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The complexity of millennial-scale variability in southwestern Europe during MIS 11

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A B S T R A C T

Climatic variability of Marine Isotope Stage (MIS) 11 is examined using a new high-resolution direct land–sea comparison from the SW Iberian margin Site U1385. This study, based on pollen and biomarker analyses, documents regional vegetation, terrestrial climate and sea surface temperature (SST) variability. Suborbital climate variability is revealed by a series of forest decline events suggesting repeated cooling and drying episodes in SW Iberia throughout MIS 11. Only the most severe events on land are coeval with SST decreases, under larger ice volume conditions. Our study shows that the diverse expression (magnitude, character and duration) of the millennial-scale cooling events in SW Europe relies on atmospheric and oceanic processes whose predominant role likely depends on baseline climate states. Repeated atmospheric shifts recalling the positive North Atlantic Oscillation mode, inducing dryness in SW Iberia without systematical SST changes, would prevail during low ice volume conditions. In contrast, disruption of the Atlantic meridional overturning circulation (AMOC), related to iceberg discharges, colder SST and increased hydrological regime, would be responsible for the coldest and driest episodes of prolonged duration in SW Europe.

Introduction

The Mediterranean region is particularly sensitive to global climate change owing to its geographical position between the mid-latitudes and subtropical climate regimes (Giorgi, 2006; Lionello et al., 2006; IPCC, 2013). Climate projections show repeated occurrence of severe drought episodes in the Mediterranean area, including the Iberian Peninsula, which will deeply affect terrestrial ecosystems (Gao and Giorgi, 2008; Anav and Mariotti, 2011; Santini et al., 2014; Sousa et al., 2015a). During past climatic cycles, it has been demonstrated that similar recurring dry conditions led to drastic forest decline in southern Europe. However, while millennial-scale climate variability has been widely documented mainly for the last glacial period (e.g., Sánchez Goñi et al., 2000, 2008; Combourieu-Nebout et al., 2002; Fletcher and Sánchez Goñi, 2008; Naughton et al., 2009; Fletcher et al., 2010), few available records report abrupt interglacial climate variability prior to the current interglacial.

Specifically, Marine Isotope Stage (MIS) 11 (425–374 ka) represents a period of primary interest to investigate natural abrupt climate variability. Despite its potential astronomical analogy with the Holocene (Loutre and Berger, 2003) remaining complex and controversial (e.g., Tzedakis, 2010; Yin and Berger, 2012), this interglacial presents additional key features, including its higher than present-day sea level related to the collapse of Greenland and West Antarctica ice sheets (Raymo and Mitrovica, 2012; Roberts et al., 2012; Reyes et al., 2014) and its greenhouse gas-driven climate warming (Raynaud et al., 2005; Yin and Berger, 2012).

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MIS 11c generally stands out as a long, warm and relatively stable interglacial in numerous records (e.g., Oppo et al., 1998; McManus et al., 2003; Bauch, 2012; Melles et al., 2012; Milker et al., 2013; Candy et al., 2014), although few high temporal resolution records from Antarctica, subtropical and subpolar North Atlantic, and northern Europe, document pronounced abrupt climate change during MIS 11c despite reduced ice caps (Oppo et al., 1998; Billups et al., 2004; Koutsodendris et al., 2011; Pol et al., 2011; Tye et al., 2016). Comparatively, suborbital climatic variability during MIS 11b (~395–374 ka) is well documented in records from the North Atlantic, particularly off western Iberia (de Abreu et al., 2005; Martrat et al., 2007; Stein et al., 2009; Voelker et al., 2010; Rodrigues et al., 2011; Amore et al., 2012; Palumbo et al., 2013; Hodell et al., 2013a; Marino et al., 2014; Maiorano et al., 2015). Three marked cooling episodes linked to deep ocean circulation changes and iceberg discharges into the North Atlantic are commonly reported (e.g., Oppo et al., 1998). Yet, the amplitude of precipitation, changes in temperature and duration of the cold episodes on land associated with these abrupt changes are not well known. In addition, phase relationship between ocean and terrestrial climatic changes remain to be assessed since air–sea decoupling was identified during some periods of ice sheet growth by European margin records (Sánchez Goñi et al., 2013; Cortina et al., 2015). So far, only two pollen records have been published in the northern and southern parts of the Iberian margin for MIS 11 (Desprat et al., 2005; Tzedakis et al., 2009). However, the temporal resolution of these records precludes a reliable assessment of the regional vegetation-based climate in response to the millennial-scale cooling throughout MIS 11.

Although millennial-scale variability is an inherent pattern of the Pleistocene climate regardless of glacial state (Oppo et al., 1998), ice sheet dynamics is one of the primary factors modulating millennial-scale cooling events. Cooling episodes in the North Atlantic associated with iceberg surges would be amplified when ice sheet size surpasses a critical threshold (McManus et al., 1999). Freshwater from melting icebergs may be responsible for the enhancement and/or prolonged duration of cold conditions through a positive feedback mechanism on AMOC (Atlantic Meridional Overturning Circulation) even if they may not be the trigger of northern stadial events (Barker et al., 2015). However, the duration and intensity of northern cold events may also rely on the background climate, such as the intensity of regional precipitation, modifying the AMOC response to freshwater forcing (Margari et al., 2010). To date, the factors modulating millennial-scale cooling of MIS 11 remain insufficiently understood.

