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Instrumental validation of *Globigerinoides ruber* Mg/Ca as a proxy for NE Pacific summer SST

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[1] Accurate reconstruction of sea surface temperature (SST) is a high research priority, given that it is such a crucial variable in the Earth's climate system. The Mg/Ca composition of *Globigerinoides ruber* (white) has been calibrated and applied for a number of tropical and extratropical paleo-SST reconstructions, though validation studies of the proxy against instrumental observations are relatively scarce. Here we present a validation of *G. ruber* Mg/Ca-derived SSTs against instrumental summer values, firstly from the modern seasonal water column perspective, and secondly from a 20th century observational time series. The study occurs in the San Lázaro Basin (SLB), one of the marginal basins in the NE Pacific known for very high sedimentation rates, excellent preservation, laminated sequences, and the ability to record upwelling processes on high-resolution timescales, from interannual climatic variability (El Niño / Southern Oscillation (ENSO)) to interdecadal (e.g., the Pacific Decadal Oscillation (PDO)). Results suggest that the proxy best reflects the summer season. The proxy-instrument time-series comparison for summer SSTs displays remarkable agreement, driven largely by ENSO cycles for the past century, with some events missing due to scarcity of foraminiferal specimens and/or lack of sufficient temporal resolution. This study validates the *G. ruber* Mg/Ca proxy for summer SSTs in this region, and suggests its high fidelity to reconstruct summer SST from SLB over longer timescales to record multi-decadal and multi-centennial variabilities. **Citation:** Mortyn, P. G., J. C. Herguera, and M. A. Martínez-Botí (2011), Instrumental validation of *Globigerinoides ruber* Mg/Ca as a proxy for NE Pacific summer SST, *Geophys. Res. Lett.*, *38*, L16601, doi:10.1029/2011GL047803.

1. Introduction

[2] Sea surface temperature (SST) is undoubtedly one of the most influential and sensitive physical parameters in the Earth's climate system [*Lea*, 2003]. As the upper few meters of the surface ocean contain as much heat as the entire atmosphere [*Trenberth*, 2002], it is easy to understand why SST is so paramount in any consideration of climate change on any timescale. Each SST reconstruction from deep-sea sediments depends heavily on the fidelity of proxy systems to record such variability, and the Mg/Ca composition of planktonic foraminifera is critical in this regard. One particular species, *Globigerinoides ruber* (white), has been widely exploited for this purpose; its affinity for warmer waters and its bearing of dinoflagellate symbionts collectively constrain its habitat to the relatively shallow tropical/subtropical surface ocean [*Fairbanks et al.*, 1982; *Farmer et al.*, 2007; *Faul et al.*, 2000; *Hemleben et al.*, 1989], and during warmer seasons (e.g., summer). Many studies have focused either on calibration of *G. ruber* Mg/Ca from a range of perspectives (culture [*Kisakurek et al.*, 2008], sediment trap [*Anand et al.*, 2003], and most often surface sediment samples [*Dekens et al.*, 2002; *Lea et al.*, 2000]), as well as application to the fossil record of SST change in the tropical and extratropical regions especially [e.g., *Sadekov et al.*, 2009]. Relatively few, however, have explicitly focused on validation in the time domain, whereby existing proxy calibrations are tested against instrumental observations of SST, since bioturbation and relatively low sedimentation rates generally make such comparisons impossible. There has been validation work [*Black et al.*, 2007] from another planktonic foraminiferal species, *Globigerina bulloides*, illustrating correspondence between its sedimentary Mg/Ca composition and instrumental SST in the Cariaco Basin (tropical Atlantic). Here we present the first known validation of the *G. ruber* Mg/Ca proxy for summer SST in the NE Pacific, with explicit focus on the San Lázaro Basin (SLB, Figure 1) in the southern Calfornia Current System (CCS).

