Booth # 2

Exploring the Consistency of Alkenone and Faunal-Based Sea Surface Temperature Reconstructions from the Southwest Pacific during the Pleistocene

Emilie A. HENRY[1], Kira T. LAWRENCE[1], and Laura C. PETERSON[2]

[1]Department of Geology and Environmental Geosciences, Lafayette College, 4 South College Drive, Easton, PA 18042, [2]Environmental Studies Program, Luther College, 700 College Drive, Decorah, IA 52101

Abstract

Geochemical and biotic proxies are useful tools for the paleoclimate community in reconstructing past climate conditions in order to better contextualize future changes in climate. Because not every proxy is viable at all geographic locations, sea surface temperature (SST) estimates from multiple proxies are often compiled into global or regional climate reconstructions with the implicit assumption that estimates derived from different proxies can be used interchangeably. However, limited evidence currently exists to support the validity of this assumption. Using paleotemperature data from sediment collected from ODP Site 1125 (42°33'S, 178°10'W, 1365 m water depth) in the southwest Pacific, we provide a ~1Myr, orbital-scale SST proxy comparison of novel alkenone-derived SST data to previously published faunal assemblage SST data from the Pleistocene. These $U^{K'}_{37}$ and faunal assemblage SST records show strong structural similarity and yield remarkably similar estimates for basic climate metrics across each of the time series, including mean (14.9°C versus 14.4°C, respectively), standard deviation (both 1.6°C), and range (7.8°C versus 7.5°C, respectively). Spectral analysis reveals that the alkenone and faunal records are spectrally similar, both containing a dominant 100 k beat, with additional spectral power in the ~41 k and 23 k bands. Regression analysis yields a fairly strong (r=0.64) and statistically significant correlation between the two SST records. Our preliminary results indicate that these two proxies would yield very similar estimates for the paleoclimate metrics most commonly used in empirical paleoclimate reconstructions that seek to document the evolution of climate over time. However, significant disparities between SST estimates exist for some time intervals, particularly during glacial times. Thus, treating these proxies interchangeably when employing the time slab or time slice approaches that are typically employed in modeling studies could be problematic.

Site

The alkenone and faunal-based SST data used in this analysis is from ODP Leg 181, Site 1125 (42°32.98'S, 178°09.99'W, 1365 meters water depth) in the Southwest Pacific Ocean. Presently, Site 1125 is located on the north side of Chatham Rise and lies under the northern edge of the Subtropical Convergence (STC), just to the east of the New Zealand micro-continent (Shipboard Scientific Party 2000). Modern mean annual SST is approximately 14°C (Hayward et al. 2008).

