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Reconstructing the carbon isotope composition of Phanerozoic atmospheric CO_2 using a Bayesian forward model

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Knowledge of the ratio of ^{13}C to ^{12}C in atmospheric CO_2 is required to reconstruct past atmospheric CO_2 concentrations (paleo-CO_2) using several widely applied proxy systems. For example, leaf-gas exchange models use the difference between leaf $\delta^{13}C$ and $\delta^{13}C_{CO2}$, in conjunction with leaf morphological and physiological measurements, to estimate paleo-CO_2. The marine algal phytoplankton proxy system similarly leverages the sensitivity of carbon isotope fractionation between CO_2 and algae during photosynthesis (i.e., ε_p) to reconstruct paleo-CO_2. The paleosol carbonate proxy system is based on a mixing model that describes how $\delta^{13}C_{CO2}$ and $\delta^{13}C$ of soil-respired CO_2 affect soil carbonate $\delta^{13}C$ at different paleo-CO_2 levels.

Traditionally, $\delta^{13}C_{CO2}$ has been estimated from marine carbonate $\delta^{13}C$ ($\delta^{13}C_{carb}$), inverting the natural relationship in which $\delta^{13}C_{carb}$ is controlled by $\delta^{13}C_{CO2}$. Here we combine established theoretical frameworks for the Cenozoic[1] and Cretaceous[2] to forward model $\delta^{13}C_{carb}$ from $\delta^{13}C_{CO2}$, incorporating archive-specific isotope fractionation (e.g., vital effects in foraminifera and brachiopods) and effects related to ocean carbonate chemistry and sample diagenesis. We account for spatio-temporal variability in temperature (which affects the magnitude of the carbonate-CO_2 fractionation factor) using a proxy-based global mean surface temperature reconstruction and spatial relationships determined by a general circulation model[3] for the Phanerozoic. Our forward model is conditioned on a recently published compilation of Phanerozoic marine carbonate $\delta^{13}C$[4] in a Bayesian hierarchical framework to generate a time series of posterior $\delta^{13}C_{CO2}$ probability distributions. We evaluate the smoothing of our new $\delta^{13}C_{CO2}$ reconstruction using different time-binning approaches and compare our record to major paleoenvironmental and paleobiologic shifts documented over the past 500 Myr.

[1] Tipple et al. (2010), *Paleoceanography*. [2] Barral et al. (2017), *Palaeog., Palaeoclim., Palaeoecol.* [3] Valdes et al. (2021), *Clim. Past*. [4] Cramer & Jarvis (2020), *Geologic Timescale.*