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Asian monsoon and Indian Ocean evolution during Heinrich and Dansgaard-Oeschger events

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It is now common knowledge that Dansgaard-Oeschger (DO) and Heinrich (H) events affected the Arabian Sea during the last glacial period through changes in the Indian monsoon and in ventilation at intermediate depths. In order to better document paleoceanographic changes, evaluate their phase relationships, and understand the underlying mechanisms of atmosphere-ocean exchanges, we still need detailed and systematic comparisons between proxy records of the monsoon upwelling and surface water mixing, and of water column changes at intermediate depths. For this purpose we studied core MD04-2876 recovered on the Pakistanese Margin at about 830 m depth within the present-day oxygen minimum zone (OMZ) and compared it to the record of nearby core MD04-2873 located below the OMZ around 2200 m depth on the isolated Murray Ridge.

The sediments within the OMZ are partly laminated and are characterized by a high sedimentation rate on the order of 50 cm/kyr. This minimizes the influence of bioturbation, in particular the mixing bias between different size fractions. We measured several independent paleoceanographic records, some of them being directly related to planktonic productivity of organic matter (content of organic carbon, nitrogen, chlorins, alkenones, marine GDGTs). Other measured profiles record conditions at depth linked to organic matter remineralization, for example the number of benthic foraminifera, the concentrations of redox sensitive trace elements (U, Mo, Cd, V…) and molecular compounds (lycopane), the δ15N record tracking water column denitrification and the content of carbonates (calcite, aragonite and Sr/Ca ratios) showing preservation changes linked to mid-depth acidification.

Collectively, these proxies show marked variations that are in stratigraphic agreement and correlate with DO and H events, independently dated in Greenland ice cores and in Chinese speleothems. However, our work on Pakistan Margin cores illustrates the usefulness of considering multiple proxies in order to build a detailed and reliable record of the monsoon and ventilation patterns. The identification of significant paleoclimate events should also take into account the stratigraphic resolution of the records. For example, the high-resolution Fe and $CaCO_3$ profiles based on XRF scanner exhibit the rather short DO event #9 that lasted less than 200 yr. By contrast, this event is more difficult to detect in geochemical records measured on discrete samples at lower resolution.

Paleo-proxies are often complex indicators of environmental conditions with additional biological, chemical or physical imprints superimposed on the main paleoceanographic control. These imperfections justify a multi-proxy approach relying on the assumption that only common features are robust paleoclimate events. In addition, the comparison of different proxy responses provides insight on the spread and mechanisms of paleoceanographic changes.

The case of DO event #12 in core MD04-2876 provides a clear illustration. This prominent DO interstadial lasted about three millennia and is characterized by the highest planktonic productivity over the past 50 kyr (highest values for TOC, TN, chlorins, marine GDGTs, δ15N, U, Mo, Cd; lowest values for $CaCO_3$, Sr/Ca and aragonite/calcite ratios). During this interval, the productivity changes were so large that they significantly affected the deeper record (TOC, TN, δ15N, Mo…) suggesting a vertical extension of the OMZ down to more than 2 km water depth. Moreover, several paleoceanographic proxies exhibit a complex behavior in the middle of the DO-12 event with thresholds values or even a transient reversal (TOC, TN, U, Mo, Cd, lycopane, crenarchaeol/caldarchaeol, benthic foraminiferal number). This shows that the biological productivity was strongly affected, in strength and species distribution, during this prominent maximum of the Asian monsoon. Overall, our multiproxy approach provides a consistent image and shows radical changes at all levels during H-DO cycles.