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The 4.2 ka BP event in the Levant

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Abstract. The 4.2 ka BP event is defined as a phase of environmental stress characterized by severe and prolonged drought of global extent. The event is recorded from the North Atlantic through Europe to Asia, leading scientists to evoke a 300-yr global mega-drought. Focusing on the Mediterranean and the Near East, this abrupt climate episode radically altered precipitation, with an estimated 30-50% drop in precipitation in the eastern basin. While many studies reveal similar trends in the northern Mediterranean (from Spain to Turkey and the northern Levant), data from northern Africa and central/southern Levant are more nuanced, suggesting a weaker imprint of this climate shift on the environment and/or different climate patterns. Here, we provide a synthesis of environmental reconstructions for the Levant and show that, while the 4.2 ka BP event also corresponds to a drier period, a different climate pattern emerges in the central/southern Levant, with two dry phases framing a wetter period, suggesting a W-shaped event, particularly well defined by records from the Dead Sea area.

1 Introduction

While severe climate changes have been recorded during the Holocene (e.g. Mayewski et al., 2004; Wanner et al., 2008; Magny et al., 2013; Solomina et al., 2015; Guiot and Kaniewski, 2015) with uncertain overall effects, one period of increasing aridity, termed the 4.2 ka BP event (e.g. Weiss, 2016, 2017), has fueled debates on the causal link between climate shifts and societal upheavals during the Bronze Age (e.g. Finné et al., 2011; Butzer, 2012; Clarke et al., 2016). The 4.2 ka BP event, that lasted ~300 years (from 4200 to 3900 cal yr BP), is probably one of the Holocene's best studied climatic events (e.g. Weiss et al., 1993; Cullen et al., 2000;

deMenocal, 2001; Weiss and Bradley, 2001; Staubwasser and Weiss, 2006; Weiss, 2017; Manning, 2018; and references therein), although its chronology may be much broader than traditionally reported, extending from 4500 to 3500 BP (Gasse, 2000; Booth et al., 2005). This phase of aridity, considered as a global event (Booth et al., 2005, 2006; Fisher et al., 2008; Baker et al., 2009; Wanner et al., 2011, 2015), is now used as a formal boundary between the Middle and Late Holocene (Walker et al., 2012; Zanchetta et al., 2016; and Letter from the International Union of Geological Sciences) while, according to Arz et al. (2006), most records show a gradual climate shift rather than a specific abrupt event. Drought concurs widespread cooling in the North Atlantic from 4300 to 4000 BP, as attested in Iceland (lake Hvítárvatn and lake Haukadalsvatn; Geirsdóttir et al., 2013; Blair et al., 2015). The event is also characterised by two short spikes of negative-type North Atlantic Oscillations (NAO) at 4300 and 3950 BP (Olsen et al., 2012). During this interval, the Atlantic subpolar and subtropical surface waters cooled by 1° to 2°C (Bond et al., 1997, 2001; Bianchi and McCave, 1999; deMenocal, 2001).

Focusing on the 4.2 ka BP event in the Mediterranean, a detailed vegetation model-based approach shows that a significant drop in precipitation began ~4300 BP in the eastern basin. These drier conditions lasted until 4000 BP with peaks in drought during the period 4300-4200 BP (Guiot and Kaniewski, 2015). Based on these model data, the Western Mediterranean was not significantly affected by the precipitation anomaly. A climate model-based approach (step of 2000 years) previously developed by Brayshaw et al. (2011) also indicates that the Eastern Mediterranean was drier while the whole Mediterranean exhibited an increase in precipitation for the period 6000-4000 BP. A bipolar east-west "climate see-saw" was proposed to explain these contrasting spatio-temporal trends during the last millennia, with the hydro-climatic schemes across the basin determined by a combination of different climate modes (Roberts et al., 2012). It has been argued that the 4.2 ka BP event resulted from changes in the direction and intensity of the cyclonic North Atlantic westerlies, controlled by the NAO (e.g. Cullen et al., 2002; Kushnir and Stein, 2010; Lionello et al., 2013). These westerlies mediate moisture transport across the Mediterranean and West Asia (see full map in Weiss et al., 2017), and, in the Mediterranean, interact with the tropical (monsoonal) climatic system (e.g. Rohling et al., 2002; Lamy et al., 2006; Lionello et al., 2006; Magny et al., 2009). The “climate see-saw” model further suggests that precipitation regimes could not have solely been modulated by NAO forcing, but also by other patterns (e.g. Polar/Eurasia and East Atlantic/Western Russia) that acted in synergy (see full details in Roberts et al., 2012). For instance, other climate regimes, such as shifts in the Intertropical Convergence Zone (ITCZ), may also have played roles in mediating climate in the southern Mediterranean. In the Mediterranean basin, the 4.2

ka BP could thus be a combination of different forcing factors (depending on the location) probably acting in synergy (e.g. Di Rita et al., 2018).

Here, we probe several records from the Levant to review the climate context of the 4.2 ka BP event in the Eastern Mediterranean (Fig. 1). Our review is based on the core area of the Central/Southern Levant, composed of Israel, the West Bank and Jordan, and on the Northern Levant with Syria and Lebanon. Other regions have also been integrated into our analysis, including Egypt (Nile Delta) and the Red Sea. All data (biotic and abiotic) were z-score transformed to facilitate inter-site comparisons (the original curves can be found in the cited references). This comprehensive west-east/north-south review of the Mediterranean data places emphasis on different climate patterns/climatic modes.

2 A west-east gradient - northern Mediterranean

While climate models based on the Mediterranean tend to suggest that the 4.2 ka BP event occurred mainly in the Eastern Mediterranean and West Asia, drought nonetheless seems to be recorded from the western to the eastern areas. A short review of the palaeoclimate data from Spain to Turkey puts these drier conditions in wider perspective.

In Spain, drier environmental conditions were recorded at several locations such as the Doñana National Park (Jiménez-Moreno et al., 2015), Sierra de Gádor (Carrión et al., 2003), Borreguiles de la Virgen (Jiménez-Moreno and Anderson, 2012) and Lake Montcortès (Scussolini et al., 2011). Further east, in Italy, several sites such as Renella Cave (Fig. 2; Drysdale et al., 2006; Zanchetta et al., 2016), Corchia Cave (Fig. 2; Regattieri et al., 2014) or Lake Accesa (Fig. 2; Magny et al., 2009) clearly point to a drought event, with drier conditions (~4100-3950 BP) bracketed by two wetter phases at Lake Accesa (Magny et al., 2009). In Croatia, a drier climate is attested at Lake Vrana (Island of Cres; Schmidt et al., 2000), Bokanjačko blato karst polje (Dalmatia; Ilijanić et al., 2018) and at Mala Špilja cave (Island of Mljet; Lončar et al., 2017). In the Balkan Peninsula, Lake Shkodra (Fig. 2; Albania/Montenegro; Zanchetta et al., 2012), Lake Prespa (Republics of Macedonia/Albania/Greece; Wagner et al., 2010), Lake Ohrid (Republics of Macedonia/Albania; Wagner et al., 2010) and Lake Dojran (Fig. 2; Macedonia/Greece; Francke et al., 2013; Thienemann et al., 2018) were also hit by drought of various intensities. In Albania, a pollen-based model underscores a moderate decline in precipitation at Lake Maliq (Korçë; Bordon et al., 2009). In Greece, the Mavri Trypa Cave (Peloponnese; Finné et al., 2017) and the Omalos Polje karstic depression (Crete; Styllas et al., 2018) displayed a period of drier conditions centred on the 4.2 ka BP event. In Turkey, the last "northern geographic step" before the Levant, drought is attested at several locations. At Nar

Gölü (Dean et al., 2015), Lake Van (Lemcke and Sturm, 1996; Wick et al., 2003), Gölhisar Gölü (Eastwood et al., 1999) and Eski Acıgöl (Roberts et al., 2008), drier conditions prevailed. These data from the northern Mediterranean point to a more or less severe drought episode, broadly correlated with the chronological window of the 4.2 ka BP event. The west-east "climate see-saw" (Xoplaki et al., 2004; Roberts et al., 2012), not perceptible in this brief synthesis because of assumed bias (only sites where drought is recorded are mentioned), is however attested in Mediterranean climate reconstructions (Guiot and Kaniewski, 2015). Knowledge gaps remain regarding the connection/synergy between different climate patterns, and their relative weight, according to the geographical location of the sites considered. The potential climate changes that may have impacted the northern Mediterranean during the 4.2 ka BP have been extensively reviewed in the literature (e.g. Drysdale et al., 2006; Magny et al., 2009; Dean et al., 2015; Zanchetta et al., 2016; Di Rita et al., 2018) and will be discussed elsewhere in this special issue.

3 A west-east gradient - southern Mediterranean

Even if the 4.2 ka BP event is clearly delineated in the northern basin, the southern Mediterranean shows different trends due to the influence of Saharan climate. While similar dry conditions occurred concurrently in Morocco (Tigalmamine, Middle Atlas; Lambs et al., 1995; Cheddadi et al., 1998) and Algeria (Gueldaman GLD1 Cave; Ruan et al., 2016), the same arid conditions led to enhanced flash-flood activity (mainly due to poor vegetation cover) during the 4.2 ka BP event, with a peak discharge in river flow regimes. Such extreme hydrological events are documented in fluvial stratigraphy from northern Africa (both in Morocco and Tunisia), especially during the period 4100-3700 BP (Faust et al., 2004; Benito et al., 2015). These hydrological events have also been identified in Central Tunisia, a desert margin zone characterized by a transition from the sub-humid Mediterranean to arid Saharan climate. Increased flood activity in river systems also occurred locally during the period 4100-3700 BP (Zielhofer and Faust, 2008). In the central Medjerda basin (northern Tunisia), enhanced fluvial dynamics started earlier, ~4700 BP, and lasted until ~3700 BP (Faust et al., 2004).

