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Ocean and atmosphere teleconnections modulate east tropical Pacific productivity at late to middle Pleistocene terminations

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ABSTRACT

The modern Eastern Equatorial Pacific (EEP) is a key oceanographic region for regulating the Earth's climate system, accounting for between 5–10% of global marine production whilst also representing a major source of carbon dioxide efflux to the atmosphere. Changes in ocean dynamics linked to the nutrient supply from the Southern Ocean have been suggested to have played a dominant role in regulating EEP productivity over glacial–interglacial timescales of the past 500 ka. Yet, the full extent of the climate and oceanic teleconnections and the mechanisms promoting the observed increase of productivity occurring at glacial terminations remain poorly understood. Here we present multi-proxy, micropaleontological, geochemical and sedimentological records from the easternmost EEP to infer changes in atmospheric patterns and oceanic processes potentially influencing regional primary productivity over glacial–interglacial cycles of the mid-late Pleistocene (∼0–650 ka). These proxy data support a leading role for the north–south migration of the Intertropical Convergence Zone (ITCZ) in shaping past productivity variability in the EEP. Productivity increases during glacial periods and notably peaks at major and "extra" glacial terminations (those occurring 1–2 precession cycles after some major terminations) coincident with the inferred southernmost position of the ITCZ. The comparison of our reconstructions with proxy records of climate variability suggests the intensification of related extratropical atmospheric and oceanic teleconnections during deglaciation events. These processes may have re-activated the supply of southern sourced nutrients to the EEP, potentially contributing to enhanced productivity in the EEP and thus counterbalancing the oceanic carbon dioxide outgassing at glacial terminations.

1. Introduction

The modern East Equatorial Pacific (EEP) plays an important role in climate regulation as it is an important source of carbon dioxide (CO_2) to the atmosphere (Takahashi et al., 2009). Yet, it accounts for 5–10% of the global oceanic primary production while comprising only 9% of the ocean area (Pennington et al., 2006). Nutrients and CO_2-rich waters are currently supplied to the EEP thermocline via Subantarctic Mode Water (Sarmiento et al., 2003). Modern biogeochemical models suggest that Subantarctic Mode Water provides a substantial fraction (30–50%) of the nutrients that reach the EEP, thereby sustaining a large proportion of the export production in this area (Palter et al., 2010). However, the mechanisms driving glacial to interglacial changes in the biological productivity and export production in the EEP remain equivocal. The supply of micronutrients (e.g., iron) have long been proposed as one of the main influences on the efficiency and strength of the oceanic biological pump in the past (e.g. Murray et al., 2012). Yet, a recent study have argued that variability in the atmospheric dust input (a major source of iron) to the EEP was not large enough to trigger a substantial increase in glacial productivity and that nutrient supply from the Southern Ocean might have played a crucial role in controlling the equatorial Pacific productivity over the Late Pleistocene (Winckler et al., 2016). The south to equatorial connection, through so called "oceanic tunnelling" (Spero and Lea, 2002) appears to have been active in the past, in particular during the last deglaciation (Martinez-Boti et al., 2015) and likely during older deglaciations (Rippert et al., 2017). However, little is known about the functioning of the oceanic tunnelling during other mid-late

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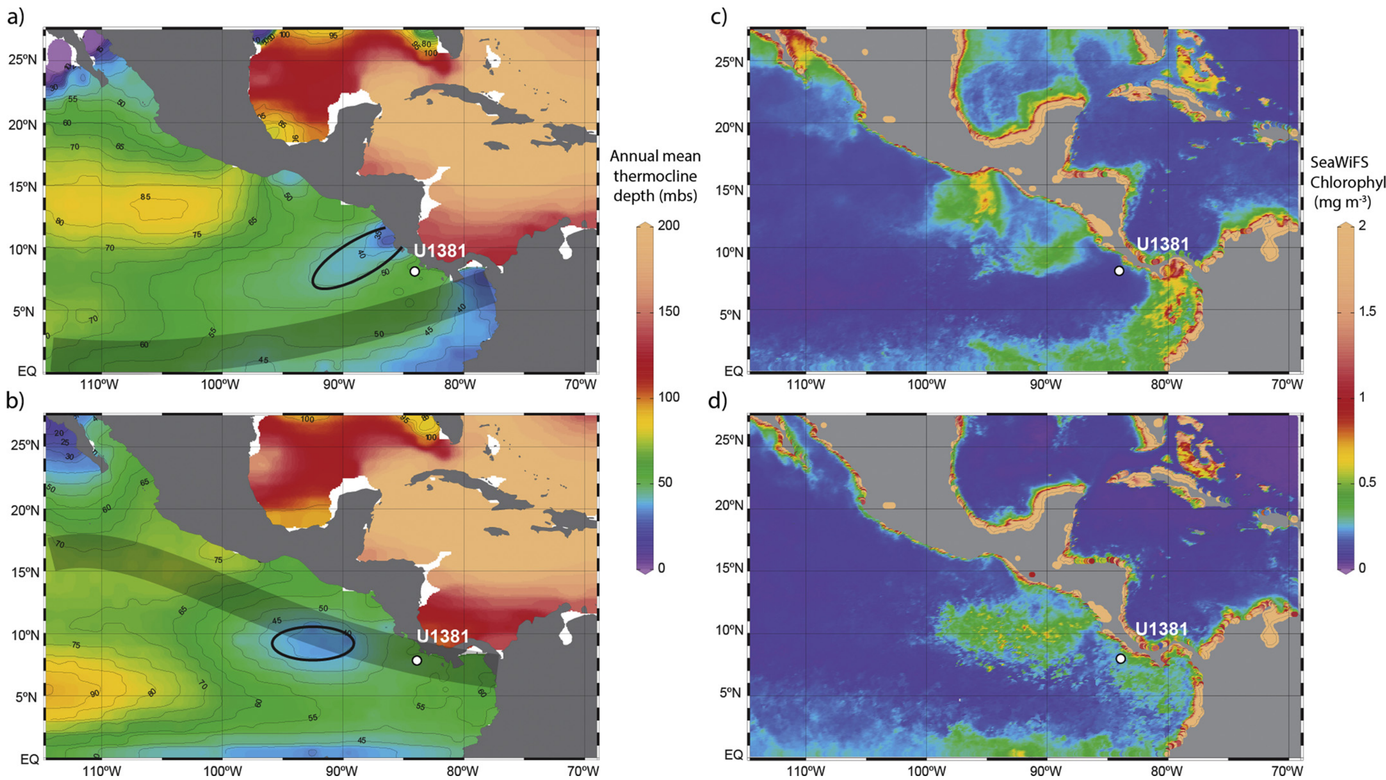

