41	8	-27	-75	197
1690	30	68	121	161	187	-94	-164	-89	56	-45
1700	49	-58	69	238	48	-162	-142	181	-158	-263
1710	-98	8	-25	0	3	40	-62	-60	-64	-173
1720	-106	-108	-74	-113	-56	49	-19	28	-152	-28
1730	110	-91	82	16	-88	-29	172	-64	168	74
1740	-30	-188	-77	-82	-5	-56	23	-102	17	-14

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1750	32	-7	169	115	139	272	105	243	80	137
1760	212	305	257	212	118	120	237	94	-36	-98
1770	-10	-68	-73	-15	71	103	109	28	80	54
1780	142	-41	29	-73	-86	-53	-128	-123	-33	2
1790	-182	-64	-64	-67	-84	-74	-36	-39	38	145
1800	-129	24	-38	-70	82	44	-137	-32	32	34
1810	-61	-13	-144	-94	-18	-46	24	16	90	225
1820	69	-149	-18	192	105	-4	369	278	244	250
1830	168	372	124	136	180	53	65	-161	-25	-123
1840	-91	-125	-37	-5	-22	85	64	161	40	-1
1850	50	72	206	112	331	251	41	19	258	83
1860	157	251	106	75	60	13	17	-47	-11	-63
1870	-12	-62	36	148	-62	61	177	81	56	142
1880	25	-134	119	236	149	48	86	80	-47	81
1890	147	106	-80	-7	129	163	147	155	220	84
1900	-16	263	-27	-162	-156	-78	-42	-42	74	-50
1910	-44	-83	68	37	163	152	129	117	258	156
1920	192	147	325	148	246	355	213	283	-36	31
1930	416	201	107	248	439	184	135	528	382	313
1940	216	415	264	331	362	415	347	453	393	380
1950	501	341	255	430	282	280	204	262	150	291
1960	390	177	115	108	263	91	138	221	153	244
1970	282	146	299	340	161	225	341	202	232	261
1980	278	91	146	219	72	288	247	101	261	276
1990	246	235	164	164	270	104	97	276	59	200

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Table S3. List of cold events shown in Figure 2a–c, calculated from tree-data in Table S2, tabulated as two-year events (a), 5-year events (b) and 10-year events (c), grouped into those before and after AD 1250. The BC/AD timeline does not have 'year zero'.

(a)

Two-year events 1000 BC to AD 1249	Z-score	Two-year events AD 1250-1900	Z-score
AD 543...544	-2.31	AD 1601...1602	-2.29
AD 1129...1130	-2.01	AD 1708...1709	-2.10
AD 339...340	-1.93	AD 1348...1349	-1.94
328...327 BC	-1.70	AD 1313...1314	-1.84
38...37 BC	-1.63	AD 1641...1642	-1.78
420...419 BC	-1.62	AD 1231...1232	-1.67
875...874 BC	-1.58	AD 1456...1457	-1.58
AD 800...801	-1.50	AD 1719...1720	-1.40
657...656 BC	-1.39	AD 1741...1742	-1.32
108...107 BC	-1.27	AD 1695...1696	-1.29
AD 356...357	-1.27	AD 1363...1364	-1.28
AD 236...237	-1.19	AD 1786...1787	-1.26
844...843 BC	-1.18	AD 1580...1581	-1.22
806...805 BC	-1.13	AD 1207...1208	-1.19
70...69 BC	-1.08	AD 1812...1813	-1.19
AD 661...662	-1.07	AD 1674...1675	-1.14
AD 574...575	-1.04	AD 1472...1473	-1.10
AD 818...819	-1.04	AD 1840...1841	-1.08

(b)

Five-year events 1000 BC to AD 1249	Z-score	Five-year events AD 1250-1900	Z-score
AD 541...545	-2.11	AD 1605...1609	-1.84
AD 1127...1131	-1.51	AD 1229...1233	-1.48
AD 339...343	-1.42	AD 1641...1645	-1.46
42...38 BC	-1.37	AD 1345...1349	-1.28
AD 800...804	-1.26	AD 1453...1457	-1.25
331...327 BC	-1.08	AD 1719...1723	-1.15
		AD 1705...1709	-1.09
		AD 1837...1841	-1.05

(c)

Ten-year events 1000 BC to AD 1249	Z-score	Ten-year events AD 1250-1900	Z-score
AD 536...545	-1.80	AD 1601...1610	-1.69
42...33 BC	-1.34		
AD 336...345	-1.15		
330...321 BC	-1.02		

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