Further east, in Libya, the most dramatic environmental change in the area, related to the onset of dry conditions, took place earlier, at ~5000 years BP in Tadrart Acacus (Lybian Sahara; Cremaschi and Di Lernia, 1999). In the Jefara Plain, northwestern Libya, the "late Holocene arid climate period" started after 4860-4620 BP (Giraudi et al., 2013). These two distant Libyan areas both show the main influence of the Saharan Africa, even though the Mediterranean is

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only 100 km from the Jefara Plain. This is consistent with data from Giraudi et al. (2013), indicating that the Saharan climate extends to the coast of the Mediterranean Sea in Libya. Focusing on the Saharan climate/African monsoon, a general deterioration of the terrestrial ecosystem is indicated at Lake Yoa, northern Chad, during the period ~4800-4300 BP. Since 4300 BP, widespread dust mobilization and a rapid transition (4200-3900 BP) from a freshwater habitat to a true salt lake are both recorded (Kröpelin et al., 2008).

In Egypt, the last "southern step" before the Levant, no major changes have been recorded at Lake Qarun (the deepest part of the Faiyum Depression; Baioumy et al., 2010) or the contrary (desiccation of Nile-fed Lake Faiyum at ~4200 BP according to Hassan, 1997). The level of Lake Moeris (Faiyum depression) dropped at ~4400 BP and rose again at ~4000 BP (Hassan, 1986). During the 4.2 ka BP event, Nile base-flow conditions changed considerably with reduced inputs from the White Nile, a dominant contribution from the Blue Nile, and diminished precipitation (Stanley et al., 2003). The source of the Blue Nile, Lake Tana, also manifests a drier phase, leading to a reduction of the Nile flow during the same period (Marshall et al., 2011), in phase with other regional palaeoclimate archives (Chalié and Gasse, 2002; Thompson et al., 2002). This drop in and/or failure of Nile floods was recorded by a decreased Nile delta sediment supply (Fig. 3; Marriner et al., 2012) while in the Burullus Lagoon (Nile Delta), reduced flow directly impacted marshland vegetation (Bernhardt et al., 2012). The Nile delta region is not directly affected by monsoonal rainfall (this was also the case during the Holocene, and at longer Pleistocene timescales; Rossignol-Strick, 1983; Arz et al., 2003; Felis et al., 2004; Grant et al., 2016). However, the Nile's hydrological regime is essentially mediated by river discharge upstream, *i.e.* by the East African monsoon regime, and only secondarily by *in situ* Mediterranean climatic conditions (Flaux et al., 2013; Macklin et al., 2015). In the northern Red Sea, located between the Mediterranean and Afro-SW-Asian monsoonal rainfall regimes, the 4.2 ka BP event has been identified by enhanced evaporation/increased salinity in the Shaban Deep basin (Fig. 3; Arz et al., 2006).

All of this evidence from the southern Mediterranean/northern Africa points to hydrological instability, both during and around the 4.2 ka BP event, due to multiple climate influences, mainly the Saharan Africa. In many North African cases, records show that climate changes at ~4200 BP are not characterized by abrupt events, but are rather part of either a long-term trend or multicentennial-scale variations, as suggested by Arz et al. (2006) for the Red Sea. Focusing on Nile flow, variations seem mainly to result from a shift in the dynamics of the ITCZ, which migrates latitudinally in response to both orbitally-controlled climatic patterns (see Gasse, 2000; Ducassou et al., 2008; Kröpelin et al., 2008; Verschuren et al., 2009; Revel et al., 2010;

Flaux et al., 2013; Marriner et al., 2013), and from changes in the El Niño Southern Oscillation (ENSO; see Moy et al., 2002; Leduc et al., 2009; Wolff et al., 2009), an important driver in decadal variations in precipitation over large parts of Africa (Indeje et al., 2000; Nicholson and Selato, 2000). The period encompassing the 4.2 ka BP event is consistent with a decrease in ENSO-like frequency, and a southern shift in the mean summer position of the ITCZ (Mayewski et al., 2004; Marshall et al., 2011) that may have reduced the interactions between the ENSO-like frequency and the Ethiopian Monsoon (Moy et al., 2002; Marriner et al., 2012).

4 The 4.2 ka BP event in Northern Levant

Environmental data from the Northern Levant originate from several locations in Syria and Lebanon, spatially distributed from the coastal strip to the dry continental areas.

4.1 Syria

The northern coastal lowlands of Syria, where Tell Tweini (Fig. 3) and Tell Sukas are located, are separated from the Ghab depression to the east by the Jabal an Nuşayriyah, a 140-km long north-south mountain range 40- to 50-km wide with peaks culminating at ~1,200 m above sea level. At Tell Tweini (Jableh), the pollen-based environmental reconstruction (TW-1 core) shows that drier conditions prevailed during the 4.2 ka BP event with weaker annual inputs of freshwater and ecological shifts induced by lower winter precipitation. The drier conditions ended at ~3950 BP (Fig. 3; Kaniewski et al., 2008). At Tell Sukas, ~10 km south of Tell Tweini, an increase in dryness during the 4.2 ka BP event only coincides with a decline in olive exploitation, implying milder conditions (Sorrel et al., 2016). Olive abundances also maintain fairly high levels at Tell Tweini during the event, but *Olea* pollen-type originated from the wild variety (oleasters; Kaniewski et al., 2009), a tree species extremely resistant to drought that can survive in arid habitats (Lo Gullo and Salleo, 1988), and cannot definitively be used as a proxy for “olive exploitation” (Kaniewski et al., 2009). In the Ghab Valley (e.g. van Zeist and Woldring, 1980; Yasuda et al., 2000), no reliable information on climate shifts can be displayed due to a floating chronology (e.g. Meadows, 2005). In continental Syria, at Qameshli (near the Turkish-Iraqi borderline; Fig. 3), modelled precipitation estimates evoke a major regional crisis in the rainfall regime starting at 4200 BP (Bryson and Bryson, 1997; Fiorentino et al., 2008), echoing Lake Neor (flank of the Talesh-Alborz Mountains, Iran), where a major dust event, resulting from drier conditions, is clearly depicted (Fig. 3; Sharifi et al., 2015). The Qameshli climate model was used to calculate a potential decline in precipitation at Tell Breda (near Ebla) and Ras El-Ain (near Tell Leilan). The two sites show similar trends to Qameshli, with a major dry event at 4200 BP (Fiorentino et al., 2008). Data from Syria suggest that while the coastal area (Tell Sukas and Tell Tweini) was less impacted, drought was widespread inland during the 4.2 ka BP event, from the south of Alep to the eastern Turkish-Iraqi borderline.

4.2 Lebanon

In Lebanon, the main climatic arguments supporting the 4.2 ka BP event derive from Jeita Cave (Fig. 4) and Al Jourd marsh (Fig. 4). Jeita Cave is located on the western flank of central Mount Lebanon. While the JeG-stm-1 stalagmite record ($\delta^{18}O$ and $\delta^{13}C$) does not show compelling evidence for a rapid climate shift around 4200 BP (Verheyden et al., 2008), new records (termed J1-J3; also based on $\delta^{18}O$ and $\delta^{13}C$) reveal that the 4.2 ka BP event is well-defined, with a pronounced phase of climate change from 4300 to 3950 BP (Fig. 4; Cheng et al., 2016). According to Verheyden et al. (2008), due to the low time resolution of this part of the JeG-stm-1 stalagmite (one sample every 180 years), the short-term 4.2 ka BP event may not have been observed. Further north, at Sofular Cave (Turkey; Fig. 3), while the Stalagmite So-1 is not affected by this low temporal resolution, no consistent and convincing signature for the 4.2 ka BP event was recorded (Göktürk et al., 2011), echoing the JeG-stm-1 stalagmite record.

The climate reconstruction from Al Jourd marsh, based on environmental data from the Al Jourd reserve (~70 km northeast of Jeita Cave), shows the same trends as the J1-J3 cores (Cheddadi and Khater, 2016). The reconstructed precipitation results display a drier phase, starting at ~4220 BP and lasting until ~3900 BP. At Ammiq (the Beqaa valley), a strong decline in precipitation is recorded from ~4700 to ~3850 BP while at Chamsine/Anjar (Bekaa Valley), the dry phase is centered on 4400 BP before a gradual return to wet conditions that peak at ~3930 BP (Cheddadi and Khater, 2016).

Data from Lebanon suggest that a drier period, centered on the 4.2 ka BP event, was recorded. Sites in the Beeka Valley (Ammiq, Chamsine) clearly delineate that the drier phase started earlier, between 4700 and 4400 BP.

5 The 4.2 ka BP event in Central/Southern Levant

The 4.2 ka BP event is here presented from northern to southern Israel.

Located in the foothills of Mount Hermon, in the Galilee Panhandle, at the sources of the Jordan River, the site of Tel Dan (Israel) shows clear imprints of a drier event. A pollen-based environmental reconstruction depicts drier conditions characterized by a sharp drop in surface water between ~4100 and ~3900 BP, with two main peaks at ~4050 and ~3950 BP (Fig. 4; Kaniewski et al., 2017). Approximately 10-km from Tel Dan, cores from the Birkat Ram crater lake (Northern Golan heights; Schwab et al., 2004), also located in the foothills of Mount Hermon, were used to reconstruct climate trends during the last 6000 years (Neuman et al., 2007a). The authors demonstrate that annual precipitation is comparatively uniform with no distinctive fluctuations during the studied period (Neuman et al., 2007a). The pollen diagram from the Hula Nature Reserve (northwestern part of former Lake Hula, Israel) shows an expansion in *Olea* before ~4110 BP (Baruch and Bottema, 1999; Van Zeist et al., 2009) but, because no distinction can be made between the wild or cultivated variety, this would suggest either i) the extension of olive orchards or ii) drier conditions that favoured drought-resistant trees, especially during a period of decreasing cereals (see diagram in Van Zeist et al., 2009). A pollen-based environmental reconstruction from the Sea of Galilee (Lake Kinneret, Israel; e.g. Baruch 1986; Miebach et al., 2017) shows two decreases in the oak-pollen curve, interpreted as drier climate conditions at 4300 and 3950 BP (Langgut et al., 2013), which may fit within the broader framework of the 4.2 ka BP event. In the same core, a decrease in tree-pollen scores was recorded around 4000 BP. According to the authors, it is uncertain whether or not this environmental signal is related to the 4.2 ka BP event (Schiebel and Litt, 2018).

