Geology Department

Characterizing the El Niño Southern Oscillation (ENSO) variability using Sr/Ca-based SST and $\delta^{18}O$-derived SSS from the Southwest Pacific

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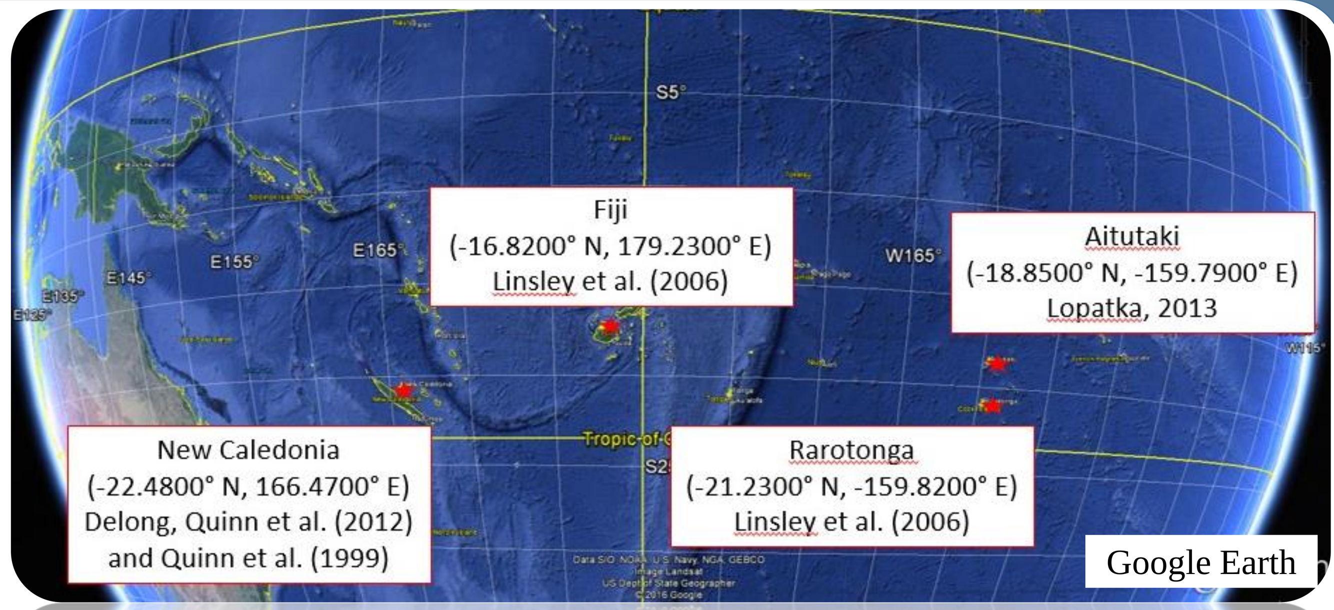
Motivation



The underlying natural mechanisms and forcings that cause climate variability are important for the better prediction and mitigation of climate change, but it can be difficult to achieve due to a lack of observations. One method used to extend the spatial and temporal coverage of information is the use of climate proxies.

In this study, the variability of the strontium to calcium ratio (Sr/Ca) and oxygen isotope ($\delta^{18}O$) anomalies within a coral's aragonite ($CaCO_3$) skeleton was examined to deduce whether the frequency and intensity of ENSO increased during the last two centuries in the southwest tropical Pacific. Data presented here includes new data from Aitutaki and pre-existing data from New Caledonia, Fiji, and Rarotonga. The null hypotheses are:

1. Climatological averages and anomalies of SSS and SST from the Southwest Pacific have no statistical difference between the late 19th century and the 20th century.
2. There is no significant difference in the frequency of ENSO warm phases and cold phases between late 19th century and the late 20th century.

Background

SST = sea surface temperature

SSS = sea surface salinity

SOI = Southern Oscillation Index is used to identify ENSO events.

ENSO = El Niño Southern Oscillation is a source of interannual variability in the atmospheric-oceanic circulation in the Tropical Pacific. During a warm phase, below average SST anomalies dominate the western Pacific and vice versa during cold phase.

ENSO event is a consecutive time period of the same ENSO phase above a certain magnitude, e.g. 1973-1976 cold phase event.

SPCZ = The South Pacific Convergence Zone is an area of low-level convergence characterized by persistent cloud-band and rainfall that extends from the western equatorial Pacific southeasterly. During a ENSO warm phase, the SPCZ's position shifts northeast, and during a ENSO cold phase, the SPCZ's position shift southwest.

Sr/Ca = The ratio between strontium and calcium in a coral aragonite skeleton is negatively correlated with SST.

$\delta^{18}O$ = The oxygen isotopic composition of an aragonite skeleton is negatively correlated to SST and positively correlated to SSS.

Methods: Ren et al. (2002) equations

Equation one was used to reconstruct SST anomalies using Sr/Ca anomalies (**Sr/Ca-SST**) and equation two to reconstruct SSS anomalies using $\delta^{18}O$ anomalies (**$\delta^{18}O$-SSS**).

