Decoupling of temperatures and ice volume in the Middle Miocene: A missing piece of the puzzle?

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Abstract

The geological record documents a dynamic Antarctic ice sheet during the Middle Miocene (23 – 14 Ma) against a background of relatively low CO_2 (Griener et al., 2015). Recent advances in coupled climate-ice sheet modelling have been able to reconcile these conflicting data somewhat (Gasson et al., 2016), but deep ocean cooling has been assumed to accompany ice sheet growth. Our new modelling results indicate that for the Middle Miocene paleogeography, global deep ocean temperatures only change at initial ice sheet growth and not when an existing continental-scale ice sheet grows further.

Recent bottom water temperature reconstructions (Lear et al., 2015) indicate significant bottom water temperature changes during the Middle Miocene Climate Optimum (MMCO, 17-14.7 Ma), but no significant cooling over the major ice sheet growth of the Middle Miocene Climate Transition (MMCT, 14.7-12 Ma). This implies the increase in seawater oxygen isotopic composition at the MMCT represents growth of a larger-than-modern ice sheet. This hypothesis is supported by multiple lines of evidence (Passchier et al., 2011; Denton et al., 1984; Denton and Sugden, 2005). Our new modelling results indicate the mechanism by which this decoupling of temperatures and ice volume can be achieved.

An ice-free Antarctic is warm and wet. Surface runoff from a very active hydrologic cycle forms a polar halocline preventing the freezing surface waters from ventilating the deep ocean. Ice sheet growth markedly reduces this precipitation and subsequent runoff, thereby making the near-freezing surface water around Antarctica saltier and able to form bottom water. Once the ice sheet has reached a continental scale, additional vertical growth does not further affect runoff significantly because precipitation has already reduced to a low level. Consequently, the polar salinity and temperatures are also little affected and hence neither is deep water production (which is in all cases produced in the south). Through the scaling up and down of deep ocean ventilation, this mechanism is able to offer explanation for both the large amplitude variations in the MMCO benthic isotope records against a background of CO_2 changes no greater than 300ppm, and the lower amplitude isotopic variations following the MMCT (Greenop et al., 2014 and references therein; Holbourn et al., 2005, 2007, 2013; Kochhann et al., 2016 and references therein).

Estimates of the Antarctic ice volume increase at the prior Eocene-Oligocene Transition (34-33 Ma) are equivalent to the modern ice sheet (Lear et al., 2008; Liu et al., 2009). Taken together, our new modelling results and the existing isotope, temperature, vegetation and CO_2 reconstructions suggests this large Oligocene Antarctic ice sheet had collapsed by the MMCO.

This implies that the dynamism during the Middle Miocene operated on a much smaller ice sheet than previously thought.

Keywords: Middle Miocene, Antarctic Bottom Water, halocline, ocean ventilation

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