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Precession forcing of productivity in the Eastern Equatorial Pacific during the last glacial cycle

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ABSTRACT

We present a new multi-proxy reconstruction of sea-surface properties spanning the last 140 ka in the IMAGES Core MD02-2529 located in the eastern tropical Pacific Ocean off Costa Rica. Spectral analysis of the records allowed us to examine the ecological imprints of orbital changes on planktic foraminiferal and coccolithophore assemblages and on the pattern of primary production in the Eastern Equatorial Pacific, north of the Equatorial upwelling. Independent productivity reconstructions based on phyto- and zooplankton assemblages show a coherent pattern dominated by orbital precession, which appears to have control productivity changes recorded in the studied core over the last glacial–interglacial cycle. The proposed mechanism of this control invokes an atmospheric forcing associated with equatorial insolation maxima in spring and fall with a period of ~20 ka. Faunal evidence for a stronger upper-ocean mixing with enhanced nutrient supply to the euphotic zone suggests a more vigorous local atmospheric circulation and associated enlargement of the Costa Rica Dome that influenced the core site at times of May insolation maxima. The last two terminations in the studied record are associated with conspicuous changes in planktic assemblages which require additional nutrient-delivery mechanisms to amplify the precession forcing. Our faunal and stable isotope data are in favour of the previously postulated nutrient advection via the Southern Ocean "tunnelling" operating during deglaciations.

1. Introduction

The Eastern Equatorial Pacific (EEP) represents one of the key regions for understanding the intratropical and tropical–extratropical teleconnections, notably due to its major role in the interannual El Niño – Southern Oscillation (ENSO) dynamics and in CO_2 release to the atmosphere (Philander, 1995; Clement et al., 1999; Lea et al., 2000, 2006; Beaufort et al., 2001). Several attempts have been made to evaluate the past bio-productivity changes in the region to decipher the intensity of the biological pump through time. However, the results obtained with different methods and proxies are contradictory. At glacial–interglacial scale, several publications suggest higher biogenic fluxes during terminations (Loubere et al., 2004; Pichevin et al., 2009) whereas other studies (Loubere, 2001; Romero et al., 2011) argue for a higher bioproductivity during the glaciation. On longer timescales, the precession control on primary production (PP) variations in the equatorial Indo-Pacific has been ascertained by the study of coccolithophore assemblages in several cores (Beaufort et al., 2001). However, the linkage between paleoceanographic changes in the tropical Pacific and orbital climate variability is still not adequately explored and thus strongly debatable. In particular, it concerns the conflicting hypothesis about the strength of the N and S trades and the atmospheric transport in the low latitudes during the glacials and terminations, and its role in nutrient advection to the photic zone (e.g. Andreasen and Ravelo, 1997; Beaufort et al., 2001).

In the EEP, the availability of high-resolution paleorecords covering the last climatic cycle is limited by carbonate and silica dissolution and by generally low sedimentation rates. Nevertheless, Late Pleistocene multi-proxy time series were obtained from a number of sediment cores and ODP sites (Lea et al., 2000, 2002, 2006; Koutavas et al., 2002; Feldberg and Mix, 2003; Martinez et al., 2003, 2006; Spero et al., 2003; Horikawa et al., 2006; López-Otálvaro et al., 2008; Pena et al., 2008; Pichevin et al., 2009; Rincón-Martínez et al., 2010; Calvo et al., 2011; Dubois et al., 2011) retrieved mainly southward or nearby the Equatorial Front, from the region affected by the open-ocean upwelling and/or by the cold Peru Current.

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In contrast, the area of this investigation, at present, displays a patchy productivity pattern with higher values associated with the coastal upwelling and the Costa Rica Dome (CRD) as compared to the low-productive surrounding tropical and subtropical waters (Fiedler, 2002; Pennington et al., 2006). The PP dynamics in this coastal region can thus be expected to follow a different climatic forcing than that of the equatorial upwelling zone. Until now, several geochemical proxy records from a few sediment cores are available from the area (Leduc et al., 2007, 2009, 2010; Klinkhammer et al., 2009; Martinez and Robinson, 2009; Pichevin et al., 2010; Rincón-Martínez et al., 2010; Romero et al., 2011). However, all the time series except those from Leduc et al. (2010) and Rincón-Martínez et al. (2010) fail to recover Termination II and none of the publications evaluates the response of plankton assemblages to paleoceanographic changes except for Romero et al. (2011).

Furthermore, proxy records from the same core sometimes show rather contradictory patterns of bioproductivity changes. In particular, the diatom and opal time series (Romero et al., 2011) as well as the alkenone concentrations (Leduc et al., 2010) demonstrate high values indicating increased productivity during MIS 2 – late MIS 5 when compared to low values during MIS 1 and Termination I. In contrast, high C_{org} values (Leduc et al., 2010) are highlighted at the Last Glacial Maximum (LGM) and the two terminations.

Thus, at present there is no direct quantitative estimate of past productivity in the area over the last glacial–interglacial cycle. Meanwhile, high-resolution records of plankton dynamics and its quantitative assessment in terms of paleoproductivity forcing are necessary to better understand the EEP dynamics and its link to global and regional glacial–interglacial climate change.

