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Millennial scale monsoon variability over the last 250,000 years in the Arabian Sea

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Dansgaard-Oeschger oscillations and Heinrich events described in Greenland ice cores are also visible in the climate of the monsoon realm as documented in Arabian Sea sediments. However, little is known about these millennial scale fluctuations beyond the reach of the Greenland ice cores. Here, we present high-resolution geochemical and micropaleontological data from two sediment cores located offshore Pakistan, extending the monsoon record to the past 250,000 years in millennial scale resolution.

The stable oxygen isotope ($d^{18}O$) record of the planktic foraminifera *G. ruber* shows a strong correspondence to Greenland ice core $d^{18}O$, whereas the $d^{18}O$ signal of benthic foraminifera (*U. peregrina* and *G. affinis*) reflects patterns similar to those observed in Antarctic ice core records. Distinct shifts in benthic $d^{18}O$ during stadials are interpreted to show frequent injections of oxygen-rich intermediate water masses of Southern Ocean origin into the Arabian Sea. Alkenone SSTs show variations between 23 and 28°C. Millennial scale SST changes of 2°C are modulated by long-term SST fluctuations. Interstadials and the cold phases of interglacials are characterized by sediments enriched in organic carbon (TOC) whereas sediments with low TOC contents appear during stadials. Abrupt shifts (50-60 year duration) at climate transitions, such as interstadial inceptions, correlate with changes in productivity-related and anoxia-indicating proxies. Interstadial inorganic data consistently show that enhanced fluxes of terrestrial-derived sediments are paralleled by productivity maxima, and are characterized by an increased fluvial contribution from the Indus River. The hydrogen isotopic composition of terrigenous plant waxes indicates that stadials are dry phases whereas humid conditions seem to have prevailed during interstadials. In contrast, stadials are characterized by an increased contribution of aeolian dust probably from the Arabian Peninsula. Heinrich events are especially dry and dusty, indicating a dramatically weakened Indian summer monsoon and increased continental aridity.

These results strengthen the evidence that North Atlantic temperature changes and shifts in the hydrological cycle of the Indian monsoon system are closely coupled, and had a massive impact on regional environmental conditions such as river discharge and ocean margin anoxia. These shifts were modulated by changes in the supply of water masses from the Southern Hemisphere.