Abstract. A flexible representation of the global carbon cycle is developed for use on multi-millennial time-scales, based upon the cycling within the ocean of carbon and alkalinity, together with the essential nutrients; phosphate, silicic acid, and iron. The diagenetic alteration of calcium carbonate ($CaCO_3$) and opal in deep-sea sediments is explicitly considered, with primary biogeochemical interactions between oceanic and sedimentary reservoirs accounted for. Material preserved in the sediments is allowed to accumulate to form synthetic sediment records. This enables a wide variety of paleoceanographic observations to be directly employed in helping to constrain the processes driving the evolution of the carbon cycle over the course of the late Quaternary.

A test harness for use in the investigation of the observed glacial-interglacial variability in the concentration of atmospheric carbon dioxide (xCO_2) is constructed by marrying the biogeochemical framework developed here with a zonally-averaged representation of ocean circulation. Potential mechanisms are evaluated on a dynamic (i.e., time-stepping) basis by reconstructing variability in the relevant model boundary conditions over the past 400,000 years. Model results suggest that a key role is played in initial deglacial xCO_2 rise by declining aeolian iron supply to the Southern Ocean. With sea ice limits also varied in this region, it is also possible to account for the glacial-interglacial variability in much of the paleoceanographic record either side of the Antarctic Polar Front. However, none of the mechanisms considered here, even operating in concert, are able to reproduce the full magnitude of observed deglacial xCO_2 rise whilst simultaneously meeting constraints dictated by the sedimentary $CaCO_3$ record. It is, therefore, likely that any combination of changes in; equatorial up-welling, high latitude surface ocean stratification, and the oceanic nitrogen cycle, play an additional and important role.