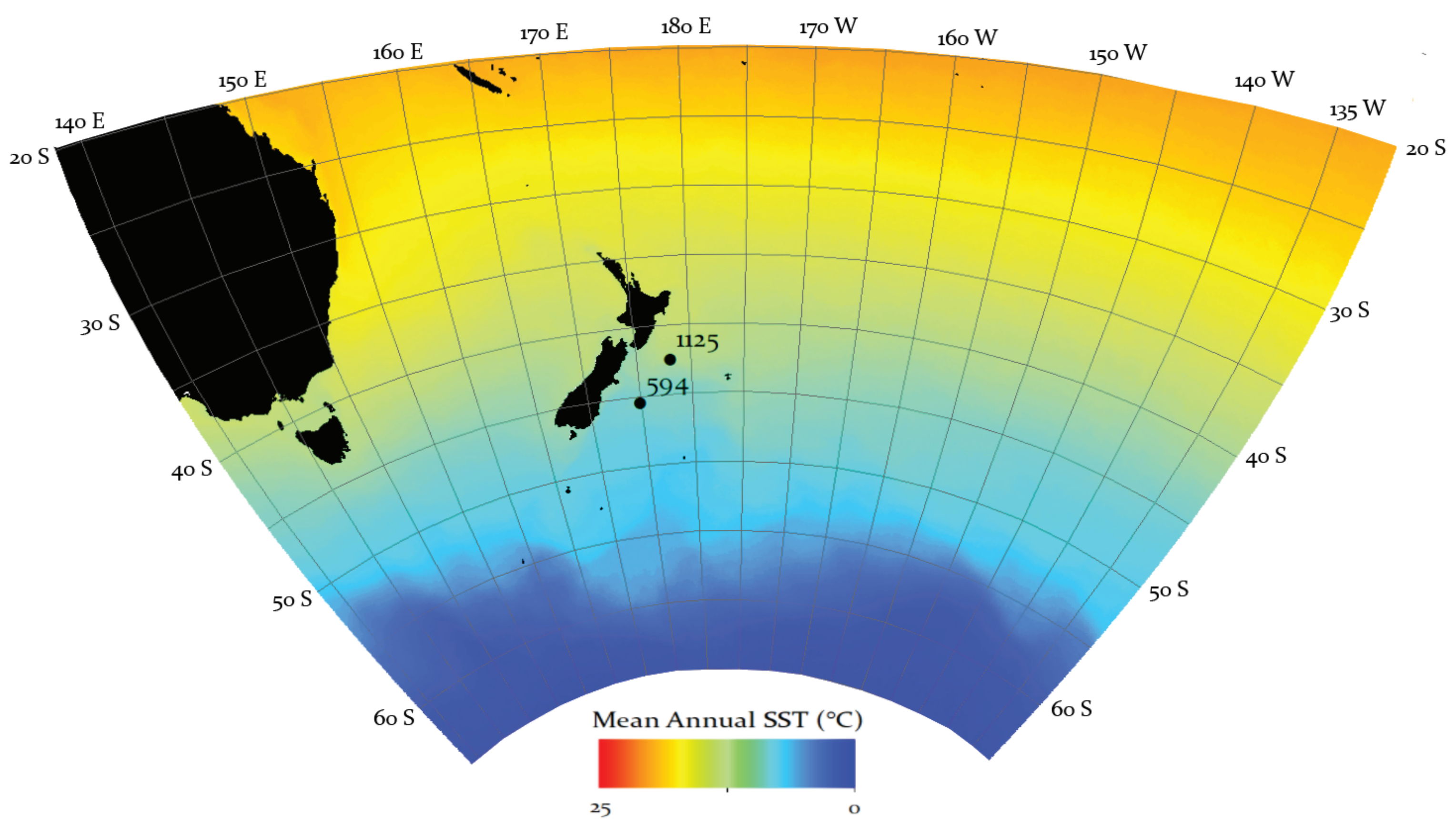


Figure 1. (Above) Locations of ODP Site 1125 and DSDP Site 594 overlain on a map of mean annual SST (NASA Ocean Biology, 2014). Country and latitude/longitude data sourced by ESRI 1996. Projection used is NZGD Chatham Circuit 2000.

Methods

Alkenone Paleothermometry

Alkenones are lipid biomarkers derived from haptophyte algae, primarily *E. huxleyi* (Fig. 2a) and *G. oceanica* (Fig. 2b). These lipids are isolated using an accelerated solvent extractor (ASE) and then analyzed by gas chromatography (Fig. 3). We then used the Muller et al. (1998) calibration equation (Eq. 1) to calculate SST values.

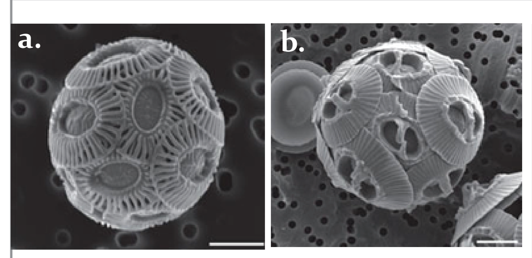


Figure 2. (Left) Species of haptophyte algae who produce alkenones, (a) *E. huxleyi* and (b) *G. oceanica* (Durak et al. 2016).

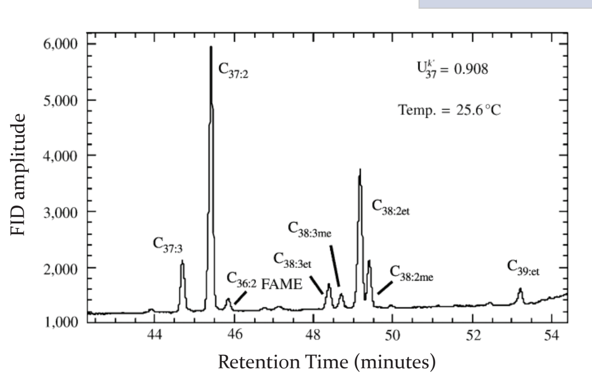


Figure 3. (Above) Typical gas chromatograph report (Herbert 2003).

