



# Comment on “A snapshot of climate variability at Tahiti at 9.5 ka using a fossil coral from IODP Expedition 310” by Kristine L. DeLong, Terrence M. Quinn, Chuan-Chou Shen, and Ke Lin

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**Components:** 2200 words, 1 figure.

**Keywords:** corals; Tahiti; sea surface temperature.

**Index Terms:** 0473 Biogeosciences: Paleoclimatology and paleoceanography (3344, 4900); 1065 Geochemistry: Major and trace element geochemistry; 1041 Geochemistry: Stable isotope geochemistry (0454, 4870).

Received 27 September 2010; Revised 10 January 2011; Accepted 14 February 2011; Published 30 March 2011.

Cahyarini, S. Y., M. Pfeiffer, W.-C. Dullo, J. Zinke, S. Hetzinger, S. Kasper, C. Grove, and D. Garbe-Schönberg (2011), Comment on “A snapshot of climate variability at Tahiti at 9.5 ka using a fossil coral from IODP Expedition 310” by Kristine L. DeLong, Terrence M. Quinn, Chuan-Chou Shen, and Ke Lin, *Geochem. Geophys. Geosyst.*, 12, Q03012, doi:10.1029/2010GC003377.

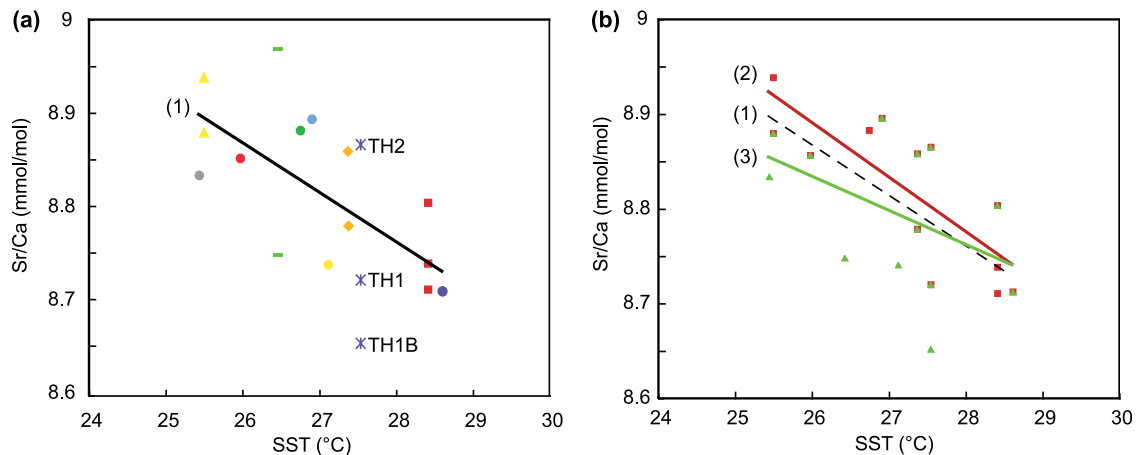
[1] The Integrated Ocean Drilling Program (IODP) Expedition 310 recovered drill cores from the drowned reefs around the island of Tahiti, many of which contained samples of massive corals from the genus *Porites*. In a recent publication, *DeLong et al.* [2010] report on the monthly  $\delta^{18}\text{O}$  and Sr/Ca record of one fossil coral sample dated by uranium series techniques at  $9523 \pm 33$  years. The interpretation of the fossil coral proxy data is based on published modern coral Sr/Ca records from Tahiti [*Cahyarini et al.*, 2009], a  $\delta^{18}\text{O}$  record from nearby Moorea [*Boiseau et al.*, 1998], as well as additional Sr/Ca records from Fiji and Rarotonga [*Linsley et al.*, 2006].

[2] The authors reevaluate the modern proxy data according to the needs of their study. However, we note significant weaknesses regarding the discussion of the modern data that make it difficult to accept the conclusions of *DeLong et al.* [2010]. Important information from previous publications has been omitted or is not reflected correctly. One relevant publication on the feasibility of  $\delta^{18}\text{O}$  seawater ( $\delta^{18}\text{O}_{\text{sw}}$ ) reconstructions using paired  $\delta^{18}\text{O}$  and Sr/Ca determinations from Tahiti corals is not even cited [*Cahyarini et al.*, 2008]. *Cahyarini et al.* [2008] provide a formula to estimate the error of  $\delta^{18}\text{O}_{\text{sw}}$  reconstructions, and show that at least on a seasonal scale, modern  $\delta^{18}\text{O}_{\text{sw}}$  variations at Tahiti are too small to measurably affect coral  $\delta^{18}\text{O}$ . The magnitude of expected  $\delta^{18}\text{O}_{\text{sw}}$  variations is smaller than the analytical error of  $\delta^{18}\text{O}$  and Sr/Ca. Coral  $\delta^{18}\text{O}$  variations at Tahiti should not be interpreted in terms of changes in the hydrological balance, unless the authors can demonstrate that the observed variations are larger than the analytical error. *DeLong et al.* [2010] ignore this study. Instead, the authors reevaluate the  $\delta^{18}\text{O}$  record from Moorea that has been originally interpreted as a temperature record [*Boiseau et al.*, 1998], and speculate that a  $\delta^{18}\text{O}$ -SST relationship of  $-0.18(\pm 0.04)$  per  $\text{mil}/^\circ\text{C}$  could indicate contributions of  $\delta^{18}\text{O}$  seawater, as inorganic aragonite has a  $\delta^{18}\text{O}$ -SST relationship of  $-0.22$  per  $\text{mil}/^\circ\text{C}$ . However, the Moorea  $\delta^{18}\text{O}$ -SST slope estimate presented by *DeLong et al.* [2010] is not significantly different from the  $\delta^{18}\text{O}$ -SST rela-

