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Supporting Information for

Coral oxygen isotopic records capture the 2015/2016 El Niño event in the central equatorial Pacific

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Materials and Methods

S1. Coral Sampling and Analytical Analyses

Six coral cores were recovered from living *Porites* coral colonies using an underwater pneumatic drill at a site on the leeward side of Kiritimati Island (see “Drill Site”, Figure S1). They were all collected from corals living 25-30 ft depth. Two of the cores were collected in April 2016 (named “X16A-Dx”), while the other four cores were retrieved in November 2016 (named “X16C-Dx”). They were slabbed along the growth axis then cleaned with distilled water, ultrasonicated, and dried at 60°C. The cores were X-radiographed for densitometry to determine the optimal location of the sampling transect (Figure S6). Along each respective growth axis, the cores were drilled at 1-mm intervals and sampled for oxygen isotopic analysis (δ18O) using either a Thermo-Finnigan Delta V or MAT253 isotope ratio mass spectrometer, both equipped with a Kiel IV Carbonate Device. The instruments have mean precisions of 0.05‰ and 0.06‰, respectively, based on long-term analysis of internal and external standards. Coral δ18O are reported in units of per mil (‰) departures from the ratio of the Pee Dee Belemnite (PDB) carbonate. Age models for each record were reconstructed by peak matching the coral δ18Odata with 1° x 1° monthly NOAA OISSTv2 SST data (Reynolds et al., 2002) from the grid box containing Kiritimati Island, following procedures outlined in Cobb (2002). The error associated with this dating method is ±1 month, given the very close correspondence between SST and coral δ18O (Cobb et al., 2002, Comboul et al., 2014). Additional details of the corals presented here can be found in Table S1.

S2. Logger and Seawater Bottle Data Collection and Analysis

The *in situ* loggers and seawater bottle samples came from multiple sites around Kiritimati Island (see Table S3 for logger locations). The loggers were located 10-15 feet below the surface of the water. We present data from a SBE56 Seabird temperature logger from “Site 5”, an open-ocean site located on the southern shoreline, which captured hourly temperature data from July 2011 to November 2015. We recovered a Seabird SBE37 conductivity-temperature-depth (CTD) sensor from “CTD Site”, also on the Southern shoreline of the island. The CTD provides us with salinity and temperature data every 3 minutes from October 2014 to November 2015.

Seawater bottle samples were collected in 60 mL amberglass bottles from sites around the island that capture open-ocean conditions. Seawater δ18O values from the 2015/16 El Niño event were measured on a Picarro L1102-I water isotope analyzer at the Georgia Institute of Technology with instrumental precision of ±0.05‰ (1σ). Seawater bottle conductivity values were measured with a Mettler Toledo conductivity meter with a precision of ±0.2 psu. See Conroy et al., 2014 for more details on salinity and seawater δ18O analysis using these methods. Seawater δ18O values from the 1997/98 El Niño event were measured on a FISONS PRISM III mass spectrometer equipped with a MicroMass Multiprep automatic sample processing system with a precision of ±0.03‰ (1σ), using standard methods (Epstein and Mayeda, 1953; Fairbanks, 1982). All seawater d18O values in this study are reported in units of per mil (‰) departures from Vienna Standard Mean Ocean Water (VSMOW; Coplen, 1994). Salinity values from the 1997 event were measured shipboard on the RV Moana Wave, in triplicate, by conductivity with a Guildline Portasal with a precision of ±0.003 psu.

S3. Offset Calculations

Following Sayani et al. (2019), we calculated offsets in mean δ18O among colonies by calculating the mean of all records across their common period of overlap and then subtracting the mean of each record from this ensemble mean. We then subtract this offset from each record to align it to the ensemble mean. The offsets are listed in tables S1 and S2 and have a maximum absolute value of 0.19. The offset values are consistent with those of Hitt et al., 2021. The offset values in all coral records analyzed here and in Hitt et al., 2021 produce a net offset value of 0 and a standard deviation of 0.11.

