Dark Ages Cold Period: a literature review and directions for future research

Abstract

Several late Quaternary studies have recorded cold and disturbed climates centred during the mid-first millennium AD and discussed these conditions under the term 'Dark Ages Cold Period' (DACP). A review of 114 palaeoclimate papers indicated that cold climates were common in the Northern Hemisphere between AD 400 and 765. There are also suggestions that some regions may have been relatively wet during the DACP while those around the Mediterranean and the China/Tibetan Plateau indicate coinciding droughts. A set of environmental responses, on the other hand, indicate a delayed DACP interval (AD 509-865) postdating the actual climate signal. Previously, the DACP has been linked with the North Atlantic ice-rafting event at about 1400 years ago while some evidence suggests an involvement of the North Atlantic Oscillation and/or El Niño-Southern Oscillation. More recently another proposed phase of widespread cooling, the Late Antique Little Ice Age (LALIA), overlaps with the DACP, and has been tentatively linked with volcanic aerosol and solar irradiance variations reinforcing the climatic downturn since AD 536. Importantly, a higher number of proxy records extending over the first millennium AD is required for more rigorous assessments of climate variability and the forcing during these centuries, and to disentangle the DACP and LALIA fingerprints in the proxy data, particularly to determine whether the DACP and the LALIA are distinct features. Also a richer network of both climate

and environmental proxies is needed to evaluate the human-environment interactions, during the historical Migration Period, and thus through the DACP.

Keywords: palaeoclimatology, North Atlantic Oscillation, El Niño-Southern Oscillation, ice rafted debris events, Late Antique Little Ice Age, volcanic forcing

Dark Ages Cold Period – key issues

Much has been written about late Holocene climate variability. An increasingly large number of proxy datasets have been analysed to reduce the uncertainties in estimating pre-industrial climate variability (Jones et al., 2001; Jones and Mann, 2004; Mann et al., 2009; Neukom et al., 2014; Wilson et al., 2016). Placing these variations in the context of ongoing change and determining their relative magnitudes shows a large representation of long-term climate features such as a putative ‘Medieval Warm Period’ (MWP) and a cooler ‘Little Ice Age’ (LIA), at least for Northern Hemisphere. Less attention has been paid to climate variability during the first millennium AD. Existing analyses show evidence for markedly variable climate through this millennium with greater proxy indications for cold events and glacier advances (Wanner et al., 2008, 2011). Magnitude and geographical spread of these variations remain, however, more poorly understood than those that took place during the later MWP and LIA. Yet, there is a growing interest to explore the first millennium AD human-environmental interactions (Büntgen et al., 2011, 2016). Probably the most frequently discussed climate anomaly of the first millennium is that commonly identified as the ‘Dark Ages Cold Period’ (DACP). Collectively, there seems to be a number of proxy indications for perturbed climates at some time before the MWP. But when exactly have these climatic events been recorded and where? Was the DACP characterized by changes only in temperature? And what are the possible forcings behind this period?

Here we aim to present a perspective on climate variability during the DACP based on literature published in international English-language peer-reviewed journals. In this context, a total of 114 palaeoclimate papers (a search was performed for ‘Dark Ages Cold Period’ and, separately, for ‘Dark Age Cold Period’ by Google Scholar (http://scholar.google.com/), accessed June 1st, 2016) were found to specify some sort of climatic and/or environmental changes during the DACP (Supplementary Appendix 1 and Table S1, available online). This approach enabled evaluation of the DACP with respect to its proxy indications. At first glance, the review of these papers appears to support the premise of the DACP. Consistent with expectations, a majority of these papers suggests a change to a colder climatic regime (Figure 1a), with no restriction to any certain geographical region (Figure 1b) or proxy type (Figure 1c), recorded in the mid-first millennium AD (Figure 1d). This first look appears to support the idea of the DACP as a climate anomaly with generally lowered temperatures and potentially wide-geographical spread, albeit with a strong emphasis towards European and North Atlantic studies, which is partly related to the greater amount of evidence and studies from these areas. A more precise analysis reveals, however, several interesting aspects that complement, and some that contrast with this picture of the DACP.

