Coral oxygen isotope and in situ records capture the 2015/2016 El Niño event in the central equatorial Pacific

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Abstract

Coral oxygen isotopes (δ18O) from the central equatorial Pacific provide monthly-resolved records of El Niño-Southern Oscillation (ENSO) activity over past centuries to millennia. However, calibration studies using in situ data to assess the relative contributions of warming and freshening to coral δ18O records are exceedingly rare. Furthermore, the fidelity of coral δ18O records under the most severe thermal stress events is difficult to assess. Here, we present six coral δ18O records and in situ temperature, salinity, and seawater δ18O data from Kiritimati Island (2°N, 15°W) spanning the very strong 2015/16 El Niño event. Local sea surface temperature (SST) anomalies of +2.4±0.4°C and seawater δ18O anomalies of -0.19±0.02of -0.58±0.05from SST and ~30% from seawater δ18O. Our results demonstrate that Kiritimati coral δ18O records can provide reliable reconstructions even during the largest class of El Niño events.

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Coral oxygen isotope and *in situ* records capture the 2015/2016 El Niño event in the central equatorial Pacific

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3 Key Points

- An ensemble of coral oxygen isotope timeseries from the central equatorial Pacific tracks the 2015/16 El Niño event.
- Coral oxygen isotope records reflect ~70% contribution from warming and ~30% from freshening during the 2015/16 El Niño event.
- *In situ* seawater oxygen isotope data provide quantitative constraints on temperature versus hydrological contributions to coral records.

Abstract

Coral oxygen isotopes ($\delta^{18}O$) from the central equatorial Pacific provide monthly-resolved records of El Niño-Southern Oscillation (ENSO) activity over past centuries to millennia. However, calibration studies using *in situ* data to assess the relative contributions of warming and freshening to coral $\delta^{18}O$ records are exceedingly rare. Furthermore, the fidelity of coral $\delta^{18}O$ records under the most severe thermal stress events is difficult to assess. Here, we present six coral $\delta^{18}O$ records and *in situ* temperature, salinity, and seawater $\delta^{18}O$ data from Kiritimati Island (2°N, 157°W) spanning the very strong 2015/16 El Niño event. Local sea surface temperature (SST) anomalies of +2.4±0.4°C and seawater $\delta^{18}O$ anomalies of -0.19±0.02‰ contribute to the observed coral $\delta^{18}O$ anomalies of -0.58±0.05‰, consistent with a ~70% contribution from SST and ~30% from seawater $\delta^{18}O$. Our results demonstrate that Kiritimati coral $\delta^{18}O$ records can provide reliable reconstructions even during the largest class of El Niño events.

Plain Language Summary

Oxygen isotope anomalies in coral skeletons provide reconstructions of year-to-year ocean temperature variations in the tropical Pacific, which in turn have a profound influence on global temperature and rainfall extremes. However, only a handful of calibrations exist that quantify the relationship between ocean temperature and coral isotopic composition at a given site, especially across extreme events where this relationship may vary most strongly. Here we compare ocean temperature data from loggers installed on the reef at Kiritimati Island (2°N, 157°W) to coral oxygen isotopic records spanning the record-breaking 2015/16 El Niño event. We find that the corals provide accurate reconstructions of ocean temperature extremes during this very strong El Niño event, with ~70% of the signal originating from ocean temperature and the remainder from increased rainfall.

1 Introduction

The El Niño/Southern Oscillation (ENSO) is the dominant mode of interannual climate variability, but its response to greenhouse warming remains highly uncertain (Stevenson, 2012, Bellenger et al., 2014, Ng et al., 2021). Although projections of ENSO-related SST variability differ across climate models, simulations forced with projected anthropogenic greenhouse gas emissions generally agree on an increase in the hydrological extremes associated with ENSO (Power et al., 2013; Cai et al., 2014, Bonfils et al., 2015, Brown et al., 2020). This tendency translates to an increase in the occurrence of ‘extreme’ El Niño events (as defined based on equatorial Pacific precipitation) under continued greenhouse warming (Cai et al., 2015), although models reflect a range of responses (Stevenson et al. 2021). Another question is whether greenhouse gas-driven changes to ENSO have already taken place: observational studies of 20th century ENSO extremes suggest a shift towards more Central Pacific warming events (Wang et al., 2019), consistent with results from analysis of a large network of coral records spanning the last several centuries (Freund et al., 2019). A number of paleoclimate ENSO reconstructions document enhanced late 20th-century ENSO variability relative to the preindustrial era (McGregor et al., 2013; Li et al., 2013; Cobb et al., 2013; Liu et al., 2017; Grothe et al., 2020), supporting the idea that greenhouse warming has already led to a significant shift in ENSO properties. However, it remains unclear how much of the observed shift in ENSO variance is due to a strengthening of SST anomalies or hydrological extremes during ENSO events. This is especially true for the largest trove of monthly-resolved ENSO reconstructions based on modern and fossil corals from the central tropical Pacific, which documents a 25% increase in interannual variability from the last millennia to the most recent decades (Grothe et al., 2020).

