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Assessing the applicability of δ^{18}O *Globigerina bulloides* to estimate palaeotemperature from the southwestern Indian Ocean

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Modern sea-water temperature has been estimated using oxygen isotopic composition of planktic foraminiferal species, *Globigerina bulloides* recovered from the surface sediments collected from southwestern Indian Ocean (IO). The sea-water temperature estimated from δ^{18}O *G. bulloides* has been compared with that measured on-board. Though a nearly constant offset is noticed between estimated and measured sea-water temperatures at locations south of 15°S latitude, the general trend is at tandem. The coherence between estimated and measured sea-water temperatures indicates that the δ^{18}O *G. bulloides* palaeotemperature equation derived from laboratory culture experiments can be applied to infer past sea-water temperature variations from southwestern IO.

Keywords: *Globigerina bulloides*, palaeotemperature, sea water, southwestern Indian Ocean.

SEA-SURFACE temperature (SST) is an important climatic parameter. A slight change in SST leads to enormous change in the rainfall pattern and intensity[1,2]. Increasing intensity and frequency of storms has also been attributed to the increasing global temperature[3,4]. SST mainly varies in response to changes in the solar irradiance[5,6]. However, the historic abrupt increase in SST has been attributed to anthropogenic influence on the global climatic variations[7]. Understanding the temperature variability during geologic past can help in deciphering human contribution to the recent abrupt increase in global temperature[8]. Various techniques such as faunal transfer functions[9,10], alkenone unsaturation ratios[11,12] and artificial neural network (ANN) analyses of planktic foraminifera[13], assemblage, morphological characteristics and shell chemistry of foraminifera, have been used to decipher past SST from the world oceans[9,14–16].

In view of the experimental evidence of temperature control on oxygen isotopic composition of the carbonate[17,18], extensive oxygen isotopic studies have been carried out on marine microorganisms, especially foraminifera, to decipher past sea-water temperature changes[19,20]. Though, in the beginning, the total change in oxygen isotopic composition of the foraminiferal shells was attributed to

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temperature change, later on it was realized that on glacial–interglacial timescale, majority of the change in oxygen isotopic composition of the foraminiferal shells is brought about by the global ice-volume changes[21]. Global ice-volume changes have since been quantified[22,23] to estimate the contribution of changing ice extent to the foraminiferal oxygen isotopic composition, over glacial/interglacial timescales. The resultant oxygen isotopic composition of foraminiferal tests can be attributed to past sea-water temperature changes. However, in such studies care must be taken, as local precipitation–evaporation changes leading to change in the oxygen isotopic composition of the sea water, will also contribute to the foraminiferal oxygen isotopic changes. However, study of temporal changes in the oxygen isotopic composition of the foraminiferal tests from a location appropriately away from the region of high monsoon discharge, can be used to infer past sea-water temperature. Such studies rely on evaluation of the temperature sensitivity of the oxygen isotopic composition of the foraminiferal species, through laboratory culture and/or field studies based on surface sediment samples and plankton tow collections[24,25].

However, differences have been noted in the temperature sensitivity of the specimens of the same species recovered from different environments[26]. Therefore, in order to apply the oxygen isotopic composition of foraminiferal species to estimate the past temperature variations, the temperature sensitivity of foraminiferal species has to be tested from different modern marine environments. Here we discuss the temperature sensitivity of oxygen isotopic composition of the planktic foraminiferal species, *Globigerina bulloides* from the southwestern Indian Ocean (IO).

G. bulloides from a set of 19 samples collected along the north-south transect in the southwestern IO (Figure 1), as part of Pilot Expedition to the Southern Ocean, was analysed for its oxygen isotopic composition. Details about sampling and oxygen isotopic analysis have been discussed elsewhere[27]. In order to determine the oxygen isotope ratio, 10–12 specimens of *G. bulloides* were picked. The isotopic composition of *G. bulloides* specimens was measured at the Alfred Wegner Institute for Polar and Marine Research, Germany, with a Finnigan MAT 251 isotope ratio gas mass spectrometer coupled to an automatic carbonate preparation device (Kiel I) and calibrated via NBS 19 to the PDB scale. The values are given in δ-notation vs VPDB (Vienna Pee Dee Belemnite). Precision of oxygen measurements based on repeated analyses of a laboratory standard over a one-year period was better than 0.09‰ for oxygen. In order to estimate the sea-water temperature from the oxygen isotopic composition of *G. bulloides*, a regression equation was derived between the sea-water salinity and oxygen isotopic composition available on the global sea-water oxygen isotopic composition database[28]. A total of 145 datapoints (Figure 2) were used to derive the regression equation.