Origins of the DACP concept

Some of the early accounts of anomalous climate conditions during the mid-first millennium AD were made by H.H. Lamb. Combining various types of proxy indications, Lamb (1982, 1995) identified “generally rather colder and more disturbed climate” especially in Europe. He placed these changes in the timeline of the written historical period referred to as Dark Ages, broadly between AD 400 and 900, with tangible evidence indicating advancing glaciers having cut an old Roman route in the Alps. In fact, the works by Lamb (1965, 1977, 1982, 1985, 1995) appear most often cited (17 out of 114 papers) when referring to the DACP. Among other investigators, Blackford and Chambers (1991) studied peat stratigraphy in the British Isles and showed multi-site indications towards wet/cold conditions around AD 550. Proxy evidence of cold climates was also found by Hass (1996) in his palaeoceanographic study in the North Sea between AD 400 and 700. Later, McDermott et al. (2001) described temperature-driven changes in an Irish speleothem $\delta^{18}O$ record showing a cold phase bracketed by relatively warmer Roman and Medieval periods (Figure 1d), for which they used the term 'Dark Ages Cold Period' but gave no detailed age ranges for the period. Yet another study, commonly cited for the DACP, appears that of Ljungqvist (2010) who compiled multi-proxy evidence around the extra-tropical Northern Hemisphere for the past two millennia (Figure 2a). In all, 37 out of 114 papers cite at least one of the foregoing papers when referring to the DACP. Even a larger proportion of papers (39 out of 114), however, make no citation to any previous literature when discussing the DACP, an approach that is also common to discussions of the MWP and the LIA. This situation is likely reflected in those viewpoints that classify DACP as an event for which chronology and wider significance are not yet well defined anywhere but are still a matter of debate (e.g. Eiríksson et al., 2006). Clearly, there is a need for studies combining evidence on the specifics of the DACP, such as this study.

Characterising the DACP climates

The DACP event has been generally regarded as cold, in more than half of the papers (55 percent), these findings representing studies around Europe, in addition to North Atlantic, Arctic regions, North America, China/Tibetan Plateau, and the northern Pacific (Figure 3). DACP conditions have been attributed not only to cold climates (Figure 1a), but in 20 percent of papers the event has also been linked with hydroclimatic changes (wet, dry, or unspecified change), most often with wet or moist conditions (11 percent). The majority of these wet events (79 percent) originated from various locations in Europe or North Africa. Dry conditions (7 percent), on the other hand, were demonstrated equivalently for the Mediterranean and the China/Tibetan Plateau (Figure 3).

More detailed chronological examination of DACP indications showed an average (median) starting and ending dates of AD 410 (AD 450) and AD 775 (AD 800) for the event, respectively (Figure 1e). Similarly, the DACP was found to have lasted, on average, for 366 (350) years. In a limited set of papers providing a date for the most extreme phase of the DACP an average (median) was given as AD 625 (650). We note that these age estimates, especially the onset dates, fall fairly close to the historically-based ranges already outlined from a less extensive set of observations by Lamb (1982, 1995).

Dividing the data into climatic (n = 96) and environmental (n = 16) indications suggested an earlier climatic start to the event, with a mean year of AD 395, in comparison to that of AD 509 as evident in palaeoenvironmental data (Figure 1e). A parallel difference was observed for the terminal years of the event, with mean years of AD 764 and AD 865, for palaeoclimate and environmental data, respectively. Both of these differences were found to be significant (*t*-test, $p < 0.05$). In these comparisons the environmental changes included glacial expansions, aeolian, coastal, and soil processes, in addition to changes in forested and aquatic ecosystems. It is possible that this delay represents the lag in these responses to an actual climatic change.

Making similar comparisons between the temperature and hydroclimate indications suggested an earlier starting year for hydroclimate (AD 356) than temperature proxies (AD 414). This difference did not, however, show statistical significance at any reasonable level. Also the difference between the terminal years was relatively unremarkable (Figure 1e).

Ocean-atmospheric interactions

Palaeoceanographic proxy data (e.g. foraminifera, alkenone) are well represented amongst DACP studies (Figure 1c), implying that DACP climates may involve ocean-atmosphere interactions. In fact, the DACP phase has been frequently (Berglund, 2003; Reimann et al., 2011; Oliva and Gómez-Ortiz 2012; Cui and Chang, 2013; Ülgen et al., 2012; Zhong et al., 2014; Li et al. 2016; Rudaya et al., 2016; Ruiz-Fernández et al., 2016) interpreted in the context of a North Atlantic event of ice-rafting debris (IRD) at about 1400 years ago (Figure 2b) (Bond et al., 1997), during which cooler surface waters had advected southward. According to this evidence, the IRD event at about 1400 years ago belongs to a series of similar events and climatic shifts through the Holocene with a cyclicity close to 1470 ± 500 years. The most recent such cycle being broadly in accord with the MWP and LIA phases (Bond et al., 2001). Solar forcing of these events was initially suggested, with a potential amplification mechanism through thermohaline circulation (Bond et al., 1997, 2001).