Equation 1. (Right) Calibration equation (Muller et al. 1998).

$$U^{K'}_{37} = \frac{[C_{37:2}]}{[C_{37:2}+C_{37:3}]}$$

where

$$U^{K'}_{37} = 0.033T+0.044,\ r^2=0.958$$

Faunal Assemblages

Faunal assemblages are composed of inorganic carbonate shells of planktonic foraminifera that are preserved in sediment. Through the Modern Analogue Technique (MAT), they are compared to modern-day assemblages around the world of known temperatures (Fig. 4). Hayward et al. (2008) used a number of different planktonic foraminifera species, including *N. pachyderma (sinistral)*, to obtain SST estimates for site 1125, and we adjusted their data to fit on our own age model.

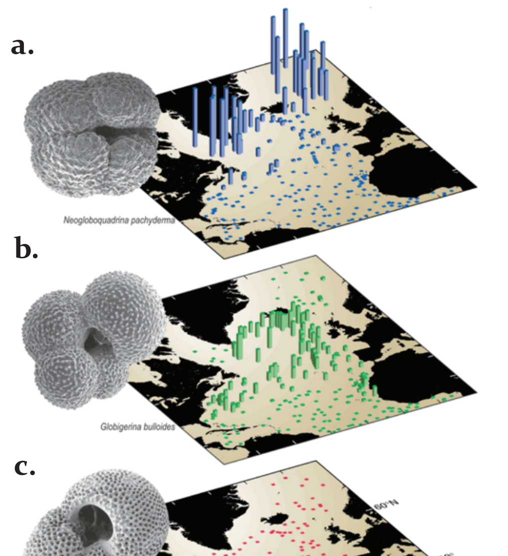


Figure 4. (Left) Geographic abundances of (a) *Neogloboquadrina pachyderma (sinistral)*, (b) *Globigerina bulloides*, and (c) *Globigerinoides ruber*. Figure courtesy of Marci Robinson.

