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Seasonality variations in the Central Mediterranean during climate change events in the Late Holocene

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ABSTRACT

Holocene rapid climate change (RCC) events, such as the Little Ice Age (LIA), are thought to have influenced average annual temperatures only marginally, but to have affected winter temperatures relatively strongly. With summer temperatures relatively unaffected, reconstructing climate change at a seasonal resolution is crucial to fully capture Holocene climate variability. Mediterranean climate is highly seasonal, being influenced by the subtropical high-pressure belt in summer and the mid-latitude westerlies combined with outbreaks of polar winds in winter. We identified events of high- and low-detrital input to the Gulf of Taranto (Central Mediterranean Sea), anticipated to be linked to humid and dry conditions, respectively and, thereby, potentially reflecting seasonal contrasts. These events represent the Bronze Age (BA), Roman Humid Period (RHP), Medieval Climate Anomaly (MCA), LIA and present-day, and were selected for the analysis of single specimen *Globigerinoides ruber* (white) carbonate chemistry (Mg/Ca, $\delta^{18}O$ and $\delta^{13}C$). The dynamic range found for these parameters for the measured single individuals in the most recent interval reflects the present-day seasonal contrasts in temperature and precipitation, albeit with a bias towards the summer season. These results are compared with high-resolution (<15 years/sample) Sea Surface Temperature (SST) and Bottom Water Temperature (BWT) reconstructions based on the $\delta^{18}O$ of *G. ruber* (white) and Mg/Ca of benthic foraminifer *Hyalinea balthica*. Although the seasonal temperature contrast remains relatively stable, significant winter cooling is observed during the BA and LIA. Connections between high-latitude climate (winter conditions) and low-latitude climate (summer conditions) appear not straightforward during RCC events. This results in changes in the moisture balance, and in shifts in seasonal dominance between RCCs. During the LIA, winter-like conditions (cold and humid) prevail throughout the year. In contrast, winters are dry and cold during the BA, and are accompanied by dry and warm summers, suggesting year-round aridity and a relatively high seasonal temperature contrast. This could have had a profound impact on early agriculture in Southern Italy.

1. Introduction

Although Holocene climate has been considered as relatively stable, for specific time intervals and regions, distinct centennial to millennial scale climate variability has been recognized (Mayewski et al., 2004; Wanner et al., 2008). This variability is thought to have been instrumental in the rise and fall of past civilizations (e.g., Haug et al., 2003; Büntgen et al., 2011). The millennial scale climate events during the Holocene expressed as cold spells in the northern hemisphere are also known as Rapid Climate Change (RCC) events (Mayewski et al., 2004). These RCC events may have affected specific parts of the climate system through deviating atmospheric patterns during certain seasons rather than impacting the year round global climate. For example, cold spells in the northern hemisphere, during RCC events as the Little Ice Age (LIA, ~150–550 cal. years BP, Grauel et al., 2013a) and the Bronze Age (BA, ~2450–3450 cal. years BP., Rohling et al., 2002, 2009; Mayewski et al, 2004), have been suggested to be primarily a winter phenomenon, implying an enhanced seasonal contrast during these periods (e.g., Denton et al., 2005). Changes in seasonality, therefore, may have played a crucial role in shaping Holocene climate variability.

High-frequency climate change has been different between regions, resulting in a complex spatial pattern, presumably reflecting interactions between low- and high-latitude climate changes (Mayewski et al., 2004;

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Wanner et al., 2008, 2011; Mann et al., 2009). The Mediterranean lies on the boundary between the subtropical high-pressure belt and the mid-latitude westerly system (Fig. 1a). During summer the Mediterranean region is under the influence of subtropical climate, which is closely linked to the position of the Inter-Tropical Convergence Zone (ITCZ; e.g., Alpert et al., 2006). In contrast, during winter the subtropical conditions are displaced southward and the Mediterranean region is primarily connected to the mid-latitude climate phenomena such as the westerly system (Trigo et al., 2006). Together, this results in relatively mild, humid winters and warm, dry summers. The Mediterranean therefore provides an ideal setting for investigating interactions between high- and low-latitude climate variability (Alpert et al., 2006; Trigo et al., 2006), but at the same time requires reconstructions at a seasonal scale. Precipitation records from the Mediterranean area indicate both increased droughts and floods during the LIA, suggesting an enhanced contrast between dry summer conditions and winter precipitation (e.g., Grove, 2001; Mann et al., 2009). Relatively humid conditions during the reign of the Romans, the Roman Humid Period (RHP, 1950–2400 cal. years BP, Grauel et al., 2013b), are generally associated with a more southern pathway of the westerlies, increasing winter precipitation in the region (Dermody et al., 2012). In general, observed millennial scale climate variability in the Northern Mediterranean during the Holocene has been explained by changes in extent of high northern latitude climate during winter (Rohling and Pälike, 2005; Peyron et al., 2011; Combourieu-Nebout et al., 2013).

Understanding seasonality (the seasonal contrast between summer and winter) is, however, not only vital for understanding the physical processes underlying short-term climate change, but is also important for unraveling proxy records, which may show a seasonal bias. Most proxies for sea surface temperature (SST) or sea surface salinity (SSS) are influenced by several environmental parameters, of which seasonality is one. Distinguishing between shifts in seasonality and the other parameters is, therefore, often difficult (Grauel et al., 2013a).