[3] Seasonality in the southern CCS results from the solar radiation cycle, changes in horizontal advection, vertical mixing associated with upwelling processes, and heat conduction [*Sverdrup et al.*, 1942]. Changes in horizontal advection driven by winds allows for the dynamically shifting boundary between waters of northern origin and those of tropical origin, as well as for changes in the mixing between surface and subsurface waters; both processes drive the observed SST variability, beyond the seasonal cycle of heating and cooling [*Espinosa-Carreon et al.*, 2004; *Linacre et al.*, 2010]. SLB is strategically located below this dynamic boundary (Figure 1) and is part of a series of California (both Alta and Baja) marginal coastal basins known for a unique combination of high sedimentation rates (>1 m/ky), resulting from both terrigenous runoff and seasonal upwelling processes that fuel the biogenic export to depth, and excellent preservation of laminated sediments due to low oxygen levels of intermediate waters that hinder bioturbation [*Esparza-Alvarez et al.*, 2007; *van Geen et al.*, 2003]. Our proxy validation study is focused on *G. ruber* specimens

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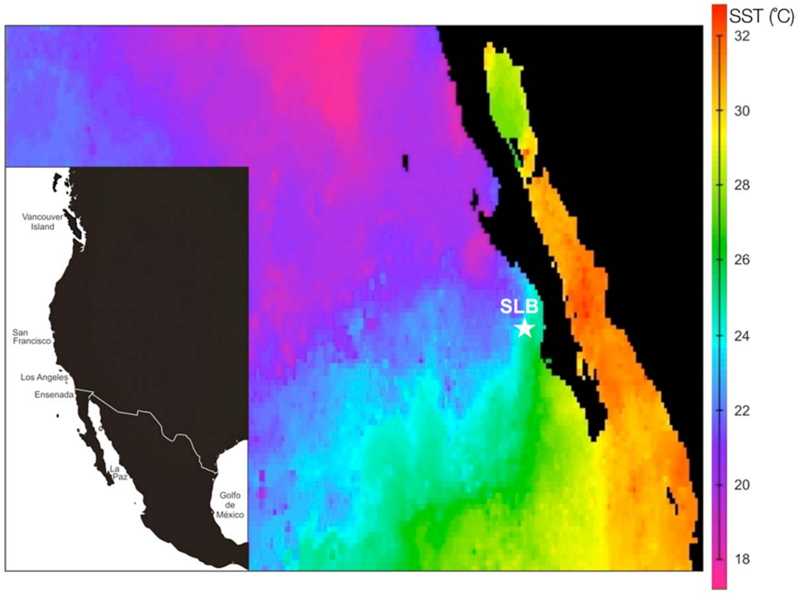

Figure 1. Map showing location of SLB superimposed on a pronounced SST gradient in the southern CCS during a strong ENSO event (July 1997). The region marks a dynamic boundary between fresher and cooler waters of northern origin, with southern waters that are both warmer and saltier.

preserved from recent SLB sediments. Here we constrain from modern seasonal water column observations how summer is the most likely season for this species, and further validate that *G. ruber* Mg/Ca is a reliable recorder of summer SST in the region.

2. Materials and Methods

[4] Climatology of seasonal water column temperature profiles is available from California Cooperative Oceanic Fisheries Investigations (CalCOFI) reports for years 1949–1976 (http://www.calcofi.org), and for years 2005–2008 from Investigaciones Mexicanas de la Corriente de California (IMECOCAL) reports (http://imecocal.cicese.mx). Autumn data are not available from IMECOCAL cruises and we therefore supplement seasonal data from the World Ocean Atlas (WOA) (Figure 2). The data are constrained from sites along a 1° × 1° grid centered at 25°N–26°N and 112°W–113°W to best facilitate comparison against sediments from SLB.

[5] Two SLB box cores (BAP96-6C and ET97-3C7) were recovered aboard the oceanographic vessel BO/ El Puma, and dated with excess ^{210}Pb and ^{135}Cs radioisotopic methods [*Esparza-Alvarez et al.*, 2007] for the past century. These cores were sampled at quasi-annual temporal resolution (averaging a sample every ~1.5 years), and collectively comprise a composite record for the last century (Figure 3). Sediments were washed and sieved at 250–350μm fraction and individual *G. ruber* specimens were picked under microscopic view in order to generate approximately 300μg shell mass per sample (approximately 30 shells at roughly 10μg per shell). In some cases pooling of samples across intervals was required in order to generate enough material for cleaning and analysis. The Figure 3 spread of proxy-derived data points, of variable time spacing, illustrates this issue at various times of the reconstruction.