In the coastal area, at Tel Akko (Acre, Israel), a pollen-based climate reconstruction shows negative precipitation anomalies centered on the period ~4200-4000 BP, corresponding to a ~12% decrease in annual precipitation (Fig. 4; Kaniewski et al., 2013, 2014). At Soreq Cave (Judean Mountains, Israel), decreases in rainfall have been interpreted to have been ~30% lower for the period 4200-4050 BP (Fig. 4; Bar-Matthews et al., 1997, 1999, 2003; Bar-Matthews and Ayalon, 2011). While it has been noted that oxygen isotope ratios in speleothems cannot be used as a simple rainfall indicator (Frumkin et al., 1999; Kolodny et al., 2005; Litt et al., 2012), a similar value was suggested for the Eastern Mediterranean with a decrease in annual precipitation of ~30% (Fig. 3; Kaniewski et al., 2013).

Focusing on the Dead Sea (Israel, Jordan and the West Bank), a lake-level reconstruction points to two drops at ~4400 BP and ~4100 BP, separated by a short rise at ~4200/4150 BP (Fig. 4; e.g. Bookman (Ken-Tor) et al., 2004; Migowski et al., 2006; Kagan et al., 2015). A similar short wet phase is recorded at Tel Akko at ~4100 BP (Kaniewski et al., 2013) and ~4000 BP at Tel Dan (Kaniewski et al., 2017), suggesting that minor chronological discrepancies can result from radiocarbon dating. The pollen-based environmental reconstruction from Ze'elim Gully (Dead Sea) echoes the Dead Sea level scores and suggests that drier climate conditions prevailed at ~4300 BP and ~3950 BP, engendering an expansion of olive horticulture during the period ~4150-3950 BP, which implies milder conditions (Neuman et al., 2007a; Langgut et al., 2014, 2016). Pollen data recovered from a core drilled on the Ein Gedi shore (Dead Sea) were also used to reconstruct the temporal variations in rainfall (Litt et al., 2012). While the 4.2 ka BP event corresponds to a relatively wet and cool period, two slightly drier phases were also recorded at ~4400-4300 BP and ~3900 BP (Litt et al., 2012). This pattern, two drier periods framing a wetter phase (~4150-3950 BP), suggest an inverted parallel with the Central Mediterranean where two wet periods are juxtaposed against a drier phase bracketed between ~4100 and 3950 BP (Magny et al., 2009).

The core DS 7-1 SC (Dead Sea; Heim et al., 1997), the core from Ein Feshkha (Dead Sea; Neuman et al., 2007b), and the marine cores off the Israeli coast (Schilman et al., 2001) were not included in our analysis because they do not cover the period under consideration.

Data from the southern Levant are complex compared to those from the northern Mediterranean. While the sites suggest that drier conditions were recorded during the 4.2 ka BP event from the Mediterranean coast to the Dead Sea, they nonetheless show that drought must be integrated into a broader chronological framework, disrupted by a short humid period. The latter is clearly highlighted in the Dead Sea records (Litt et al., 2012; Langgut et al., 2014, 2016; Kagan et al., 2015; see Fig. 4) as well as at Soreq Cave ($\delta^{18}O$, Fig. 4; Bar-Matthews et al., 2003; Bar-Matthews and Ayalon, 2011) and is more or less attested in the Sea of Galilee (Langgut et al., 2013; Schiebel and Litt, 2018), at Tel Dan, and Tel Akko (Kaniewski et al., 2013, 2017). This W-shaped event may be a local expression of the North-Atlantic Bond event 3 (Bond et al., 1997) as it has already been demonstrated that drier/wetter phases in the eastern Mediterranean were associated with cooling/warming periods in the North Atlantic during the past 55 kyr (Bartov et al., 2003).

6 Climatic hypotheses behind the 4.2 ka BP event in the Levant

6.1 North Atlantic

Kushnir and Stein (2010) have clearly noted that southern Levant precipitation variability is closely linked with a seesaw pressure gradient between the eastern North Atlantic and Eurasia, and they also evoked the apparent link between Atlantic Multidecadal Variability [Atlantic Multidecadal Sea Surface Temperature (SST) variability] and atmospheric circulation (see Kushnir, 1994; Ziv et al. 2006; Kushnir and Stein, 2010). Slowly paced Holocene variability is generally modulated by: a colder than normal North Atlantic resulting in higher than normal precipitation in the central Levant while a warmer than normal North Atlantic leads to lower precipitation. This suggests that i) the North Atlantic is a key pacemaker with regards to the long-term hydroclimatic variability of the Levant during the Holocene, and ii) there is a nonlinear response to global climatic events, such as the 4.2 ka BP event, consistent with pronounced cooling in Eastern Mediterranean winter SSTs and cold events in northern latitudes (Kushnir and Stein, 2010). It appears that sudden Northern Hemisphere cold episodes contrast with milder and more slowly paced Holocene variability.

6.2 A climate see-saw model

A bipolar southeast-southwest "climate see-saw" in the Mediterranean is one of the climatic modes that explains the spatio-temporal variability of precipitation over the basin during winter-time (Kutiel et al., 1996; Xoplaki et al., 2004), in connection with a positive or negative NAO. The dipole precipitation pattern results both from local cyclogenesis and southward shifts of storm tracks from Western Europe towards the Mediterranean (and vice-versa). Drier conditions in the Eastern Mediterranean mainly derive from high pressure systems over Greenland/Iceland and relatively low pressure over southwestern Europe (Roberts et al., 2012), pointing to a weakening of the zonal atmospheric circulation over Europe (Guiot and Kaniewski, 2015). According to Xoplaki et al. (2004), the outcomes of such a pattern over most of the Mediterranean region result in above normal precipitation, with peak values on the western seaboard and lower values in the southeastern part of the basin. This scheme fits with the model of Brayshaw et al. (2011) that displays wetter conditions over large part of the Mediterranean basin while the Eastern Mediterranean was drier, and also mirrors the model developed by Guiot and Kaniewski (2015). According to Roberts et al. (2012), this mode also prevailed during the Little Ice Age, with drier conditions over the Eastern Mediterranean and wetter patterns over the Western Mediterranean (with an opposite scheme during the Medieval Climate Anomaly).

6.3 Cyprus lows

While a dominant NAO forcing may explain Western Mediterranean aridity, the Eastern Mediterranean appears to be mostly mediated by other climatic modes, and precipitation variability has also not been uniform according to cyclone-migration tracks (northern/southern). Rainfall in the Levant mostly originates from mid-latitude cyclones (Cyprus lows) during their eastward passage over the eastern Mediterranean (Enzel et al., 2003; Zangvil et al., 2003; Saaroni et al., 2010). During wet years, more intense cyclones frequently migrate over the Eastern Mediterranean (and vice-versa), reflecting variants of the long-term mean low pressure, with positive pressure anomalies consistent with reduced cyclonic activity near the surface. Under this scenario, the most probable cause for drought events in the Levant is that the 500-

hPa (upper level anomalies) and sea-level pressure patterns were not conducive to cyclone migration over the Eastern Mediterranean. Instead, their tracks were probably farther to the north, potentially impacting western Turkey and Greece (Enzel et al., 2003).

7 Conclusions

The comparison of multiple records of the 4.2 ka BP event involves assumptions regarding the relative weight of such variables in shaping the final outcomes, and also requires strong evidence about the sensitivity of each proxy to fully record the environmental parameters. Our study also underscores the importance of robust chronologies in looking to probe the spatial dimensions of the 4.2 event and its driving mechanisms. Concerning the Levant, the various palaeoclimate proxies sometimes show contrasting outcomes, suggesting variable sensitivity or the absence of forcing agents. At the scale of the Levant, the 4.2 ka BP event is clearly recorded but several locations show that other regional/local patterns may be involved, yielding different outcomes that must be more closely addressed in the future. Concerning the climate shift driving the 4.2 ka BP event, we can assume that, despite the clear geographical articulation of the 4.2 ka event (Zanchetta et al., 2016; Di Rita et al., 2018), the patterns responsible for the event are not yet fully understood. This also raises a key question, how did societies adapt to this ~300 year (or longer) drought? This knowledge gap is still widely debated and must be addressed locally to fully understand the resilience and adaptive strategies of the Levant's diverse peoples and polities.

8 Author contributions

DK, NM, RC, JG and EVC conceived the review and wrote the paper.

9 Competing interests

The authors declare that they have no conflict of interest.

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References

Arz, H.W., Lamy, F., Pätzold, P., Müller, P.J., and Prins, M.: Mediterranean moisture source for early-Holocene humid period in the Red Sea, Science, 300, 118-121, 2003.

Arz, H.W., Lamy, F., and Pätzold, J.: A pronounced dry event recorded around 4.2 ka in brine sediments from the northern Red Sea. Quaternary research, 66, 432-441, 2006.

Baioumy, H.M., Kayanne, H., and Tada, R.: Reconstruction of lake-level and climate changes in Lake Qarun, Egypt, during the last 7000 years, Journal of Great Lakes Research, 36, 318-327, 2010.

Baker, P., Fritz, S., Burns, S., Ekdahl, E., and Rigsby, C.: The nature and origin of decadal to millennial scale climate variability in the southern tropics of South America: the Holocene record of Lago Umayo, Peru, in: Past climate variability in South America and surrounding regions: from the last glacial maximum to the Holocene, Developments in Paleoenvironmental Research 14, Vimeux, F., Sylvestre, F., and Khodri, M. (Eds), Springer-Verlag, 301-322, 2009.

Bar-Matthews, M., Ayalon, A., and Kaufman, A.: Late Quaternary paleoclimate in the Eastern Mediterranean region from stable isotope analysis of speleothems at Soreq Cave, Israel, Quaternary Research, 47, 155-168, 1997.

Bar-Matthews, M., Ayalon, A., Kaufman, A., and Wasserburg, G.J.: The Eastern Mediterranean palaeoclimate as a reflection of regional events: Soreq Cave, Israel, Earth and Planetary Science Letters, 166, 85-95, 1999.

Bar-Matthews, M., Ayalon, A., Gilmour, M., Matthews, A., and Hawkesworth, C.J.: Sea-land oxygen isotopic relationship from planktonic foraminifera and speleothems in the Eastern Mediterranean region and their implication for paleorainfall during interglacial intervals, Geochimica et Cosmochimica Acta, 67, 3181-3199, 2003

Bar-Matthews, M., and Ayalon, A.: Mid-Holocene climate variations revealed by high-resolution speleothem records from Soreq Cave, Israel and their correlation with cultural changes, The Holocene, 21, 163-171, 2011.