Here we present a new high resolution record of MIS 11 from Site U1385, also known as the "Shackleton Site", collected recently during the Integrated Ocean Drilling Program (IODP) Expedition 339. Site U1385 is located on the SW Iberian margin (Fig. 1), considered as a unique and exceptional area for paleoclimate research since Nick Shackleton's seminal study of the last climatic cycle recorded at the nearby site MD95-2042 (Shackleton et al., 2000, 2004), and the publication of the first direct land–sea comparison from the same site (Sánchez Goñi et al., 1999, 2000; Shackleton et al., 2003). We provide a detailed record of atmospherically-driven southern European vegetation changes at suborbital time scales that we directly compare with sea surface temperatures in eastern subtropical North Atlantic. Cooling events, differing in terms of magnitude, character and duration, are discussed in the light of a larger European and North Atlantic context and global ice volume changes. In addition, we discuss the potential atmospheric and oceanic configurations behind this complexity of millennial-scale climate variability during MIS 11.

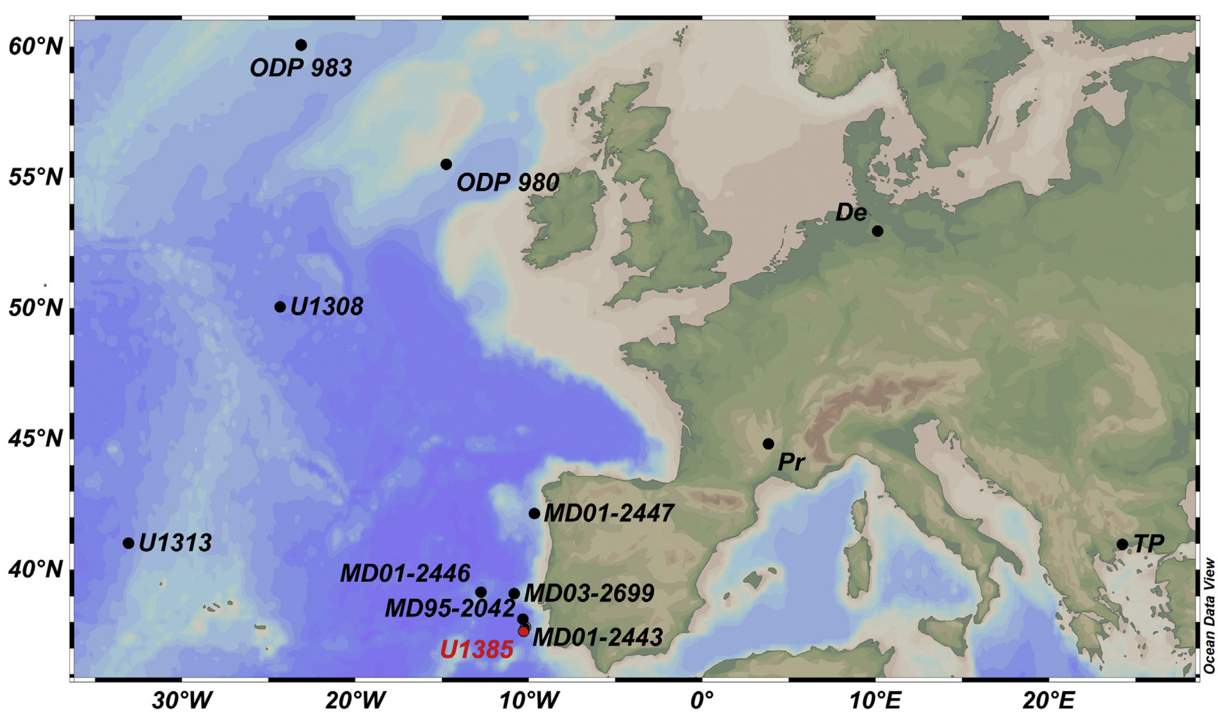

Figure 1. Location of the IODP Site U1385 and available European and North Atlantic records discussed in the text: ODP Site 983 (Barker et al., 2015); ODP Site 980 (Oppo et al., 1998; McManus et al., 1999); De: Dethlingen (Koutsodendris et al., 2010); Site U1308 (Hodell et al., 2008); Pr: Praclaux (Reille et al., 2000); MD01-2447 (Desprat et al., 2005); Site U1313 (Stein et al., 2009); TP: Tenaghi Philippon (Wijmstra and Smit, 1976); MD01-2446 (Voelker et al., 2010; Marino et al., 2014); MD03-2699 (Voelker et al., 2010; Rodrigues et al., 2011; Amore et al., 2012; Palumbo et al., 2013); MD95-2042 (Sánchez Goñi et al., 1999, 2002; Shackleton et al., 2000; Chabaud et al., 2014); MD01-2443 (de Abreu et al., 2005; Martrat et al., 2007; Tzedakis et al., 2009).

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