Abstract

This study is an endeavor in paleoclimatic reconstruction of the Northern Indian Ocean with a special emphasis on deciphering the variations in Southwest (SW) Monsoon intensity during the Late Quaternary (~35,000 a BP to the present). Earlier, many studies regarding paleomonsoon variations were carried out in the Arabian Sea but most of them were confined to the western/northern Arabian Sea with little attention paid to other regions such as eastern and equatorial Arabian Sea, which are equally important. This thesis is an improvement over the previous work in the following ways:

i. I have selected three sedimentary cores from three different locations of the Arabian Sea viz. western Arabian Sea off the Somalian coast (near the mouth of the Gulf of Aden), eastern Arabian Sea off the western Indian coast and the southern/equatorial Arabian Sea, east of Maldives. Thus I could study various processes that are manifestations of SW monsoon at different locations and delineate local versus regional responses.

ii. Paleomonsoon studies from the western Arabian Sea invariably looked at proxies for the SW monsoon wind strength and not the monsoon precipitation. The response of these might differ significantly. By the study of equatorial and eastern Arabian Sea cores I have attempted to document the past variations in the SW monsoon precipitation.

iii. The resolution of many of the previous studies in India was poor (typically ~2000 years/cm) because of which high-frequency/rapid changes were not detected. I have carried out high-resolution analysis on sub-centennial to centennial timescales that will facilitate the documentation of past monsoon variation in great detail.

iv. Most of the earlier studies from India were based on the bulk radiocarbon chronology (e.g. Sarkar et al, 1990) that might be relatively inaccurate due to possible dead carbon contribution. I have obtained a large number of AMS dates on selected species of foraminifera that provide better chronological control.

v. Further, a few studies relied on a single proxy (e.g. Gupta et al, 2003) that might mislead, as the observed variations might be an interplay of many competing processes. I have carried out multi-proxy chemical and isotopic analysis that corroborate each other and hence provide better confidence on the inferences.

The specific aims of this study are:

1) To document past monsoon variations on millennial to centennial scales by high-resolution sampling on accurately dated sediment cores.
2) To assess the strengthening of Northeast monsoon relative to SW monsoon by determining the past variations in the transport of low salinity water from the Bay of Bengal via the North East Monsoon Current using the equatorial core.
3) To assess how different locations/proxies respond to the same climatic forcing on different time scales by comparing the proxy data for wind strength from the western Arabian Sea with the proxy data for precipitation from the eastern Arabian Sea.
4) The proxies for SW monsoon precipitation were compared with the polar ice core records to assess the similarity of the low and high latitude climates.
5) The winds known as Indian Ocean Equatorial Westerlies (IEW) are strongest during the intermonsoon periods in the equatorial region and cause wind-induced mixed-layer deepening that enhances productivity. IEW exhibit a positive correlation with the Southern Oscillation index, which in turn is positively correlated with the SW monsoon, East African rains and negatively with El Nino frequency. Thus study of paleoproductivity variations in the equatorial core can trace the fluctuations in the IEW intensity and related phenomena.
6) The proposed solar connection with the SW monsoon has also been tested by comparing high-resolution $\delta^{18}O$ record with the reconstructed Total Solar Irradiance (TSI) curve along with the spectral analysis of various SW monsoon proxies.

To achieve the above objectives, various chemical (such as $CaCO_3$, C_{org}) and isotopic proxies e.g. $\delta^{15}N$ in the sedimentary organic matter and $\delta^{18}O$, $\delta^{13}C$ of selected planktonic foraminiferal species were measured. The following inferences regarding the past monsoon fluctuation have been drawn by analyzing both the western and equatorial Arabian Sea cores. SW monsoon exhibits a decreasing trend since ~35 ka BP with a minimum at LGM. SW monsoon weakens during the early deglacial period as well and a sudden intensification is observed at ~14.5 ka BP, which coincides with the first step of deglaciation (T IA) that can be attributed to albedo changes over central Asia and Tibetan plateau. The glacial to Holocene transition period is characterized by several millennial to centennial scale fluctuations in SW monsoon precipitation with higher precipitation during the periods of global warmth and reduced precipitation during cooler times. During 10 – 9 ka BP, another episode of monsoon intensification takes place that occurs just after the maximum summer insolation at ~10 ka BP between 20^0N and 35^0N. Thereafter SW monsoon strengthens during the Holocene as indicated by multi-proxy isotopic and chemical data. Monsoon does not appear to have decreased during the Holocene as proposed by some of the earlier single-proxy results from this region.

