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Early Eocene hyperthermals: evidence of million-year orbital pacing in lacustrine records

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The early Eocene (∼55-48 Ma) was punctuated by multiple hyperthermal events in which atmospheric CO2 and global temperatures rose with unprecedented and as of yet unexplained rapidity. Relative temporal spacing of three such events – the Paleocene-Eocene Thermal Maximum (PETM), Eocene Thermal Maximum 2 (ETM2, aka "Elmo") and Eocene Thermal Maximum 3, (ETM3, aka “X” event) – have led to the hypothesis that Eocene hyperthermals are paced by million-year-scale orbital cyclicity. Here we present evidence of a fourth early Eocene carbon cycle perturbation, identified through high resolution carbon isotopic analysis of Green River Formation lacustrine strata. A new age model for the Green River Formation based on frequency analysis supports the hypothesis that Eocene carbon isotope excursions are paced by the 1.2 Myr cycle that modulates eccentricity. We propose that this cycle is a significant forcing mechanism for hyperthermals not only because it modulates eccentricity, but because it also dictates the placement of nodes in obliquity. Each Eocene hyperthermal occurs shortly (< 400kyr) after a node in obliquity, suggesting that reorganization of high-latitude carbon pools when moving from low-seasonality to high-seasonality regimes (ie, out of an obliquity node) control the timing of extreme climate events.