Geophysical Research Abstracts
Vol. 17, EGU2015-10397, 2015
EGU General Assembly 2015

Astronomical forcing, insolation and millennial-scale climate variability: evidence from the North Atlantic Ocean (IODP Expedition 306, Site U1313) during the Early-Middle Pleistocene

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Since the seminal work by Hays, Imbrie and Shackleton (1976), a plethora of studies mostly based on marine sediments collected during DSDP-ODP-IODP Expeditions has demonstrated a correlation between orbital variations and climatic change. However, information on how changes in orbital boundary conditions affected the frequency and amplitude of millennial-scale climate variability is still fragmentary. Here we examine the record of climatic conditions from MIS 23 to 17 (c. 920-670 ka) using high-resolution stable isotope records from benthic and planktonic foraminifera from a sedimentary sequence in the North Atlantic (Integrated Ocean Drilling Program Expedition 306, Site U1313) in order to evaluate the climate system's response in the millennial band to known orbitally induced insolation changes. Special emphasis is placed on Marine Isotope Stage (MIS) 19, an interglacial centred at around 785 ka during which the insolation appears comparable to the current orbital geometry: MIS 19 is characterised by a minimum of the 400-kyr eccentricity cycle, subdued amplitude of precessional changes, and small amplitude variations in insolation making this marine isotopic stage a potential astronomical analogue for the Holocene and its future evolution, if this remains governed by natural forcing (Loutre and Berger 2000). Benthic and planktonic foraminiferal oxygen isotope values indicate relatively stable conditions during the peak warmth of MIS 19, but sea-surface and deep-water reconstructions start diverging during the transition towards the glacial MIS 18, when large, cold excursions disrupt the surface waters whereas low amplitude millennial scale fluctuations persist in the deep waters as recorded by the oxygen isotope signal (Ferretti et al., 2015). The glacial inception occurred at $\sim$779 ka, in agreement with an increased abundance of tetra-unsaturated alkenones, reflecting the influence of icebergs and associated meltwater pulses and high-latitude waters at the study site. Using a variety of time series analysis techniques, we evaluate the evolution of millennial climate variability in response to changing orbital boundary conditions during the early-middle Pleistocene. Suborbital variability in both surface- and deep-water records is mainly concentrated at a period of $\sim$11 kyr and, additionally, at $\sim$5.8 and $\sim$3.9 kyr in the deep ocean; these periods are equal to harmonics of precession band oscillations. The fact that the response at the 11 kyr period increased over the same interval during which the amplitude of the response to the precessional cycle increased supports the notion that most of the variance in the 11 kyr band in the sedimentary record is nonlinearly transferred from precession band oscillations. Considering that these periodicities are important features in the equatorial and intertropical insolation, these observations are in line with the view that the low-latitude regions play an important role in the response of the climate system to the astronomical forcing. We conclude that the effect of the orbitally induced insolation is of fundamental importance in regulating the timing and amplitude of millennial scale climate variability.

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