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A biomarker perspective on dust, productivity, and sea surface temperature in the Pacific sector of the Southern Ocean

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Abstract

In this study, we present a new multiproxy data set of terrigenous input, marine productivity and sea surface temperature (SST) from 52 surface sediment samples collected along E–W transects in the Pacific sector of the Southern Ocean. Allochthonous terrigenous input was characterized by the distribution of plant wax *n*-alkanes and soil-derived branched glycerol dialkyl glycerol tetraethers (brGDGTs). ^{230}Th-normalized burial of both compound groups were highest close to the potential sources in Australia and New Zealand and are strongly related to lithogenic contents (^{232}Th), indicating common sources and transport. Detection of both long-chain *n*-alkanes and brGDGTs at the most remote sites in the open ocean strongly suggests a primarily eolian transport mechanism to at least 110°W, i.e. by prevailing westerly winds. Two independent organic SST proxies were used, the $U^{K'}_{37}$ based on alkenones, and the TEX_{86} based on isoprenoid GDGTs. Both, $U^{K'}_{37}$ and TEX_{86} indices show robust relationships with temperature over a temperature range between 0.5 and 20 °C, likely implying different seasonal and regional imprints on the temperature signal. Alkenone-based temperature estimates best reflect modern summer SST in the study area when using the polar calibration of Sikes et al. (1997). In contrast, TEX_{86}-derived temperatures may reflect a subsurface signal rather than surface. ^{230}Th-normalized burial of alkenones is highest close to the Subtropical Front and is positively related to the deposition of lithogenic material throughout the study area. In contrast, highest isoGDGT burial south of the Antarctic Polar Front may be largely controlled by diatom blooms, and thus high opal fluxes during austral summer.

Keywords: Biomarkers; Southern Ocean; Dust; ^{230}Th; GDGT; $U^{K'}_{37}$; TEX_{86}

1. INTRODUCTION

The Southern Ocean (SO) plays a crucial role in the climate system by influencing the meridional overturning circulation and the global carbon cycle (Fischer et al., 2010; Marshall and Speer, 2012). Wind-borne mineral aerosol (dust) is an important feedback in the climate system affecting radiation budgets, atmospheric chemistry, and providing nutrients to terrestrial and marine ecosystems (Jickells et al., 2005). According to the iron hypothesis (Martin, 1990), an increase in the supply of iron by dust may stimulate marine productivity in so-called high-nutrient low-chlorophyll (HNLC) regions, leading to the reduction of atmospheric CO_2 concentrations. In the Southern Hemisphere, the largest amount of dust is transported by the predominant mid-latitude westerly winds, which are an important driver of the large scale ocean circulation and

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play a major role in determining climate dynamics and precipitation regimes on adjacent land masses between 30°S and 60°S over seasonal to millennial timescales (Lamy et al., 2010, 2014; Fletcher and Moreno, 2012). A tight connection between eolian dust, climate state and ocean biogeochemistry was suggested, indicating that the world was much dustier during glacial climate stages, and consistent with overall cooler and drier conditions (Kohfeld and Harrison, 2001; Maher et al., 2010; Lamy et al., 2014; Martinez-Garcia et al., 2014). The large variations in dust loading in the past may reflect changes in the source areas, wind speed, pattern, and gustiness as well as deposition along the dust transport pathway (Winckler et al., 2008; Martinez-Garcia et al., 2009; Kohfeld et al., 2013). Several modeling attempts have been made to characterize the generation and transport of dust and its impacts on climate. However, estimates of modern dust sources, mobilization rates and deposition are still poorly constrained, resulting primarily from the scarcity of spatial data coverage for the Pacific sector of the SO. Therefore, major discrepancies exist about the contribution and relative importance of major dust sources in the Southern Hemisphere, i.e., South America and Australia/New Zealand (Prospero et al., 2002; Li et al., 2008; Maher et al., 2010; Albani et al., 2014; Neff and Bertler, 2015).

