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Changes in latitudinal sea surface temperature gradients along the Southern Chilean margin since the last glacial

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The comparison between different climate model simulations of water hosing experiments under glacial conditions points toward diverging responses in Sea Surface Temperature changes (SST) especially in the Southeast Pacific (SEP). This suggests that reconstituting the latitudinal SST gradient in the SEP is a critical parameter for a better understanding of the mechanisms behind the abrupt climatic events since the last glacial period. Here we present, high-resolution records of SST, using planktonic foraminiferal assemblages and alkenone temperature reconstructions and stable oxygen and carbon isotopes from three deep-sea sediment cores along a latitudinal transect off the southern Chilean coast. This allowed us to reconstruct the variations of the latitudinal SST gradient and the Subtropical Front movements in the SEP. The SST results suggest a clear Antarctic timing consistent with the bipolar seesaw control, especially during the late glacial and the deglaciation. Our records do not suggest a complete oceanic heat transfer signal, highlighting the implication of an atmospheric component in the heat transfers between the two hemispheres, controlled by the latitudinal movements of the intertropical convergence zone in the Atlantic and the associated weaker South Pacific westerly split jet. Furthermore, our records indicate variable conditions during the Holocene, and also emphasize the influence of local fresh water inputs from the Patagonian ice sheet and/or precipitation on the SST fresh water input estimates along the Chilean margin (North and South of 49° S) from the onset of the deglaciation until 8 kyr cal. BP.

1. Introduction

The climatic links between the northern and southern hemispheres since the late glacial period give rise to numerous questions whether both respond synchronously to millennial-scale climatic events, and the mechanisms triggering these events (e.g. Barker et al., 2009; Stenni et al., 2011). It has been proposed that non-synchronous climatic variations are the result of varying heat transfer efficiency by the thermohaline circulation between the southern and the northern hemispheres, generating a bipolar seesaw pattern (Crowley, 1992; Broecker, 1998; Stocker, 1998). In this context, the Southern Ocean probably played an amplifying role during these events, through the action of the Southern Westerly Winds (SWW; Anderson et al., 2009; Lamy et al., 2007) that control Southern Ocean upwelling at the Antarctic Divergence and the associated overturning circulation, which influences heat, salinity, nutrients and CO_2 transport at a global scale (e.g. Toggweiler and Russell, 2008; Marshall and Speer, 2012). Yet, the past latitudinal position of the SWW remains an open question in paleoclimate studies (e.g. Chavaillaz et al., 2013; Chiang et al., 2014; Kilian and Lamy, 2012; Moreno et al., 2012; Sime et al., 2013;

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Toggweiler et al., 2006). In this context, model simulations suggest a direct impact of the sea surface temperature (SST) gradients in the mid-latitudes on the modulation of the intensity and latitudinal position of the SWW (Brayshaw et al., 2008). An enhanced (decreased) SST gradient would generate stronger (weaker) and more southward (northward) SWW (Brayshaw et al., 2008), stressing the importance of extending the knowledge of SST variations in the past.

So far, several alkenone-based SST studies have been carried out on sediment cores along the Chilean margin in the SEP. These reconstructions showed an Antarctic driven timing in the millennial-scale temperature changes of the SEP, with a decline in the SST consistent with the bipolar seesaw mechanism (Lamy et al., 2004, 2007; Kaiser et al., 2005; Caniupán et al., 2011) even though the Antarctic Cold Reversal (ACR) was not well marked in all the records (Pedro et al., 2015). It was also suggested that Sub-Antarctic surface water masses extended up to 41° S during the Last Glacial Maximum (LGM) (Lamy et al., 2004; Kaiser et al., 2005), and that a northward migration of the Sub-Antarctic Front (SAF), probably reached ~53° S (Caniupán et al., 2011), which led to a larger glacial than Holocene temperature gradient. However, the question whether the large amplitude of the SST changes in the high latitudes (south of ~46° S) of the SEP are due to local or regional effects still remains unclear (Caniupán et al., 2011). According to the comparison of different SST records in the southern Pacific region, the SST gradient between the LGM and the Holocene in the eastern SEP, south of ~46° S, is higher (≥5 °C) compared to the western part of the SEP (~3 °C) (Lamy et al., 2015). This difference has been interpreted as a LGM northward extension of the antarctic surface water in the eastern SEP (Lamy et al., 2015). Conversely, dinoflagellate cyst reconstructions at 41° S suggest a more pronounced equatorward shift (~7°–~10°) of the SAF and Polar Front (PF) during the late glacial (Verleye and Louwye, 2010). Comparison between the different climate model simulations of water hosing experiments under glacial conditions also lead to diverging interpretations concerning the influence of the bipolar seesaw in terms of SST changes in the SEP (Kageyama et al., 2013). A purely Atlantic Meridional Overturning Circulation (AMOC) bi-polar seesaw mechanism, without the implication of atmospheric heat transfer, would lead to a reduced latitudinal SST gradient along the SEP, whereas an atmospheric forcing would induce an increase in the latitudinal SST gradient (Kageyama et al., 2013; Chiang et al., 2014).