Solar proxy data (Steinhilber et al., 2009) consistently illustrate low activity between AD 400 and 700, with a notable seventh-century solar minimum (Figure 2c), the millennial-scale solar changes culminating over these centuries and thus during the DACP (Scafetta, 2012). Interestingly, there is multiple proxy evidence showing that reduced solar activity may modulate the North Atlantic Oscillation (NAO) towards its negative phase (Gray et al., 2010).

Since the NAO is a leading pattern of climate variability in the global atmosphere, and the negative NAO phase is generally associated with cooler temperatures particularly over western Europe and eastern North-America for both the winter (Wanner et al., 2001; Hurrell and Deser, 2010) and summer seasons (Folland et al., 2009), a prolonged negative NAO phase could thus result in cold temperatures at least over some parts of the Northern Hemisphere continents.

The only indications of warm DACP climates appear to originate from Greenland (Figure 3) and thus from a region central to the NAO temperature seesaw (Andresen et al., 2010; Ribeiro et al., 2012) whereby cooling over western Europe is associated with warming over Greenland (van Loon and Rogers, 1978), especially during the winter half of the year as also observed for instrumental temperature trends since the mid-nineteenth century (Jones et al., 2014). These findings would generally agree with the suggestion of negative NAO phase during the DACP. Alternative explanatory mechanisms (Krawczyk et al., 2010) are required to explain the coinciding proxy indications of cold and warm DACP conditions off the West Greenland margin. However, we note that the longest existing reconstructions of the NAO-index (Olsen et al., 2012; Baker et al., 2015; Faust et al., 2016) do not illustrate any striking agreement over the DACP period but they do exhibit negative indices at some point during the DACP (Figure 2d, e, f).

Coexisting cold/wet conditions at European sites during the DACP (Figure 3) are consistent with the earlier studies of peat humification from the British Isles (Blackford and Chambers, 1991). When the seasonal sensitivity of these proxy records is specifically stated, the wet DACP conditions appear to reflect spring and summer seasons (Helama et al., 2009; Swierczynski et al., 2012; Grauel et al., 2013). The NAO effects during the warm-season are less extensively studied than those for the winter-season (Hurrell, 1995; Jones et al., 1997), however, highly negative correlations between the instrumentally based NAO-index and precipitation prevail largely for the British Isles and northern Europe, in contrast to weaker, negative correlations for the southern part of the continent (Folland et al., 2009). These issues raise the critical question of seasonality in proxy responsiveness, especially regarding the NAO-reconstructions (Jones et al., 2014). While the longest NAO-reconstructions are indicative of variations in the winter season (Olsen et al., 2012; Baker et al., 2015; Faust et al., 2016), the existing reconstructions of summer-NAO-index (Linderholm et al., 2008; Folland et al., 2009) remain too short to extend over the DACP interval. Consequently, there is a need for developing longer and seasonally specific reconstructions for the winter and summer half years (Jones et al., 2014).

A range of DACP indications of Pacific origin (Figure 1b; Figure 3) suggests that the event may have extended to areas quite distant from the key regions of the NAO. Climatic oscillations similar to that of IRD cyclicity of 1470-years in the North Atlantic (Bond et al., 1997, 2001) have been reported in the North Pacific Gyre system (Isono et al., 2009), with a possibility of a climatic link between the North Pacific Gyre Oscillation (NPGO; Di Lorenzo et al., 2008) and the North Atlantic component of the thermohaline circulation (Isono et al., 2009). The low-frequency NPGO is driven by the central tropical Pacific El Niño mode of sea surface temperatures (SST) and affects the climate variability over Eurasia and North America (Di Lorenzo et al., 2008, 2010). A recently produced 2000-year-long reconstruction of El Niño-Southern Oscillation (ENSO) variability suggests La Niña-like SST mean state (basin-wide cooling of the tropical Pacific) during the DACP (Figure 2g) (Yan et al., 2011). This would be qualitatively consistent with observation of Conroy et al. (2008) in a set of independent ENSO-sensitive proxy records showing higher ENSO frequency and longer, stronger El Niño events (warming of the tropical Pacific), between 2000 and 1500 years ago,, i.e. the centuries predating the DACP event. Moreover, in one of these records (Moy et al., 2002) the periods of low ENSO activity were seen to follow the events in the North Atlantic (Bond et al., 1997, 2001). Despite this broad acceptance, the hardships of reconstructing the low-frequency band of ENSO variability have been recognised (Wilson et al., 2009; Yan et al., 2011). As a result, a pressing need remains for extending the network of proxy records, sensitive to a range of climate/environmental parameters (temperature, precipitation, salinity) reflecting the various aspects of ENSO effects at local/regional scale, spanning not only the second but also the first millennium AD.