In this paper, we present the first dataset ascertaining an orbital control on primary productivity in the EEP, north of the equator, and investigate the mechanisms driving variations in bioproductivity and planktic assemblages during the last 140 ka. The IMAGES Core MD02-2529 offers the opportunity to reconstruct primary production (PP) and sea-surface temperatures (SST) off Costa Rica, several hundred kilometers northward from the Equator, to exclude the equatorial upwelling impact. As the core was retrieved 1200 m above the lysocline level established at about 2800 m in the Panama Basin (Thunell et al., 1981), it generally contains abundant calcareous microfossils of medium to good preservation. This allows monitoring the ecological imprints of the regional wind system and nearby Costa Rica Dome on the phyto- and zooplankton productivity on the orbital scale using independent coccolithophore and planktic foraminiferal time series. Comparison of these data with available proxy records from the same core (Leduc et al., 2007, 2009, 2010; Rincón-Martínez et al., 2010; Romero et al., 2011) and with formerly published data from the tropical Pacific lends itself to evaluate the orbital, atmospheric and oceanic forcings on bioproductivity changes.

2. Core location, oceanographic settings and modern climatology

Sediment core MD02-2529 (8°12.33′N, 84°07.32′W, water depth 1619 m) was retrieved from the northern flank of the Cocos Ridge, about 40 miles offshore, during the IMAGES VIII MONA cruise aboard RV Marion Dufresne (Beaufort and Scientific Party, 2002) (Fig. 1a). At the core location, mean-annual SST reaches ∼28.2 °C at 10 m water depth (and 28.5 °C at sea-surface) whereas the magnitude of interannual and seasonal variability is about 2 °C (WOA, 2005; Fiedler and Talley, 2006). The shallow position of the core facilitates a better carbonate preservation than at most sites in the region and the coastal position induces higher than EEP average sedimentation rate of about 13 cm/ka (Leduc et al., 2007, 2009). The confluence of these two factors makes this core ideal for the study of calcareous plankton assemblages and their relationship with temperature and productivity forcing.

In the EEP, the surface circulation is mainly represented by zonal currents (Fig. 1a). The subsurface to upper intermediate water layer (∼70–150 m) at MD02-2529 site is ventilated by the Equatorial Undercurrent (EUC) that transports eastward the nutrient-rich and high-oxygen waters of mainly southern origin (Toggweiler et al., 1991; Tomczak and Godfrey, 1994; Fiedler and Talley, 2006; Kessler, 2006).

The coastal wind jets associated with the NE trade winds blowing from the Caribbean create coastal upwelling in the gulfs of Panama and Papagayo, while the site MD02-2529 is located in the lee of the Cordillera de Talamanca (Chelton et al., 2000). NE trades, wind jets, eddies and coastal upwelling are particularly intense during boreal winter. In summer, NE trades relax whereas strong SE trades are deflected eastward and penetrate as far as 8°N (Fiedler, 2002; Kessler, 2006). The seasonal changes in the global atmospheric circulation induce meridional shifts of the regional intertropical convergence zone (ITCZ), from 9°N in August to 1°S in February.

North of site MD02-2529, regional winds create a dome structure at the eastern terminus of the countercurrent thermocline ridge, the so-called Costa Rica Dome (CRD, Fig. 1a) (Wyrkti, 1964; Fiedler, 2002). Conspicuous seasonal changes in winds and surface current patterns result in a well pronounced annual cycle of the CRD development, migration and weakening linked to ITCZ (Fiedler, 2002). The CRD diameter ranges 100–900 km. The dome is centred at 9°N, 90°W and extends deeper than 300 m. It is characterized by an ascended thermocline (∼35 m) and a shallow chlorophyll maximum as the strong vertical temperature gradient creates a pronounced pycnocline in the area whereas Ekman pumping brings nutrients to the surface (Wyrkti, 1964; Fiedler, 2002; Fiedler and Talley, 2006). The annual cycle of the CRD is initiated in March by the coastal wind jets, particularly by the Papagayo jet, and by atmospheric circulation, surface currents and mesoscale coastal eddies (Tomczak and Godfrey, 1994; Fiedler, 2002; Fiedler and Talley, 2006). Then the CRD evolves rapidly in boreal spring-early summer with the greatest development in the late summer associated with the northward shift of the ITCZ and strengthened North Equatorial Countercurrent (Pennington et al., 2006).

The site MD02-2529 is characterized by strong, seasonally variable and relatively deep thermocline and pycnocline between 30 and 70 m, whereas the mixed-layer depth is about 30 m according to in situ CTD measurements and WOA (2001) database (Fig. 1c) (Conkright et al., 2002). Therefore, annual nutrients (phosphate ≤0.4 μm L^{-1} (WOA, 2005)), chlorophyll "a" (∼2 mg Chl m^{-3} estimated from the satellite imagery Modis-SeaWif: http://oceancolor.gsfc.nasa.gov/) and PP (∼160–170 g C/m^2/yr (Behrenfeld et al., 2001)) values are relatively low. However, they are higher than in tropical oligotrophic regions likely due to the local effects of eddies and mesoscale filaments associated with the CRD and coastal upwelling. The ecological imprints of these local hydrological features are not yet explored in details (Kessler, 2006; Pennington et al., 2006). At site MD02-2529, the chlorophyll concentrations reach maximum values in May–June and especially in October (Fig. 1b). These peaks correspond to seasonal maxima in wind stress, to relatively shallow thermocline depth and to a period of low values of outgoing long wave radiation, i.e. presence of the ITCZ (Fig. 1c).

The oxygen minimum zone (OMZ) well established along the Central American coast is manifested at the core location from subsurface to intermediate depth (∼100 to ∼1000 m) whereas