Bartov, Y., Goldstien, S.L., Stein, M., and Enzel, Y.: Catastrophic arid events in the East Mediterranean linked with the North Atlantic Heinrich events, Geology, 31, 439-442, 2003.

Baruch, U.: The late Holocene vegetational history of Lake Kinneret (sea of Galilee), Israel, Paléorient, 12, 37-47, 1986.

Baruch, U., and Bottema, S.: A new pollen diagram from Lake Hula: vegetational, climatic and anthropogenic implications, in: Ancient lakes: their cultural and biological diversity,

Clim. Past Discuss., https://doi.org/10.5194/cp-2018-82
Manuscript under review for journal Clim. Past
Discussion started: 17 July 2018

Kawanabe, H., Coulter, G.W., and Roosevelt, A.C. (Eds), Kenobi Productions, Ghent, 75-86, 1999.

Benito, G., Macklin, M.G., Zielhofer, C., Jones, A.F., and Machado, M.J.: Holocene flooding and climate change in the Mediterranean, Catena, 130, 13-33, 2015.

Bernhardt, C., Horton, B.P., and Stanley, J.D.: Nile Delta vegetation response to Holocene climate variability, Geology, 40, 615-618, 2012.

Bianchi, G.G., and McCave, I.N.: Holocene periodicity in North Atlantic climate and deep-ocean flow south of Iceland, Nature, 397, 515-517, 1999.

Blair, C.L., Geirsdóttir, Á., and Miller, G.H.: A high-resolution multi-proxy lake record of Holocene environmental change in southern Iceland, Journal of Quaternary Science, 30, 281-292, 2015.

Bond, G., Showers, W., Cheseby, M., Lotti, R., Almasi, P., deMenocal, P., Priore, P., Cullen, H., Hadjas, I., and Bonani, G.: A pervasive millennial-scale cycle in North Atlantic Holocene and glacial climates, Science, 278, 1257-1266, 1997.

Bond, G., Kromer, B., Beer, J., Muscheler, R., Evans, M.N., Showers, W., Hoffmann, S., Lotti-Bond, R., Hajdas, I., and Bonani, G.: Persistent Solar Influence on North Atlantic Climate during the Holocene, Science, 294, 3130-2136, 2001.

Bookman (Ken-Tor), R., Enzel, Y., Agnon, A., and Stein, M.: Late Holocene lake levels of the Dead Sea, Geological Society of America Bulletin, 116, 555-571, 2004.

Booth, R.K., Jackson, S.T., Forman, S.L., Kutzbach, J.E., Bettis, E.A., Kreig, J., and Wright, D.K.: A severe centennial-scale drought in mid-continental North America 4200 years ago and apparent global linkages, The Holocene 15, 321-328, 2005.

Booth, R., Jackson, S., Forman, S., Kutzbach, J., Bettis, E., Kreig, J., and Wright D.: A severe centennial-scale drought in mid-continental North America 4200 years ago and apparent global linkages, The Holocene 15, 321-328, 2006.

Bordon, A., Peyron, O., Lézine, A.M., Brewer, S., and Fouache, E.: Pollen-inferred Late-Glacial and Holocene climate in southern Balkans (Lake Maliq), Quaternary International, 200, 19-30, 2009.

Brayshaw, D.J., Rambeau, C.M.C., and Smith, S.J.: Changes in Mediterranean climate during the Holocene: Insights from global and regional climate modelling, The Holocene, 21, 15-31, 2011.

Bryson, R.A., Bryson, R.U.: High resolution simulations of regional Holocene climate: North Africa and the Near East., in: Third millennium B.C. climate change and old world collapse, NATO ASI Series, vol. I 49, Dalfes, H.N., Kukla, G., and Weiss, H. (Eds.), Springer-Verlag, Berlin Heidelberg, 565-593, 1997.

Butzer, K.W.: Collapse, environment, and society, Proceedings of the National Academy of Sciences of the United States of America, 109, 3632-3639, 2012.

Carrión, J.S., Sánchez-Gómez, P., Mota, J.F., Yll, E.I., and Chaín, C.: Fire and grazing are contingent on the Holocene vegetation dynamics of Sierra de Gádor, southern Spain, The Holocene, 13, 839-849, 2003.

Chalié, F., and Gasse, F.: Late-GlacialeHolocene diatom record of water chemistry and lake-level change from the tropical East African Rift Lake Abiyata (Ethiopa), Palaeogeography, Palaeoclimatology, Palaeoecology, 187, 259-283, 2002.

Cheddadi, R., Lamb, H.F., Guiot, J., and van der Kaars, S.: Holocene climatic change in Morocco: a quantitative reconstruction from pollen data, Climate Dynamics, 14, 883-890, 1998.

Cheddadi, R., and Khater, C.: Climate change since the last glacial period in Lebanon and the persistence of Mediterranean species, Quaternary Science Reviews, 150, 146-157, 2016.

Cheng, H., Sinha, A., Verheyden, S., Nader, F.H., Li, X.L., Zhang, P.Z., Yin, J.J., Yi, L., Peng, Y.B., Rao, Z.G., Ning, Y.F., and Edwards, R.L.: The climate variability in northern Levant over the past 20,000years, Geophysical Research Letters, 42, 8641-8650, 2015.

Clarke, J., Brooks, N., Banning, E.B., Bar-Matthews, M., Campbell, S., Clare, L., Cremaschi, M., di Lernia, S., Drake, N., Gallinaro, M., and Manning, S.: Climatic changes and social transformations in the Near East and North Africa during the ‘long’4th millennium BC: A comparative study of environmental and archaeological evidence, Quaternary Science Reviews 136, 96-121, 2016.

Cremaschi, M., and Di Lernia, S.: Holocene Climatic Changes and Cultural Dynamics in the Libyan Sahara, African Archaeological Review, 16, 211-238, 1999.

Cullen, H.M., deMenocal, P.B., Hemming, S., Brown, F., Guilderson, T., and Sirocko, F.: Climate change and the collapse of the Akkadian Empire: evidence from the deep sea, Geology, 28, 379-382, 2000.

Cullen, H.M., Kaplan, A., Arkin, P.A., and deMenocal, P.B.: Impact of the North Atlantic Oscillation on Middle Eastern climate and streamflow, Climatic Change, 55, 315-338, 2002.

Dean, J.R., Jones, M.D., Leng, M.J., Noble, S.R., Metcalfe, S.E., Sloane, H.J., Sahy, D., Eastwood, W.J., and Roberts, N.: Eastern Mediterranean hydroclimate over the late glacial and Holocene, reconstructed from the sediments of Nar lake, central Turkey, using stable isotopes and carbonate mineralogy, Quaternary Science Reviews, 124, 162-174, 2015.

deMenocal, P.B.: Cultural responses to climatic change during the late Holocene, Science, 292, 667-673, 2001.

Di Rita, F., Fletcher, W.J., Aranbarri, J., Margaritelli, G., Lirer, F., and Magri, D.: Holocene forest dynamics in central and western Mediterranean: periodicity, spatio-temporal patterns and climate influence, Scientific Reports, 8, 8929, DOI:10.1038/s41598-018-27056-2, 2018.

Drysdale, R.N., Zanchetta, G., Hellstrom, J., Maas, R., Fallick, A.E., Pickett, M., Cartwright, I., and Piccini, L.: Late Holocene drought responsible for the collapse of Old World civilizations is recorded in an Italian cave flowstone, Geology, 34, 101-104, 2006.

Ducassou, E., Mulder, T., Migeon, S., Gonthier, E., Murat, A., Revel, M., Capotondi, L., Bernasconi, S.M., Mascle, J., and Zaragosi, S.: Nile floods recorded in deep Mediterranean sediments, Quaternary Research, 70, 382-391, 2008.

Eastwood, W.J., Roberts, N., Lamb, H.F., and Tibby, J.C.: Holocene environmental change in southwest Turkey: a palaeoecological record of lake and catchment-related changes, Quaternary Science Reviews, 18, 671-695, 1999.

Enzel, Y., Bookman, R., Sharon, D., Gvirtzman, H., Dayan, U., Ziv, B., and Stein, M.: Late Holocene climates of the Near East deduced from Dead Sea level variations and modern regional winter rainfall, Quaternary Research, 60, 263-273, 2003.

Faust, D., Zielhofer, C., Baena Escudero, R., and Diaz del Olmo, F.: High-resolution fluvial record of late Holocene geomorphic change in northern Tunisia: climatic or human impact?, Quaternary Science Reviews, 23, 1757-1775, 2004.

Felis, T., Lohmann, G., Kuhnert, H., Lorenz, S.J., Scholz, D., Pätzold, J., Al-Rousan, S.A., Al-Moghrabi, S.M.: Increased seasonality in Middle East temperatures during the last interglacial period, Nature, 429, 164-168, 2004.

Finné, M., Holmgren, K., Sundqvist, H.S., Weiberg, E., and Lindblom, M.: Climate in the Eastern Mediterranean, and adjacent regions, during the past 6000 years - a review, Journal of Archaeological Science, 28, 3153-3173, 2011.

Finné, M., Holmgren, K., Shen, C.C., Hu, H.M., Boyd, M., Stocker, S.: Late Bronze Age climate change and the destruction of the Mycenaean Palace of Nestor at Pylos, Plos One, 12, e0189447, doi.org/10.1371/journal. pone.0189447, 2017.

Fiorentinon, G., Caracuta, V., Calcagnile, L., D'Elia, M., Matthiae, P., Mavelli, F., Quarta, G.: Third millennium B.C. climate change in Syria highlighted by carbon stable isotope analysis of ^{14}C-AMS dated plant remains from Ebla, Palaeogeography, Palaeoclimatology, Palaeoecology, 266, 51-58, 2008

Fisher, D., Osterberg, E., Dyke, A., Dahl-Jensen, D., Demuth, M., Zdanowicz, C., Bourgeois, J., Koerner, R., Mayewski, P., Wake, C., Kreutz, K., Steig, E., Zheng, J., Yalcin, K., Goto-Azuma, K., Luckman, B., and Rupper, S.: The Mt Logan Holocene late Wisconsinan isotope record: tropical Pacific-Yukon connections, The Holocene, 18, 667-677, 2008.