Results

ODP 1125 Alkenone vs. Faunal Assemblage SST

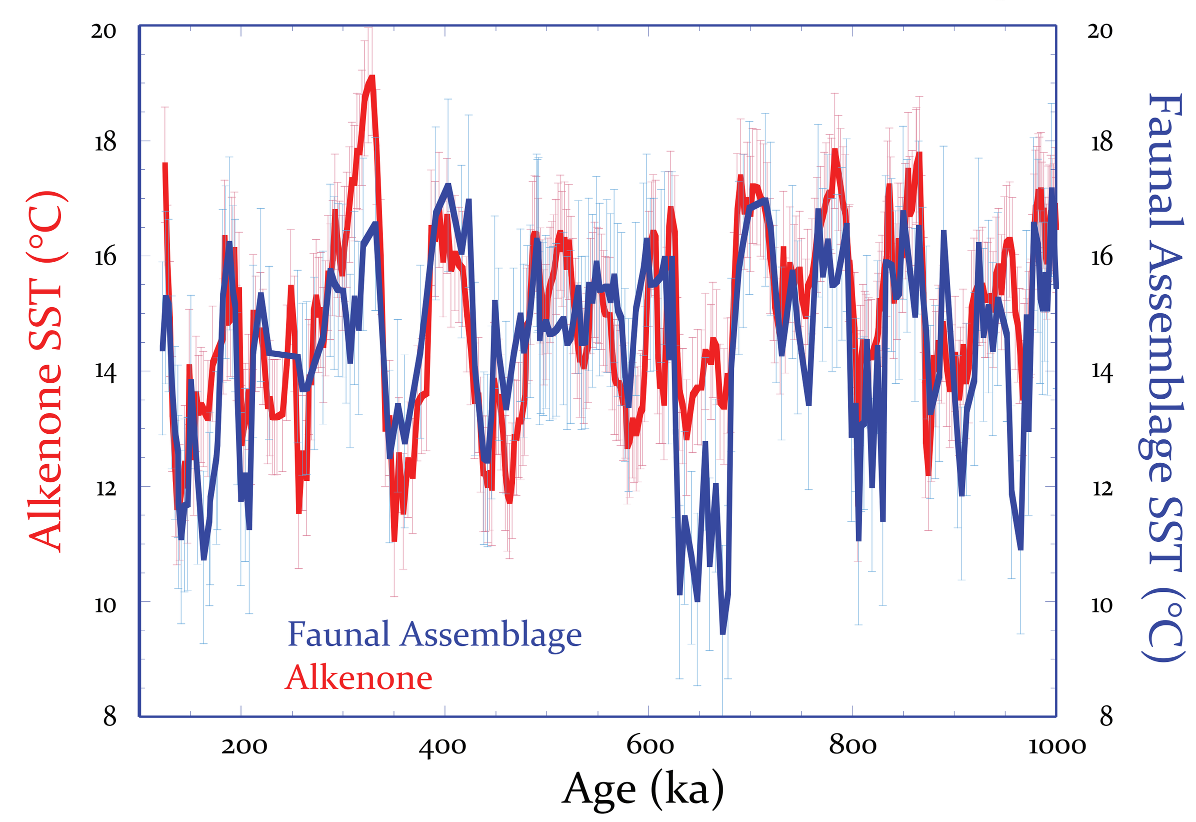


Figure 5. (Above) ODP 1125 novel alkenone-based SST data calibrated to the Muller et al. (1998) equation (Eq.1) and faunal assemblage SST data from Hayward et al. (2008) plotted against age (100-1000 ka BP).

Overall, both records display significant structural similarity. For the majority of the time, the alkenone and faunal SST records are within error of one another, except during the coldest glacials in the older part of the record (600-1000 ka BP) and the warmest interglacial in the younger part of the record (100-600 ka BP).

Table 1. (Below) Summary Temperature Data

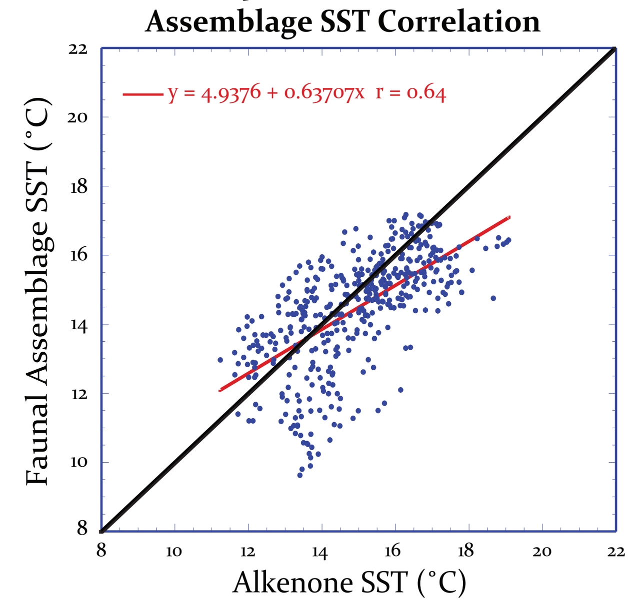
SST Proxy/Calibration	Mean (°C)	Range (°C)	Standard Deviation (°C)
Alkenone SST (Muller et al. 1998 Calibration)	14.9	7.8	1.6
Faunal Assemblage SST (Hayward et al. 2008)	14.4	7.5	1.6

Mean, standard deviation, and range are remarkably similar between the two records.

Figure 6. (Right) Correlation between alkenone-based SST data calibrated to the Muller et al. (1998) equation (Eq. 1) and faunal assemblage SST data from Hayward et al. (2008) (red line). Black line represents ideal 1:1 correlation.

A statistically significant correlation of r=0.64 was found between the two records. The data cloud is more oblong along the x-axis, indicating a greater variability in the alkenone record relative to the faunal.

ODP 1125 Alkenone vs. Faunal Assemblage SST Correlation



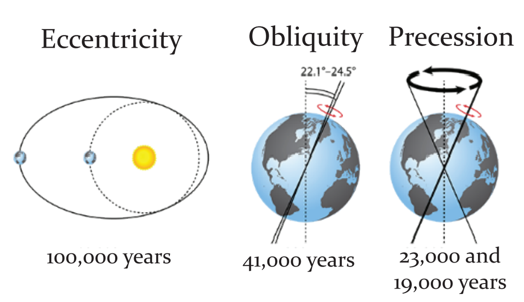


Figure 7. (Left) Standard Milankovitch cycles (Rosen 2016).

