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Modelling the Middle Miocene fluctuations in ocean biological productivity, ocean carbon isotopic composition and atmospheric CO_2 level

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The Middle Miocene (17.5-13.5 Ma) is characterized by high frequency fluctuations in the seawater δ^{13}C record with six distinct δ^{13}C maxima linked to Earth orbital cycles (mainly the 400 kyr eccentricity cycle). These fluctuations are negatively correlated with the δ^{18}O variations and, on the other hand, marine data show that the ocean productivity tends to be higher during warmer periods. However, on the long term, these three indicators show a different relationship: the productivity does not show any major trend, while a positive excursion of the δ^{13}C is observed (the so-called Monterey event) and is accompanied by a warming, i.e., a decrease in the δ^{18}O. The question of the long-term trend has already been addressed in a previous study (Diester-Haass et al., Paleoceanography, 24, PA1209, 2008), where the positive excursion in δ^{13}C was explained by the storage in sediments of organic carbon from continental origin. In the current study we hypothesize that the short-term (400 kyr cycle) fluctuations of the marine δ^{13}C are mainly linked to sea level and marine productivity changes and not to changes in the terrestrial environment, explaining the different relationship between the isotopic indicators for this shorter as compared to the longer timescale. We test this hypothesis by using a global geochemical box model representing the carbon, alkalinity, phosphorus and oxygen cycles and coupled to an energy balance climate model. The model is forced with sea level fluctuations associated with the observed variations of ocean δ^{18}O. We first evaluate the changes in continental weathering associated with these sea level fluctuations and the related climate change. The model shows that these changes in weathering cannot explain the observed amplitude of marine productivity and ocean δ^{13}C variations over the 400 kyr eccentricity cycle. We then test the assumption that these high frequency δ^{13}C variations were the result of a change in the turnover rate of the oceans, with higher upwelling rates and higher productivity during warmer periods. Results of model sensitivity tests indicate that this hypothesis is plausible, since it leads to approximately correct amplitudes and phases of the oceanic productivity and δ^{13}C signals. Thus, the following picture emerges that, in the Middle Miocene, the short-term fluctuations in oceanic δ^{13}C are driven by ocean circulation and productivity changes, while the trends at longer timescales are linked to a change in the burial rate of continental organic carbon. From this picture, the model is able to provide a geochemical history of the Middle Miocene ocean-atmosphere system consistent with the marine δ^{13}C record. In this reconstructed history, the atmospheric CO_2 level only shows small variations, with a slight decrease from the Lower Miocene (about 310 ppmv at 19 Ma) to the Middle Miocene (280 ppmv at 16 Ma) followed by a small increase thereafter (310 to 320 ppmv near 12 Ma). This history is relatively consistent with the marine ^{13}C isotopic proxies for atmospheric CO_2.