Flaux, C., Claude, C., Marriner, N., and Morhange, C.: A 7500-year strontium isotope record from the northwestern Nile delta (Maryut lagoon, Egypt), Quaternary Science Reviews, 78, 22–33, 2013.

Francke, A., Wagner, B., Leng, M.J., and Rethemeyer, J.: A Late Glacial to Holocene record of environmental change from Lake Dojran (Macedonia, Greece), Climate of the Past, 9, 481-498, 2013.

Frumkin, A., Ford, D.C., and Schwarcz, H.P.: Continental oxygen isotopic record of the last 170,000 years in Jerusalem, Quaternary Research, 51, 317-327, 1999.

Gasse, F.: Hydrological changes in the African tropics since the last glacial maximum, Quaternary Science Reviews 19, 189-212, 2000.

Geirsdóttir, Á., Miller, G.H., Larsen, D.J., and Ólafsdóttir, S.: Abrupt Holocene climate transitions in the northern North Atlantic region recorded by synchronized lacustrine records in Iceland, Quaternary Science Reviews, 70, 48-62, 2013.

Giraudi, C., Mercuri, A.M., and Esu, D.: Holocene palaeoclimate in the northern Sahara margin (Jefara Plain, northwestern Libya), The Holocene, 23, 339-352, 2013.

Göktürk, O.M., Fleitmann, D., Badertscher, S., Cheng, H., Edwards, R.L., Leuenberger, M., Fankhauser, A., Tüysüz, O., and Kramers, J.: Climate on the southern Black Sea coast during the Holocene: implications from the Sofular Cave record, Quaternary Science Reviews, 30, 2433-2445, 2011.

Grant, K.M., Grimm, R., Mikolajewicz, U., Marino, G., Ziegler, M., and Rholing, E.J.: The timing of Mediterranean sapropel deposition relative to insolation, sea-level and African monsoon changes, Quaternary Science Reviews, 140, 125-141, 2016.

Guiot, J., and Kaniewski, D.:The Mediterranean basin in a warmer and drier world: what can we learn from the past?, Frontiers in Earth Science, 3, 28, doi: 10.3389/feart.2015.00028, 2015.

Hassan, F.A.: Holocene lakes and prehistoric settlements of the western Faiyum, Egypt, Journal of Archaeological Science, 13, 483-501, 1986.

Hassan, F.A.: The dynamics of a riverine civilization: a geoarchaeological perspective on the Nile Valley, Egypt. World Archaeology, 29, 51-74, 1997.

Heim, C., Nowaczyk, N.R., and Negendank, J.F.W.: Near East desertification: evidence from the Dead Sea, Naturwissenschaften, 84, 398-401, 1997.

Ilijanič, N., Miko, S., Hasan, O., and Bakrač, K.: Holocene environmental record from lake sediments in the Bokanjačko blato karst polje (Dalmatia, Croatia), Quaternary International, In press, 2018.

Indeje, M., Semazzi, F.H.M., and Ogallo, L.J.: ENSO signals in East African rainfall seasons, International Journal of Climatology, 20, 19-46, 2000.

Jiménez-Moreno, G., Rodríguez-Ramírez, A., Pérez-Asensio, J.N., Carrión, J.S., López-Sáez, J.A., Villarías-Robles, J.J., Celestino-Pérez, S., Cerrillo-Cuenca, E., León, Á., and Contreras, C.: Impact of late-Holocene aridification trend, climate variability and geodynamic control on the environment from a coastal area in SW Spain, Holocene, 25, 607-617, 2015.

Jiménez-Moreno, G., and Anderson, R.S.: Holocene vegetation and climate change recorded in alpine bog sediments from the Borreguiles de la Virgen, Sierra Nevada, southern Spain, Quaternary Research, 77, 44-53, 2012.

Kagan, E.J., Langgut, D., Boaretto, E., Neumann, F.H., and Stein, M.: Dead Sea levels during the Bronze and Iron Ages, Radiocarbon 57, 237-252, 2015.

Kaniewski, D., Paulissen, E., Van Campo, E., Al-Maqdissi, M., Bretschneider, J., and Van Lerberghe, K.: Middle East coastal ecosystem response to middle-to-late Holocene abrupt climate changes, Proceedings of the National Academy of Sciences of the United States of America,105, 13941-13946, 2008

Kaniewski, D., Paulissen, E., Van Campo, E., Bakker, J., Van Lerberghe, K., and Waelkens, M.: Wild or cultivated Olea europaea L. in the Eastern Mediterranean during the middle-late Holocene? A pollen-numerical approach, The Holocene, 19, 1039-1047, 2009.

Kaniewski, D., Marriner, N., Ilan, D., Morhange, C., Thareani, Y., and Van Campo, E.: Climate change and water management in the biblical city of Dan, Science Advances, 3, e1700954, 2017.

Kaniewski, D., Van Campo, E., Morhange, C., Guiot, J., Zviely, D., Shaked, I., Otto, T., and Artzy, M.: Early urban impact on Mediterranean coastal environments, Scientific Reports, 3, 354, doi: 10.1038/srep03540, 2013.

Clim. Past Discuss., https://doi.org/10.5194/cp-2018-82
Manuscript under review for journal Clim. Past
Discussion started: 17 July 2018

Climate of the Past Discussions
Open Access
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Kaniewski, D., Van Campo, E., Morhange, C., Guiot, J., Zviely, D., Le Burel, S., Otto, T., and Artzy, M.: Vulnerability of Mediterranean ecosystems to long-term changes along the coast of Israel, Plos One, 9, e102090. doi:10.1371/journal.pone.0102090, 2014.

Kolodny, Y., Stein, M., and Machlus, M.: Sea-rain-lake relation in the last glacial east Mediterranean revealed by $d^{18}O$ - $d^{13}C$ in lake Lisan aragonites. Geochimica et Cosmochimica Acta 69, 4045-4060, 2005.

Kröpelin, S., Verschuren, D., Lézine, A.M., Eggermont, H., Cocquyt, C., Francus, P., Cazet, J.P., Fagot, M., Rumes, B., Russel, J.M., Darius, F., Conley, D.J., Schuster, M., von Suchodoletz, H., and Engstrom, D.R.: Climate-driven ecosystem succession in the Sahara: the past 6000 years, Science, 320, 765-768, 2008.

Kushnir, Y.: Interdecadal variations in North-Atlantic sea-surface temperature and associated atmospheric conditions, Journal of Climate, 7, 141-157, 1994.

Kushnir, Y., and Stein, M.: North Atlantic influence on 19^{th}-20^{th} century rainfall in the Dead Sea watershed, teleconnections with the Sahel, and implication for the Holocene climate fluctuations, Quaternary Science Reviews, 29, 3843-3860, 2010.

Kutiel, H., Maheras, P., and Guika, S.: Circulation and extreme rainfall conditions in the eastern Mediterranean during the last century, International Journal of Climatology 16, 73-92, 1996.

Lamb, H.F., Gasse, F., Benkaddour, A., El Hamouti, N., van der Kaars, S., Perkins, W.T., Pearce, N.J., and Roberts, C.N.: Relation between century-scale Holocene arid intervals in tropical and temperate zones, Nature, 373, 134-137, 1995.

Lamy, F., Arz, H.W., Bond, G.C., Bahr, A., and Pätzold, J.: Multicentennial-scale hydrological changes in the Black Sea and northern Red Sea during the Holocene and the Arctic/North Atlantic Oscillation, Paleoceanography, 21, doi:10.1029/2005PA001184, 2006.

Langgut, D., Finkelstein, I., and Litt, T.: Climate and the Late Bronze collapse: new evidence from the Southern Levant, Tel Aviv, 40, 149-175, 2013.

Langgut, D., Neumann, F.H., Stein, M., Wagner, A., Kagan, E.J., Boaretto, E., and Finkelstein, I.: Dead Sea pollen record and history of human activity in the Judean Highlands (Israel) from the Intermediate Bronze into the Iron Ages (~2500-500 BCE), Palynology, 38, 280-302, 2014.

Langgut, D., Adams, M.J., and Finkelstein, I.: Climate, settlement patterns and olive horticulture in the southern Levant during the Early Bronze and Intermediate Bronze Ages (c. 3600-1950 BC), Levant, 48, 117-134, 2016.

Leduc, G., Vidal, L., Cartapanis, O., and Bard, E., Modes of Eastern Equatorial Pacific thermocline variability: implications for ENSO dynamics over the last glacial period, Paleoceanography, 24, PA3202, doi:10.1029/2008PA1701, 2009.

Lemcke, G., and Sturm, M.: ^{18}O and trace elements measurements as proxy for reconstruction of climate change at Lake Van (Turkey), in: Third Millenium BC: climate change and old world collapse, NATO ASI Series I vol. 49, Dalfes, H.N., Kukla, G.H., and Weiss, H. (Eds), Springer, Berlin, 653-678, 1996.

Lionello, P., Malanotte-Rizzoli, P., and Boscolo, R.: The Mediterranean climate: an overview of the main characteristics and issues, Elsevier, Netherlands, 2006.

Lionello, P., Malanotte-Rizzoli, P., and Boscolo, R.: Mediterranean climate variability: 4 (Developments in Earth and Environmental Sciences), Elsevier, Amsterdam, 2013.

Litt, T., Ohlwein, C., Neumann, F.H., Hense, A., and Stein, M.: Holocene climate variability in the Levant from the Dead Sea pollen record, Quaternary Science Reviews, 49, 95-105, 2012.

Lo Gullo, M.A., and Salleo, S.: Different strategies of drought resistance in three Mediterranean sclerophyllous trees growing in the same environmental conditions, New Phytologist, 108, 267-76, 1988.

Lončar, N., Bar-Matthews, M., Ayalon, A., Surić, M., and Faivre, S.: Early and Mid-Holocene environmental conditions in the Eastern Adriatic recorded in speleothems from Mala špilja Cave and Velika špilja Cave (Mljet Island, Croatia), Acta Carsologica, 46, 229-249, 2017.