ODP 1125 Spectral Analysis

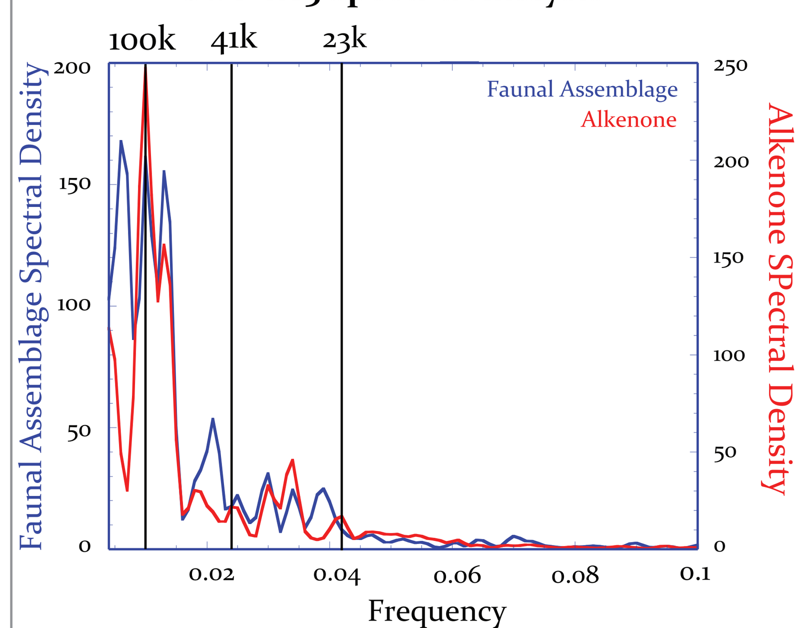


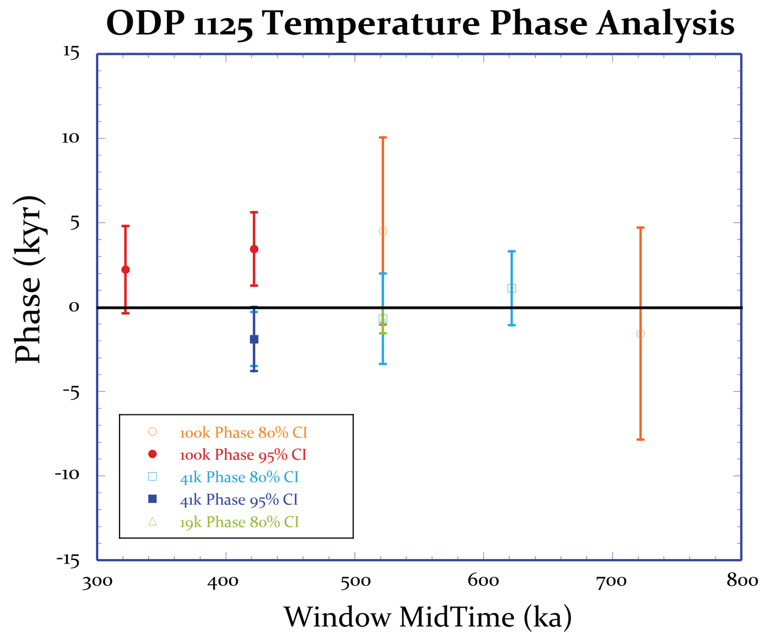
Figure 8. (Left) Simple spectra of both $U^{K'}_{37}$ and faunal assemblage records. Both records were interpolated to even intervals of 2 kyr resolution prior to analysis. We used the Arand software spectral program and applied a full linear detrend, the autocovariance function, and 225 lags.

Both records show the most strength in the 100 k (eccentricity) beat, with comparable strength in both the 41 k (obliquity) and 23 k (precession) beats, suggesting that both proxies respond similarly to orbital forcing.

Figure 9. (Right) Phase analysis of alkenone and faunal spectra. We interpolated both time series to an even 2 kyr interval before analysis to estimate phases. We used the Arand software iterative cosspec program with a 500 kyr increment. All phases are coherent at or above the 80% confidence interval.

Temperature estimates between the two proxies are mostly coherent and close to in-phase in both the eccentricity and obliquity bands. There is limited coherency at precession beats.

ODP 1125 Temperature Phase Analysis



Interpretation

The interchangeability of these two temperature proxies is dependent on which types of climate study one wishes to undertake, two of the most common being (1) empirical studies on the evolution of time series and (2) modeling studies that depict climate at a specific, narrow interval of time.

