Geophysical Research Abstracts
Vol. 14, EGU2012-11650, 2012
EGU General Assembly 2012

Methane and environmental change during the Paleocene-Eocene thermal maximum (PETM): Modeling the PETM as a multistage event

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The Paleocene-Eocene thermal maximum (PETM), approximately 55 million years ago, was a period of intense climate and environmental change that was associated with the release of unprecedented amounts of light carbon to the ocean-atmosphere system. This event is documented by large negative carbon isotope excursions (CIEs) in oceanic and terrestrial environments, by an abrupt shoaling of the lysocline and calcite compensation depth, and by significant increases in average global temperature. Due to its 13C-depleted isotopic composition and strong atmospheric radiative forcing, methane is thought to have played a pivotal role during the PETM. Recent high-resolution geochemical records indicate that the PETM has a more complex structure than was apparent in earlier records. In particular, ocean sediment cores indicate that the PETM CIE was composed of three notable excursions separated by two 20-ky periods of negligible del13C change. Moreover, a 3-ky warming period that occurred prior to the PETM CIE has indicated that the carbon release that caused the initial CIE may not have produced the initial warming, as was previously postulated and modeled.

In this study, we couple an atmospheric methane box model to a box model of the global carbon cycle, which is tuned to the background state of the PETM, in order to constrain the carbon emission and assess the role of methane. The initial 4 ky of the PETM are modeled as two separate stages involving: 1) a gradual warming with little or no lysocline shoaling or CIE, and 2) an abrupt warming, lysocline shoaling, and a CIE. For each stage, a range of atmospheric and oceanic emission scenarios representing different amounts, rates, and isotopic content of emitted carbon are simulated, and then compared to the sedimentary record. The sensitivity of the results to changes in climate sensitivity, global temperature change, lysocline shoaling, CIE, and background carbon dioxide concentration, among other variables, is tested. We find that more than a single source of carbon is required to explain the first two stages of the PETM. Stage 1 results cannot be directly associated with a known hypothesis; however, an abrupt emission of methane to the atmosphere is required to explain the sedimentary record. The results of Stage 2 are consistent with an abrupt release of methane hydrate to the ocean and atmosphere.