Lipid biomarkers are widely used to characterize the sources and distribution of organic matter (OM) in terrestrial and marine environments and are therefore a powerful tool for paleoclimate reconstructions (Eglinton and Eglinton, 2008). Land plant biomarkers in marine sedimentary archives provide useful information about past vegetation and its climate history on adjacent continents. This includes long-chain *n*-alkanes, which represent major lipid components of the protective waxes that coat the surface of higher land plants. They typically occur in the C_{25}–C_{35} range with a strong odd over even carbon number predominance (Eglinton and Hamilton, 1967). Such plant-wax lipids are persistent in soil and can reach marine sediments by erosion, wind and river transport of particulates, and smoke aerosols (Eglinton and Eglinton, 2008). The transport of wind-borne terrestrial OM has been documented for dust in sediments from remote oceanic locations, and most studies focused on lipid components from higher plant leaf waxes, i.e. *n*-alkanes, *n*-alkanols, *n*-fatty acids (Simoneit, 1977; Kawamura, 1995; Bendle et al., 2007). There is, however, a wealth of biological aerosol particles in the atmosphere including pollen, spores, and microorganisms (Griffin et al., 2006; Despres et al., 2012; Fröhlich-Nowoisky et al., 2014). A large proportion of the aerosol organic fraction thus likely remains overlooked. Branched glycerol dialkyl glycerol tetraethers (brGDGT) were recently detected in aerosol samples off NW-Africa (Fietz et al., 2013). These lipids are commonly used as a proxy for terrestrial (soil) OM input to the ocean, namely the branched and isoprenoid tetraether (BIT) index (Hopmans et al., 2004). BrGDGTs were first identified in peat bogs and are thought to derive from anaerobic soil bacteria (Weijers et al., 2006b), likely from members of the *Acidobacteria* (Sinninghe Damsté et al., 2011). They are frequently detected in lacustrine and coastal marine sediments, but also at remote ocean sites, where no direct impact from land erosion via rivers takes place (Fietz et al., 2011; Schouten et al., 2013; Jaeschke et al., 2014). Long-chain *n*-alkanes have been applied as a dust proxy in individual sediment cores from the subpolar Atlantic and Pacific Oceans, where they co-varied with iron and CO_2 concentrations over multiple glacial/interglacial cycles (Martinez-Garcia et al., 2009, 2011; Lamy et al., 2014). Application of brGDGTs as important additional dust tracers for paleoclimate reconstructions remains as yet unexplored.

At present, subtropical to polar SST gradients vary seasonally and zonally in conjunction with changes in surface circulation, the position and intensity of the westerly wind belt and regional climate (e.g. Lamy et al., 2010; Kohfeld et al., 2013). Accurate determination of present and past sea surface temperature (SST) variations is therefore essential for assessing the Southern Ocean's influence on global climate. The most commonly used organic proxy for SST estimation is the $U^{K'}_{37}$ index (Prahl and Wakeham, 1987), which is based on the relative abundance of di- and tri-unsaturated alkenones produced by haptophyte algae (e.g. Brassell et al., 1986). The $U^{K'}_{37}$ index has been proposed to quantify the degree of alkenone unsaturation, which is a function of growth temperature of the precursor organism. The initial *Emiliania huxleyi* culture-based calibration was later confirmed by those based on global core-top compilations (Müller et al., 1998; Conte et al., 2006). A more recently developed SST proxy is based on the relative abundance of isoprenoid GDGTs, produced by Marine Group I Thaumarchaeota (Sinninghe Damsté et al., 2011), namely the TEX_{86} index (Schouten et al., 2002). The initial linear TEX_{86} calibration has been extended including core-top sediments from (sub)polar oceans, and new indices and calibration models were defined for surface and subsurface temperatures (Kim et al., 2010, 2012a,b; Tierney and Tingley, 2014; Ho and Laepple, 2016). The fact that Thaumarchaeota and thus GDGTs occur ubiquitously in the global ocean, including the polar regions where alkenones (and in general carbonate-rich sediments) are basically absent, suggests a major advantage of the TEX_{86} paleothermometer in these regions. However, both alkenone- and GDGT-based temperature proxies suffer from uncertainties, e.g. the nonlinearity of $U^{K'}_{37}/TEX_{86}$ and SST at low temperatures, where changes in both index values are relatively minor. This effect may be related to low growth rates at such temperatures, which makes reliable SST reconstructions challenging for (sub)polar regions (Sikes et al., 1997; Kim et al., 2010; Ho et al., 2014). Recent studies also suggest that in addition to temperature, non-thermal secondary effects such as nutrient availability, archaeal ecotype and growth phase may have a strong control on individual TEX_{86} records (Elling et al., 2014; Qin et al., 2015; Hurley et al., 2016).

In this study, we present new comprehensive data sets of terrigenous input, marine productivity, and SST from surface sediments collected in the mid- and high-latitude Pacific SO based on lipid biomarker analyses. We use ^{230}Th normalization to correct for post-depositional sediment