Macklin, M.G., Toonen, W.H.J., Woodward, J.C., Williams, M.A.J., Flaux, C., Marriner, N., Nicoll, K., Verstraeten, G., Spencer, N., and Welsby, D.: A new model of river dynamics, hydroclimatic change and human settlement in the Nile Valley derived from meta-analysis of the Holocene fluvial archive, Quaternary Science Reviews, 130, 109-123, 2015.

Manning, J.G.: The open sea, the economy and life of the ancient Mediterranean world from the Iron Age to the rise of Rome, Princeton University Press, Princeton and Oxford, 2018.

Magny, M., Vannière, B., Zanchetta, G., Fouache, E., Touchais, G., Petrika, L., Coussot, C., Walter-Simonnet, A.V., and Arnaud, F.: Possible complexity of the climatic event around 4300–3800 cal. BP in the central and western Mediterranean, The Holocene, 19, 823-833, 2009.

Magny, M., Combourieu-Nebout, N., De Beaulieu, J. L., Bout-Roumazeilles, V., Colombaroli, D., Desprat, S., Francke A., Joannin S., Peyron O., Revel M., Siani G., Sicre M.A., Samartin S., Simmonneau A., Tinner W., Vanniere B., Wagner B., Zanchetta G., Anselmetti F., Brugiapaglia E., Chapron E., Debret M., Desmet M., Didier J., Essallami

Clim. Past Discuss., https://doi.org/10.5194/cp-2018-82
Manuscript under review for journal Clim. Past
Discussion started: 17 July 2018

L., Galop D., Gilli A., Haas J.N., Kallel N., Millet L., Stock A., Turon J.L., and Wirth, S.: North-south palaeohydrological contrasts in the central Mediterranean during the Holocene: tentative synthesis and working hypotheses. Climate of the Past Discussions, 9, 1901-1967, 2013.

Marriner, N., Flaux, C., Kaniewski, D., Morhange, C., Leduc, G., Moron, V., Chen, Z., Gasse, F., Empereur, J.Y., and Stanley, J.D.: ITCZ and ENSO-like modulation of Nile delta hydro-geomorphology during the Holocene, Quaternary Science Reviews, 45, 73-84, 2012.

Marriner, N., Flaux, C., Morhange, C. and Stanley, J.D.: Tracking Nile Delta vulnerability to Holocene change, Plos One, 8, 7, e69195, 2013.

Marshall, M., Lamb, H.F., Huws, D., Davies, S.J., Bates, R., Bloemendal, J., Boyle, J., Leng, M.J., Umer, M., and Bryant, C.: Late Pleistocene and Holocene drought events at Lake Tana, the source of the Blue Nile, Global and Planetary Change, 78, 147-161, 2011.

Mayewski, P.A., Rohling, E.J., Stager, J.C., Karlén, W., Maasch, K.A., Meeker, L.D., Meyerson, E.A., Gasse, F., Van Kreveld, S., Holmgren, K., Lee-Thorp, K., Rosqvist, G., Rack, F., Staubwasser, M., Schneider, R.R., and Steig, E.J.: Holocene Climate Variability, Quaternary Research, 62, 243-255, 2004.

Meadows, J.: The Younger Dryas episode and the radiocarbon chronologies of the Lake Huleh and Ghab Valley pollen diagrams, Israel and Syria, The Holocene, 15, 631-636, 2005.

Miebach, A., Chen, C.Z., Schwab, M.J., Stein, M., and Litt, T.: Vegetation and climate during the Last Glacial high stand (ca. 28-22 ka bp) of the Sea of Galilee, northern Israel. Quaternary Science Reviews, 156, 47-56, 2017.

Migowski, C., Stin, M., Prasad, S., Negendank, J.F.W., and Agnon, A.: Holocene climate variability and cultural evolution in the Near East from the Dead Sea sedimentary record, Quaternary Research, 66, 421-431, 2006.

Moy, C.M., Seltzer, G.O., Rodbell, D.T., and Anderson, D.M.: Variability of El Niño southern oscillation activity at millennial timescales during the Holocene epoch, Nature, 420, 162-165, 2002.

Neumann, F., Schölzel, C., Litt, T., Hense, A., and Stein, M.: Holocene vegetation history and climate history of the north Golan Heights (Near East), Vegetation History and Archaeobotany, 16, 329-46, 2007a.

Neumann, F.H., Kagan, E.J., Schwab, M.J., and Stein, M.: Palynology, sedimentology and palaeoecology of the late Holocene Dead Sea, Quaternary Science Reviews, 26, 1476-1498, 2007b.

Clim. Past Discuss., https://doi.org/10.5194/cp-2018-82
Manuscript under review for journal Clim. Past
Discussion started: 17 July 2018

Nicholson, S.E., and Selato, J.C.: The influence of La Nina on African rainfall, International Journal of Climatology, 20, 1761-1776, 2000.

Olsen, J., Anderson, N.J., and Knudsen, M.F.: Variability of the North Atlantic Oscillation over the past 5,200 years, Nature Geoscience, 5, DOI: 10.1038/ngeo1589, 2012.

Regattieri, E., Zanchetta, G., Drysdale, R.N., Isola, I., Hellstrom, J.C., and Dallai, L.: Lateglacial to Holocene trace element record (Ba, Mg, Sr) from Corchia Cave (Apuan Alps, central Italy): paleoenvironmental implications, Journal of Quaternary Science, 29, 381-392, 2014.

Revel, M., Ducassou, E., Grousset, F.E., Bernasconi, S.M., Migeon, S., Revillon, S., Mascle, J., Murat, A., Zaragosi, S., and Bosch, D.: 100,000 years of African monsoon variability recorded in sediments of the Nile next term margin. Quaternary Science Reviews, 29, 1342-1362, 2010.

Roberts, N., Jones, M.D., Benkaddour, A., Eastwood, W.J., Filippi, M.L., Frogley, M.R., Lamb, H.F., Leng, M.J., Reed, J.M., Stein, M., Stevens, L., Valero-Garces, B., and Zanchetta, G.: Stable isotope records of Late Quaternary climate and hydrology from Mediterranean lakes: the ISOMED synthesis, Quaternary Science Reviews, 27, 2426-2441, 2008.

Roberts, N., Moreno, A., Valero-Garces, B. L., Corella, J. P., Jones, M., Allcock, S., Woodbridge, J., Morellon, M., Luterbacher, J., Xoplaki, E., and Turkes, M.: Palaeolimnological evidence for an east-west climate see-saw in the Mediterranean since AD 900, Global and Planetary Change, 84-85, 23-34, 2012.

Rohling, E.J., Mayewski, P.A., Abu-Zied, R.H., Caford, J.S.L. and Hayes, A.: Holocene atmosphere–ocean interactions: records from Greenland and the Aegean Sea, Climate Dynamics, 18, 587-93, 2002.

Rossignol-Strick, M.: African monsoons, an immediate climate response to orbital insolation, Nature, 304, 46-49, 1983.

Ruan, J., Kherbouche, F., Genty, D., Blamart, D., Cheng, H., Dewilde, F., Hachi, S., Edwards, R.L., Régnier E., and Michelot, J.L.: Evidence of a prolonged drought ca. 4200 yrBP correlated with prehistoric settlement abandonment from the Gueldaman GLD1 Cave, Northern Algeria, Climate of the Past, 12, 1-14, 2016.

Saaroni, H., Halfon, N., Ziv, B., Alpert, P., and Kutiel, H.: Links between the rainfall regime in Israel and location and intensity of Cyprus lows, International Journal of Climatology, 30, 1014-1025, 2010.

Clim. Past Discuss., https://doi.org/10.5194/cp-2018-82
Manuscript under review for journal Clim. Past
Discussion started: 17 July 2018

Schiebel V., and Litt, T.: Holocene vegetation history of the southern Levant based on a pollen record from Lake Kinneret (Sea of Galilee), Israel, Vegetation History and Archaeobotany, 27, 577-590, 2018.

Schilman, B., Bar-Matthews, M., Almogi-Labin, A., and Luz, B.: Global climate instability reflected by Eastern Mediterranean marine records during the Late Holocene, Palaeogeography, Palaeoclimatology, Palaeoecology, 176, 157-176, 2001.

Schmidt, R., Müller, J., Drescher-Schneider, R., Krisai, R., Szeroczyńska, K., and Barić, A.: Changes in lake level and trophy at Lake Vrana, a large karstic lake on the Island of Cres (Croatia), with respect to palaeoclimate and anthropogenic impacts during the last approx. 16,000 years, Journal of Limnology, 59, 113-130, 2000.

Schwab, M.J., Neumann, F., Litt, T., Negendank, J.F.W., and Stein, M.: Holocene palaeoecology of the Golan Heights (Near East): investigation of lacustrine sediments from Birkat Ram crater lake, Quaternary Science Reviews, 23, 1723-1731, 2004.

Scussolini, P., Vegas-Vilarrúbia, T., Rull, V., Corella J.P., Valero-Garcés, B., and Gomà, J.: Middle and late Holocene climate change and human impact inferred from diatoms, algae and aquatic macrophyte pollen in sediments from Lake Montcortès (NE Iberian Peninsula), Journal of Paleolimnology, 46, 369-385, 2011.

Sharifi, A., Pourmand, A., Canuel, E. A., Ferer-Tyler, E., Peterson, L. C., Aichner, B., Feakins, S. J., Daryaee, T., Djamali, M., Naderi, A., Lahijani, H. A. K., and Swart, P. K.: Abrupt climate variability since the last deglaciation based on a high-resolution, multi-proxy peat record from NW Iran: the hand that rocked the Cradle of Civilization?, Quaternary Science Reviews, 123, 215-230, 2015.

Solomina, O.N., Bradley, R.S., Hodgson, D.A., Ivy-Ochs, S., Jomelli, V., Mackintosh, A.N., Nesje, A., Owen, L.A., Wanner, H., Wiles, G.C., and Young, N.E.: Holocene glacier fluctuations, Quaternary Science Reviews, 111, 9-34, 2015.

Sorrel, P., and Mathis, M.: Mid- to late Holocene coastal vegetation patterns in Northern Levant (Tell Sukas, coastal Syria): Olive tree cultivation history and climatic change, The Holocene, 26, 858-873, 2016.