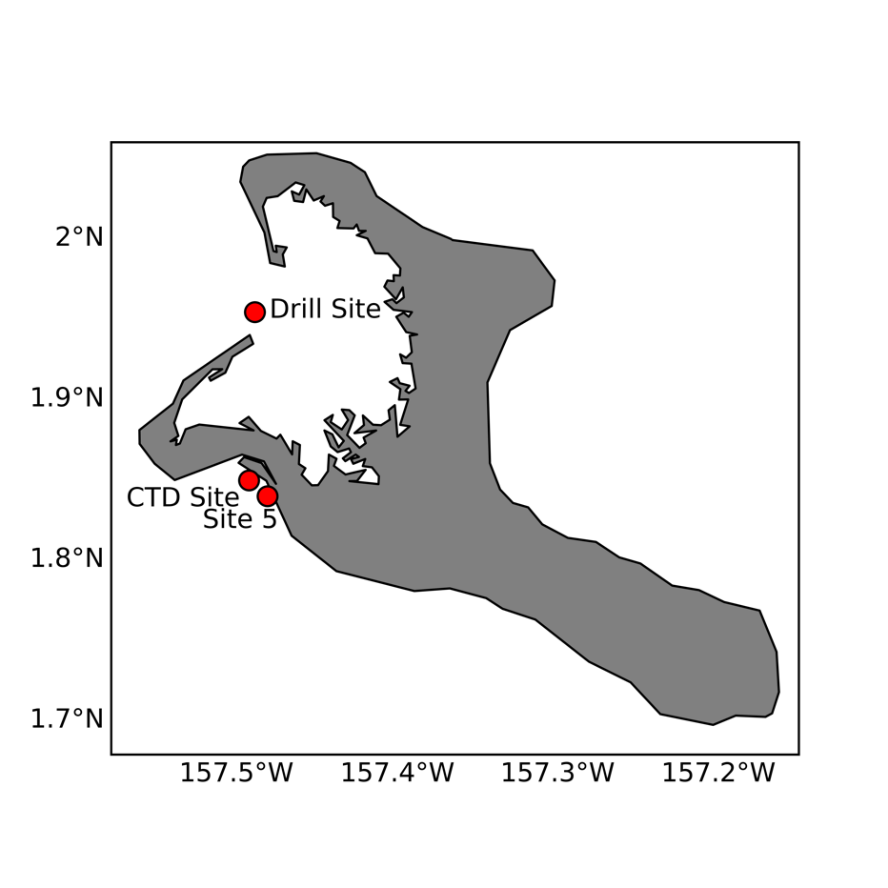
S4. Error and correlation calculations

We use standard error (SE) as the metric to account for uncertainty in our calculations, as the focus of this study is on quantifying means and mean differences during El Niño events from coral oxygen isotopes and *in situ* data. For uncertainty calculations of means (i.e., mean during the base or mean during the peak), we use , where neff is the number of independent values, accounting for autocorrelation. For changes in coral δ18O, SST, δ18Osw, and salinity from the baseline to the peak of an El Niño event, we perform this calculation as: where σbase (σpeak) is the standard deviation of the baseline (peak) values and nbase (npeak) is the number of the effective baseline (peak) values, after accounting for autocorrelation. Correlations are calculated using the Pearson correlation. Correlations are considered significant with 95% confidence if the 95% confidence interval, calculated using the number of independent values after accounting for autocorrelation, does not overlap with zero.

S5. Seawater δ18O Contribution Calculations

Because change in coral δ18O is the sum of change in seawater δ18O and change in SST, and these two signals strongly covary in the central equatorial Pacific (Cobb et al., 2001, Cobb et al, 2002, Nurhati et al, 2011, Sayani et al., 2019), we calculate the seawater δ18O contribution by subtracting an estimated SST-driven change in coral δ18O from the total observed change in coral δ18O (Ren et al., 2002, Cahyarini et al., 2008). We calculate the estimated SST-driven change in coral δ18O using the empirical relationship of -0.2‰ °C-1 (Epstein et al., 1951). This slope has proven to be more reliable than performing linear regression analysis on individual corals in this region, as large month-to-month variability makes such analyses sensitive to the start and end dates of the short coral records (Sayani et al., 2019).

We perform the contribution calculations three times, to reflect differences in SST captured by the three gridded datasets ERSSTv5, OISSTv2, and HadISST. The change in all components is calculated as the mean during the peak minus the mean during the baseline. The peak of the event is determined as the three months centered around the month of greatest SST, and the 2-year baseline ends 9 months prior to the start of the peak. We use a baseline of 2 years, finding little difference in results between 1 and 2 years (Table S7). We use the 1SE uncertainties in SST to capture the full range of uncertainty in the calculation of these contributions, as the 1SE for coral δ18O is small in comparison. The calculations laid out in Table 1 in the main text and tables S4 - S7 are as follows: the estimated SST-driven change in coral δ18O is calculated as the product of the change in SST (calculated from each of the gridded products) and the coral δ18O-SST slope of -0.2‰ °C-1 (Epstein et al., 1951). The mean SST contribution to the coral δ18O signal is calculated as the fraction of SST-driven change in coral δ18O over the total observed change in coral δ18O. The seawater δ18O contribution is calculated as the remaining percentage not accounted for by SST, or 100 x (1 – SST contribution). The results from these calculations using ERSSTv5 are presented in the main text, given its close correspondence to *in situ* logger data during the 2015/16 El Niño. Our main conclusions are based on analysis from all three data products, which show similar results.