tionship of inorganic aragonite, so this argument is not convincing.

[3] *Cahyarini et al.* [2009] present Sr/Ca ratios measured at three Tahiti coral cores. Two cores are from the same colony (located near Taehupoo), and were drilled vertically (TH1) and horizontally (TH1B). A third core (TH2) was drilled vertically from another coral located near Vairao. The mean values of the intracolony cores (TH1 and TH1b) exhibit significantly different means (0.06 mmol/mol) and the Vairao core has a higher mean than the other two cores (0.15 mmol/mol). While the results of *Cahyarini et al.* [2009] appear to be troublesome for the estimation of mean temperature changes from the fossil coral sample presented by *DeLong et al.* [2010], similar spreads of mean Sr/Ca values have been observed (1) in cultured corals grown in thermostated seawater [*Inoue et al.*, 2007] and (2) at other sites where multiple coral cores have been analyzed. Examples include the Red Sea [*Felis et al.*, 2004], Madagascar (Sainte Marie, Figure 1a), the Chagos Archipelago [*Pfeiffer et al.*, 2009], Fiji and Rarotonga [*Linsley et al.*, 2006], as well as Sumatra and Papua New Guinea [*Abram et al.*, 2009]. The exact cause of the observed spread in mean Sr/Ca ratios is not clear, but biological factors (often referred to as “vital effects”) clearly are important. In a seminal study, *Abram et al.* [2009] included the observed spread of modern coral Sr/Ca values in the error estimate of mean SSTs derived from fossil coral Sr/Ca.

[4] *DeLong et al.* [2010] argue that such a spread of mean Sr/Ca values has not been observed at New Caledonia [*DeLong et al.*, 2007], where three intercolony and three intracolony cores have been analyzed, and therefore reject the results of TH2 and TH1. The authors invoke sampling anomalies to explain the higher mean Sr/Ca values of TH2. TH1 is rejected because, according to *DeLong et al.* [2010, paragraph 6], “...[*Cahyarini et al.*, 2009] state that the top of the coral colony had reached the sea surface. The surface breach may have biased the geochemical record in TH1, reducing intracolony correlation.” This is not correct. *Cahyarini et al.* [2009] state that the living surface of the coral



**Figure 1.** (a) OLS regression of mean Sr/Ca versus mean SST (OI SST) [Reynolds *et al.*, 2002] of all coral Sr/Ca records measured at the University of Kiel (time period: January 1982–December 1994). The regression equation is  $SST = -0.053(\pm 0.017) * Sr/Ca + 10.25(\pm 0.45)$ ;  $r = -0.62$ ,  $\sigma = 0.07$ ,  $p < 0.01$ ,  $n = 18$  (line 1). Sites are as follows: the Chagos Archipelago (71°E, 5°S) (red squares, *Porites* sp.) [Pfeiffer *et al.*, 2009], Tahiti (17°S, 149°E) (purple crosses, *Porites* sp. [Cahyarini *et al.*, 2009], Guadeloupe (61°W, 16°N) (orange diamonds, *Diploria strigosa*) [Hetzinger *et al.*, 2006, also unpublished data, 2011], Sainte Marie, Madagascar (49°E, 17°S) (green rectangles, *Porites* sp.), Rodrigues (63°E, 19°S) (yellow triangles, *Porites* sp.), La Reunion (55°E, 21°S) (gray circle, *Porites* sp.), Archipelago Los Roques, Venezuela (66°W, 11°N) (blue circle, *Diploria strigosa*), Chichiriviche, Venezuela (67°W, 10°N) (green circle, *Diploria strigosa*), Ifaty, Madagascar (45°W, 23°S) (red circle, *Porites* sp.), Diego, Madagascar (49°E, 12°S) (yellow circle, *Porites* sp.), and Timor, Indonesia (124°E, 10°S) (purple circle, *Porites* sp.). The largest spread of mean Sr/Ca values at one site is observed at Sainte Marie, Madagascar (0.23 mmol/mol) followed by Tahiti (0.21 mmol/mol). (b) Same as Figure 1a, but number of samples is arbitrarily reduced to 13. Examples for possible regression equations are as follows. Line 2:  $SST = -0.058(\pm 0.013) * Sr/Ca + 10.39(\pm 0.36)$ ;  $r = -0.80$ ,  $\sigma = 0.05$ ,  $p < 0.01$ ,  $n = 13$ . Line 3:  $SST = -0.036(\pm 0.021) * Sr/Ca + 9.77(\pm 0.56)$ ;  $r = -0.47$ ,  $\sigma = 0.07$ ,  $p = 0.11$ ,  $n = 13$ .