$$\delta^{18}O_{sw} = 0.5217 * \text{salinity} - 17.918. \quad (1)$$

Using the regression equation (Figure 3), sea-water oxygen isotopic composition at 100 m water depth was calcu-

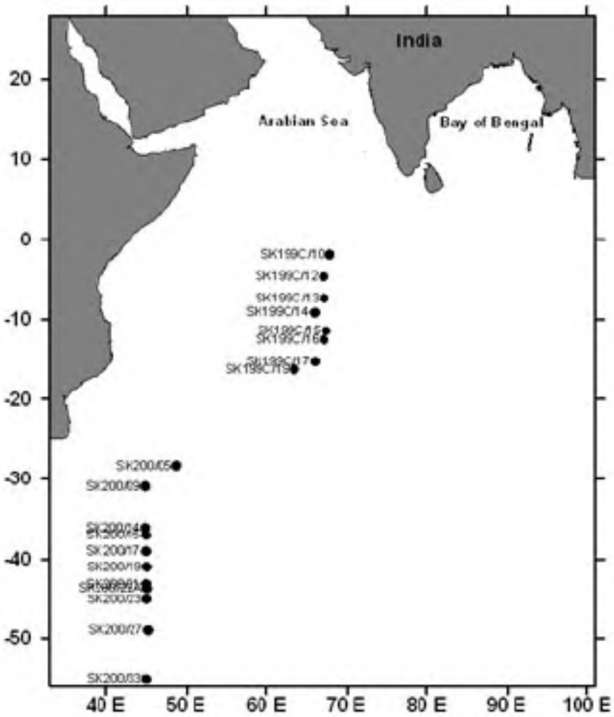

Figure 1. Location of sediment samples used for the study.

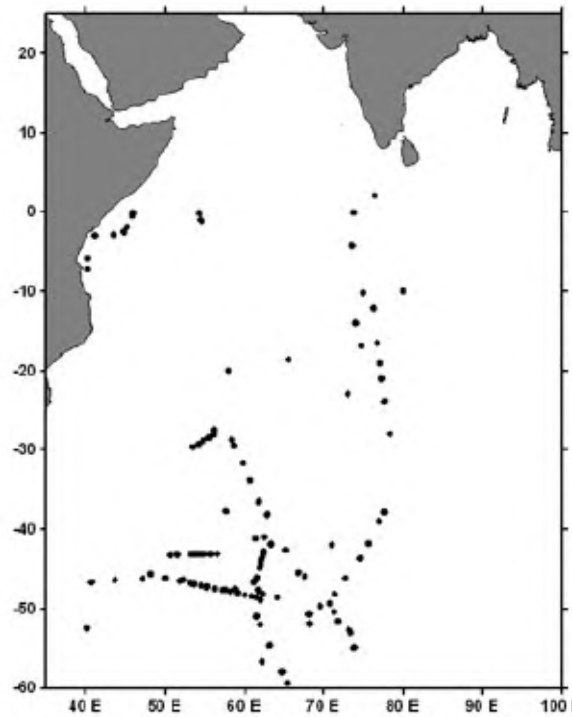

Figure 2. Location of datapoints used to derive the regression equation between sea water salinity and oxygen isotopic composition.

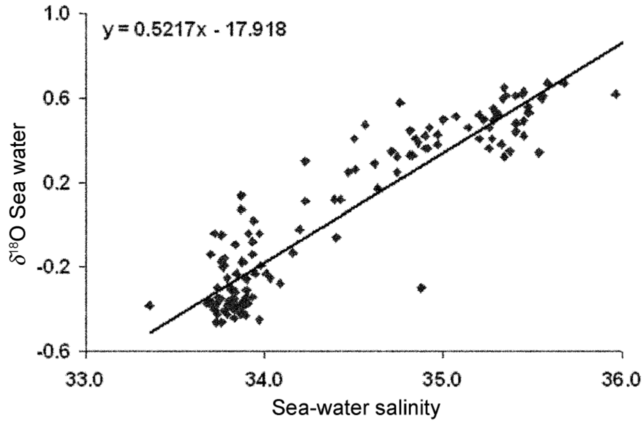

Figure 3. Relationship between sea water salinity and oxygen isotopic composition.