**Figure S1.** Map of site locations for coral drill site and logger sites around Kiritimati Island. Coordinates for each site are listed in Table S3.

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**Figure S3**. Ensemble mean and 95% confidence intervals from a student t-test of the changes in coral δ18O from the 1982/82, 1997/98, and 2015/16 El Niño events (blue) and the changes in SST calculated with ERSSTv5.

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**Figure S4.** Comparison of gridded SST products during the 1982/83, 1997/98, and 2015/16 El Niño events. For the 2015/16 El Niño event, *in situ* data products are also shown.

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**Figure S5.** Stacked bar plots of budget constraints on the observed change in coral δ18O during the 2015/16 event (following values shown on Table S4). Observed mean change in coral δ18O is shown in the purple bar, with the 1SE uncertainty shown by the black vertical line. The observed mean change in seawater δ18O is shown in the blue bars, and its 1SE uncertainty is shown by the black vertical line. The SST-derived estimate of the change in coral δ18O is shown by the red bars. The left red bar reflects the lower 1SE SST bound calculated from ERSSTv5, and the right red bar reflects the upper 1SE SST bound. The corresponding percentages of the relative contributions of seawater δ18O and SST to the observed change in coral δ18O are also shown.A picture containing text, blur

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**Figure S6**. X-ray images of coral slabs. Red lines approximately denote the transect line used for sampling. We note that the x-ray shown for coral X16C-D10 was taken after completion of sampling for this study; the darker tracks that appear are due to sampling for another study.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Coral** | **Date collected** | **Core length (mm)** | **Years covered** | **Offset (**‰) |
| X16A-D1 | April 2016 | 70 | 2012-2015 | +0.076 |
| X16A-D2 | April 2016 | 61 | 2012-2016 | -0.027 |
| X16C-D3 | November 2016 | 72 | 2012-2016 | +0.036 |
| X16C-D4 | November 2016 | 67 | 2012-2016 | +0.015 |
| X16C-D5 | November 2016 | 69 | 2011-2016 | -0.178 |
| X16C-D10 | November 2016 | 168 | 2006-2016 | +0.089 |

**Table S1.** Overview of *Porites* corals presented in this study.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Coral** | **Coral Type** | **Year collected** | **Offset (**‰) | **Source** |
| X14-1 | Modern | 2014 | +0.088 | Grothe et al., 2020 |
| X14-7 | Modern | 2014 | -0.260 | Grothe et al., 2020 |
| X14-9 | Modern | 2014 | +0.033 | Grothe et al., 2020 |
| X14-14 | Modern | 2014 | +0.194 | Grothe et al., 2020 |
| X12-3 | Modern | 2012 | -0.099 | Grothe et al., 2020 |
| X12-6 | Modern | 2012 | +0.019 | Grothe et al., 2020 |
| X12-FS 9-10 | Fossil | 2012 | +0.061 | Hitt et al., 2021 |
| X12-FS15-7 | Fossil | 2012 | +0.006 | Hitt et al., 2021 |
| X12-FS 9-5 | Fossil | 2012 | -0.011 | Hitt et al., 2021 |
| Nurhati-09 | Modern | 1998 | +0.025 | Nurhati et al., 2009 |
| Evans-99 | Modern | 1993 | -0.137 | Evans et al., 1999 |
| X12-D6-1 | Fossil | 2012 | +0.047 | Hitt et al., 2021 |

**Table S2.** Overview of additional *Porites* corals from Kiritimati Island used in this analysis.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Logger name** | **Logger type** | **Site name** | **Site location** | **Source** |
| CTD | Seabird SBE37 CTD sensor | CTD Site | N1° 50.984’ W157° 29.523’ | This study |
| Site 5 Logger | Seabird SBE56 Logger | Site 5 | N1° 50.400' W157° 28.860' | This study |
| CTD Site Logger | Seabird SBE56 Logger | CTD Site | N1° 50.984’ W157° 29.523' | Claar et al., 2019 |
| Drill Site Logger | Seabird SBE56 Logger | Drill Site | N1° 57.263' W157° 29.301' | Claar et al., 2019 |

