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You *can* teach an old dog new tricks – what the $\delta^{13}C$ record may be telling us about global carbon cycle dynamics.

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Once upon a time, our conceptualization of the global carbon-climate system was pleasantly simple. Atmospheric CO_2 was regulated on 100kyr time-scales by silicate weathering, and perturbations in carbon-climate state seemingly magically and monotonically recovered back to initial conditions. Negative excursions in stable carbon isotope ratios ($d^{13}C$) recorded in marine sediments could be mapped onto a reduced carbon release (and trigger) event, while positive $d^{13}C$ excursions following negative ones meant enhanced reduced carbon removal induced by initial greenhouse warming. This did raise the question of whether organic carbon burial rather than silicate weathering was controlling CO_2 drawdown and recovery, but numerical modelling of shallow depositional environments on a global scale (and for >100kyr) was difficult. However, even a cursory glance at the geological record of carbonate $d^{13}C$ reveals billions of years of Earth history shot full of repeated, back-to-back, and often large (+/- 5‰) amplitude fluctuations [1]. Do all of these reflect major events? Is the carbon-climate system really being incessantly hit with massive releases of carbon? Inability to identify all of the required corresponding carbon sources and triggers might then lead one to question whether the isotope record was even primary.

Our recent modelling work [2] – using a relatively geologically-complete representation of interacting carbon sources and sinks, climate and ocean circulation change – hinted at a very different explanation for $d^{13}C$ variability. Crucially, we found that the network of strong negative and positive feedbacks involving global nutrient, oxygen, and carbon cycling, creates inherent instability in the system, particularly under lower-than-modern atmospheric oxygen. Now, utilizing new extended (multi-Myr) simulations of the 'GENIE' Earth system model, we show how a sequence of large amplitude +vs and -ve $d^{13}C$ excursions can arise from almost undetectable triggers. Carbon isotopic variability as a manifestation of instability internal to the surficial carbon cycle contrasts both with a need to assume frequent large triggering events, or dismissing the record as largely one of diagenetic alteration. Continued improvement in models shows us that we can still learn something new from an old proxy.

[1] *Cramer and Jarvis* (2020), DOI:10.1016/B978-0-12-824360-2.00011-5

[2] *Hülse and Ridgwell* (2025), DOI:10.1126/science.adh7730