Oxygen isotope ratios ($\delta^{18}O$) in corals from the central tropical Pacific track ENSO-related changes in SST and hydrology, with warmer and wetter conditions during El Niño events driving negative coral $\delta^{18}O$ anomalies, while cool and dry conditions during La Niña events drive positive coral $\delta^{18}O$ anomalies (Evans et al., 1999; Cobb et al., 2001; Nurhati et al., 2009). Cores collected from living and fossil coral colonies have provided high-fidelity records of past ENSO activity over recent decades (Cobb et al., 2001; Nurhati et al., 2009, 2011), centuries (Cobb et al., 2003), and millennia (Cobb et al., 2013; McGregor et al., 2013; Grothe et al., 2020). The largest such dataset comes from Kiritimati Island (2°N, 157°W), where ENSO dominates coral $\delta^{18}O$ variability as evidenced by correlation coefficients of ~0.80 between modern coral $\delta^{18}O$ records and the NIÑO3.4 index (Grothe et al., 2020) - a key index of large-scale ENSO variability.

Despite their high-fidelity representation of instrumental SST variability over the satellite era, coral $\delta^{18}O$-based ENSO reconstructions are associated with a number of uncertainties. For one, extremely high SSTs during strong El Niño events can induce thermal stress, which slows or halts coral calcification, limiting the ability of coral proxies to capture the full extent of temperature SST change during such events (e.g., Carilli et al., 2017). Indeed, previous coral studies from the Eastern Pacific and Western Atlantic have found skeletal growth hiatuses during very strong El Niño events (Dunbar et al., 1994), as well as systematic geochemical biases initiated by extreme El Niño events (Hetzinger et al., 2016). Due to limited coral ensemble sizes and *in situ* climate data, it remains unknown how well corals from the central tropical Pacific record ENSO activity during extreme events. Second, coral $\delta^{18}O$ values reflect the combined influence of SST and seawater $\delta^{18}O$ ($\delta^{18}O_{sw}$), but the relative contribution of SST vs. seawater $\delta^{18}O$ to Kiritimati coral $\delta^{18}O$ records during ENSO extremes is difficult to assess without *in situ* data. Previous work using paired Sr/Ca and coral $\delta^{18}O$ measurements showed a stronger than normal $\delta^{18}O_{sw}$ contribution in Kiritimati coral $\delta^{18}O$ during the very strong 1997/98 El Niño event (McGregor et al., 2013), but coverage among multiple strong events paired with *in situ* data is needed to better understand these contributions. In particular, there are no systematic surveys of seawater $\delta^{18}O$ variations across El Niño events, even though such variability has been inferred from both models and observational data (Fairbanks et al., 1997, Russon et al., 2013, Conroy et al., 2014).

In this study, we present six new coral $\delta^{18}O$ records as well as *in situ* records of SST, salinity, and $\delta^{18}O_{sw}$ from Kiritimati Island spanning the 2015/16 El Niño event, one of the strongest El Niño events on record. These data allow us to quantify the oceanographic changes that occurred across this event, and their contribution to the observed coral $\delta^{18}O$ anomalies. By comparing our results from the 2015/16 El Niño event to available coral $\delta^{18}O$ records and *in situ* SST, salinity, and $\delta^{18}O_{sw}$ data from Kiritimati across past strong El Niño events of the 20th

century, we assess the stability of the relationship between SST, $\delta^{18}O_{sw}$, and coral $\delta^{18}O$ across different El Niño events. This assessment is key to improving interpretation of coral $\delta^{18}O$ records from the region.

2 Methods

Six modern coral cores from *Porites* spp. were recovered from a leeward open ocean reef flat ranging from 20-30 ft depth (labelled “drill site” on Figure S1) at Kiritimati Island during expeditions in April and November 2016. The cores were prepared and analyzed for coral $\delta^{18}O$ composition using standard procedures (Sayani et al., 2019, see Supplement for X-rays) on either a Thermo-Finnigan Delta V or MAT253, both equipped with a Kiel IV Carbonate Device, with analytical precisions of ±0.05‰ (1σ) and ±0.06‰ (1σ), respectively. Age models for each record were reconstructed by peak matching the coral $\delta^{18}O$ data 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). Each record covers the 2015/16 El Niño event and extends back 3-9 years prior to the event, depending on core length. Following Sayani et al. (2019), we apply offsets of up to 0.19‰ to each record to align them to a common ensemble mean (see Supplement).