Late Antique Little Ice Age

Recently, a collection of multi-proxy evidence illustrated a cooling phase around the Northern Hemisphere which was tree-ring dated to AD 536-660 and termed the Late Antique Little Ice Age (LALIA) (Büntgen et al., 2016). This event was shown to follow a multitude of large unknown volcanic eruptions in AD 536, 540 and 547, for which evidence was derived from bipolar ice-core timescales and sulphur records (Figure 2h) (Sigl et al., 2015). The cooling, having once initiated from volcanic aerosol forcing (Larsen et al. 2008), may have been sustained over extended intervals possibly because of the coinciding solar minimum and through sea-ice/ocean feedback mechanisms (Büntgen et al., 2016; Matskovsky and Helama, 2016), analogous to findings from equivalent proxy data (Gennaretti et al., 2014) and transient climate model simulations (Miller et al., 2012) during the LIA. Despite there being no mention of the DACP given by Büntgen et al. (2016), both the common signal of large-scale cooling and the overlap of the LALIA (i.e. AD 536-660) and the DACP (i.e. AD 410-775) climatic episodes are eye-catching. It seems odd therefore to invoke a new cold period such as the LALIA within a previously defined cold period, the DACP! Whereas the DACP has frequently been deduced in the context of North Atlantic ice rafted debris events representing, if true, a continuum of natural variability through the Pleistocene and Holocene climates, the LALIA has been suggested as being triggered by volcanic forcing and would represent an episodic phase of abrupt cooling. It is likely that all these signals are superimposed within the palaeoclimatic archive, so it is important to combine the diverse proxy records as opposed to looking at just one type of proxy record (trees in this case) when considering large-scale averages. Obviously, there remains a pressing need for more detailed analyses of climate variability over these centuries, taking into account the hypothesised forcings behind both the LALIA and DACP. Such work is necessary to determine the nature of the climate during these events and the effect this may have caused on a series of societal unrest and humanitarian crises in both the western and eastern zones of Eurasia (Büntgen et al., 2011, 2016). Additionally, both the LALIA and DACP overlap with the Migration Period, the years AD 400-600 being regarded as one the 'hinges' of human history (Randsborg, 1991). The role of climatic perturbations in these multifaceted societal events remains, however, largely undiscussed (Haldon, 2016).

From past to future DACP studies

The first millennium AD was characterised by cold and disturbed climates. Climatic events discussed under the term 'Dark Ages Cold Period' represent various geographical regions and types of palaeoclimate information (Figure 1). Yet, these variations remain far less studied in comparison to the second millennium AD climate cooling, the LIA (Bradley and Jones, 1992, 1993; Matthews and Briffa, 2005). Interestingly, the DACP and LIA have both been characterised by predominantly cool climates, hydroclimatic changes, glacier advances, and may be tentatively linked with reduced solar activity, changes in ocean-atmospheric circulation patterns (i.e. NAO, ENSO), and the North Atlantic ice rafted debris events. Moreover, tree-ring evidence suggests increases in volcanic forcing at least during the mid-sixth century AD. Similar to the LIA evidence (Bradley and Jones, 1992), however, the DACP literature shows no evidence for a synchronous multi-centennial coldness prevailing around the Northern

Hemisphere and the globe. This evidence notwithstanding, there appears no consensus in the literature about which of the forcings may have dominated in triggering/sustaining the climatic changes, nor even the chronology of the event. As with the LIA, it is likely to be a combination of a number of factors, particularly volcanic and solar forcing. In this paper, we have specifically assessed proxy evidence from palaeoclimate literature for climatic events referred to as DACP. As a result, the intervals AD 400-765 and AD 509-865 were defined for climatic and environmental DACP representations, respectively, from a wide variety of proxy data. We are under no illusion that the approach is perfect. The results, however, outline and categorise the characteristics of the anomalies that palaeoclimatologists have identified as DACP climates with implications for those factors that may have influenced the climatic/environmental changes as their forcings.

