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Research paper

Comparison of qualitative and quantitative dinoflagellate cyst approaches in reconstructing glacial-interglacial climate variability at West Iberian Margin IODP 'Shackleton' Site U1385

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ABSTRACT

Dinoflagellate cysts (dinocysts) are commonly used to reconstruct past environmental conditions at the sea surface, such as primary production, temperature and salinity. Abundances of selected dinocyst taxa are used in qualitative indices, whereas the modern analogue technique (MAT) is used for quantitative reconstructions. Qualitative indices use process-based knowledge of present-day relations between the environmental variables and the distribution of dinocysts, whereas the MAT is based on the assumption that past assemblages have modern counterparts that correspond to similar sea-surface conditions. Here we explore the potential of both approaches to reconstruct sea surface temperature (SST), production (SSP), salinity (SSS) and seasonality during the last 22 thousand years along the West Iberian Margin (WIM), at Integrated Ocean Drilling Program (IODP) Site U1385. We compare results to published paleoclimatic reconstructions. Our SST and SSS reconstructions provide the first continuous dinocyst MAT-based SST and SSS records for this area and time interval.

Qualitative and quantitative dinocyst-based SST estimates from the WIM are similar and resemble previous SST estimates from dinocysts, alkenones and foraminifers from nearby sites. The surface temperature trends and millennial-scale variations largely match those from the Greenland ice core records. Quantitative MAT-based SST estimates show increased seasonality in the glacial stage resulting from strong winter cooling. Dinocyst MAT-based salinity decreases concomitantly with cooling during the Younger Dryas and Heinrich Stadial 1 (HS1), likely related to the melting of icebergs that reached the region during HS1. Our qualitative and quantitative SSP estimates show higher values in the glacial stage compared to the Holocene, which is consistent with published records and supports the usefulness of both approaches. Small differences between SST tracer records may be explained by the limited number of modern analogues from warm ocean regions in the dinocyst reference dataset for MAT, the small number of dinocysts used in the qualitative estimates, the possible effect of a parameter other than temperature that might amplify noise, and/or seasonal biases of the tracer species.

In any case, the advantage of the qualitative approach is to allow reconstructions in non-analogue situations. Regression of the qualitative index versus present-day SST also allows for a quantitative reconstruction, although over a limited range of SSTs (especially towards the lower end) and with quite some uncertainty, but produces reasonable values beyond the upper limit of the MAT. The MAT reconstructs more reliable SSTs, with a much smaller error of prediction, but only up to present-day WIM values, because it is based on the assumption that past assemblages have modern counterparts that correspond to similar sea-surface conditions, which is not always valid. The advantages of the MAT approach include its quantitative nature and insights into seasonality. Hence both approaches are complementary. At Site U1385, MAT can be used for reconstructions in the colder periods (YD, HS1 and glacial stage), with a small error of prediction and the quantified index can be used to estimate SST beyond the limit of the MAT (Holocene and B-A).

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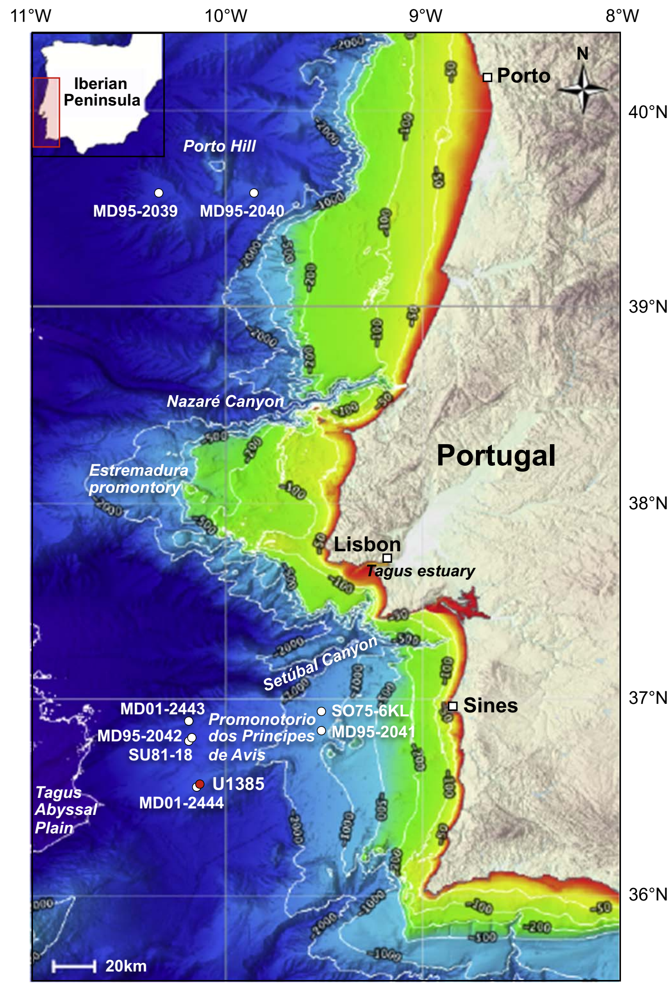

Fig. 1. Location of Shackleton Site U1385 and bathymetry of the (southern) West Iberian Margin. The Iberian Peninsula (inset adapted from Ribeiro et al., 2016), location of Shackleton Site U1385 (red circle) and other sites discussed in the text (white circles), depth (blue color for deeper zones), isobaths (50, 100, 200, 500, 1000 and 2000 m) and some of the main topographic features are shown. The bathymetric metadata and Digital Terrain Model data products have been derived from the EMODnet Bathymetry portal (http://www.emodnet-bathymetry.eu). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