We also present *in situ* SST, salinity, and $\delta^{18}O_{sw}$ data spanning the 2015/16 El Niño event from Kiritimati Island. We present continuous time series of SST from a Seabird SBE56 temperature logger (Site 5 logger), and SST and salinity from a Seabird SBE37 conductivity-temperature-depth (CTD) sensor (see Figure S1 for locations). We present 97 paired salinity and $\delta^{18}O_{sw}$ data from seawater samples collected during field expeditions to Kiritimati Island from 2014 to 2016, and ~30 paired salinity and $\delta^{18}O_{sw}$ samples collected on the RV Moana Wave from October to November, 1997. We include two *in situ* SST logger datasets from Kiritimati Island presented by Claar et al., 2019 in our analyses: the first from the drill site, where corals in this study were collected, and the second from a southward-facing reef flat several kilometers away (Figure S1). We also use data from three gridded SST products, using the grid point closest to Kiritimati Island: 1°x1° weekly OISSTv2, 1°x1° monthly HadISSTv1.1 (Rayner et al., 2003), and 2°x2° monthly ERSSTv5 (Huang et al., 2017).

3 Results

3.1 Coral $\delta^{18}O$ records

All six coral $\delta^{18}O$ records closely follow instrumental SST and are highly reproducible on monthly to annual timescales (Figure 1). Most of the variability in coral $\delta^{18}O$ is driven by ENSO, as seasonal SST variability at this site is relatively small. The records are well correlated with ERSSTv5, HadISST, and OISSTv2 (R between -0.81 and -0.91, $p<0.05$, Table S8). A composite coral $\delta^{18}O$ record formed by averaging overlapping records has a greater correlation with these SST products than any individual record (R ~ -0.93; Figure 1b, Table S8). All coral $\delta^{18}O$ records demonstrate consistent monthly variability across the study period, with correlations among records ranging between 0.64 and 0.90 ($p<0.05$). The 1σ spread in coral $\delta^{18}O$ values during any given month of overlapping coral $\delta^{18}O$ records ranges from 0.04‰ to 0.24‰, with the maximum variance occurring in November 2015, during the peak of the 2015/16 El Nino event.

During the 3-month peak of the event (October 2015 to December 2015), all six coral records exhibit significant coral $\delta^{18}O$ depletion (mean of -5.59 ± 0.05‰ (1SE)) coinciding with warmer and fresher conditions. For the two-year baseline preceding the El Niño event (from January 2013 to January 2015, ending 9 months prior to the 3-month peak), the coral $\delta^{18}O$ records exhibit a mean isotopic value of -5.01 ± 0.02‰ (1 standard error (1SE)), reflecting a change in coral δ^{18}O of -0.58 ± 0.05‰ (1SE).

