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A new mechanism for the two-step benthic stable isotope signal at the Eocene-Oligocene boundary

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The Eocene-Oligocene ($E-O$) boundary at 33.7 Ma presents a major step in the global climate transition from a greenhouse to icehouse world. Evidence for the large climatic changes comes from many sources, including the marine benthic $\delta^{18}O$ and $\delta^{13}C$ records. The $\delta^{18}O$ record shows an increase by 1.2–1.5‰, characterised by two 40-kyr steps, separated by a plateau of about 200 kyr. The increase in $\delta^{18}O$ values has been attributed to rapid glaciation of the Antarctic continent, previously ice-free. Simultaneous changes in the $\delta^{13}C$ record and the calcite compensation depth are suggestive of a greenhouse gas control on climate.

Indeed previous modeling studies have shown, that decreasing atmospheric CO_2 concentrations below a threshold value may have initiated the growth of an Antarctic ice sheet. However, these studies were not able to conclusively explain the remarkable two-step profile in $\delta^{18}O$ and $\delta^{13}C$. Furthermore, they considered changes in the ocean circulation only regionally, or indirectly through the oceanic heat transport. The potential role of global ocean circulation changes in the $E-O$ transition has not been addressed yet.

Here we present a new interpretation of the benthic $\delta^{18}O$ signal based on model simulations using a simple coupled 8-box-ocean, 4-box-atmosphere model with an added land ice component. In a first experiment, the model is forced with a slowly decreasing atmospheric carbon dioxide concentration. In this model context, it turns out that the first step in the $\delta^{18}O$ record reflects a shift in the meridional overturning circulation from a Southern Ocean to a bipolar source of deep-water formation, which is associated with a cooling of the deep sea. The second step in the $\delta^{18}O$ profile occurs due to a rapid glaciation of the Antarctic continent. This new mechanism is a robust outcome of our model and is qualitatively in good agreement with proxy data.

In order to explain the simultaneous changes in the $\delta^{13}C$ record, we couple in a next step a simple biogeochemical box model to the climate model and study the impact of a shift in the pattern of the oceanic meridional overturning circulation on the global carbon cycle, in particular changes in atmospheric CO_2 concentration.