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Comparison of eastern tropical Pacific TEX_{86} and *Globigerinoides ruber* Mg/Ca derived sea surface temperatures: Insights from the Holocene and Last Glacial Maximum

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ABSTRACT

The use of the TEX_{86} temperature proxy has thus far come to differing results as to whether TEX_{86} temperatures are representative of surface or subsurface conditions. In addition, although TEX_{86} temperatures might reflect sea surface temperatures based on core-top (Holocene) values, this relationship might not hold further back in time. Here, we investigate the TEX_{86} temperature proxy by comparing TEX_{86} temperatures to Mg/Ca temperatures of multiple species of planktonic foraminifera for two sites in the eastern tropical Pacific (on the Cocos and Carnegie Ridges) across the Holocene and Last Glacial Maximum. Core-top and Holocene TEX_{86}^{H} temperatures at both study regions agree well, within error, with the Mg/Ca temperatures of *Globigerinoides ruber*, a surface dwelling planktonic foraminifera. However, during the Last Glacial Maximum, TEX_{86}^{H} temperatures are more representative of upper thermocline temperatures, and are offset from *G. ruber* Mg/Ca temperatures by 5.8 °C and 2.9 °C on the Cocos Ridge and Carnegie Ridge, respectively. This offset between proxies cannot be reconciled by using different TEX_{86} temperature calibrations, and instead, we suggest that the offset is due to a deeper export depth of GDGTs at the LGM. We also compare the degree of glacial cooling at both sites based on both temperature proxies, and find that TEX_{86}^{H} temperatures greatly overestimate glacial cooling, especially on the Cocos Ridge. This study has important implications for applying the TEX_{86} paleothermometer in the eastern tropical Pacific.

1. Introduction

Paleothermometers have been developed to enable reconstructions of past sea surface temperature (SST). Foraminifera-based SSTs have been reconstructed from transfer functions (Imbrie and Kipp, 1971), and oxygen isotopes (Erez and Luz, 1983) and Mg/Ca ratios (Nürnberg et al., 1996) of surface dwelling planktonic foraminifera. However, foraminifera-based SST reconstructions can be limited by availability of material, and secondary influences such as dissolution (Dekens et al., 2002). Additionally, Mg/Ca reconstructions are temporally limited by the use of modern foraminifera species for which Mg/Ca-SST calibrations exist. Biomarker-based SST proxies, such as the TEX_{86} (Schouten et al., 2002) and alkenone $U_{37}^{k'}$ (Brassell et al., 1986) indices, can be advantageous due to the ubiquitous appearance of the associated biomarkers in marine sediments temporally and spatially, especially during times and in regions where calcareous fossils do not exist. Unfortunately, the alkenone $U_{37}^{k'}$ index saturates around 28 °C (Prahl and Wakeham, 1987), thus the TEX_{86} index holds promise for reconstructing a wider range of temperatures (Schouten et al., 2007a).

The TEX_{86} temperature proxy (TetraEther indeX of 86 carbons) is based on the degree of cyclization of isoprenoidal archaeal membrane lipids, known as glycerol dialkyl glycerol tetraethers (GDGTs),

