Deep-Sea Research I 112 (2016) 14–24

Contents lists available at ScienceDirect

Deep-Sea Research I

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

Concentrations and abundance ratios of long-chain alkenones and glycerol dialkyl glycerol tetraethers in sinking particles south of Java

Wenwen Chen [a], Mahyar Mohtadi [b], Enno Schefuß [b], Gesine Mollenhauer [a,b,c,*]

[a] Department of Geosciences, University of Bremen, Bremen, Germany
[b] MARUM-Center for Marine Environmental Sciences, University of Bremen, Bremen, Germany
[c] Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research, Bremerhaven, Germany

ARTICLE INFO

Article history:
Received 30 September 2015
Received in revised form
29 January 2016
Accepted 18 February 2016
Available online 9 March 2016

Keywords:
$U^{K'}_{37}$
TEX^{H}_{86}
Sediment trap
Upwelling system
Indonesia
Indian Ocean

ABSTRACT

In this study, we obtained concentrations and abundance ratios of long-chain alkenones and glycerol dialkyl glycerol tetraethers (GDGTs) in a one-year time-series of sinking particles collected with a sediment trap moored from December 2001 to November 2002 at 2200 m water depth south of Java in the eastern Indian Ocean. We investigate the seasonality of alkenone and GDGT fluxes as well as the potential habitat depth of the Thaumarchaeota producing the GDGTs entrained in sinking particles. The alkenone flux shows a pronounced seasonality and ranges from 1 μg m^{-2} d^{-1} to 35 μg m^{-2} d^{-1}. The highest alkenone flux is observed in late September during the Southeast monsoon, coincident with high total organic carbon fluxes as well as high net primary productivity. Flux-weighted mean temperature for the high flux period using the alkenone-based sea-surface temperature (SST) index $U^{K'}_{37}$ is 26.7 °C, which is similar to satellite-derived Southeast (SE) monsoon SST (26.4 °C). The GDGT flux displays a weaker seasonality than that of the alkenones. It is elevated during the SE monsoon period compared to the Northwest (NW) monsoon and intermonsoon periods (approximately 2.5 times), which is probably related to seasonal variation of the abundance of Thaumarchaeota, or to enhanced export of GDGTs by aggregation with sinking phytoplankton detritus. Flux-weighted mean temperature inferred from the GDGT-based TEX^{H}_{86} index is 26.2 °C, which is 1.8 °C lower than mean annual (ma) SST but similar to SE monsoon SST. As the time series of TEX^{H}_{86} temperature estimates, however, does not record a strong seasonal amplitude, we infer that TEX^{H}_{86} reflects ma upper thermocline temperature at approximately 50 m water depth.

1. Introduction

Two biomarker-based temperature proxies, $U^{K'}_{37}$ and TEX_{86}, are commonly used in paleoclimate studies (e.g. Huguet et al., 2006; Rommerskirchen et al., 2011; Wang et al., 2013). $U^{K'}_{37}$ quantifies the relative abundance of di- and tri-unsaturated C_{37} alkenones, which are produced by certain prymnesiophytes, including coccolithophorids *Emiliania huxleyi* and *Gephyrocapsa oceanica* (Marlowe et al., 1984; Prahl and Wakeham, 1987; Volkman et al., 1980). TEX_{86} is another organic geochemical proxy suggested to reflect sea surface temperature (SST), which is based on glycerol dialkyl glycerol tetraethers (GDGTs) and defined as the abundance ratio of specific types of GDGTs with variable numbers of cyclopentane rings (Schouten et al., 2002). These compounds are synthesised as membrane lipids by the ubiquitous marine Thaumarchaeota (formerly named Crenarchaeota; Brochier-Armanet et al., 2008; Schouten et al., 2002; Sinninghe Damsté et al., 2002). Although core-top calibrations established robust correlations between $U^{K'}_{37}$ and TEX_{86} with mean annual SST (ma SST) (e.g., Conte et al., 1998, 2006; Kim et al., 2008, 2010; Müller et al., 1998; Schouten et al., 2002), some studies have shown that deviations of both proxy temperature estimates from ma SST can be attributed to seasonal production and/or a subsurface depth habitat of the source organisms (e.g., Huguet et al., 2007; Jia et al., 2012; Kim et al., 2012; Lee et al., 2008; Leider et al., 2010; Prahl et al., 2005; Rommerskirchen et al., 2011; Seki et al., 2007; Wuchter et al., 2006).

