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Eocene hyperthermals and orbitally paced biosphere, permafrost, and soil organic carbon dynamics

Robert DeConto (1), Simone Galeotti (2), Mark Pagani (3), David Pollard (4), David Tracy (1), and David Beerling (5)

(1) Department of Geosciences, University of Massachusetts, Amherst, MA, United States (deconto@geo.umass.edu), (2) Università degli Studi di Urbino, Dipartimento GeoTeCA, Urbino, Italy, (3) Department of Geology and Geophysics, Yale University, New Haven, CT, USA, (4) Earth and Environmental Systems Institute, Pennsylvania State University, University Park, PA, USA, (5) Department of Animal and Plant Sciences, University of Sheffield, Sheffield, UK

The sudden and extreme global warming events (hyperthermals) that occurred between ∼55.5 and 52 million years ago are superposed on a long-term warming trend and are characterized by massive inputs of carbon, ocean acidification, and global warming. During the first and largest of these events, the PETM (Paleocene-Eocene Thermal Maximum), global temperatures increased by ∼5 deg. C within a few thousand years. Although various explanations for the PETM have been proposed, a satisfactory model that accounts for the source, magnitude, and timing of carbon release at both the PETM and subsequent hyperthermal events remains elusive. Using astronomically calibrated cyclostratigraphic records combined with numerical climate-ecosystem simulations, we show that the PETM and all subsequent Early Eocene hyperthermals were orbitally paced and triggered by carbon released from soil carbon reservoirs. Model simulations accounting for rising background greenhouse gas concentrations and orbital variability show that terrestrial permafrost, particularly on an unglaciated Antarctica, thawed during high eccentricity and high obliquity orbital nodes once a long-term warming threshold was reached. This reservoir had the potential to rapidly release several thousand petagrams of carbon (PgC) to the atmosphere-ocean system, increasing greenhouse gas concentrations and initiating additional warming feedbacks capable of producing extreme warming. Replenishment of permafrost-soil carbon stocks between orbital nodes aided the recovery from each warming episode, while providing a new and vulnerable carbon reservoir for subsequent hyperthermals. Although these simulated ancient permafrost-soil carbon reservoirs are much larger than today's, this trigger mechanism for extreme warming events implies serious consequences for the thawing of similar environments in today's northern high latitudes.