ARTICLE IN PRESS

Quaternary International xxx (2017) 1–13

Contents lists available at ScienceDirect

Quaternary International

journal homepage: www.elsevier.com/locate/quaint

# Indian monsoon variability in the last 2000 years as inferred from benthic foraminifera

Thejasino Suokhrie, S.M. Saalim, R. Saraswat*, R. Nigam

*Micropaleontology Laboratory, Geological Oceanography Division, National Institute of Oceanography, Goa, India*

ARTICLE INFO

*Article history:*
Received 15 December 2016
Received in revised form
11 May 2017
Accepted 22 May 2017
Available online xxx

*Keywords:*
Benthic foraminifera
Morpho-group
Ecology
Indian monsoon
Bay of Bengal

ABSTRACT

The effect of ambient conditions on living (Rose-Bengal stained) benthic foraminifera has been studied from the shelf and slope of the central-western Bay of Bengal to assess the applicability of temporal changes in benthic foraminiferal morpho-groups (angular asymmetrical and rounded symmetrical) to reconstruct past monsoon changes. We report that the riverine influx and associated processes control the relative abundance of angular asymmetrical (AABF) and rounded symmetrical (RSBF) benthic foraminiferal morpho-groups in the central-western Bay of Bengal. Subsequently, temporal variations in relative abundance of AABF in a gravity core collected from outfall region of the Pennar River, are used to reconstruct decadal scale past monsoon variability during the last ~1887 years. An increased monsoon discharge is observed during the Medieval Warm Period (MWP) and lower during the Little Ice Age (LIA). The periodic changes with a frequency of ~123 and ~238 years are also identified, indicating a close relationship between monsoon and solar activity.

## 1. Introduction

About 65% of the major produce in India comes from agriculture (Gadgil et al., 1999) and it is highly dependent on the monsoon rainfall. Minor changes in rainfall result in severe drought in many parts of the country and a drop in food production and gross domestic product (Gadgil et al., 2004). Hence, prediction of future trends in monsoon is necessary for sustainable development. Monsoon prediction requires proper understanding of monsoon dynamics. Even though the effect of various regional and global processes on Indian monsoon is known (Halley, 1686; Charney, 1969; Chao and Chen, 2001; Gadgil, 2003; Wang et al., 2009), the inconsistent relationship (Kumar et al., 1999) hampers proper monsoon prediction. Additionally, long-term trends in monsoon variability are also hard to infer from limited instrumental data (Goswami, 2006). The knowledge of the past monsoon can help in understanding long-term trends in monsoon behavior under various boundary conditions (Clift and Plumb, 2008; Mohtadi et al., 2016). Various proxies from both continent and marine environment have helped in the reconstruction of past monsoon (Henderson, 2002; Staubwasser and Weiss, 2006; Clift and Plumb, 2008; Achyuthan et al., 2013; Bradley, 2014; Mohtadi et al., 2016; Saraswat et al., 2014; Saraswat, 2015). Proxies from the marine environment, in particular, offer long, continuous and uninterrupted records.

Several attempts have been made to reconstruct past monsoon from the northern Indian Ocean by using both faunal census (Clemens and Prell, 1991; Nigam et al., 1992, 1995; Naidu and Malmgren, 1996; Gupta et al., 2003, 2005; Saraswat et al., 2005, 2016; Singh et al., 2011, 2015) and other proxies (Sirocko et al., 1993; Kudrass et al., 2001; Chauhan, 2003; AnilKumar et al., 2005; Tiwari et al., 2005; Govil and Naidu, 2011; Saraswat et al., 2012, 2013; Kessarkar et al., 2013; Mahesh and Banakar, 2014; Mohtadi et al., 2016; Sijinkumar et al., 2016). A majority of these records were based on cores collected from regions with comparatively low sedimentation rate and thus had centennial to multi-centennial resolution. The reconstruction of past monsoon from high sedimentation rate areas can help to generate sub-centennial to decadal resolution records that can help in understanding short-term monsoon variability. A huge amount of sediment discharge in the Bay of Bengal provides an ideal location to reconstruct high-resolution paleo-monsoon records. High resolution sub-centennial to decadal resolution records from the core monsoon region of the northern Bay of Bengal are, however, limited mainly because of the sparse presence of planktic foraminifera (Kudrass et al., 2001; Chauhan, 2003; Rana and Nigam, 2009; Rashid et al.,

---

* Corresponding author.
*E-mail address:* rsaraswat@nio.org (R. Saraswat).

http://dx.doi.org/10.1016/j.quaint.2017.05.037
1040-6182/

Please cite this article in press as: Suokhrie, T., et al., Indian monsoon variability in the last 2000 years as inferred from benthic foraminifera, Quaternary International (2017), http://dx.doi.org/10.1016/j.quaint.2017.05.037

2011; Panchang and Nigam, 2012; Ponton et al., 2012). The abundant presence of benthic foraminifera in these sediments can help to reconstruct high-resolution past monsoon changes. Earlier, temporal changes in benthic foraminiferal morpho-groups, namely angular asymmetrical benthic foraminifera and rounded symmetrical benthic foraminifera were suggested as a proxy to reconstruct past monsoon from the riverine influx dominated continental shelf regions of the Arabian Sea (Nigam et al., 1992). The application of benthic foraminiferal morpho-groups for paleoclimatic studies stemmed from their preference for characteristic ambient conditions, especially depth (Severin, 1983), organic carbon (Corliss and Chen, 1988) and dissolved oxygen concentration (Bernhard, 1986; Kaiho, 1994; Nigam et al., 2007; Mazumder and Nigam, 2014). The relationship between a particular morpho-group and ambient environment, however, may vary regionally. The western Bay of Bengal is ideal to assess the applicability of such benthic foraminiferal morpho-groups to reconstruct past monsoon and use it to reconstruct decadal resolution monsoon changes.

