Breaking ice: cryosphere-carbon cycle interactions

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The impacts of the growth and decay of continental ice sheets reach far throughout the Earth System. Yet the local records of these changes are constantly edited and rewritten through geological time, so their history must be determined using indirect evidence. The oxygen isotopic composition of foraminifera reflects both the changing salinity of the ocean as the ice sheets waxed and waned and also the changing temperature of that ocean. Independent proxies such as the Mg/Ca-paleothermometer can be used to separate these two climate signals. What do such geochemical proxy records tell us about ice sheet dynamics? First and foremost they demonstrate that the cryosphere does not respond linearly to external forcing of Earth's climate system. For example, the establishment of the Antarctic ice sheet at the Eocene-Oligocene Transition (~34Ma) was the rapid culmination of a long-term cooling trend that began several million years earlier, as a threshold in the climate system was passed. Defining the thresholds for ice sheet growth and decay is challenging because it integrates different aspects of the climate system, including radiative forcing and paleogeography. Nevertheless, most ice sheet models agree that the climate threshold for melting the Antarctic ice sheet is higher (warmer) than for its inception, due to the cold, elevated nature of its upper surface. The geochemical proxy records of the orbitally-paced ice sheet growth and decay at the Oligocene-Miocene Boundary (~24 Ma) therefore present something of a geological puzzle, because at first sight they seem to contain little evidence of this hysteresis effect. However, there are several potential solutions to this problem. One possibility is that the deglaciation of the Antarctic ice sheet at the Oligocene-Miocene Boundary was facilitated by an input of carbon to the ocean-atmosphere system. Carbon cycle feedbacks have also been implicated in the switch from ~40 kyr to ~100 kyr glacial cycles at the Mid-Pleistocene Transition. Multi-proxy records from the North Atlantic suggest that this climate transition may have been facilitated by changes in the ocean carbonate system. Earth's ice sheets are not static components of our climate system, and paleoclimate records point to complex feedbacks that are not yet fully understood.