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The Ocean δ^{18}O Record, Ice Volume, and Sea Level: Four Million Years of Natural Climate Variability (Milutin Milankovitc Medal Lecture)

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How have the interactions between orbitally-controlled variations in insolation and geologically and biologically controlled variations in atmospheric CO_2 influenced Earth's climate over the last four million years? Evidence is growing that the late Pliocene intensification of northern hemisphere glaciation was likely driven by a modest decrease in atmospheric CO_2 levels possibly driven by enchanced chemical weathering on the continents. CO_2 levels during the mid-Pliocene warm period appear to have been between 350-450 ppm and the Antarctic ice sheet appears to have been far more dynamic than at present. Exactly how much of the south polar ice sheet melted during the warmest intervals of the mid Pliocene is unknown; geochemical proxies for ice volume are fraught with uncertainty due to the possible influence of diagenesis and changing ocean chemistry; geomorphologic evidence for sea level highstands are complicated by the influence of dynamic topography and glacial isostasy. I will present some recent results of the Pliomax project and discuss how we are using predicted global patterns of glacial isostatic adjustment (GIA) and dynamic topography to guide field efforts aimed at extracting the eustatic component of sea level change for the mid Pliocene. I also discuss how our field data is helping, in turn, to constrain uncertainties in models of both GIA and the long-term convective evolution of the Earth (uncertainties in mantle viscosity, for instance) as well as eustatic sea level during more recent warm extremes of the Quaternary.
By 2.7 Ma ago, large changes in polar ice volume were also occurring in the northern hemisphere, however the timing, physics, and amplitude of the ice response remain uncertain, especially for the early Pleistocene. How, for instance, do we explain the lack of significant precession variability in early Pleistocene climate records (e.g. the "41kyr world")? This observation has proven to be a conundrum for many decades because the canonical Milankovic hypothesis (as well as most climate-ice sheet models) predict that polar ice volume is most sensitive to high-latitude northern summer insolation, which is dominated by the 23 kyr precession period. However, the possibility of a more dynamic Antarctic ice sheet also opens the possibility that the δ^{18}O record is not, in fact, providing us with an accurate representation of the history of northern hemisphere ice sheets. We showed that if one allowed for the possibility of Antarctic ice volume change between 3 and 1 Myr, ice volume changes in both the northern and southern hemispheres, each controlled by local summer insolation, would result in the anti-phased precession component cancelling in the globally integrated marine δ^{18}O record. Only a modest ice mass change in Antarctic ice volume, at the precession frequency, is required to "hide" a much larger northern hemisphere ice volume signal at this frequency.