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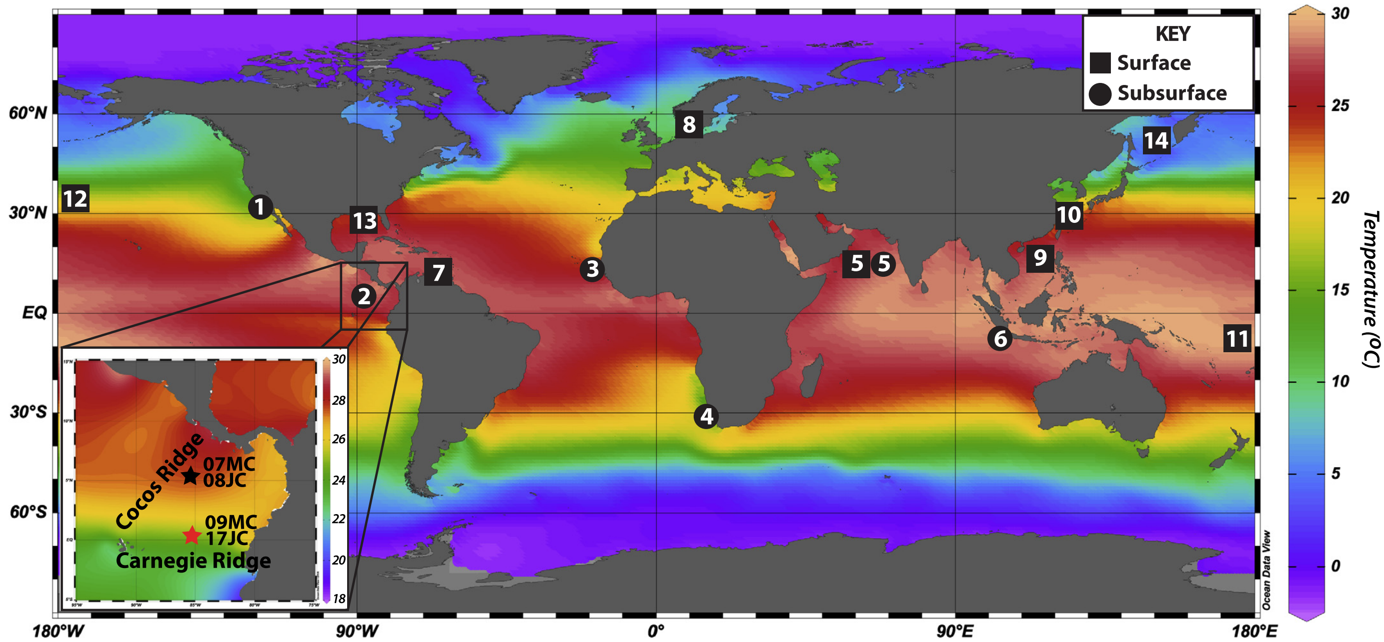

Fig. 1. Locations of previous studies finding that TEX_{86} temperatures were representative of surface conditions (black squares) or subsurface conditions (black circles). Numbers correspond to references as follows: (1) Huget et al., 2007; (2) Seki et al., 2012; (3) Lopes dos Santos et al., 2010; (4) Lee et al., 2008; (5) Wuchter et al., 2006; (6) Chen et al., 2014; (7) Turich et al., 2013; (8) Rueda et al., 2009; (9) Wei et al., 2011; (10) Zhu et al., 2011; (11) Ho et al., 2011; (12) Wuchter et al., 2006; (13) Richey et al., 2011; (14) Seki et al., 2014. Note that this is not an exhaustive list of all available TEX_{86} studies, but rather a sampling of studies to exemplify the distributions of surface and subsurface findings. Studies are plotted on a surface map of average annual sea surface temperatures from the World Ocean Atlas 2013 (Locarnini et al., 2013). Inset: Location of the Cocos Ridge and Carnegie Ridge study areas. 07MC (6°14.037′N, 86°2.613′W; 1995 m depth) and 08JC (6°14.038′N, 86°2.613′W; 1993 m depth) were recovered from the Cocos Ridge location shown with black star and 09MC (0°41.630′S, 85°19.995′W; 2452 m depth) and 17JC (0°10.832′S, 85°52.004′W; 2867 m depth) were recovered from the Carnegie Ridge location shown with red star. Note that the temperature scales on the main figure and inset are not the same. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

produced by marine Thaumarchaeota (formerly Group 1 Crenarchaeota) (Schouten et al., 2002). The TEX_{86} index was first defined by Schouten et al. (2002) as:

$$TEX_{86} = \frac{[\text{GDGT-2}] + [\text{GDGT-3}] + [\text{Cren}']}{[\text{GDGT-1}] + [\text{GDGT-2}] + [\text{GDGT-3}] + [\text{Cren}']} \quad (1)$$