Fig. 1. Location of Hole U1381C and regional hydrography. Figures on the left (a, b) represent the seasonal (winter above; summer below) depth (in meters below surface, mbs) of the 20 °C isotherm in region of the EEP, which is used to identify the position of the Costa Rica Dome (Fiedler, 2002). The shadowed area represents the position of the ITCZ in winter (a) and summer (b). Thermocline temperature data are from World Ocean Database 2013 (Locarnini et al., 2013). The white circle indicates the location of Hole U1381C. Plots on the right (c, d) represents the winter (c) and summer (d) mean fields of SeaWiFS (September 1997 to July 2001) chlorophyll concentration in the region of the Costa Rica Dome. SeaWiFS data produced by NASA SeaWiFS Project and distributed by the Distributed Active Archive Center at NASA/Goddard Space Flight Center (http://oceancolor.gsfc.nasa.gov, accessed on 1st February 2018). (For interpretation of the colours in the figure(s), the reader is referred to the web version of this article.)

Pleistocene terminations and its influence on the biological pump in the EEP and therefore global climate.

Furthermore, the EEP is involved in interhemispheric thermal and moisture transport through changes in the mean position and strength of the Hadley circulation cells, which are intimately linked to the meridional position of the Intertropical Convergence Zone (ITCZ) (Schneider et al., 2014). Changes in the average position of the ITCZ are relevant not only at a global scale, controlling global atmospheric reorganizations (Chiang et al., 2014), but also regionally, involving changes in the position of oceanographic structures such as the Costa Rica Dome (CRD). The CRD is an open-ocean upwelling system in the EEP that develops seasonally off the coast of Central America (Fiedler, 2002). It has been previously suggested that past changes in the intensity and location of the CRD upwelling system depends on the intensity of the trade winds linked to the meridional position of the ITCZ (Hofmann et al., 1981), and that such variability could influence regional productivity patterns in the EEP during the last glacial cycle (Ivanova et al., 2012). It is unclear to what extent atmospheric processes (e.g., ITCZ-related CRD variability), in addition to oceanic processes (e.g., ocean tunnelling), might have influenced past productivity patterns in the EEP during the mid to late Pleistocene.

Here we present a multi-proxy record to investigate the mechanisms controlling past variability in productivity in the EEP at glacial–interglacial time scales. The record is obtained from the Integrated Ocean Drilling Program (IODP), Expedition 344, Site U1381 (Hole U1381C) located off the Costa Rica margin (Fig. 1). The core site is ideally located to capture signals related to the past changes in the EEP productivity which might have occurred either through variations in the position of the ITCZ, which controls the extension and location of the CRD, and/or through fluctuations in the nutrient supply from southern sourced waters. Accordingly, we use proxies providing information for the quantity and quality of the organic carbon supply to the seafloor (e.g., benthic foraminiferal faunal composition, planktonic foraminiferal abundance, organic carbon and opal content) and sediment chemical composition (e.g., calcium carbonate and major elemental content). These multi-proxy derived records allow us to investigate the mechanisms controlling past variability in productivity and make inferences on the contribution of atmospheric and oceanic processes at the glacial terminations throughout the Middle to Late Pleistocene (the last 650 ka).

2. Core location and oceanography

The Hole U1381C (08°25.7027′N; 84°09.4800′W, Harris et al., 2013, Fig. 1) is located ∼4.5 km offshore the Osa Peninsula, on the Costa Rica margin at the southern end of the East Pacific Warm Pool (Fiedler and Talley, 2006). Hole 1381C was recovered at 2065 m, well above the depth of the modern sedimentary lysocline, which is established at ∼2900 m water depth for the Panama basin (Thunell et al., 1981). At present, primary production in surface waters at Site U1381 is relatively low as its location is not directly influenced by the seasonal (wind-driven) upwelling or the current position of the open ocean upwelling centre of the CRD (Fig. 1a–b). The lack of seasonal coastal (wind-driven) upwelling at our site is because of the proximity to the Talamanca mountains (3000–4000 m height) which favour the convergence of local wind curl patterns (Pennington et al., 2006). This contrasts with the seasonal coastal upwelling processes occurring south (Gulf of Panama, Panamá) and north (Gulf of Papagayo, Nicaragua) of the Site U1381 (Fig. 1c–d). The CRD is a “permanent” anticlinal thermal structure