[6] Foraminiferal tests were gently cracked between 2 methanol-cleaned glass plates under microscopic view to open chambers and expose the fill and protoplasm, but not enough to pulverize the sample. They were then loaded into acid-cleaned microvials and subjected to a rigorous wet-chemical cleaning procedure (conducted at the UAB) according to the "Cd-method" [*Barker et al.*, 2005; *Rosenthal*

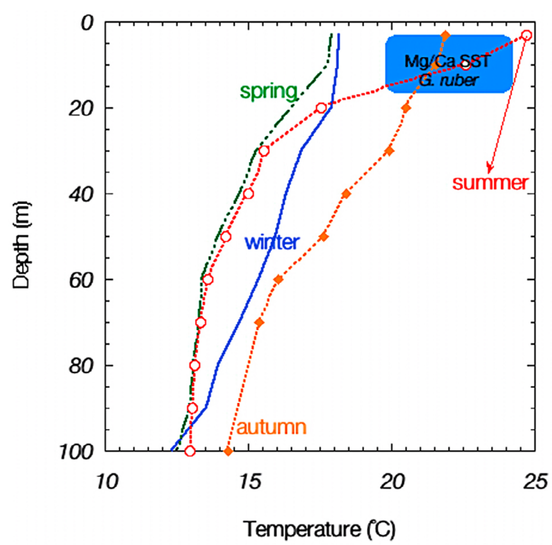

Figure 2. Seasonal water column temperature (T) profiles from SLB showing winter, spring, and summer averages from 2005–2008 IMECOCAL data; autumn data is supplemented from the World Ocean Atlas (WOA) [*Locarnini et al.*, 2006]. Blue shaded box shows the calculated spread of *G. ruber* Mg/Ca-derived T values (19.8–24.3°C) and depth conditions for *G. ruber* based on observational constraints presented here (see text for details), and recent literature [*Fairbanks et al.*, 1982; *Farmer et al.*, 2007; *Faul et al.*, 2000; *Hemleben et al.*, 1989].

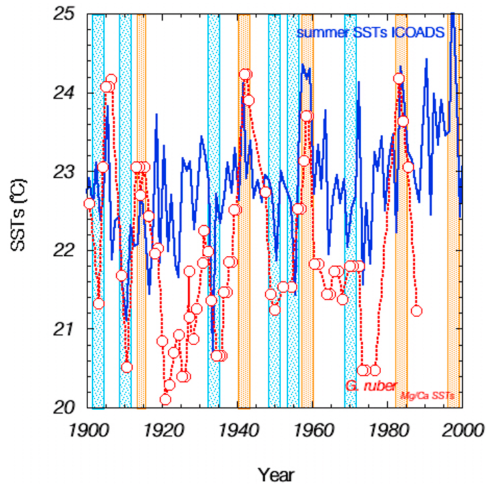

Figure 3. *G. ruber* Mg/Ca-derived SSTs (red) compared against an instrumental summer (July–August) SST time series from ICOADS for 25°N, 113°W (blue), all for the 20th century. Strong *El Niño* (EN) and *La Niña* (LN) events are indicated by orange and blue stippling, respectively.

et al., 2004] that includes a reductive step for the removal of Fe-Mn oxide coatings; the procedure also includes steps for clay removal, organic matter oxidation, and elimination of adhering surficial particles. The procedure has been established internationally for some years now, and has included a recent interlaboratory calibration exercise to standardize methods and approaches [*Greaves et al.*, 2008]. Analyses were conducted at the UAB using quadrupole inductively coupled plasma – mass spectrometry, with procedures and data reduction generally following those previously established [*Yu et al.*, 2005].