This study is motivated by the uncertainty of whether the atmospheric or the oceanic circulations control the heat transfer between northern and southern hemispheres. It should also be noted that the major discrepancies in both model and SST data reconstructions occurred mostly in the mid to high latitudes of the SEP during the last glacial-interglacial transition emphasizing the importance of reliable documentation of the latitudinal SST gradient in this area (Kageyama et al., 2013). The aim is to improve our understanding of latitudinal SST changes over the last glacial termination along the southern Chilean margin, and to identify regional versus global mechanisms influencing this temperature gradient. Here, we present new SST reconstructions from three deep-sea cores collected in the SEP covering a latitudinal transect from 41° to 49° S along the South Chilean margin. SST reconstructions are obtained by planktonic foraminiferal assemblages using the Modern Analog Technique (MAT; Prell, 1985), based on a recent Southern Hemisphere Ocean (SHO) core-top database (Haddam et al., 2016). We compare our SST reconstructions, including a new alkenone-based SST record at 46° S, and the available SST data close to the study area with $\delta^{18}O$ values of the surface water ($\delta^{18}O_w$). The comparison provides information about the potential influence of fresh water inputs, related to the local glaciers melting, and the regional mechanisms controlling the latitudinal SST gradient in the SEP.

2. Climatic context

2.1. Atmospheric setting

The most prominent atmospheric feature characterizing the studied region is the presence of the SWW, almost perceived as zonally symmetric. However, reanalyses data from the National Centers for Environmental Prediction (NCEP) show that during the austral winter the SWW are strongly asymmetric in the Pacific ocean, as the core of the westerlies splits south of Australia into a subantarctic and a subtropical branch (Chiang et al., 2014). This austral winter feature is known as the South Pacific Split Jet.

These winds bring considerable amounts of precipitation that are intercepted by the southern South American continent, especially the Andes mountain ranges, which covers the northern and central parts of the latitudinal range of the SWW. Actually, they are centered at around 50° S, and present a seasonal variation in latitude and intensity consisting of a southward (northward) migration during austral summer (winter) (e.g. Garreaud et al., 2013). The high precipitation rates on land display a southward increasing gradient with mean annual precipitation up to 7000 mm yr^{-1} at 50° S, and up to 4000 mm yr^{-1} at 42° S (Garreaud et al., 2013; DGA, 2016).

Between 40° S and 50° S, the Chilean margin features an irregular coastline, formed by islands and fjords, that receive considerable amounts of fresh water due to high precipitation and ice-melting of the two main ice fields of the area: the northern and southern Patagonian Ice Sheets (PIS, 46°–52° S) (Pantoja et al., 2011).

2.2. Oceanographic setting

The SEP is under the influence of the Antarctic Circumpolar Current (ACC) (Strub et al., 1998). The ACC is an important oceanographic feature in the southern hemisphere connecting each of the oceanic basins of the Southern Ocean. It is characterized by several frontal systems acting as zonal boundaries with abrupt temperature and salinity gradients. The ACC is largely controlled by the SWW, and meso-scale eddies (Marshall and Speer, 2012). These eddies contribute to impede (enhance) the velocity of the ACC downstream (upstream) of large topographic entities (Trani et al., 2014). Our study area is located between the Subtropical Front (STF) (~35° S) to the north and the Sub-Antarctic and Polar Fronts (SAF and PF, at ~56° S and ~58° S in the Drake Passage, respectively) to the south (Fig. 1). When reaching the coast, the STF position becomes difficult to place (between ~30° S and ~37° S, Chaigneau and Pizarro, 2005). The SAF and the PF are the principal fronts of the ACC, and the latitudinal extent of the ACC continues south of the PF (Orsi et al., 1995; Rintoul et al., 2001). The main body of the ACC is constrained to flow through the Drake Passage, with a mean zonal position between 50° S and 55° S (Rintoul et al., 2001). Our study area is influenced by the northern branch of the ACC, which divides at ~46° S into two coastal currents: the northward flowing Peru-Chile Current (PCC), exporting the subantarctic surface water (SSW) of the ACC (~53° S - 100° W) to lower coastal latitudes (~40° S - 75° W), and the southward flowing Cape-Horn Current (CHC, 100–150 km offshore) which returns as part of the SSW back to the ACC (Chaigneau and Pizarro, 2005) (Fig. 1). This divergence has an impact on the location of latitudinal SST gradients in the SEP. Accordingly, the closest SST gradient to our study area is positioned at the location of the STF. The second and