Continuing needs for developing proxy datasets over the first millennium AD are evident for more rigorous examination of the DACP (and LALIA) signals, their coherence and spatial structure in palaeoclimate analyses at regional, hemispheric and global scales. Dating accuracy is an important issue in the development of these concepts. Oceanic links are almost certainly needed to help explain the solar influence behind the climatic changes, yet, the proxy records from these archives should be dated to similar accuracy as the terrestrial records indicative of DACP and LALIA signals. Environmental proxies are needed to evaluate the human-environmental interactions during the historical Migration Period. Some weight should be assigned in particular in the developing network of proxy records (also non-temperature) to differentiate the winter and summer half years for the key regions of the NAO and ENSO. Only more extensive data will detail the variable nature of these circulation modes on large-scale averages, particularly their low-frequency phases, to enable validations of their roles behind the first millennium AD climate anomalies.

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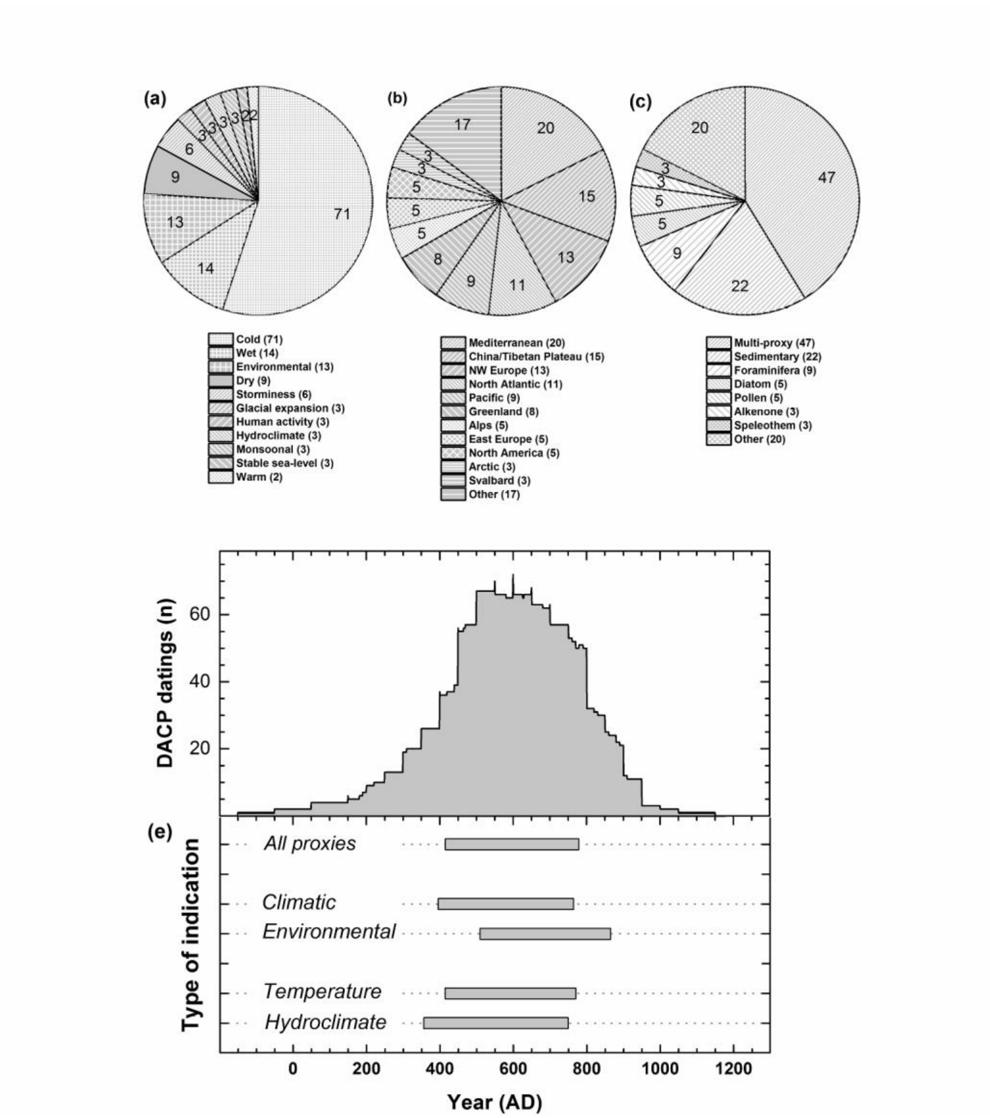
FIGURE CAPTIONS

Figure 1. Proportions of different climatic and environmental characteristics attributable to Dark Ages Cold Period (DACP) in the palaeoclimate literature (a), with corresponding proportions of geographical regions (b) and proxy type (c), and the temporal distribution of dating placements shown as bars covering a window with average starting and ending dates attributable to corresponding climatic and environmental events (d).