1. Introduction

To understand the functioning of the climate system and the mechanisms underlying millennial-scale changes, sedimentary records that allow sufficiently high temporal resolution and tracers sensitive enough to capture these changes are needed. Ideally, the tracers should provide robust reconstructions of the important parameters of the climate system. Over the past decades, the West Iberian Margin (WIM), where several cruises retrieved sediment cores for paleoclimate reconstructions, proved to be an ideal location (Fig. 1). These cores provided high-resolution records of millennial-scale climate variability for the last glacial cycles (e.g. Martrat et al., 2007), which correlate very well to changes observed earlier in polar ice cores of both hemispheres and to existing European terrestrial climate records (e.g. Shackleton et al., 2000; Tzedakis et al., 2009).

Sediments from the WIM have been extensively studied for many time intervals using various (quantitative and qualitative) approaches and proxies, such as planktic foraminifera (e.g. Salgueiro et al., 2010; Voelker and de Abreu, 2011) and their isotopic composition (e.g. Shackleton et al., 2000, 2004; Eynaud et al., 2009), alkenones (e.g. Bard et al., 2000), pollen (e.g. Sanchez Goñi et al., 1999, 2000a, 2000b, 2002, 2006, 2008, 2009, 2013, 2016; Turon et al., 2003; Naughton et al., 2007), and other (multi-proxy) studies (e.g. Pailler and Bard, 2002; de Vernal et al., 2006; Martrat et al., 2007; Penaud et al., 2011a, 2011b; Hodell et al., 2013a). The fossil remains of dinoflagellates (dinocysts) have also been successfully used to reconstruct past environmental conditions at the WIM (e.g. Zippi, 1992; Ribeiro and Amorim, 2008; Penaud et al., 2011a, 2011b; Ribeiro et al., 2016) and are commonly used to reconstruct past environmental conditions at the sea surface, including production (SSP), temperature (SST) and salinity (SSS).

Accurate reconstructions of past conditions ideally require process-based knowledge of the relations between the environmental variables and the distribution of dinocysts. On a global scale, a wealth of information on present-day dinocyst ecology is available (Zonneveld et al., 2013), which allows for qualitative reconstructions of environmental parameters based on taxa abundances. This approach is simple and can be used on long time scales, but does not provide quantitative results. For the Northern Hemisphere, a standardized database of present-day dinocyst assemblages and physico-chemical seawater parameters allows for quantification of paleoenvironmental conditions using the modern analogue technique (MAT) (Radi and de Vernal, 2008; de Vernal et al., 2001, 2005, 2013a, 2013b). In addition, this database can be used to verify and quantify the relation between present-day dinocyst abundances and SST. However, these quantitative estimates are based on the assumption that the past assemblages have modern counterparts that correspond to similar sea-surface conditions, which may not always be valid. All approaches thus have advantages and limitations.

Our principal aim is to compare qualitative and quantitative approaches to explore their potential to reconstruct the glacial-interglacial climate and environmental variability. We use sediments deposited over the last 22 thousand years (kyr) along the WIM, recovered during Integrated Ocean Drilling Program (IODP) Expedition 339 at Site U1385 (Hodell et al., 2013a). To this end we have generated sea surface temperature (warm/cold SST_{dino} index) and production estimates based on a qualitative approach (dinocyst abundances) and SST_{MAT}, SSS_{MAT}, SSP_{MAT} and seasonality based on MAT applied to the Modern n = 1492 database of de Vernal et al. (2013a). In addition, we use the n = 1492 database to quantify the relation between present-day SST_{dino} and SST to reconstruct quantitative SST from the index as a third approach. We compare these qualitative and quantitative dinocyst-based estimates to each other and to existing reconstructions, based on dinocysts, foraminifera, alkenones and oxygen isotopes, from nearby sites.

Studies that report winter SSTs in addition to summer and/or annual SSTs along the WIM are rare. Therefore, we generate a qualitative SST_{dino} record that we compare to quantitative summer SST (SST_{MATsu}) and winter SST (SST_{MATwi}) as well as to independent SST records that may yield a seasonal bias. Importantly, we also present new reconstructions of sea surface salinity (SSS_{MAT}) for the last 22 kyr at the WIM. Approaches to reconstruct salinity are not straightforward and paleosalinity records along the WIM are rare. Although dinocyst assemblages permit salinity estimates (e.g. de Vernal et al., 2001, 2005), only few dinocyst publications from the WIM provide SSS reconstructions (e.g. Penaud et al., 2011a). In addition, we document variability in production over the last glacial-interglacial transition, using accumulation rates of cysts resistant to oxidative degradation and MAT-based SSP reconstructions (SSP_{MAT}). We present a critical evaluation of the advantages and limitations of the different tracers used for paleoclimatic and paleoceanographic reconstructions along the WIM.

2. Oceanographic setting of the West Iberian Margin

2.1. Present-day oceanography

In the North Atlantic Ocean, the Polar Front separates cold low-salinity Polar Water, characterized by seasonal sea ice and iceberg drift, from warm, high-salinity Atlantic Water (e.g. Eynaud et al., 2009). The