[7] A number of potential equations from the literature are available to convert *G. ruber* Mg/Ca values to temperature. For this we explored 2 equations in particular that have focused on surface sediment core-top samples of this species in the tropical Pacific [*Lea et al.*, 2000] and a range of tropical and extratropical sites in both the Pacific and Atlantic basins [*Dekens et al.*, 2002]. We found that the former produced warmer SST values than the 20th century instrumental record at 1m depth, while the latter produced cooler values that closely match the expected ones for the upper 10–20 m water column depths where *G. ruber* specimens are expected to precipitate their shells [*Fairbanks et al.*, 1982; *Farmer et al.*, 2007; *Faul et al.*, 2000; *Hemleben et al.*, 1989]. We thus developed our century-long composite record (Figure 3) with the equation of *Dekens et al.* [2002], and compared it against instrumental data from 1m depth for the 1° × 1° grid box for SLB described above, available from the International Comprehensive Ocean Atmosphere Data Set (ICOADS) [*Worley et al.*, 2005]. ICOADS offers surface marine data spanning the past 3 centuries, and simple gridded monthly summary products for 2° × 2° boxes back to 1800 (and 1° × 1° boxes since 1960). As it contains observations from several observing systems reflecting measurement technology evolution over 100's of years, ICOADS is probably the most complete and heterogeneous collection of surface marine instrumental data in existence.

3. Results and Discussion

[8] The seasonal water column profiles (Figure 2) suggest that only during the summer/autumn months are the observed instrumental temperature values warm enough to correspond reasonably with the proxy-derived values; the shaded box shows the spread of proxy-derived SSTs (19.8–24.3°C), and thus emphasizes summer/autumn as the only seasons where such warm values can occur in the shallow habitat of this planktic fauna [*Fairbanks et al.*, 1982; *Farmer et al.*, 2007; *Faul et al.*, 2000; *Hemleben et al.*, 1989]. Proxy-derived SST values are clearly not indicative of winter- nor spring-associated temperature values, as these seasons display more isothermal water column profiles with maximum SST values of ~18°C, due to cooling and downward mixing (winter) and upwelling processes (spring). Furthermore, if we consider the depth habitat range of *G. ruber*, previously inferred at 10–20 m depth in the water column [*Fairbanks et al.*, 1982; *Farmer et al.*, 2007; *Faul et al.*, 2000; *Hemleben et al.*, 1989] (shaded box of Figure 2), then during the isothermal and cooler winter and spring seasons we would not expect this species to flourish at any depth.

[9] This suggested *G. ruber* summer dominance is potentially at odds with previous work [*Field*, 2004] from the Santa Barbara Basin (SBB) about 800 km NW of SLB. In that plankton tow survey study comparable fluxes of *G. ruber* were estimated for both winter and summer not only at SBB but also nearby in the Southern California Bight, the California Current core and offshore region. The same study also revealed evidence for a ranging *G. ruber* vertical habitat from within the mixed layer to the base of the mixed layer or even within the thermocline of the CCS, which could potentially confound interpretations based on stable temperature recording of a relatively fixed depth.

[10] We emphasize a number of important differences however between the findings from SBB and the implied summer dominance of *G. ruber* suggested here for SLB. *G. ruber* is a spinose species colonized by algal symbionts, which probably limits its habitat to depths of high light penetration [*Hemleben et al.*, 1989], and further implies its preference for well-stratified surface ocean conditions, which in the southern CCS arises only during summer and autumn. Furthermore, despite the appreciable *G. ruber* fluxes for contrasting seasons reported at SBB, the water column temperature profiles for SLB (Figure 2) present strong evidence that *G. ruber* preserved in these sediments are limited to the warmer months when conditions are favorable for maxima in *G. ruber* production and transfer through the water column, to explain their regularity and dominance in the laminated sedimentary record. As we have no published sediment-trap data of *G. ruber* fluxes to SLB to refer to, we emphasize this as the most likely explanation for the observations to date. Another major difference between the 2 sites results from the more southerly location of SLB, which on the one hand allows for a greater relative influence of the warm Davidson Counter-Current [*Robert*, 2004] as a seeding source of tropical species to the southern CCS, while on the other hand it offers greater proximity to the boundary with the tropical and subtropical waters that allows for mesoscale surface mixing and aids as a transport agent for these organisms.