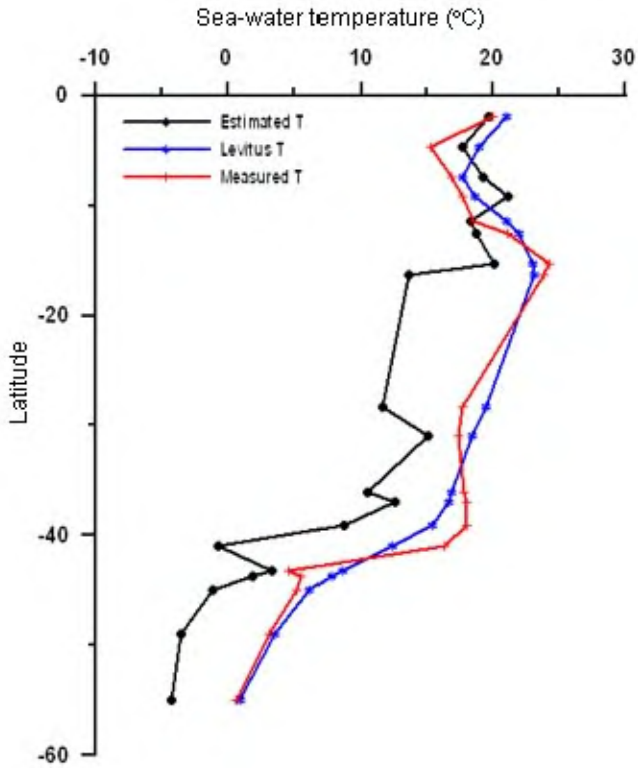

Figure 4. Plot of sea-water temperature as estimated from oxygen isotopic ratio of *Globigerina bulloides*, and Levitus and measured sea-water temperature.

lated for the 19 locations of the present study. The 100 m water depth was chosen, as it is the average thermocline depth in the study area[29,30], and *G. bulloides* has been reported as a thermocline dweller[31]. Here we would like to mention that the thermocline depth varies over the studied area and a zonal comparison of δ^{18}O *G. bulloides* estimated sea-water temperature with the measured temperature will be more appropriate and will be published later. Subsequently, sea-water temperature was estimated using the palaeotemperature equation of Bemis *et al.*[25] for the 12-chambered *G. bulloides* shell.

$$T(°C) = 13.2 - 4.89\,(\delta^{18}O_c - \delta^{18}O_{sw}), \qquad (2)$$

where *T* is the temperature, $\delta^{18}O_c$ is the oxygen isotopic composition of *G. bulloides* and $\delta^{18}O_{sw}$ is the oxygen isotopic composition of sea water estimated for the respective locations using eq. (1).

The plot of sea-water temperature estimated for 100 m water depth, as mentioned above, matches well with the measured sea-water temperature (Figure 4). However, an offset is noticed between ~20 and ~32°S lat. The estimated and measured sea-water temperatures at the respective locations show highly significant correlation (0.94).

The comparable sea-water temperatures, as estimated from the δ^{18}O *G. bulloides* recovered from the surface sediments collected from the southwestern IO, and the measured sea-water temperature in the northern part of the studied area, show that the calibration equation developed by Bemis *et al.*[25] based on laboratory culture experiments holds good in the southwestern IO. However, mismatch is noticed between the estimated and measured sea-water temperatures at the further southward locations, which probably arises because of the influence of factors other than sea-water temperature in that part of the study area, as well as the change in thermocline depth along the transect. This apparent relationship between δ^{18}O *G. bulloides* and sea-water temperature established in the surface sediments can thus be applied to infer past sea-water temperature from the southwestern IO.

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Estimation of retreat rate of Gangotri glacier using rapid static and kinematic GPS survey

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The Gangotri glacier is retreating like other glaciers in the Himalaya and its volume and size are shrinking as well. Reoccupying the historical snout positions using Global Positioning System (GPS) in rapid static mode indicates the varying rates of retreat during different time-spans of the last century, with the total retreat of 1519.13 m in the last 69 years. Post 1971, the rate of retreat of the glacier has declined. Monitoring of glacier terminus using GPS survey in kinematic mode reveals that the glacier has retreated at much lower rate (12.10 ± 0.041 ma^{-1}) between 2004 and 2005. The study further shows that the southern portion of the snout is retreating at significantly lower rate in comparison to the northern part. However, maximum recession (13.76 ± 0.048 m in 2004–05) took place along the centreline of the glacier.

Keywords: Gangotri glacier, GPS and kinematic survey, retreat rate.

IN the Himalaya, about 1400 cubic km of snow and ice is locked in the glacier systems[1], spread over nearly 33,200 sq. km area, at altitudes 4300–5800 m asl. The glaciers are amongst the best recorders of climatic changes. It is a well-established fact that the glaciers are passing through a recessional phase globally[2,3]. The Himalayan glaciers are also receding like the rest of the glaciers in the world. Fluctuation in the recession rate of the glaciers during recent years has initiated widespread discussions, especially in context to global warming and its effects. Climatic variations and other topographical features ob-

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