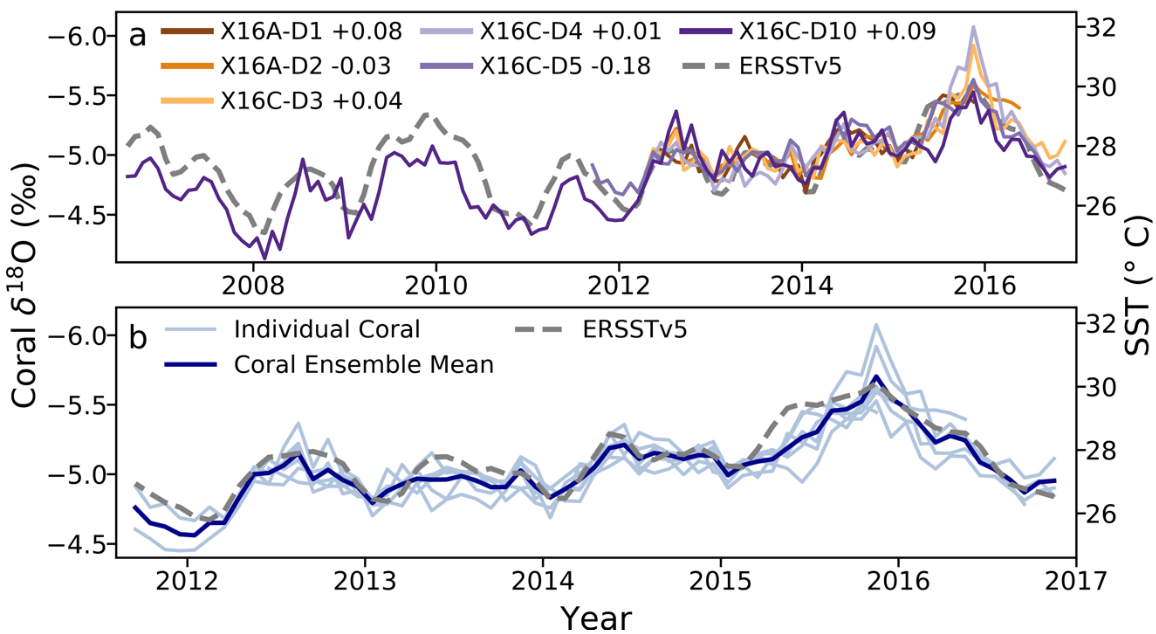

Figure 1. Coral δ^{18}O records (colored lines) from Kiritimati Island plotted with monthly resolved ERSSTv5 (gray dashed line) at Kiritimati Island (note inverted y-axis for coral δ^{18}O). (a) New modern coral δ^{18}O records spanning the 2015/16 El Niño event as presented in this study. (b) Same as in (a), but with the ensemble mean of the corals shown. Coral δ^{18}O offsets have been applied (Supplement) and are denoted in the legend in panel (a) in units of per mil.

3.2 *In situ* SST, salinity, and seawater δ^{18}O measurements

We compare *in situ* SST, salinity, and $\delta^{18}O_{sw}$ from Kiritimati Island to constrain the individual contributions of SST and $\delta^{18}O_{sw}$ to coral δ^{18}O during 2015/16 El Niño event. The four *in situ* SST datasets all capture the 2015/16 El Niño event with varying coverage (Figure

2a). Monthly averaged *in situ* SST timeseries exhibit strong correlations with all three gridded SST data products (R values of 0.90 to 0.99, Table S8). We calculate change in SST across the 2015/16 El Niño by subtracting the 2-year-averaged baseline SST (2013-2015) from the 3-month peak of the event. Using just the Site 5 logger (which has the longest coverage across this event), we calculate an increase in SST of 2.4 ± 0.4°C (1SE) at Kiritimati Island. In comparison, ERSSTv5 and HadISST show similar warming of 2.4 ± 0.4°C (1SE) and 2.4 ± 0.3°C (1SE), respectively, and OISSTv2 shows a slightly larger change of 2.8 ± 0.5°C (1SE).

To constrain the hydrological contribution to the interannual variability in the coral records, we analyze *in situ* CTD salinity and salinity/ $\delta^{18}O_{sw}$ from seawater bottle samples (Figures 2b and 2c). Due to the shorter duration of these timeseries, we use a 1-year baseline from mid-2014 to mid-2015 to calculate the change in salinity during the event. The CTD tracks a decrease in salinity of 0.91 ± 0.05 psu (1SE), reaching a value of 34.14 psu during the peak of the El Niño event. Salinity data from 148 seawater bottle samples show a mean decrease of 0.96 ± 0.08 psu (1SE), reaching a mean value of 34.41 psu during the peak of the event. Although the absolute salinity of the two data sources is offset by approximately 0.3 psu (which may be attributed to differences in instrumental calibration), they capture the same relative change across the study interval. Using the same time periods as the salinity calculation, the $\delta^{18}O_{sw}$ data capture a decrease of 0.19 ± 0.02‰ (1SE), reaching a mean of 0.19‰ during the peak of the event. We note that the use of a 1-year baseline here may underestimate the magnitude of the El Niño anomalies, as there is less warming (and likely less freshening) from this 2014/15 baseline (Figure 1). We account for this in conclusions based on this calculation.