Seasonal production and flux of biomarkers has the potential to bias a proxy signal towards the season of maximum production. It is debated in the literature whether or not a seasonally variable flux of alkenones results in a seasonal bias of the $U^{K'}_{37}$ signal in sediments, or if preserved alkenones reflect mean annual conditions (e.g., Conte et al., 2006, Leduc et al., 2010, Schneider et al.,

* Corresponding author at: Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research, Am Handelshafen 12, 27570 Bremerhaven, Germany.
E-mail address: gesine.mollenhauer@awi.de (G. Mollenhauer).

http://dx.doi.org/10.1016/j.dsr.2016.02.010
0967-0637/

2010). For GDGTs, the ongoing debate relates not only to the season of export but also to the production depth of the lipids constituting the sedimentary TEX_{86} record (e.g., Herfort et al., 2006; Lopes dos Santos et al., 2010, Kim et al., 2012). Thaumarchaeota are known to thrive throughout the water column and are reported to occur at maximum abundance at a depth of 100–200 m (e.g., Tolar et al., 2013). Seasonality and production depth effects of alkenones and GDGTs likely depend on the different oceanic settings and thus, it is necessary to investigate their respective response in individual regions for a better interpretation of local sedimentary records.

Sediment trap studies are an excellent tool to shed light on the seasonality and depth of alkenone and GDGT production exported to the sediment. Rosell-Melé and Prahl (2013) recently compiled published sediment trap time series data for alkenones from 34 sampling locations and found that the seasonality of alkenone flux varies strongly between sites and depends on the local oceanographic settings. The seasonal patterns of export production are complex, resulting from the interplay of seasonality in production and particle flux. No clear biogeographic or latitudinal pattern in alkenone flux seasonality could be deduced from the existing data set. The seasonality is not necessarily coupled to bulk export primary productivity and varies markedly across the oceans. Moreover, $U^{K'}_{37}$ of flux-weighted averages in sediment traps is not always biased by seasonality but instead resembles global trends in surface sediments. Notably, approximately ninety percent of the sites complied by Rosell-Melé and Prahl (2013) are located in the northern hemisphere. Only two studies are from the southern hemisphere and only one study was performed in the Indian Ocean. According to this synthesis, our record is the second sediment trap record for alkenone from the Indian Ocean.

The ecology of GDGT producers, i.e. the seasonality of their production and/or export, and the depth of their habitat, is still poorly constrained. Thaumarchaeota occur throughout the year and the abundance of Thaumarchaeota varies seasonally (Schouten et al., 2013 and reference therein). However, there are thus far only seven seasonal TEX_{86} records from sediment traps available. To date, published records exist from the northeastern Pacific and the Arabian Sea (Wuchter et al., 2006), the Santa Barbara Basin (Huguet et al., 2007), the Mozambique Channel (Fallet et al., 2011), the western North Pacific (Yamamoto et al., 2012), the Gulf of California (McClymont et al., 2012), the Cariaco Basin (Turich et al., 2013) and Cape Blanc, Mauritania (Mollenhauer et al., 2015). In several studies it was observed that TEX_{86} temperature estimates reflect the temperature of specific seasons and were explained by either seasonality in Thamarchaeota growth or seasonal variation in export of GDGTs (e.g. Mollenhauer et al., 2015; Turich et al., 2013; Yamamoto et al., 2012). On the other hand, some sediment trap records suggest that the TEX_{86}-derived temperatures reflect the temperature of subsurface water (McClymont et al., 2012; Wuchter et al., 2006). This conclusion was also reached by some recent studies investigating suspended matter samples (Nakanishi et al., 2012) and shallow water surface sediments (Xing et al., 2015). In contrast, TEX_{86} temperature variations in the sediment trap from the Santa Barbara Basin was not coupled to changes in SST or deep-water temperatures, which was attributed to a complex contribution of GDGTs produced at different depths and hydrologic conditions (Huguet et al., 2007).