**almost** reached the sea surface. The top of TH1 has always been covered by at least 20 cm of water.

[5] A serious problem noted by DeLong *et al.* [2010] is the lack of a “universal” Sr/Ca to SST calibration [e.g., Corregge, 2006], as this hinders the estimation of mean SST changes from fossil corals. DeLong *et al.* [2010] therefore present a new southwest Pacific mean coral Sr/Ca to mean SST calibration. The regression includes 13 corals from various sites in the southwest Pacific that were calibrated against the same standards as the fossil Tahiti coral (it does not include any data from modern Tahiti corals). This is an interesting approach, as the lack of a “universal” Sr/Ca to SST calibration also hinders a proper assessment of vital effects, and the resulting uncertainties for SST estimates based on coral Sr/Ca. However, we find that the spread of mean Sr/Ca values for a given temperature setting is surprisingly low. It is much lower than the spread of mean Sr/Ca values reported by Inoue *et al.* [2007] for cultured corals grown at fixed temperatures. We have therefore repeated this exercise using corals measured at the University of Kiel. Over the years, a number of coral cores ( $n = 18$ ) from the Pacific, the Indian

Ocean and the Caribbean Sea have been measured at this lab using exactly the same instruments, analytical procedures and standards (see Cahyarini *et al.* [2008, 2009] for a description of methodology). The external analytical precision as determined from a series of more than 4,000 analyses over a couple of months was better than 0.1%RSD (1sigma). Our regression includes the modern Tahiti cores presented by Cahyarini *et al.* [2009]. We decided to use an Ordinary Least Squares (OLS) regression, as this approach is commonly used for coral Sr/Ca–SST regressions [e.g., Corregge, 2006; Inoue *et al.*, 2007]. The use of OLS regression is justified as the residual of the Sr/Ca–SST regression (not shown) is normally distributed. We find a significant correlation between mean coral Sr/Ca and mean SST, and the regression parameters are consistent with other Sr/Ca–SST relationships. However, the scatter of mean Sr/Ca values for any temperature setting is fairly large (Figure 1a). This becomes particularly clear when comparing the mean Sr/Ca values from corals sampled at the same site. We note, however, that this result is consistent with the lab-based data from Inoue *et al.* [2007]. We therefore conclude that the spread of mean Sr/Ca values observed at Tahiti is not unusual. Hence, the

evaluation of the Tahiti Sr/Ca records is not straightforward (see the extensive discussion by Cahyarini *et al.* [2009]). We would have preferred DeLong *et al.* [2010] to use all modern Sr/Ca records from Tahiti as a basis for the interpretation of their fossil coral, rather than selecting only one Sr/Ca record that appears to fit best. This would yield much larger uncertainties for mean Sr/Ca-SST reconstructions, than the  $\pm 0.3^\circ\text{C}$  reported by DeLong *et al.* [2010], but we believe this error would be much more realistic. Numerous studies have demonstrated the large uncertainties of mean SST estimates derived from individual fossil coral specimens [see Abram *et al.*, 2009, and references therein].

[6] Due to the large spread of mean Sr/Ca for a given mean temperature, the Sr/Ca-SST regression still changes considerably when only a few data points are added or removed (Figure 1b). Arbitrarily reducing the number of coral Sr/Ca records to the same number of corals used by DeLong *et al.* [2010] ( $n = 13$ ) can either lead to an improved correlation, or to a reduction to almost non-significant levels (Figure 1b). We therefore conclude that the database of the mean Sr/Ca-SST regression presented by DeLong *et al.* [2010] is not sufficient to estimate past SSTs from fossil corals or their uncertainties. Nevertheless, this approach may become useful for determining mean SSTs and their uncertainties from fossil corals in the future, provided that a much larger database becomes available. This would require the use of external Sr/Ca standards in order to ensure consistency between labs. An international certified reference material “JCP-1 coral powder *Porites sp.*” is provided by the Geological survey of Japan [Inoue *et al.*, 2004].

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