Empirical Studies: Evolution over Time

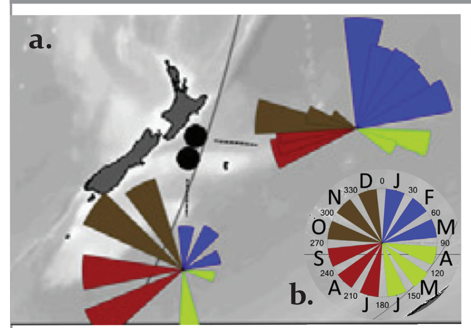
Our data suggests that these two proxies can be confidently used interchangeably in studies analyzing the evolution of climate over time. Both proxies display similarity in statistical metrics (Table 1), structure (Fig. 5), and spectral fingerprints (Fig. 8).

Modeling Studies: Time-Slice Approach

In the context of time-slice modeling studies, however, our data suggests that the use of these proxies interchangeably should be done cautiously. The correlation between the two proxies is strongly dependent on the specific time interval used (ex: 630-680 ka [bad correlation] vs. 380-430 ka [good correlation]) (Fig. 5).

Possible Explanations for Disagreement

Hypothesis #1: Seasonal Alkenone Bias

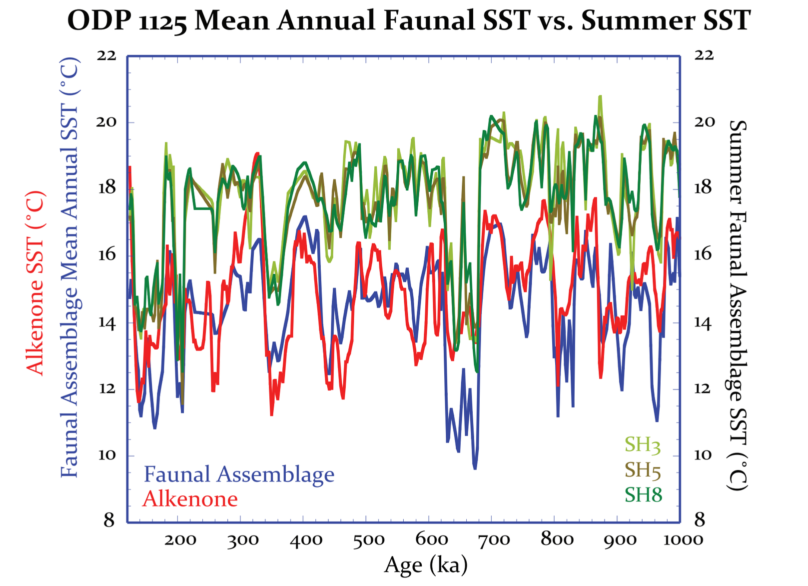


Sediment trap data suggests a dominantly summer season production of alkenones (Janurary, February, and March for the Southern Hemisphere) (Rosell-Mele and Prahl 2013, Fig. 10). Our alkenone data, however, is cooler on average than summer season faunal assemblage SST records (Fig. 11), indicating that alkenones from this site are more representative of mean annual SST.

Figure 10. (Above) (a) Seasonal production of alkenones near site 1125 by month. (b) Key for months of the year, with January, February, and March composing the bulk of Southern Hemisphere summer (Rosell-Mele and Prahl 2013).

Figure 11. (Right) Alkenone (this study) and mean annual faunal assemblage records (Hayward et al. 2008) plotted with summer faunal assemblage SST records (Schaefer et al. 2005) for ODP 1125. Schaefer et al. (2005) produced three summer faunal SST calculations using the three (SH3), five (SH5) and eight (SH8) assemblages in the Southern Hemisphere that had the best correlation with their faunal assemblage data.

ODP 1125 Mean Annual Faunal SST vs. Summer SST



Hypothesis #2: Movement of the STF

As shown in Fig. 13, the Subtropical Front (STF)-of which ODP 1125 is north and DSDP 594 is south (Fig. 12)-has remained in relatively the same location throughout the past million years. However, based on the strong correlation between faunal SST and *N. pachyderma (sinistral)* data from 1125 in the older half of the record (Fig. 14), we suggest that incursions of cold water across the STF may be responsible for the disagreement between the alkenone and faunal SST records during the coldest glacial periods.

