# Earth system feedbacks statistically extracted from the Indian Ocean deep-sea sediments during the early Eocene hyperthermals

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The most prominent global warming event in the Cenozoic era was the Paleocene-Eocene Thermal Maximum (PETM) at ~56 Ma, which is characterized by a rapid global warming by 5 to 8°C, severe ocean acidification, and a distinct negative carbon isotope ($\delta^{13}C$) excursion both in the marine and terrestrial realm. These features suggest a massive injection of $^{13}C$-depleted greenhouse gas to the ocean-atmosphere system. Moreover, multiple PETM-like global warming episodes termed 'hyperthermals' during the early Eocene period (56~52 Ma), accompanying rapid and pronounced negative excursions in $\delta^{13}C$, have also been recognized over the past dozen years. Geologic records of the hyperthermals have so far been reported from around the globe (e.g., the Pacific, Atlantic, and Arctic Oceans, Europe and North America). However, albeit the third largest ocean on the planet, the Indian Ocean is almost a blank area where only a few published data of the hyperthermals are available.
Here we have constructed a comprehensive geochemical data set including major- and trace-element contents, $\delta^{13}C$, and $CaCO_3$ contents of 250 bulk sediment samples taken from ODP Sites 752 and 738, located in the southeastern Indian Ocean and the Indian sector of the Southern Ocean, respectively. The analytical results show that the sediments of these cores record multiple carbon isotope excursions and reductions of carbonate contents, probably corresponding to the PETM and the early Eocene hyperthermals including the Eocene Thermal Maximum 2 (ETM2), H2 and I1/I2 events, and ETM3. We applied Independent Component Analysis to the high-dimensional compositional data matrix, and extracted four geochemical independent components that collectively account for 85.6% of the total sample variance. One of the components involving Ba content and $\delta^{13}C$ indicates a signature of a negative feedback in Earth system that efficiently sequestered the excess carbon in recovery phases of the hyperthermals.

Keywords: deep-sea sediment, Indian Ocean, climate change, Eocene hyperthermals, Independent Component Analysis, multivariate analysis

 