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Surface and thermocline ocean circulation intensity changes in the western Arabian Sea during ~172 kyr

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A B S T R A C T

The relationship between monsoon-induced productivity and ocean circulation over millennial timescales is crucial. However, a study regarding the circulation of the western Arabian Sea (WAS) needs to be conducted. Understanding the seasonal, surface, and thermocline ocean circulation throughout the glacial-Interglacial period in the WAS is also elusive and essential. The long distant Antarctic Intermediate Water (AAIW) flow, and Sub-antarctic Mode Water (SAMW) penetration to the north side of the equator in the Indian Ocean needs to be understood and underlined using the micropaleontological (planktonic foraminiferal assemblages) and geochemical analysis such as oxygen isotope of *Globigerinoides ruber* and *Neogloboquadrina dutertrei* ($\delta^{18}O_{G.ruber}$ and $\delta^{18}O_{N.dutertrei}$) in this study. Furthermore, understanding the variations in paleoproductivity, upper oceanic water column stratification, surface mixing, and thermocline layer variability in the WAS is also helpful. According to the results, the variation in the upwelling intensity during Glacial-Interglacial and monsoon variation suggest the upper water stratification/vertical mixing in the WAS. Here, we provide new evidence of poorly ventilated water mass in our region. Our results indicate that enhanced northward expansion of AAIW coincides with the weakening of summer monsoon during glacial periods except mid-MIS4, reflected by isotopic study and assemblages. In this context, depleted $\delta^{18}O_{N.\ dutertrei}$ value and high concentration of *Globorotalia menardii* (*G. menardii*) were due to lack/absence of AAIW ventilation and SAMW; therefore, warming occurred in the mid-MIS4.

1. Introduction

The dynamics of the tropical Indian Ocean response to the seasonally reversing surface wind, which governs the monsoonal circulation. The movement of the Intertropical Convergence Zone (ITCZ) and the atmospheric pressure cell formed over central Asia control the precipitation. This dynamic interaction between the atmosphere, ocean (surface mixed layer and thermocline), and land provides valuable information about ocean heat budgets. The driving mechanism of the mixed layer is different in both monsoon seasons, which are southwest monsoon (SWM) and northeast monsoon (NEM) (White et al., 1998; Ramesh and Krishnan, 2005). The intense wind speed accompanied by a stronger SWM causes the deepening of the mixed layer, driven by turbulent kinetic energy and mixing (Chen et al., 1994; Ramesh and Krishnan, 2005).

On the other hand, the winter monsoon is characterized by moderate and dry winds, enhanced evaporation over precipitation, and net heat loss from the ocean, which strikes the deep convective mixing and cooling of the mixed layer (Ramesh and Krishnan, 2005). Deeper mixed layers suggest stronger wind speeds associated with the stronger SWM, weaker surface stratification, and deepening of the thermocline. In addition, strong wind speeds and the formation of shear through turbulence and mixing cause the mixed layer to deepen into the open ocean. These factors accelerate toward weak stratification in the upper water column and a deepening thermocline linked to negative and positive wind stress curls (Murtugudde et al., 2007). Regarding heat budget, the peak

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