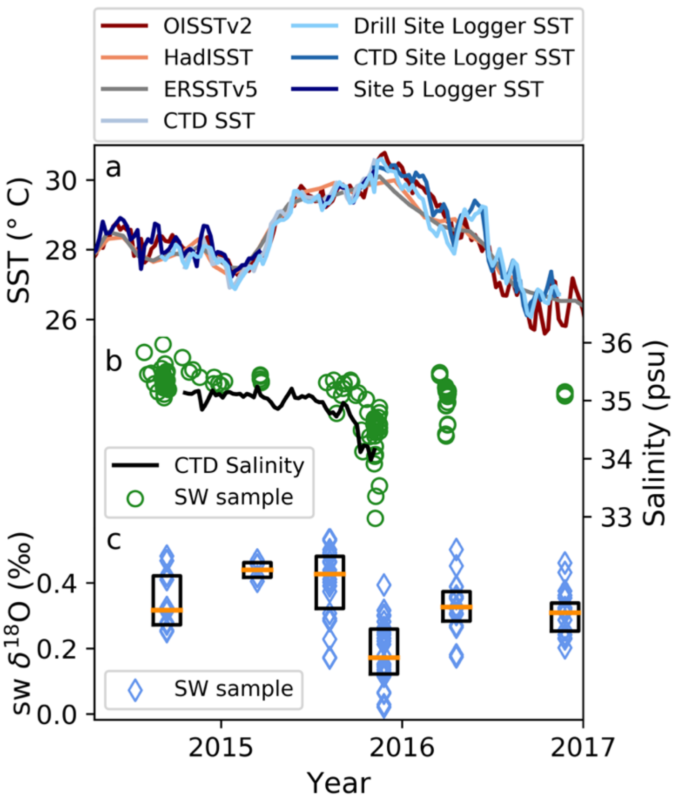

Figure 2. *In situ* SST, salinity, and $\delta^{18}O_{sw}$ data spanning the 2015/16 El Niño event at Kiritimati Island. (a) Weekly SST records from 4 *in situ* temperature loggers (see Figure S1 for locations). Also plotted are weekly OISSTv2, monthly HadISSTv1.1, and monthly ERSSTv5. (b) Salinity records from the CTD (red) and seawater bottle samples (green circles). (c) Seawater $\delta^{18}O$ measurements from seawater bottle samples (blue diamonds). Orange lines represent the median of the $\delta^{18}O_{sw}$ data, the boxes show the 25-75% interquartile range.

3.3 Comparison to past strong El Niño events

Coral $\delta^{18}O$ timeseries from Kiritimati Island show progressive depletion in mean coral $\delta^{18}O$ during the peaks of the 1982/83, 1997/98, and 2015/16 strong El Niño events. Mean coral $\delta^{18}O$ anomalies (3-month average centered around the peak of each event) were -5.23‰ during the peak of the 1982/83 El Niño event, decreased to -5.49‰ during the 1997/98 event, and then decreased to -5.59‰ during the 2015/16 event (Figure 3, Table 1). However, these El Niño are superimposed on background warming and freshening trends in the tropical Pacific (Nurhati et al., 2009), which produce more depleted coral $\delta^{18}O$ values over this time interval. When the magnitude of each event is isolated from the mean state of the Pacific (by taking the difference between the 3-month average during the peak and the 2-year baseline prior to the event; Figure 3), a student t-test ($p<0.05$) shows no statistically significant difference in coral $\delta^{18}O$ magnitude of these three events (Figure S3).

The amplitude of the 1997/98 event, both in terms of coral $\delta^{18}O$ and observed SST, is similar to that of the 2015/16 event. Five out of six corals that span the 1997/98 event show similar depletion in coral $\delta^{18}O$ during the peak of the 1997/98 event. The sixth coral (Nurhati-09) does not fully capture SST and SSS changes across this event (Figure 3), possibly due to thermal stress or sublethal bleaching (Nurthati et al., 2009). Excluding this record, the amplitude of the 1997/98 event is -0.56 ± 0.06‰ (1SE), which is indistinguishable from the -0.58 ± 0.05‰ (1SE) amplitude of the 2015/2016 event. Similarly, ERSSTv5 shows statistically indistinguishable SST anomalies during the 1997/98 El Niño and 2015/16 El Niño (+2.1 ± 0.8°C vs 2.4 ± 0.4 °C, respectively; Figure 3). Similar results are found when this calculation is performed with OISSTv2 and HadISST (Figure S4, Table S8).

As limited salinity and $\delta^{18}O_{sw}$ data is available from the 1997/98 event, we only compare bottle $\delta^{18}O_{sw}$ measurements from the peaks of the 1997/98 and 2015/16 events. Salinity during November 1997 reached a mean of 34.17 psu, slightly lower than that of the 2015/16 event mean in SW bottles (34.41 psu). Seawater $\delta^{18}O$ reached a minimum of 0.11‰ during October 1997, significantly less than the 0.19‰ observed during the peak of the 2015/16 event. Thus, available data show that the 1997/98 El Niño event was characterized by similar changes in coral $\delta^{18}O$ and SST but slightly lower minimum salinity and seawater $\delta^{18}O$ values compared to the 2015/16 event.

For the 1982/83 event, we use two of the three coral $\delta^{18}O$ records that span this interval to calculate anomalies associated with this strong El Niño, excluding the Nurhati et al., 2009 record as the authors note that it does not fully capture SST and SSS changes across the peak of the event. We calculate a coral $\delta^{18}O$ amplitude of -0.52 ± 0.05‰ (1SE) for the 1982/83 event, which is statistically indistinguishable from the 1997/98 and 2015/16 events (Figure S3). ERSSTv5 shows an increase of +1.7 ± 0.3°C (1SE) at Kiritimati across the 1982/83 El Niño, again statistically indistinguishable from SST during the 1997/98 and 2015/16 events (Figure S3) and consistent with previous work (Huang et al., 2016).

