Geophysical Research Abstracts
Vol. 16, EGU2014-13907, 2014
EGU General Assembly 2014

Impact of CO_2 and continental configuration on Late Cretaceous ocean dynamics

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The Late Cretaceous period is characterized by a long-term climatic cooling (Huber et al., 1995; Pucéat et al., 2003; Friedrich et al., 2012) and by major changes in continental configuration with the widening of the Atlantic Ocean, the initiation of the Tethyan ocean closure, and the deepening of the Central Atlantic Gateway. The Late Cretaceous also marks the end of the occurrence of Oceanic Anoxic Events (OAEs), that are associated to enhanced organic carbon burial, to major crises of calcifying organisms, and to possible ocean acidification (Jenkyns, 2010). It has been suggested that the evolution in continental configuration and climate occurring during the Late Cretaceous could have induced a reorganization in the oceanic circulation, that may have impacted the oxygenation state of the oceanic basins and contributed to the disappearance of OAEs (Robinson et al., 2010; Robinson and Vance, 2012). Yet there is no consensus existing on the oceanic circulation modes and on their possible evolution during the Late Cretaceous, despite recent improvement of the spatial and temporal coverage of neodymium isotopic data (εNd), a proxy of oceanic circulation (MacLeod et al., 2008; Robinson et al., 2010; Murphy and Thomas, 2012; Robinson and Vance, 2012; Martin et al., 2012; Moiroud et al., 2012).
Using the fully coupled ocean-atmosphere General Circulation Model FOAM, we explore in this work the impact on oceanic circulation of changes in continental configuration between the mid- and latest Cretaceous. Two paleogeography published by Sewall et al. (2007) were used, for the Cenomanian/Turonian boundary and for the Maastrichtian. For each paleogeography, 3 simulations have been realized, at 2x, 4x, and 8x the pre-industrial atmospheric CO_2 level, in order to test the sensitivity of the modelled circulation to CO_2.
Our results show for both continental configurations a bipolar mode for the oceanic circulation displayed by FOAM. Using the Cenomanian/Turonian land-sea mask, two major areas of deep-water production are simulated in the model, one located in the northern and northwestern Pacific area, and the other located in the southern Pacific. An additional area is present in the southern Atlantic Ocean, near the modern Weddell Sea area, but remains very limited. Using the Maastrichtian land-sea mask, the simulations show a major change in the ocean dynamic with the disappearance of the southern Pacific convection cell. The northern Pacific area of deep-water production is reduced to the northwestern Pacific region only. By contrast, the simulations show a marked development of the southern Atlantic deep-water production, that intensifies and extends eastward along the Antarctic coast. These southern Atlantic deep-waters are conveyed northward into the North Atlantic and eastward to the Indian Ocean. Importantly, changes in atmospheric CO_2 level do not impact the oceanic circulation simulated by FOAM, at least in the range of tested values.
The circulation simulated by FOAM is coherent with existing εNd data for the two studied periods and support an intensification of southern Atlantic deep-water production along with a reversal of the deep-water fluxes through the Carribean Seaway as the main causes of the decrease in εNd values recorded in the Atlantic and Indian deep-waters during the Late Cretaceous. The simulations reveal a change from a sluggish circulation in the south Atlantic simulated with the Cenomanian/Turonian paleogeography to a much more active circulation in this basin using the Maastrichtian paleogeography, that may have favoured the disappearance of OAEs after the Late Cretaceous.

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