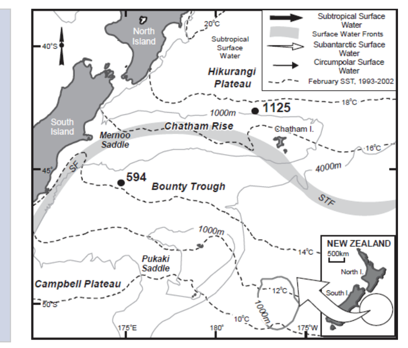


Figure 12. (Right) Map of currents and bathymetry surrounding ODP 1125 and DSDP 594 (Schaefer et al. 2005).

ODP 1125 Alkenone and Faunal Assemblage SST vs. DSDP 594 Faunal Assemblage SST

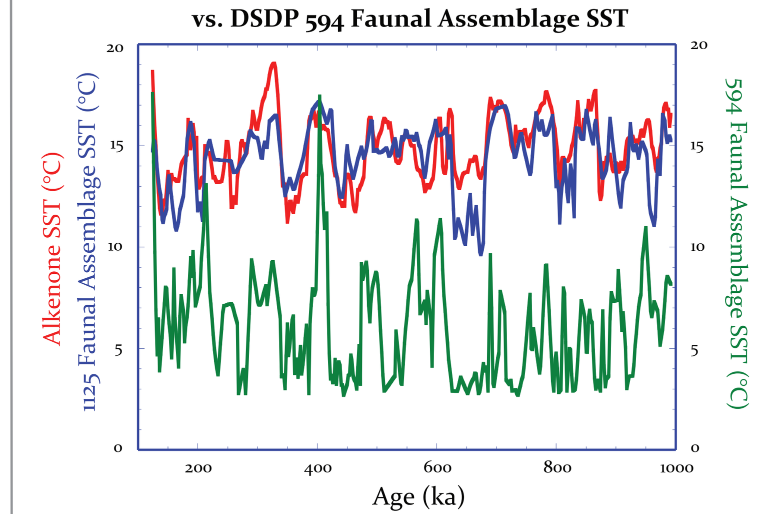


Figure 13. (Above) DSDP 594 faunal assemblage SST (Schaefer et al. 2005) plotted against novel alkenone (this study) and mean annual faunal assemblage records from ODP 1125 (Hayward et al. 2008).

ODP 1125 Faunal Assemblage Mean Annual SST vs. % *N. pachyderma*

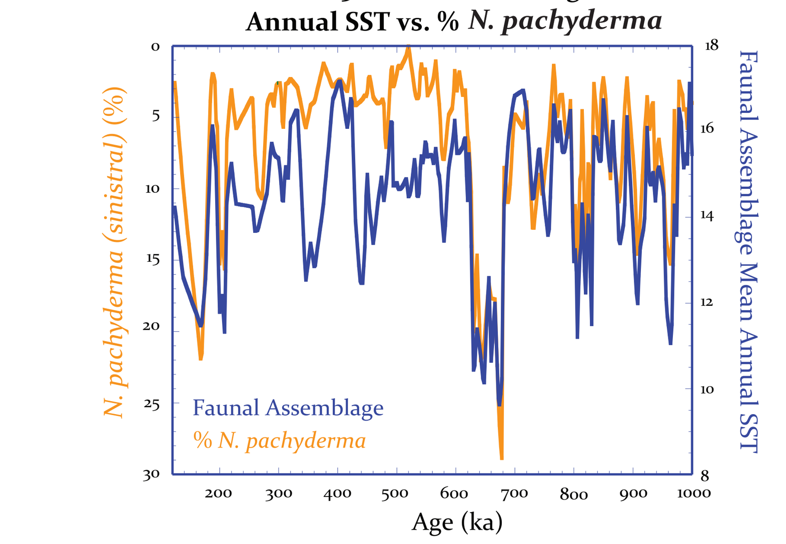


Figure 14. (Above) Hayward et al. (2008) mean annual faunal SST and Schaefer et al. (2005) % *N. pachyderma* from ODP 1125 show high % *N. pachyderma* during cold times.

Conclusions

(1) Alkenone- and faunal assemblage-based SST records could be used interchangeably in empirical studies to reconstruct climate evolution over time but could be problematic for modeling studies that rely on time slabs or time slices.
(2) Cold and warm water incursions across the STF during the past million years have likely contributed to the mismatch between the two records during pronounced glacial and interglacial intervals.

Acknowledgments and References

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