Figure 2. Reconstructed extra-tropical Northern Hemisphere (90–30°N) decadal mean temperature relative to the 1961-1990 (Ljungqvist, 2010), the stacked North Atlantic multi-core record of percent hematite stained grains (% HSG) indicative of ice-rafted debris (IRD) events corresponding to the Little Ice Age (IRD-0) and Dark Ages Cold Period (IRD-1) (Bond et al., 2001), the ice-core derived solar forcing as total solar irradiance (ΔTSI) (Steinhilber et al., 2009), the proxy records indicative of the North Atlantic Oscillation (NAO) based on stalagmite band widths (Baker et al. 2015), and lake (NAO_{PCA3}) (Olsen et al., 2012), and fjord sediments (NAO_{TFJ}) (Faust et al., 2016), the reconstructed Southern Oscillation-index (SOI_{pr}) (Yan et al., 2011), and the ice-core derived global volcanic forcing (GVF) (Sigl et al., 2015). The timeframes of the Dark Ages Cold Period (AD 400-765) and the Late Antique Little Ice Age (AD 536-660) are illustrated as areas of light and dark grey shading, respectively.

Figure 3. Geographical distribution of different climatic and environmental characteristics attributable to Dark Ages Cold Period (DACP) in the palaeoclimate literature shown for regions with at least five indications including Mediterranean, China/Tibetan Plateau, NW Europe, Greenland, North Atlantic, Pacific, East Europe, North America, and Alps.



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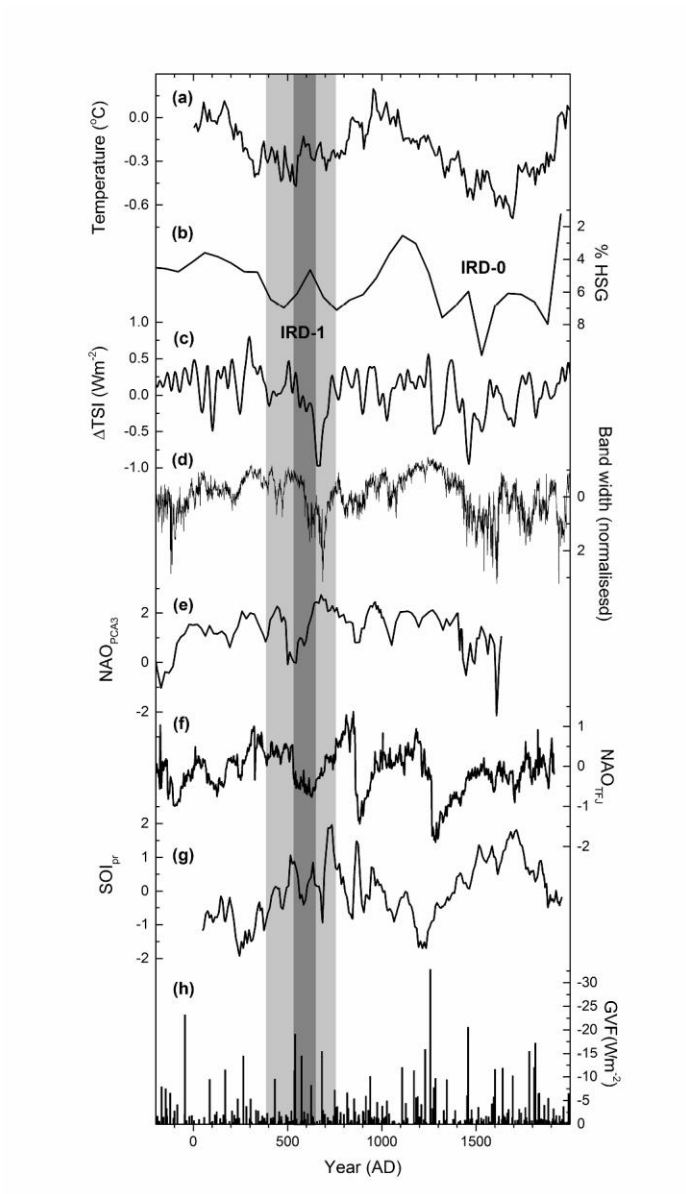
277x307mm (300 x 300 DPI)