ΔSST = SST anomalies

ΔSSS = SSS anomalies

$\frac{\partial \frac{Sr}{Ca}}{\partial SST}$ = -0.062 ± .008 mmol/mol/°C (Ren et al., 2002)

$\frac{\partial \delta^{18}O}{\partial SST}$ = -.21 ± 0.02 mmol/mol/°C (Ren et al., 2002)

$\frac{\partial \delta^{18}O}{\partial SSS}$ = 0.45 +/- 0.028 permil/psu Thompson et al., 2011)

$\Delta \frac{Sr}{Ca}$ = Sr/Ca anomalies based on long-term trends removed from data series

$\Delta \delta^{18}O = \delta^{18}O$ anomalies based on long-term trends removed from data series

$$\Delta \delta^{18}O = \frac{\partial \delta^{18}O}{\partial SST} * \Delta SST + \frac{\partial \delta^{18}O}{\partial SSS} * \Delta SSS \quad \textbf{equation 2}$$

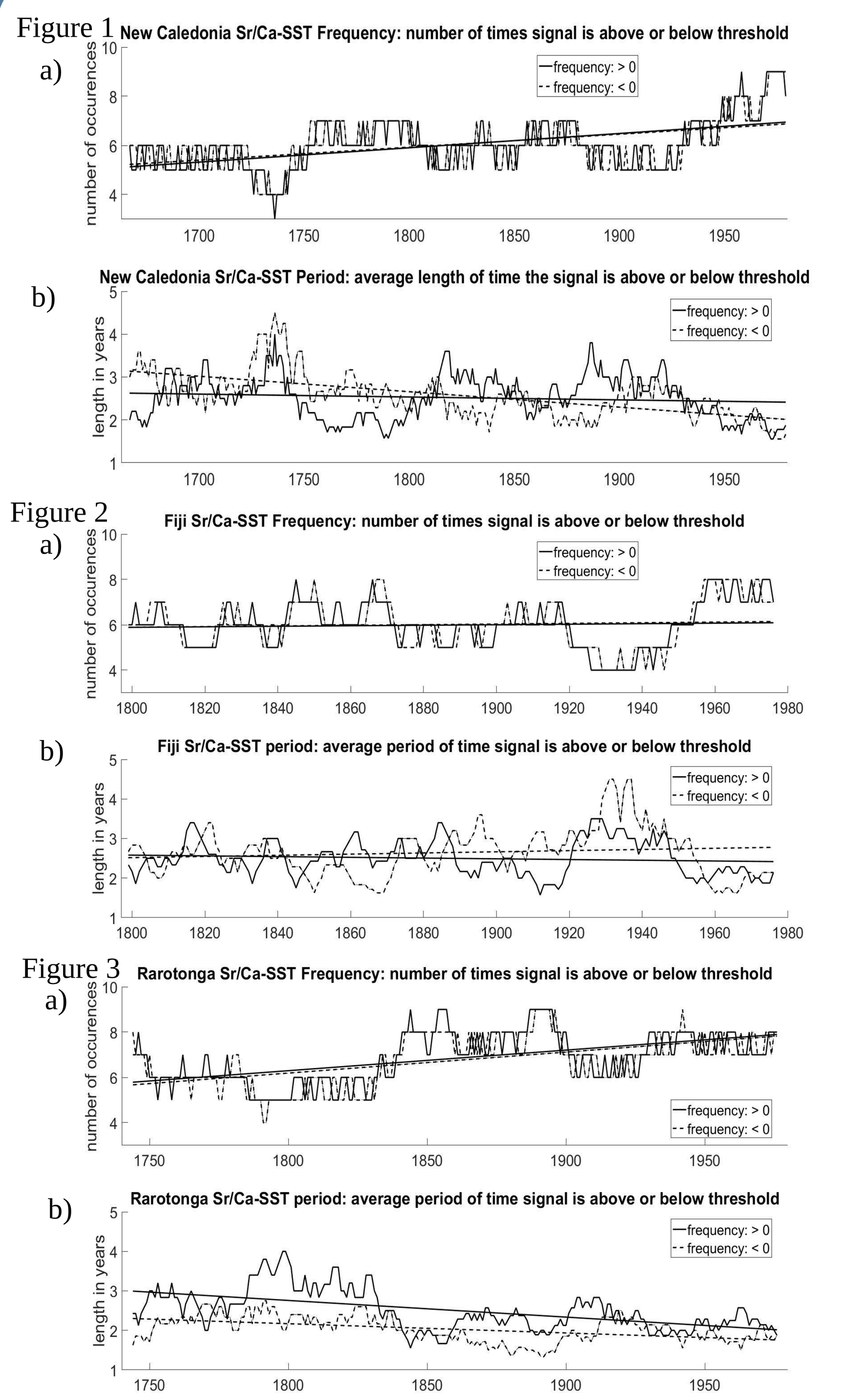
$$\Delta SST = \frac{\Delta \frac{Sr}{Ca}}{\left(\frac{\partial \frac{Sr}{Ca}}{\partial SST}\right)} \quad \textbf{equation 1}$$

