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CCD, pCO_2 and $d^{13}C$ constraints on changes in the Neogene carbon cycle

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Since the Early Miocene the Earth experienced an anomalous warming event (MMCO) and began a quasi-continuous cooling to the late Pleistocene. Changes in the global carbon cycle are often invoked to explain the climate shifts. Here we ask how can direct measures of the carbon cycle inform this question. We focus on records for atmospheric pCO_2, marine $\delta^{13}C$, and the CCD. Recent estimates show the Pacific CCD deepens by ca. 740±180m since the early Miocene (1). We evaluate the effects of changes in ocean T and chemical changes on carbonate equilibria, shelf-basin partitioning, and riverine alkalinity fluxes. We consider both simple analytical models for carbonate distribution and employ the LOSCAR ocean carbon system model to investigate these effects. Ocean T and major ion changes and pCO_2 alone have limited direct impact on the CCD, while shelf-basin partitioning, driven by sea level change, can explain at most only half the CCD drop. Increases in alkalinity fluxes of $\approx 28\pm18\%$ are required to match the CCD deepening, but exactly how much depends on shelf-basin partitioning and pCO_2. Estimates of Early-mid Miocene pCO_2 range from 400 to >900 ppm. Total ocean-atmosphere C (98% oceanic DIC) is impacted by SW T and ion changes and varies from 2.95 to 4.20×10^{18}mol (280 ppm pre-anthro = 3.20×10^{18} mol). Early Miocene 450 ppm yields < σC than preindustrial 280 ppm. To go from 600- 900 to 280 ppm the $d\sigma C/dt$ since 20 Ma is small, requiring a mean annual source-sink imbalance < 0.7%. The net balance of degassing vs. silicate weathering or changes in OC weathering vs. burial is tightly constrained. Neogene global carbonate weathering shows significant increase during the Neogene while silicate weathering does not, likely in part a consequence of closure of the carbonate-rich Tethys basin. Changes in $\delta^{13}C$ accounting for variable fractionation are consistent with both increased carbonate weathering and modest net increases in OC burial, ≈ offsetting OC oxidation. CO_2 produced by sulfide oxidation does not play a major role in these mass balances, likely< 5%.

1. Campbell SB, Moucha R, Derry LA, Raymo M. *Geophys. Geosys.* 19*,* 2018. *doi:* 10.1002/2017GC007386