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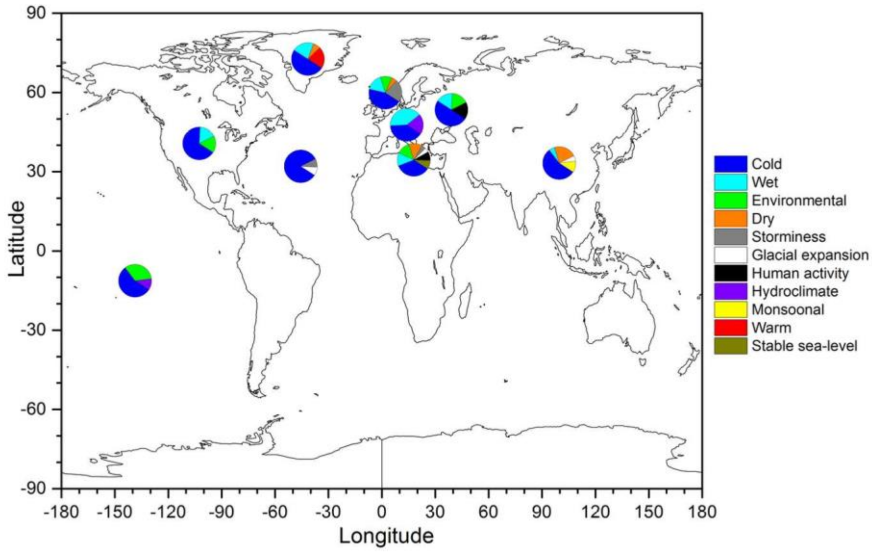
292x505mm (300 x 300 DPI)



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140x92mm (300 x 300 DPI)

Dark Ages Cold Period: a literature review and directions for future research

Samuli Helama, Phil D. Jones, Keith R. Briffa

Supplementary Appendix 1

Palaeoclimate literature

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Dark Ages Cold Period: a literature review and directions for future research

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Supplementary Table

Table S1. Characteristics of the Dark Ages Cold Period (DACP) in 114 palaeoclimate papers (Ref; see Supplementary Appendix 1), with proxy type (MPR – multi-proxy, SED – sedimentary, FOR – foraminifera, DIA – diatom, POL – pollen, ALK – alkenone, SPE – speleothem, OTH – other), geographical regions (MED – Mediterranean, CTP – China/Tibetan Plateau, NWE – NW Europe, GRE – Greenland, PCF – Pacific, ALP – Alps, EAE – East Europe, NAM – North America, ARC – Arctic, SVB – Svalbard, OTH – other), starting date (Year-1), most extreme phase of the DACP (Year-2), ending date (Year-3), and the actual proxy indications.

Ref	Proxy	Region	Year-1	Year-2	Year-3	Indications
1	MPR	GRE	-50	n/a	450	warm
2	MPR	GRE	n/a	n/a	n/a	cold
3	OTH	OTH	n/a	n/a	n/a	wet
4	MPR	MED	650	n/a	950	dry
5	MPR	MED	500	n/a	800	human activity
6	POL	NWE	500	n/a	600	cold
7	SED	NWE	400	n/a	700	cold, wet, storminess
8	OTH	ALP	450	n/a	800	hydroclimate
9	OTH	OTH	450	n/a	950	cold
10	MPR	NWE	350	n/a	820	dry
11	MPR	CTP	400	n/a	700	cold
12	SED	EAE	n/a	n/a	n/a	cold, wet
13	MPR	OTH	300	n/a	800	cold
14	SED	NWE	n/a	n/a	n/a	environmental
15	SED	MED	450	n/a	900	cold
16	MPR	MED	465	n/a	890	cold, wet
17	OTH	EAE	500	n/a	1000	cold, glacial expansion
18	MPR	CTP	420	n/a	550	cold, dry, monsoonal
19	SED	MED	400	n/a	800	storminess
20	SED	OTH	181	n/a	625	wet
21	MPR	MED	450	n/a	950	cold, human activity
22	MPR	NWE	780	n/a	880	cold, storminess
23	MPR	NAT	400	n/a	800	cold
24	MPR	NAT	n/a	n/a	n/a	cold
25	MPR	GRE	350	n/a	800	cold
26	OTH	MED	550	n/a	770	stable sea-level
27	DIA	PCF	600	n/a	800	environmental
28	MPR	MED	600	n/a	800	glacial expansion
29	MPR	CTP	221	n/a	580	dry
30	MPR	NAT	n/a	500	n/a	cold
31	FOR	MED	500	n/a	750	wet
32	MPR	SVB	600	n/a	800	environmental