So far, there are only four published sediment trap records for both indices including the interpretation of difference between the two proxies (Fallet et al., 2011; McClymont et al., 2012; Mollenhauer et al., 2015; Turich et al., 2013). The observations made in these studies differ between the regions. While as expected alkenones in most of these studies are in close agreement with satellite SST, TEX_{86}-based temperature estimates are more similar to subsurface temperatures or display reduced seasonal temperature amplitudes.

In this study, we present a one-year time-series record of alkenones and GDGTs from samples obtained with a sediment trap deployed in the eastern Indian Ocean off Java. The aim of this study is to investigate the seasonality of production and export of biomarkers, and to test the hypothesis of sub-surface production of GDGTs in the upwelling environment off southern Java.

2. Study area

The Australian–Indonesian Monsoon (AIM), displaying contrasting seasonal features, is the dominating climate feature in the Eastern Indian Ocean (Fig. 1), influencing wind and precipitation patterns and, consequently, surface ocean hydrography and currents. During the NW monsoon season (January–March), northwest trade winds from the Asian continent cause a rainy season with increased precipitation over Indonesia resulting in maximum

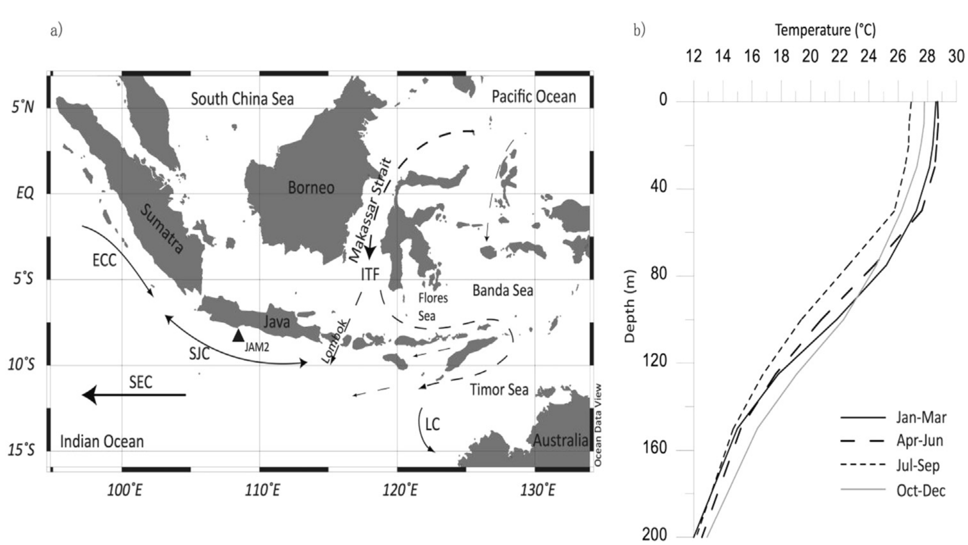

Fig.1. a) Map of the study region showing the surface currents (solid arrows) and subsurface currents (dashed arrows). The black triangle shows the position of the sediment trap. Ocean currents are denoted as: ECC: Equatorial Counter Current; ITF: Indonesian Throughflow; LC: Leeuwin Current; SEC: South Equatorial Current; SJC: South Java Current. Double arrows of SJC indicate the change of direction of SJC during the NW (eastward) and SE monsoon (northwestward), respectively. b) the depth profiles of World Ocean Atlas temperatures at the site of Jam 2 in different seasons (Locarnini et al., 2006).