By high-resolution analysis of the eastern Arabian Sea core, we find a widespread arid period at ~2000 a BP as exhibited by the decline in precipitation on the southwest Indian landmass. Thereafter several arid periods are observed at ~1500 a BP, ~1100 a BP, ~850 a BP and ~500 a BP. A comparison with another study from the western Arabian Sea (Gupta et al, 2003) indicates that SW monsoon wind intensity exhibits an excellent correlation with the SW monsoon precipitation over southwestern coastal India on centennial scale. The weak winds were accompanied by reduced precipitation whereas stronger winds corresponded to enhanced precipitation. But this relation is not linear as minimum precipitation is found at ~2000 a BP while minimum SW monsoon winds is recorded at ~1500 a BP.

The equatorial core reveals that the effect of low salinity Bay of Bengal water is experienced during early deglacial period (~19 to ~17 ka BP) at the core site as Northeast Monsoon Current and hence the NE monsoon appear to strengthen during that time and not during LGM as proposed earlier based on bulk ^{14}C dates (Sarkar et al, 1990).

Comparison with studies from the eastern Arabian Sea (Agnihotri, 2003 a) and western Arabian Sea (this study) has shown that IEW and SW monsoon winds declined and strengthened in tandem indicating a common forcing factor on a millennial scale, most probably insolation, at least during the last 35 ka.

Variations in the SW monsoon precipitation correspond very well with the polar δ^{18}O record with enhanced monsoons during interstadials and reduced precipitation during the stadials. This indicates that low latitudes could be instrumental in bringing about high latitude climatic changes by greenhouse gases or *vice versa* by albedo feedback.

This study has shown that IEW declined from ~35 ka BP to LGM with minimum values at LGM signifying decreasing SW monsoon and East African rains. A sudden intensification in IEW intensity is observed at ~14.5 ka BP and since then to the core top (~2.2 ka BP) including the Holocene, calcareous productivity exhibits a uniformly increasing trend. This implies a uniform strengthening of IEW (and perhaps the Southern oscillation index) and hence strengthening SW monsoon and east African rains along with a possibly declining El Nino frequency.

The high-resolution record from the eastern Arabian Sea was compared with the reconstructed Total Solar Irradiance curve for the past 1000 years. Broadly, the periods of lower TSI are accompanied by reduced SW monsoon precipitation whereas during the periods of higher TSI, the precipitation increases indicating a possible solar forcing on the SW monsoon on centennial timescale. Spectral analyses show that on Milankovitch timescales the SW monsoon is influenced by the insolation changes induced by precessional cycle of the earth's orbit. A common periodicity of ~1400 ± 500 years is exhibited both by the monsoon proxies and the high latitude climatic proxies indicating perhaps a common linking mechanism. On centennial timescale the solar forcing seems to control the SW monsoon variations as exhibited by the common quasi-periodicity of ~200 yrs exhibited both by the monsoon proxies as well as solar activity proxy *viz.* TSI.

Thus this thesis in addition to documenting past variations in SW monsoon in great detail, provides a new and comprehensive data set for testing paleoclimate models. Further it raises several important points such as SW monsoon strengthening during the Holocene, NE monsoon intensification during the early deglacial period, good correlation exhibited by SW monsoon precipitation intensity with SW monsoon wind and high latitude climate. Moreover this study indicates that solar forcing appears to govern the SW monsoon on centennial and Milankovitch timescales.