33	FOR	NAT	400	n/a	800	cold
34	MPR	ARC	600	n/a	900	cold
35	SED	OTH	300	n/a	400	cold
36	SED	CTP	50	n/a	700	wet
37	ALK	CTP	50	n/a	700	cold
38	OTH	NWE	n/a	800	n/a	wet
39	DIA	PCF	150	n/a	600	cold
40	OTH	ALP	n/a	n/a	n/a	cold
41	ALK	PCF	n/a	500	n/a	cold
42	OTH	EAE	n/a	n/a	n/a	cold
43	SED	CTP	-150	n/a	150	dry
44	MPR	CTP	n/a	n/a	n/a	cold
45	FOR	NAT	n/a	n/a	n/a	cold
46	FOR	PCF	450	n/a	750	environmental
47	MPR	ARC	600	n/a	900	cold
48	SED	OTH	700	n/a	900	environmental
49	DIA	PCF	310	n/a	650	cold
50	DIA	GRE	450	n/a	650	cold
51	POL	NAM	350	n/a	650	cold
52	SED	NWE	550	n/a	900	cold
53	MPR	NAT	n/a	600	n/a	cold
54	OTH	NAM	n/a	n/a	n/a	cold
55	ALK	CTP	450	n/a	850	cold
56	SED	CTP	250	n/a	880	glacial expansion
57	SED	CTP	350	n/a	600	cold
58	MPR	CTP	450	n/a	850	cold
59	MPR	OTH	300	n/a	800	cold
60	MPR	OTH	300	n/a	800	cold
61	MPR	MED	550	n/a	860	cold
62	SPE	MED	300	n/a	600	cold
63	SPE	NWE	n/a	n/a	n/a	cold
64	OTH	GRE	440	n/a	910	cold, dry
65	OTH	ALP	400	n/a	680	cold
66	FOR	MED	400	n/a	700	cold
67	MPR	OTH	200	n/a	900	wet
68	FOR	NAT	n/a	700	n/a	cold
69	SED	NAM	300	n/a	800	cold, wet
70	MPR	MED	600	n/a	800	cold
71	MPR	MED	450	n/a	950	environmental
72	OTH	NWE	450	n/a	950	storminess
73	MPR	OTH	400	n/a	800	cold
74	OTH	NAT	400	n/a	600	cold
75	OTH	MED	450	n/a	950	environmental
76	OTH	SVB	450	n/a	850	cold
77	FOR	SVB	450	n/a	850	cold
78	MPR	NWE	470	n/a	760	cold, storminess
79	POL	GRE	500	n/a	1050	warm
80	SED	NAM	n/a	n/a	n/a	environmental

81	POL	OTH	600	n/a	700	cold
82	MPR	MED	n/a	800	n/a	environmental
83	OTH	NWE	500	n/a	790	cold, environmental
84	MPR	PCF	500	n/a	900	environmental
85	FOR	OTH	350	n/a	950	cold
86	SED	GRE	450	n/a	650	cold
87	POL	NWE	450	n/a	550	cold
88	DIA	GRE	440	n/a	830	cold
89	MPR	ARC	630	n/a	770	cold
90	MPR	NAT	500	n/a	800	cold
91	SED	NAT	n/a	n/a	n/a	cold
92	MPR	EAE	350	n/a	750	human activity
93	MPR	CTP	201	n/a	550	cold
94	OTH	EAE	n/a	n/a	n/a	environmental
95	MPR	MED	n/a	n/a	n/a	stable-sea level
96	SED	ALP	250	n/a	600	wet
97	SED	ALP	450	n/a	750	wet
98	MPR	NWE	550	n/a	n/a	wet
99	OTH	OTH	n/a	n/a	n/a	hydroclimate
100	OTH	OTH	n/a	n/a	n/a	cold
101	MPR	NAT	150	n/a	650	storminess
102	MPR	NAM	500	n/a	800	cold
103	MPR	MED	n/a	n/a	n/a	wet
104	SED	CTP	450	n/a	1150	cold
105	MPR	OTH	n/a	n/a	n/a	environmental
106	FOR	OTH	n/a	700	n/a	cold
107	SED	MED	n/a	400	n/a	cold, dry
108	OTH	PCF	400	n/a	550	cold
109	MPR	OTH	n/a	n/a	n/a	monsoonal
110	MPR	PCF	400	n/a	800	cold
111	MPR	PCF	500	n/a	900	hydroclimate
112	SED	MED	650	n/a	900	dry
113	SPE	CTP	190	n/a	850	monsoonal
114	MPR	CTP	250	n/a	950	cold, dry