Here we use a sediment core from the Gulf of Taranto (Fig. 1b, Central Mediterranean) to reconstruct past changes in seasonality from selected time slices, using both novel and more traditional approaches. Recently Wit et al. (2010) showed that Mg/Ca values measured on single specimens of the planktonic foraminifer *Globigerinoides ruber* (white) reflect the year round fluctuations of SST in the Mediterranean Sea. As precipitation patterns in the Mediterranean are highly seasonal

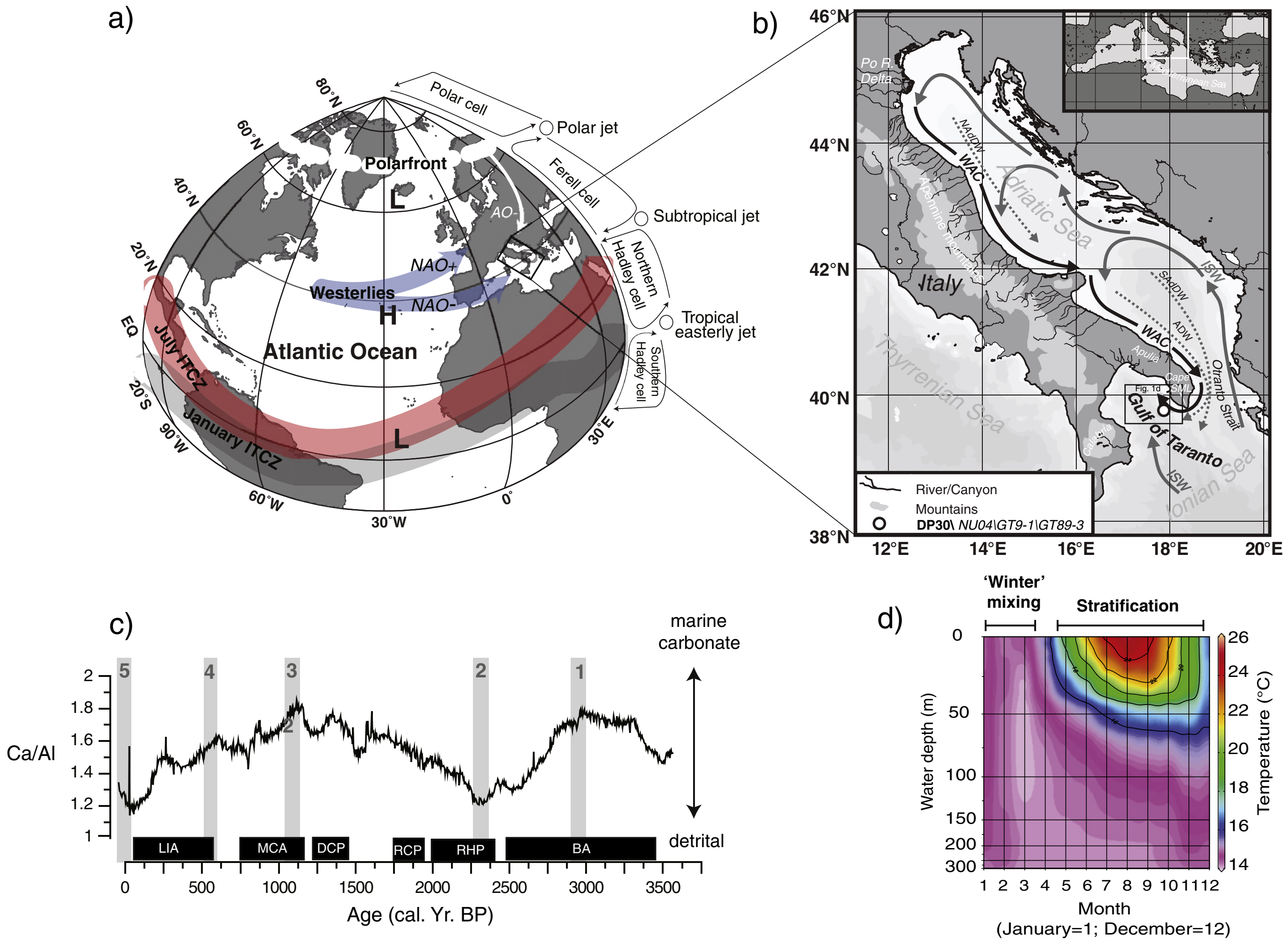

Fig. 1. (a) Atmospheric circulation patterns in the northern hemisphere influencing climate in the study area. AO—is negative Arctic Oscillation, NAO is Northern Atlantic Oscillation, NAO+ reflects the precipitation pattern under a positive mode and NAO— the precipitation patterns when the NAO is in a negative mode. ITCZ stands for the Inter Tropical Convergence Zone. H is high pressure cell, and L is low pressure cell. (b) Map of the study area showing the Adriatic Sea and Ionian Sea, general water circulation and water masses (WAC—Western Adriatic Current; nADW, sADW, and ADW is North-, South-, and Adriatic deep water, ISW is Ionian Surface Water), and the core locations in the Gulf of Taranto discussed in this study (adapted after Grauel et al., 2013a). (c) The Ca/Al ratio of the sediments of core DP30 (Goudeau et al., 2014) with the intervals (gray bars) selected for individual *G. ruber* (white) test chemistry (see Table 1). Dark rectangles correspond to various periods mentioned in the text: Bronze Age (BA, Mayewski et al., 2004) and the Roman Humid Period (RHP), Roman Classical Period (RCP), Medieval Climate Anomaly (MCA) and Little Ice age (LIA) as defined by Grauel et al. (2013b). (d) The monthly distribution of water column temperatures in the Gulf of Taranto (Locarnini et al., 2010; data retrieved from world ocean atlas, 2009, http://www.nodc.noaa.gov), averaged for 38.875°N/17.125°E–40.375°N/18.375°E (adapted after Grauel et al., 2013a).