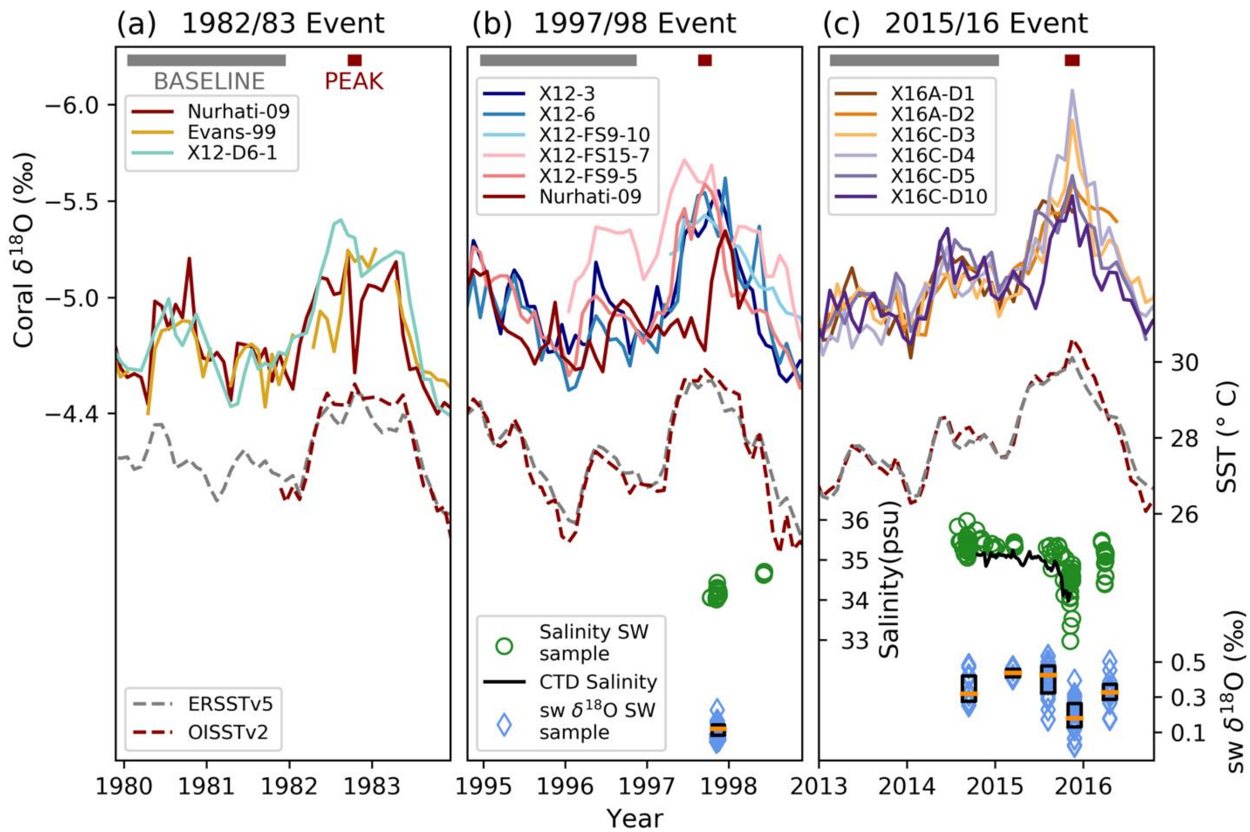

Figure 3. Coral $\delta^{18}O$ records (solid lines) and monthly SST (dashed lines) during the (a) 1982/83, (b) 1997/98, and (c) 2015/16 El Niño. Horizontal bars at the top of each panel show the 2-year baseline (gray) and 3-month peak (red) periods used to calculate SST and coral $\delta^{18}O$ anomalies for each El Niño event. Coral $\delta^{18}O$ records shown are the “X16” corals (this study), “X12-3” and “X12-6” (Grothe et al., 2020), “X12-FS” fossil corals and “X12-D6-1” fossil coral (Hitt et al., submitted), “Nurhati-09” (Nurhati et al., 2009), and “Evans-99” (Evans et al., 1999). Coral records are plotted with offsets applied, as shown in Tables S1 and S2. Gridded SST data are from ERSSTv5 and OISSTv2. Seawater $\delta^{18}O$ (open circles) and sea surface salinity (open diamonds) measurements are shown where available.