Stanley, J.D., Krom, M.D., Cliff, R.A., and Woodward J.C.: Short Contribution: Nile flow failure at the end of the Old Kingdom, Egypt: strontium isotopic and petrologic evidence, Geoarchaeology, 18, 395-402, 2003.

Staubwasser, M., and Weiss, H.: Holocene climate and cultural evolution in late prehistoric-early historic West Asia, Quaternary Research, 66, 372-387, 2006.

Clim. Past Discuss., https://doi.org/10.5194/cp-2018-82
Manuscript under review for journal Clim. Past
Discussion started: 17 July 2018

Climate of the Past
Discussions

Styllas, M., Dimitriou, E., Gritzalis, K., Koutsodimou, M., Karaouzas, I., Skoulikidis, N., and Gogou, A.: Mid-Holocene changes in the geochemical and biotic conditions of an aquatic ecosystem, in Eastern Mediterranean. Annales de Limnologie-International Journal of Limnology, 54, 21, doi.org/10.1051/limn/2018013, 2018.

Thienemann, M., Masi, A., Kusch, S., Sadori, L., John, S., Francke, A., Wagner, B., and Rethemeyer, J.: Organic geochemical and palynological evidence for Holocene natural and anthropogenic environmental change at Lake Dojran (Macedonia/Greece), The Holocene, In press, 2018.

Thompson, L.G., Mosley-Thompson, E., Davis, M.E., Henderson, K.A., Brecher, H.H., Zagorodnov, V.S., Mashiotta, T.A., and Lin, P.N.: Kilimanjaro ice core records: evidence of Holocene climate change in tropical Africa, Science, 298, 589-593, 2002.

van Zeist, W., and Woldring, H.: Holocene vegetation and climate of northwestern Syria, Palaeohistoria, 22, 111-125, 1980.

Van Zeist, W., Baruch, U., and Bottema, S.: Holocene palaeoecology of the Hula area, northeastern Israel, in: A timeless vale, Archaeological Studies Leiden University 19, Kaptijn, E, and Petit, LP (Eds), Leiden University Press, Leiden, 29–64, 2009.

Verheyden, S., Nader, F.H., Cheng, H.J., Edwards, L.R., and Swennen, R.: Paleoclimate reconstruction in the Levant region from the geochemistry of a Holocene stalagmite from the Jeita cave, Lebanon, Quaternary Research, 2008, 70, 368-381, 2008.

Verschuren, D., Sinninghe Damsté, J.S., Moernaut, J., Kristen, I., Blaauw, M., Fagot, M., Haug, G.H., and Challacea Project Members: Half-precessional dynamics of monsoon rainfall near the East African Equator, Nature, 462, 637-641, 2009.

Wagner, B., Vogel, H., Zanchetta, G., and Sulpizio, R.: Environmental change within the Balkan region during the past ca. 50 ka recorded in the sediments from lakes Prespa and Ohrid, Biogeosciences, 7, 3187-3198, 2010.

Walker, M.J.C., Berkelhammer, M., Björck, S., Cwynar, L.C., Fisher, D.A., Long, A.J., Lowe, J.J., Newnham, R.M., Rasmussen, S.O., and Weiss, H.: Formal subdivision of the Holocene Series/Epoch: A discussion paper by a Working Group of INTIMATE (Integration of ice-core, marine and terrestrial records) and the subcommission on quaternary stratigraphy (International Commission on Stratigraphy), Journal of Quaternary Science, 27, 649-659, 2012.

Wanner, H., Beer, J., Bütikofer, J., Crowley, T.J., Cubasch, U., Flükiger, J., Goosse, H., Grosjean, M., Joos, F., Kaplan, J.O., Küttel, M., Müller, S.A., Prentice, I.C., Solomina, O., Stocker, T.F., Tarasov, P., Wagner, M., and Widmann, M.: Mid- to Late Holocene climate change: an overview, Quaternary Science Reviews, 27, 1791-1828, 2008.

Wanner, H., Solomina, O., Grosjean, M., Ritz, S.P., and Jetel, M.: Structure and origin of Holocene cold events, Quaternary Science Reviews, 30, 3109-3123, 2011.

Wanner, H., Mercolli, L., Grosjean, M., and Ritz, S.: Holocene climate variability and change; a data-based review. Journal of the Geological Society, 172, 254-263, 2015.

Weiss, H.: Global megadrought, societal collapse and resilience at 4.2-3.9 ka BP across the Mediterranean and west Asia, PAGES 24, doi: 10.22498/pages.24.2.62, 2016.

Weiss, H.: Megadrought and collapse, from early agriculture to Angkor, Oxford University Press, Oxford, 2017.

Weiss, H., Courty, M.A.,Wetterstrom, W., Guichard, F., Senior, L., Meadow, R., and Curnow, A.: The genesis and collapse of 3rd millennium north Mesopotamian civilization, Science, 261, 995-1004, 1993.

Weiss, H., and Bradley, R.S.: What drives societal collapse?, Science 291, 609-610, 2001.

Wick, L., Lemcke, G., and Sturm, M.: Evidence of Lateglacial and Holocene climatic change and human impact in eastern Anatolia: high-resolution pollen, charcoal, isotopic and geochemical records from the laminated sediments of Lake Van, Turkey, The Holocene, 13, 665-675, 2003.

Wolff, C., Haug, G.H., Timmermann, A., Sinninghe Damsté, J.S., Brauer, A., Sigman, D.M., Cane, M.A., and Verschuren, D.: Reduced interannual rainfall variability in East Africa during the last ice age, Science, 333, 743-747, 2011.

Xoplaki, E., Gonzalez-Rouco, J. F., Luterbacher, J., and Wanner, H.: Wet season Mediterranean precipitation variability: influence of large-scale dynamics and trends, Climate Dynamics, 23, 63-78, doi: 10.1007/s00382-004-0422-0, 2004.

Yasuda, Y., Kitagawa, H., and Nakagawa, T.: The earliest record of major anthropogenic deforestation in the Ghab Valley, northwest Syria: a palynological study, Quaternary International, 73/74, 127-136, 2000.

Zanchetta, G., Van Welden, A., Baneschi, I., Drysdale, R.N., Sadori, L., Roberts, N., Giardini, M., Beck, C., Pascucci, V., and Sulpizio, R.: Multiproxy record for the last 4500 years from Lake Shkodra (Albania/Montenegro), Journal of Quaternary Science 27, 780-789, 2012.

Zanchetta, G., Regattier, E., Isola, I., Drysdale, R.N., Bini, M., Baneschi, I., and Hellstrom, J.C.: The so-called "4.2 event" in the central Mediterranean and its climatic teleconnections, Alpine and Mediterranean Quaternary, 29, 5-17, 2016.

Zangvil, A., Karas, S., and Sasson, A.: Connection between eastern Mediterranean seasonal mean 500 hPa height and sea-level pressure patterns and the spatial rainfall distribution over Israel, International Journal of Climatology, 23, 1567-1576, 2003.

Zielhofer, C., and Faust, D.: Mid- and Late Holocene fluvial chronology of Tunisia, Quaternary Science Reviews, 27, 580-588, 2008.

Ziv, B., Dayan, U., Kushnir, Y., Roth, C., and Enzel, Y.: Regional and global atmospheric patterns governing rainfall in the southern Levant, International Journal of Climatology 26, 55-73, 2006.

Clim. Past Discuss., https://doi.org/10.5194/cp-2018-82
Manuscript under review for journal Clim. Past
Discussion started: 17 July 2018

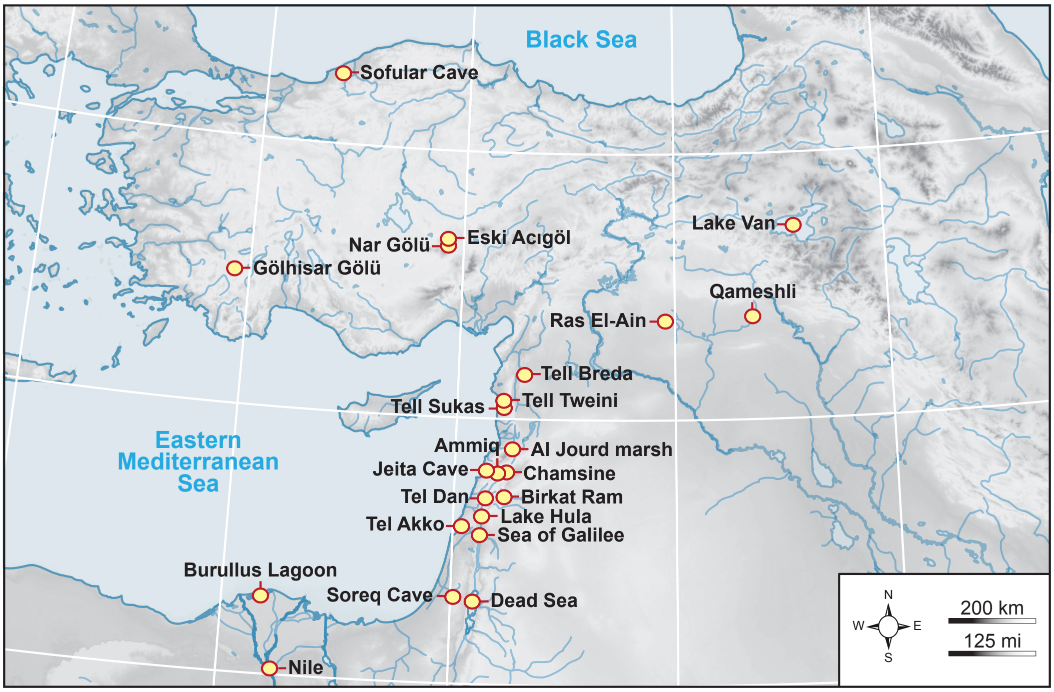

Figure 1. Geographical location of some of the main Levantine sites discussed in this study. Nearby sites in Turkey and Egypt are also displayed on the map (see the manuscript for full references).