[11] With the direct proxy-observation analysis (Figure 3) we can validate the fidelity of *G. ruber* Mg/Ca in tracking the 20th century ICOADS instrumental data they are being evaluated against [*Worley et al.*, 2005]. The observational data of Figure 3 is restricted to the 20th century for the months of July and August, and thus facilitates a summer-focused comparison against the sediment-based proxy record over the same time frame. We calculated the correlation coefficients between the proxy-derived temperatures from *G. ruber* and the instrumental monthly and bimonthly SST time series and determined the best correspondence with the July-August instrumental data, even compared to other warm autumn months (averaging about R = 0.55 for July and August (summer) and R = 0.25 for September and October (autumn)).

[12] Figure 3 highlights warm and cool patterns of the 20th century, indicated by orange and blue shading indicative of major *El Niño* and *La Niña* events respectively, and how expected SST variations associated with them are recorded well by both the summer instrumental and *G. ruber* Mg/Ca proxy-derived SST. The ability of the proxy to record such variability is of course imperfect, and in this case specifically limited by likely insufficient temporal resolution of the signal carrier. In some instances *G. ruber* foraminiferal abundances are not high enough at discrete time intervals, something that is especially apparent for the last few decades of the past century. Another noteworthy caveat is that warm ENSO events typically produce deeper and thicker mixed layers and depressed thermoclines [*Durazo and Baumgartner*, 2002], which lead to lowered biological productivity and thus foraminiferal production and abundance; this implies that our proxy may not always be able to capture ENSO events.

[13] Another notable point from Figure 3 is that the instrument – proxy disagreement appears enhanced in the absolute sense during certain extended cool reconstructed periods (e.g., the 1920s and the mid-1970s), associated with increasingly positive phases of the PDO [*Chhak and Di Lorenzo*, 2007; *Mantua et al.*, 1997]. A possible explanation could be a slightly more stratified mixed layer during these times, such that the proxy values are especially cool considering the 10–20 m *G. ruber* depth habitat relative to the 1m depth instrumental values. Alternatively, it is possible that the habitat of *G. ruber* during these times was slightly deeper and cooler. There is also a potential bias introduced by the fact that we did not attempt to separate the two morphotypes of *G. ruber*, *G. ruber* sensu strictu (s.s.) and *G. ruber* sensu lato (s.l.), which may record slightly different depth habitats in the water column [*Steinke et al.*, 2005; *Wang*, 2000]; a changing relative proportion of *G. ruber* s.l. over s.s. could account for the especially cool reconstructed SSTs during these periods. We currently have no basis for exploring these issues deeply, which goes beyond the scope of the present study.

[14] Despite these caveats however, general correspondence is illustrated not only by comparable amplitudes, but also in the phasing of peaks and troughs; thus this reconstruction can capture quite well the warm and cool cycles related to ENSO events. The proxy-instrument comparison further validates that *G. ruber* Mg/Ca can likely work on longer timescales to reconstruct interdecadal/multidecadal to centennial summer SST in the region, provided sufficient foraminiferal specimens are available for analysis. This validation clearly paves the way for further *G. ruber* Mg/Ca-derived SST reconstructions at SLB on longer time-scales in order to capture and resolve a host of decadal and centennial phenomena, such as the PDO [*Miller and Schneider*, 2000], the Medieval Warm Period [*Trouet et al.*, 2009], and the Little Ice Age [*Mann et al.*, 2009].

4. Conclusions

[15] Seasonal water column T profiles with depth in SLB effectively constrain our *G. ruber* Mg/Ca proxy data to the warmer seasons, and suggest that 10–20 m depth habitat is most likely for this species. Furthermore, our proxy–instrumental (summer) SST comparison for the 20th century displays a higher degree of correspondence with July–August SSTs than with any other bimonthly time-series, confirming shallow habitat during summer. Proxy-derived SSTs closely match warm/cool cycles largely driven by ENSO variability and likely enhanced by decadal to interdecadal variability in this region, provided that sufficient foraminifera are available at appropriate temporal resolution in the sediments. This validation clearly places the proxy on a firm footing to reconstruct decadal and centennial phenomena further in the past at SLB.

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