3.4 SST and hydrological contributions to coral $\delta^{18}O$

To quantify the relative contributions of SST and $\delta^{18}O_{sw}$ to coral $\delta^{18}O$ during the 2015/16 El Niño event, we calculated the expected temperature contribution to coral $\delta^{18}O$ using the empirical relationship of -0.2‰ $°C^{-1}$ (Epstein et al., 1951), and then subtract the temperature contribution from coral $\delta^{18}O$ to isolate $\delta^{18}O_{sw}$ changes (Supplement). The SST change of +2.4 ± 0.4°C (1SE) calculated from ERSSTv5 during the 2015/16 event corresponds to an expected coral $\delta^{18}O$ change of -0.48 ± 0.08‰ (1SE). As the observed coral $\delta^{18}O$ change during this event is -0.58 ± 0.05‰ (1SE), we estimate a $\delta^{18}O_{sw}$ contribution of -0.10 ± 0.08‰ (1SE), which implies that $\delta^{18}O_{sw}$ accounts for 18 ± 13% (1SE) of the observed coral $\delta^{18}O$ change during the 2015/16 event, with SST contributing to the remaining 82 ± 13% (1SE ; Table 1 and S4). We find similar results when repeating this calculation with OISSTv2 and HadISST (Tables S5-S8). We note that SST uncertainty dominates this calculation, and a full propagation of the 2SE uncertainties through SST, coral $\delta^{18}O$, and $\delta^{18}O_{sw}$ would likely double the range of permissible percentages.

The *in situ* $\delta^{18}O_{sw}$ measurements provide a powerful additional constraint on the coral $\delta^{18}O$ budget, given the weak constraints afforded by SST and coral $\delta^{18}O$ observations outlined above. Given the observed change in $\delta^{18}O_{sw}$ of -0.19 ± 0.02‰ (1SE) during the peak of the 2015/16 El Niño, the $\delta^{18}O_{sw}$ contribution is constrained to ~30-35% (including all values that fall within the 1 SE uncertainty range; Tables 1, S4, Figure S5). These values do not change if different SST products are used (Tables S5, S6), and are relatively insensitive to the choice of 1-year versus 2-year baselines for the calculations of anomalies (Table S7).

Using the same approach, we calculate the SST and $\delta^{18}O_{sw}$ contributions to coral $\delta^{18}O$ changes across the 1997/98 and 1982/83 El Niño events (Tables 1, S5), although the lack of observed $\delta^{18}O_{sw}$ data translates to large uncertainties in these estimates. For the 1997/98 event, we find a hydrological contribution of approximately 26 ± 28% (1SE), which is similar in mean but associated with larger uncertainty. For the 1982/83 event, we find a $\delta^{18}O_{sw}$ contribution of 34 ± 13% (1SE). In short, we find consistent relative contributions from SST and $\delta^{18}O_{sw}$ anomalies (roughly 70% and 30%, respectively) to coral $\delta^{18}O$ anomalies across the three strong El Niño events in question.

Table 1. Comparison of SST (from ERSSTv5) and estimated $\delta^{18}O_{sw}$ contributions to observed coral $\delta^{18}O$ anomalies associated with strong El Niño events at Kiritimati Island. Changes are calculated as the 3-month peak of the event minus a 2-year baseline, reported with 1SE uncertainties (Supplement, Table S4). For the 2015/16 event, observed changes in $\delta^{18}O_{sw}$ and associated contributions are also shown, with 1SE uncertainty, calculating using the available 1-year baseline.

		1982/83 Event	1997/98 Event	2015/16 Event
A	Observed peak mean coral $\delta^{18}O$	-5.23 ± 0.07 ‰	-5.49 ± 0.10 ‰	-5.59 ± 0.05 ‰
B	Observed Δ coral $\delta^{18}O$	-0.52 ± 0.05 ‰	-0.56 ± 0.06 ‰	-0.58 ± 0.05 ‰
C	Observed ΔSST (ERSSTv5)	+1.7 ± 0.3 °C	+2.1 ± 0.8 °C	+2.4 ± 0.4 °C
D	Estimated SST-driven Δ coral $\delta^{18}O$ (*C* x 0.2 ‰°C^{-1})	-0.35 ± 0.07 ‰	-0.42 ± 0.16 ‰	-0.48 ± 0.08 ‰
E	Estimated Δ sw $\delta^{18}O$ (*B* – *D*)	-0.18 ± 0.07 ‰	-0.14 ± 0.15 ‰	-0.10 ± 0.08 ‰
F	Observed Δ sw $\delta^{18}O$ (SW bottle samples)	N/A	N/A	-0.19 ± 0.02 ‰
G	Estimated sw $\delta^{18}O$ contribution (*E/B* x 100)	34 ± 13 %	26 ± 28 %	18 ± 13 %
H	Observed sw $\delta^{18}O$ contribution (*F/B* * 100)	N/A	N/A	33 ± 4 %