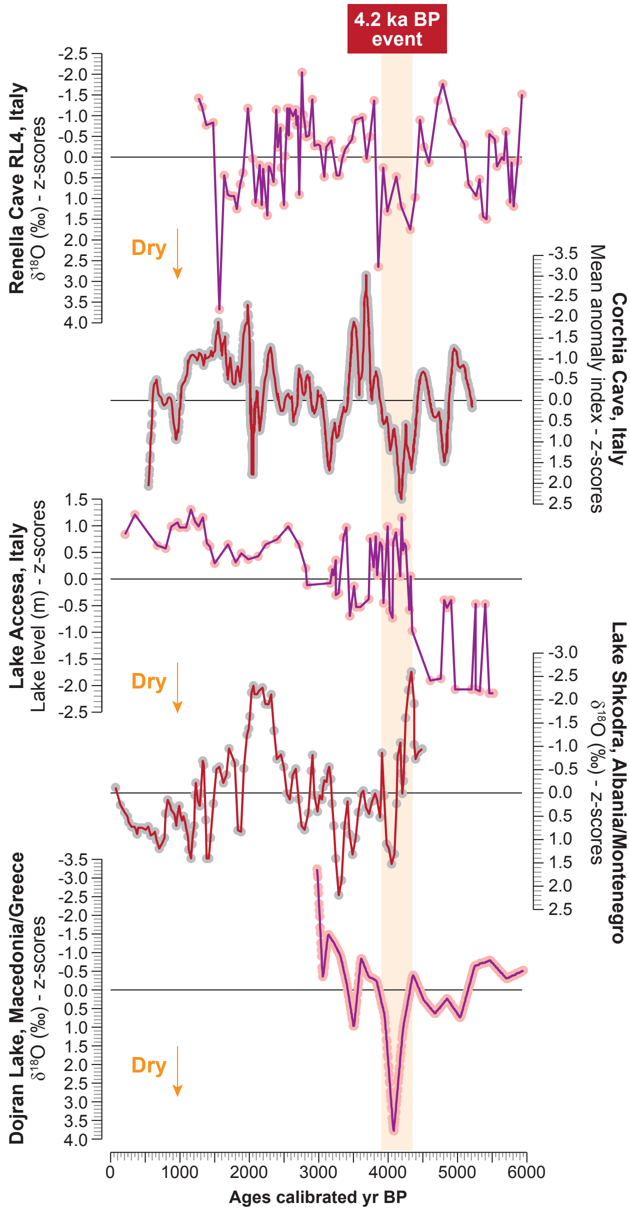

Figure 2. Paleoclimate series (z-score transformed), with the type of climate proxy noted. The orange vertical band represents the 4.2 ka BP event. From top to bottom, Renella Cave (Italy, Drysdale et al., 2006; Zanchetta et al., 2016), Corchia Cave (Italy, Regattieri et al., 2014), Lake Accesa (Italy, Magny et al., 2009), Lake Shkodra (Albania / Montenegro, Zanchetta et al., 2012), and Lake Dojran (Macedonia / Greece, Francke et al., 2013; Thienemann et al., 2018).

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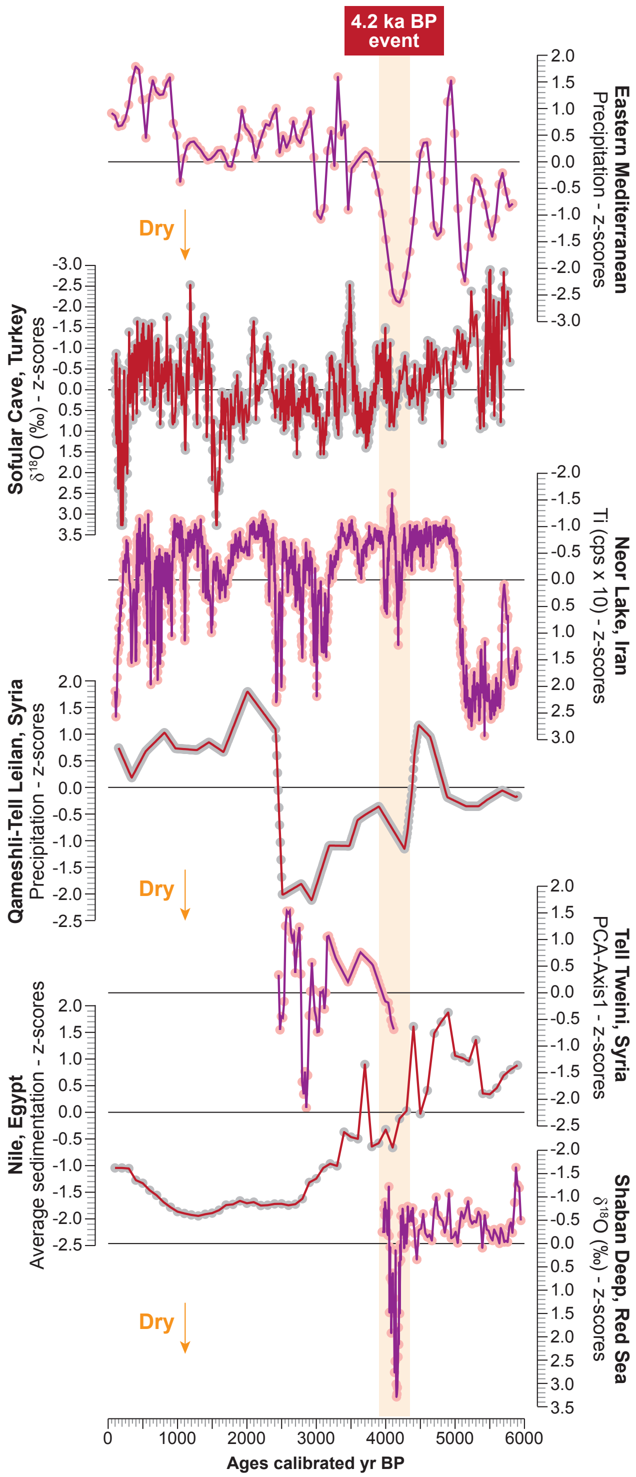

Figure 3. Paleoclimate series (z-score transformed), with the type of climate proxy noted. The orange vertical band represents the 4.2 ka BP event. From top to bottom, Eastern Mediterranean (Kaniewski et al., 2013), Sofular cave (Turkey, Göktürk et al., 2011), Neor Lake (Iran, Sharifi et al., 2015), Qameshli (Syria, Bryson and Bryson, 1997; Fiorentino et al., 2008), Tell Tweini (Syria, Kaniewski et al., 2008), Nile (Egypt, Marriner et al., 2012), and Shaban deep (Red Sea, Arz et al., 2006).

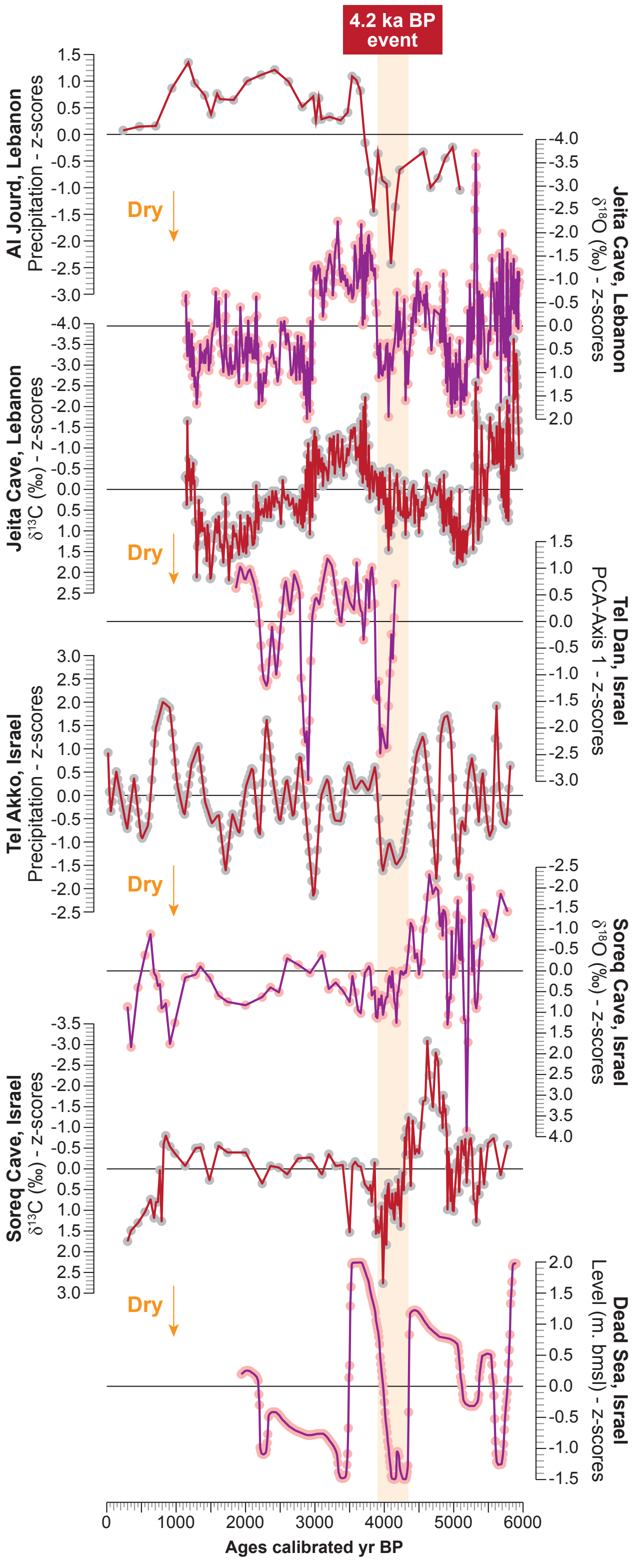

Figure 4. Paleoclimate series (z-score transformed), with the type of climate proxy noted. The orange vertical band represents the 4.2 ka BP event. From top to bottom, Al Jourd (Lebanon, Cheddadi and Khater, 2016), Jeita Cave (Lebanon, Cheng et al., 2016), Tel Dan (Israel, Kaniewski et al., 2017), Tel Akko (Israel, Kaniewski et al., 2013), Soreq Cave (Israel, Bar-Matthews et al., 2003; Bar-Matthews and Ayalon, 2011), and Dead Sea (Israel, Bookman (Ken-Tor) et al., 2004; Migowski et al., 2006; Kagan et al., 2015).