where GDGTs 1–3 indicate lipids containing 1–3 cyclopentyl moieties, respectively, and Cren' designates the regioisomer of crenarchaeol, a biomarker for marine Thaumarchaeota (Sinninghe Damsté et al., 2002a). Lincoln et al. (2014a) recently found that Cren′ may also be produced by Euryarchaeota, however, the conclusions of this study were called into question by Schouten et al. (2014) (see reply by Lincoln et al., 2014b). The TEX_{86} temperature proxy is based on observations from culturing and mesocosm experiments that the number of cyclopentane rings in GDGTs increases with increasing growth temperature (de Rosa et al., 1980; Schouten et al., 2007a; Uda et al., 2001; Wuchter et al., 2004). It is thought that the addition of rings into GDGTs raises the melting point of the cell membrane and alters membrane packing (Gliozzi et al., 1983; Uda et al., 2001), enabling archaea to adjust membrane stability in response to temperature changes (Chong, 2010).

Schouten et al. (2002) first noted a relationship between the degree of cyclization in marine surface sediments and overlying SST, developing the TEX_{86} index (Eq. (1)) as the ratio expressing the degree of cyclization that best correlated with SST. In addition, Schouten et al. (2002) developed the first TEX_{86} temperature calibration based on 40 sediment core-top samples from 15 locations. This calibration equation and subsequent calibrations involving the addition of hundreds of core-top samples (Kim et al., 2008, 2010) all note the highest correlation between the TEX_{86} index and SSTs. However, recent studies have arrived at differing conclusions as to whether the TEX_{86} index actually reflects sea surface (Ho et al., 2011; Richey et al., 2011; Rueda et al., 2009; Seki et al., 2014; Turich et al., 2013; Wei et al., 2011; Wuchter et al., 2006; Zhu et al., 2011) or subsurface temperatures (Chen et al., 2014; Huguet et al., 2007; Lee et al., 2008; Lopes dos Santos et al., 2010; Seki et al., 2012; Wuchter et al., 2006). The distribution of these studies (Fig. 1) would suggest there appears to be no single factor controlling regions where the TEX_{86} index reflects surface or subsurface temperatures (i.e. within one ocean basin, high versus low latitude, coastal versus open ocean, etc.).

Water column studies of GDGT lipids and archaeal genetic material suggest that Thaumarchaeota preferentially reside in the mesopelagic zone, below the surface photic zone (e.g. Huguet et al., 2007; Karner et al., 2001; Massana et al., 1997; Turich et al., 2007 (see also Schouten et al., 2008 and Turich et al., 2008); Wakeham et al., 2003; Wuchter et al., 2005, 2006). Könneke et al. (2005) found that Thaumarchaeota are aerobic ammonia oxidizers, and would thus dwell in the subsurface nitrite maximum below the photic zone (Meeder et al., 2012; Wada and Hattori, 1971). While these studies would suggest a subsurface signal for the TEX_{86} temperature proxy, sediment calibration studies find the highest correlation between the TEX_{86} index and SST (Kim et al., 2008, 2010; Schouten et al., 2002). One explanation for this disagreement is the 'surface export hypothesis' (Tierney, 2014), which speculates that the absence of grazers (and their fecal pellets) in deeper waters excludes the export and preservation of GDGTs from these depths in sediments (Wakeham et al., 2003). Alternatively, subsurface temperatures are highly and significantly correlated with SSTs, and thus, while TEX_{86} may actually record subsurface temperatures, a high correlation with SSTs is also noted (Tierney, 2014). This may be compounded by the fact that SSTs are known to a higher precision than subsurface temperatures, resulting in artificially higher correlations between TEX_{86} and SSTs (Tierney, 2014).

The recent availability of pure cultures of marine thaumarchaeal isolates has allowed for the evaluation of a number of other influences on the TEX_{86} paleothermometer, including growth phase