4 Discussion and Conclusions

Our analysis of Kiritimati coral records demonstrates that corals $\delta^{18}O$ at this site faithfully record SST and hydrological anomalies associated with the strongest El Niño events. Paired *in situ* temperature, seawater $\delta^{18}O$, and coral $\delta^{18}O$ confirm that all six cores collected in 2016 accurately capture the SST and $\delta^{18}O_{sw}$ changes observed during the 2015/2016 El Nino event, within uncertainties (Figure S5). We observe no evidence of hiatuses in x-rays of our cores (Figure S6), such as those found in Galapagos coral during strong El Niños (Dunbar et al., 1994, Jimenez et al., 2018), nor do we observe any signs of thermal stress in our coral $\delta^{18}O$ data (e.g., Hetzinger et al., 2016). However, we observe the largest variance in coral $\delta^{18}O$ during peak El Niño warming, which could bias studies of past El Niño amplitudes based on single coral $\delta^{18}O$ records. Nurhati et al., 2009 hypothesized that the attenuated signal of the 1997/98 El Niño event in their Kiritimati coral $\delta^{18}O$ records may have resulted from a reduced precipitation or a growth hiatus. Alternatively, high coral $\delta^{18}O$ variance during peak El Niño conditions may reflect more meter-scale variance in temperature and seawater $\delta^{18}O$ during El Niño extremes, given the strong gradients that occur at this time between the surface and depth, and between the lagoon and the open ocean, during a prolonged period of reduced wind-driven mixing.

Our investigation of the relative contributions of SST and $\delta^{18}O_{sw}$ anomalies to Kiritimati coral $\delta^{18}O$ anomalies across the 2015/16 El Niño event shows that SST conditions are responsible for ~70% of the coral $\delta^{18}O$ signal. Similar estimates for SST contributions to Kiritimati coral $\delta^{18}O$ records spanning the 1982/83 and 1997/98 El Niño events (mean values of 66 ± 13 and 74 ± 28%, respectively) bolsters our confidence in our findings from the 2015/16 El Niño event, although these estimates are associated with much larger uncertainties given the lack of *in situ* $\delta^{18}O_{sw}$ observations. Our findings are consistent with isotope-enabled climate model studies (Russon et al., 2013) which found an upper bound of 75% for the SST contribution to Kiritimati coral $\delta^{18}O$, as well as with previous empirically derived estimates (e.g., McGregor et al., 2011).

When placed within the context of centuries worth of coral $\delta^{18}O$ data from Kiritimati Island and nearby sites, our results provide key constraints on the physical drivers of the recent intensification of interannual coral $\delta^{18}O$ variability in central tropical Pacific corals (Grothe et al., 2020). Given that our results show a ~30% contribution from $\delta^{18}O_{sw}$ to the coral $\delta^{18}O$ anomalies during the three largest El Niño events in recent decades, it is unlikely that the observed ~25% increase in interannual coral $\delta^{18}O$ variability in recent decades relative to the past millennia (Grothe et al., 2020) is caused exclusively by an amplification of the hydrologic response to ENSO-related SST anomalies. Furthermore, instrumental climate data indicate that regional freshening is dynamically linked to warm SST anomalies during El Niño events in this location (Ropelewski and Halpert, 1987), suggesting that the observed increase in coral $\delta^{18}O$ variability is driven by an increase in both temperature and hydrological variability.

Our data support the fidelity of Kiritimati coral $\delta^{18}O$ records for long-term ENSO reconstruction, even under extreme temperature stress associated with a very strong El Niño event. Taken together, the coral $\delta^{18}O$ records, *in situ* SST, and $\delta^{18}O_{sw}$ data analyzed here show that SST dominates the ENSO-related coral $\delta^{18}O$ signal (~70%), with a smaller influence from $\delta^{18}O_{sw}$ (~30%). Such quantitative constraints are made possible by *in situ* seawater $\delta^{18}O$ observations collected across the event, demonstrating the value of prioritizing *in situ* seawater $\delta^{18}O$ observations in the design of regional to global-scale ocean observing systems, including TPOS2020 (Kessler et al., 2019). Calibration studies such as these are necessary to better understand the ENSO signals captured in coral $\delta^{18}O$ records and provide insight on signals captured by coral records over longer timescales. Our results suggest that a documented increase in interannual coral $\delta^{18}O$ variability at the site from the preindustrial to the present (Grothe et al., 2020) likely reflects an increase in ENSO-related SST.

5 Acknowledgments, Samples, and Data

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