## 2. Study area

The study area is in the central-western Bay of Bengal and covers major rivers, namely Krishna-Godavari, Pennar and Cauvery (Fig. 1). The Bay of Bengal is the largest bay in the world and forms the north-eastern part of the Indian Ocean. The hydrographic parameters in the Bay of Bengal are strongly influenced by the seasonally reversing monsoon currents and resulting immense fresh water run-off (during southwest monsoon freshwater discharge is 183 × $10^{11}$ $m^3$) (Varkey et al., 1996). The sediment accumulation in this river dominated bay is huge (1350 million tons/yr, Milliman, 2001). This freshwater influx combined with the monsoon winds strongly influences surface water circulation and stratification (Gomes et al., 2000). The freshwater influx reduces the surface water salinity by ~7 psu in the northern bay (Levitus and Boyer, 1994) and enhances primary productivity by increasing nutrient supply (Ramaswamy and Nair, 1994). However, biological productivity in the Bay of Bengal is comparatively lower than in the Arabian Sea due to strong stratification, more cloud cover and turbidity (Prasanna Kumar et al., 2010). The eddy pumping mechanism in the Bay of Bengal has, however, explained how the biological productivity is enhanced (Ostlund et al., 1980; Prasanna Kumar et al., 2004) resulting in comparable annual organic flux with that of Arabian Sea (Ramaswamy and Nair, 1994). The distribution of oxygen is influenced by physical processes like freshwater influx, upwelling, atmospheric interaction, water mass transport and biological processes like photosynthesis and respiration. In the Bay of Bengal, the waters experience intense oxygen depletion at intermediate depths of 200–800 m resulting in a pronounced oxygen minimum zone (OMZ), with the resultant dissolved oxygen content as low as >5 μM (Wyrtki, 1971; Rao et al., 1994; Sardessai

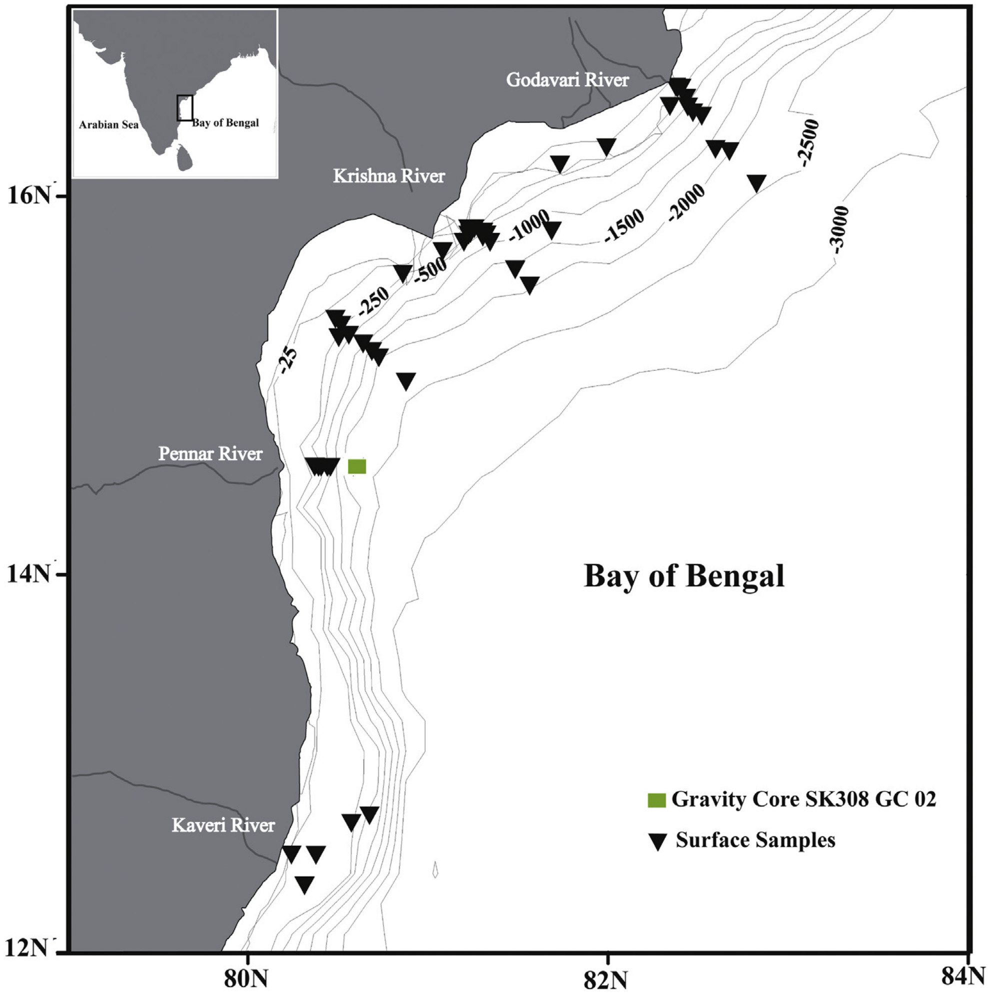

**Fig. 1.** Location of surface sediment samples (black-filled inverted triangles) and gravity core (green filled square). The contour are bathymetry in meters. The location of major rivers is marked on the map. The study area in the northern Indian Ocean is marked by the black rectangle in the inset. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Please cite this article in press as: Suokhrie, T., et al., Indian monsoon variability in the last 2000 years as inferred from benthic foraminifera, Quaternary International (2017), http://dx.doi.org/10.1016/j.quaint.2017.05.037