**Table S3.** Overview of *in situ* logger data used in this study.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | A | B | C | D | E | F |
|  | **Δ SST bound** | **Observed**  **Δ coral δ18O** | **Estimated SST-driven Δ coral δ 18O** | **Estimated**  **Δ δ 18Osw**  **(B-C)** | **% δ18Osw contri-bution (D/B)\*100** | **Observed Δ δ 18Osw** |
| **2015/16 Event** | Upper 1SE (2.8°C) | -0.58 ± 0.05‰ | -0.55‰ | -0.03‰ ± 0.05‰ | 5% | -0.19 ± 0.02‰ |
| Mean  (2.4°C) | -0.48‰ | -0.10‰ ± 0.05‰ | 18% |
|  | -0.43‰ | ***-0.17‰*** | ***29%*** |
| Lower 1SE (2.0°C) | -0.40‰ | **-0.18‰ ± 0.05‰** | **31%** |
|  | -0.35‰ | ***-0.21‰*** | ***36%*** |
| **1997/98 Event** | Upper 1SE (2.9°C) | -0.56 ± 0.06‰ | -0.58‰ | 0.02‰ ± 0.06‰ | 0% | N/A |
| Mean  (2.1°C) | -0.42‰ | -0.14‰ ± 0.06‰ | 26% |
| Lower 1SE (1.3°C) | -0.26‰ | -0.30‰ ± 0.06‰ | 54% |
| **1982/83 Event** | Upper 1SE (2.1°C) | -0.52 ± 0.05‰ | -0.42‰ | -0.11‰ ± 0.05‰ | 20% | N/A |
| Mean  (1.7°C) | -0.35‰ | -0.18‰ ± 0.05‰ | 34% |
| Lower 1SE (1.4°C) | -0.28‰ | -0.25‰ ± 0.05‰ | 47% |

**Table S4.** Calculations of SST and δ18Osw contributions to the 2015/16, 1997/98, and 1982/83 El Niño events, accounting for 1SE uncertainty in changes in ERSSTv5 (note that we propagate the 1SE uncertainty in observed coral δ18O to column D, which is small relative to the uncertainty in SST). The 1SE bounds of the observed changes in δ18Osw are shown in bold italics. The estimated value in column D is bolded to show that it fits within the observed 1SE bounds.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | A | B | C | D | E | F |
|  | **Δ SST bound** | **Observed**  **Δ coral δ18O** | **Estimated SST-driven Δ coral δ 18O** | **Estimated**  **Δ δ 18Osw**  **(B-C)** | **% δ18Osw contri-bution (D/B)\*100** | **Observed Δ δ 18Osw** |
| **2015/16 Event** | Upper (1SE) (3.3°C) | -0.58 ± 0.05‰ | -0.66‰ | 0.08‰ ± 0.05‰ | 0% | -0.19 ± 0.02‰ |
| Mean  (2.8°C) | -0.56‰ | -0.03‰ ± 0.05‰ | 4% |
| Lower (1SE) (2.3°C) | -0.45‰ | **-0.13‰ ± 0.05‰** | **23%** |
|  | -0.43‰ | **-0.17‰** | **29%** |
|  | -0.35‰ | **-0.21‰** | **36%** |
| **1997/98 Event** | Upper (1SE) (3.5°C) | -0.56 ± 0.06‰ | -0.69‰ | 0.13‰ ± 0.06‰ | 0% | N/A |
| Mean  (2.5°C) | -0.50‰ | -0.06‰ ± 0.06‰ | 10% |
| Lower (1SE)  (1.5°C) | -0.31‰ | -0.25‰ ± 0.06‰ | 44% |

**Table S5.** Same as table S4, but with SST calculations from OISSTv2 for the 2015/16 and 1997/98 events (OISSTv2 not available for baseline calculation for 1982/83 event).

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | A | B | C | D | E | F |
|  | **Δ SST bound** | **Observed**  **Δ coral δ18O** | **Estimated SST-driven Δ coral δ 18O** | **Estimated**  **Δ δ 18Osw**  **(B-C)** | **% δ18Osw contri-bution (D/B)\*100** | **Observed Δ δ 18Osw** |
| **2015/16 Event** | Upper (1SE) (2.7°C) | -0.58 ± 0.05‰ | -0.55‰ | -0.03‰ ± 0.05‰ | 6% | -0.19 ± 0.02‰ |
| Mean  (2.4°C) | -0.49‰ | -0.09‰ ± 0.05‰ | 16% |
| Lower (1SE)  (2.1°C) | -0.43‰ | ***-0.15‰ ± 0.05‰*** | ***26%*** |
|  | -0.35‰ | ***-0.17‰*** | ***29%*** |
|  | -0.35‰ | ***-0.21‰*** | ***36%*** |
| **1997/98 Event** | Upper (1SE) (3.1°C) | -0.56 ± 0.06‰ | -0.63‰ | 0.07‰ | 0% | N/A |
| Mean  (2.4°C) | -0.49‰ | -0.08‰ | 14% |
| Lower (1SE) (1.7°C) | -0.34‰ | -0.23‰ | 40% |
| **1982/83 Event** | Upper (1SE) (2.4°C) | -0.52 ± 0.05‰ | -0.49‰ | -0.04‰ | 7% | N/A |
| Mean  (2.0°C) | -0.40‰ | -0.12‰ | 24% |
| Lower (1SE) (1.6°C) | -0.31‰ | -0.21‰ | 40% |

**Table S6.** Same as table S4, but with SST calculations from HadISST.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | A | B | C | D | E | F |
|  | **Δ SST bound** | **Observed**  **Δ coral δ18O** | **Estimated SST-driven Δ coral δ 18O** | **Estimated**  **Δ δ 18Osw** | **% δ18Osw contri-bution** | **Observed Δ δ 18Osw** |
| **ERSST**  **v5** | Upper (1SE)  (2.5°C) | -0.51 ± 0.05‰ | -0.51‰ | 0.00 ± 0.05‰ | 0% | -0.19 ± 0.02‰ |
| Mean  (2.1°C) | -0.42‰ | -0.08 ± 0.05‰ | 16% |
| Lower (1SE) (1.7°C) | -0.34‰ | **-0.17 ± 0.05‰** | **33%** |
|  | -0.28‰ | ***-0.21‰*** | ***41%*** |
| **OISSTv2** | Upper (1SE)  (2.9°C) | -0.51 ± 0.05‰ | -0.59‰ | 0.09 ± 0.05‰ | 0% | -0.19 ± 0.02‰ |
| Mean  (2.4°C) | -0.49‰ | -0.02 ± 0.05‰ | 3% |
| Lower (1SE)  (1.9°C) | -0.38‰ | **-0.12 ± 0.05‰** | **25%** |
|  |  | ***-0.17‰*** | ***33%*** |
|  |  | ***-0.21‰*** | ***41%*** |

**Table S7.** Comparison of calculations for the relative contributions of SST and δ 18Osw during the 2015/16 El Niño event with a 1-year baseline, following the same formatting as in Table S4.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | OISSTv2 | HadISST | ERSSTv5 | Logger change in SST |
| Correlations | | | | |
| Drill Site Logger  (26 months) | 0.93 | 0.90 | 0.94 | - |
| CTD Site Logger  (12 months) | 0.97 | 0.93 | 0.97 | - |
| CTD  (11 months) | 0.99 | 0.99 | 0.98 | - |
| Site 5 Logger  (46 months) | 0.96 | 0.93 | 0.93 | - |
| 2015/16 coral 18O records (min and max correlations with 6 records) | [-0.84, -0.91] | [-0.83, -0.90] | [-0.81, -0.90] | - |
| 2015/16 coral 18O ensemble mean | -0.92 | -0.93 | -0.93 | - |
| 2015/16 Event | | | | |
| Change in SST (1SE) | 2.8 ± 0.5 °C | 2.4 ± 0.3 °C | 2.4 ± 0.4 °C | 2.4 ± 0.4 °C  (Site 5 logger) |
| Estimated 18Osw contribution (1SE) | 4 ± 19 % | 16 ± 10 % | 18 ± 13 % | N/A |
| 1997/98 Event | | | | |
| Change in SST (1SE) | 2.5 ± 1.0 °C | 2.4 ± 0.7 °C | 2.1 ± 0.8 °C | N/A |
| Estimated 18Osw contribution (1SE) | 10 ± 34 % | 14 ± 26 % | 26 ± 28% | N/A |
| 1982/83 Event | | | | |
| Change in SST (1SE) | N/A | 2.0 ± 0.4 | 1.7 ± 0.3 | N/A |
| Estimated 18Osw contribution (1SE) | N/A | 24 ± 17 % | 34 ± 13 % | N/A |

**Table S8.** Correlations of monthly SST products and changes in SST and seawater 18O (18Osw) during the three events for three gridded SST products (changes are calculated using a 2-year baseline). All correlations are significant with 95% confidence.

**Supplemental References**

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