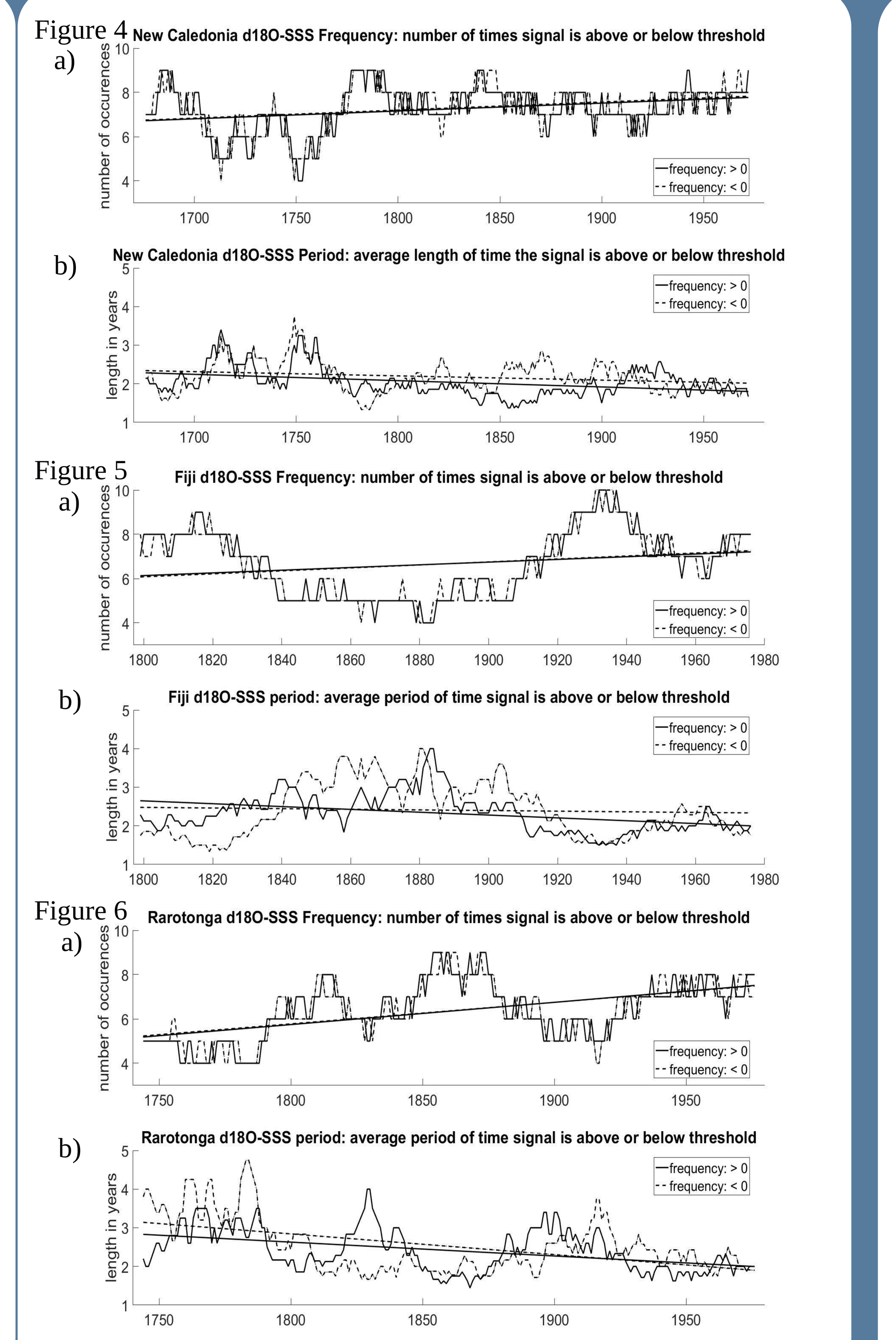
References for methods

Ren L., Braddock K. Linsley, Gerald M. Wellington, Daniel P. Schrag and Ove Hoegh-Guldberg (2002), Deconvolving the δ18O seawater component from subseasonal coral δ18O and Sr/Ca at Rarotonga in the Southwestern subtropical Pacific for the period 1726 to 1992, Geochimica et Cosmochimica Acta, vol. 67 (9), pp. 1609-1621.

Thompson, D.M, T.R Ault, M.N Evans, J.E Cole, J. Emile-Geay (2011), Comparison of observed and simulated tropical climate trends using a forward model of d18O, Geophysical Research Letters, 38, L14706. doi:10.1029/2011GL048224.

Analysis





In order to investigate the natural frequency of ENSO's signal, this study adopted a threshold of zero to examine the interannual frequency of the unstandardized detrended, reconstructed $\delta^{18}O$-SSS and Sr/Ca-SST annual anomalies. Using a moving 30 year period, the following calculations were made for an unique 30-year period:

1. Frequency: the number of occurrences in which the data series fell above or below zero for a consecutive amount of time.
2. Period: the average length of consecutive time in which a data series were above or below zero.

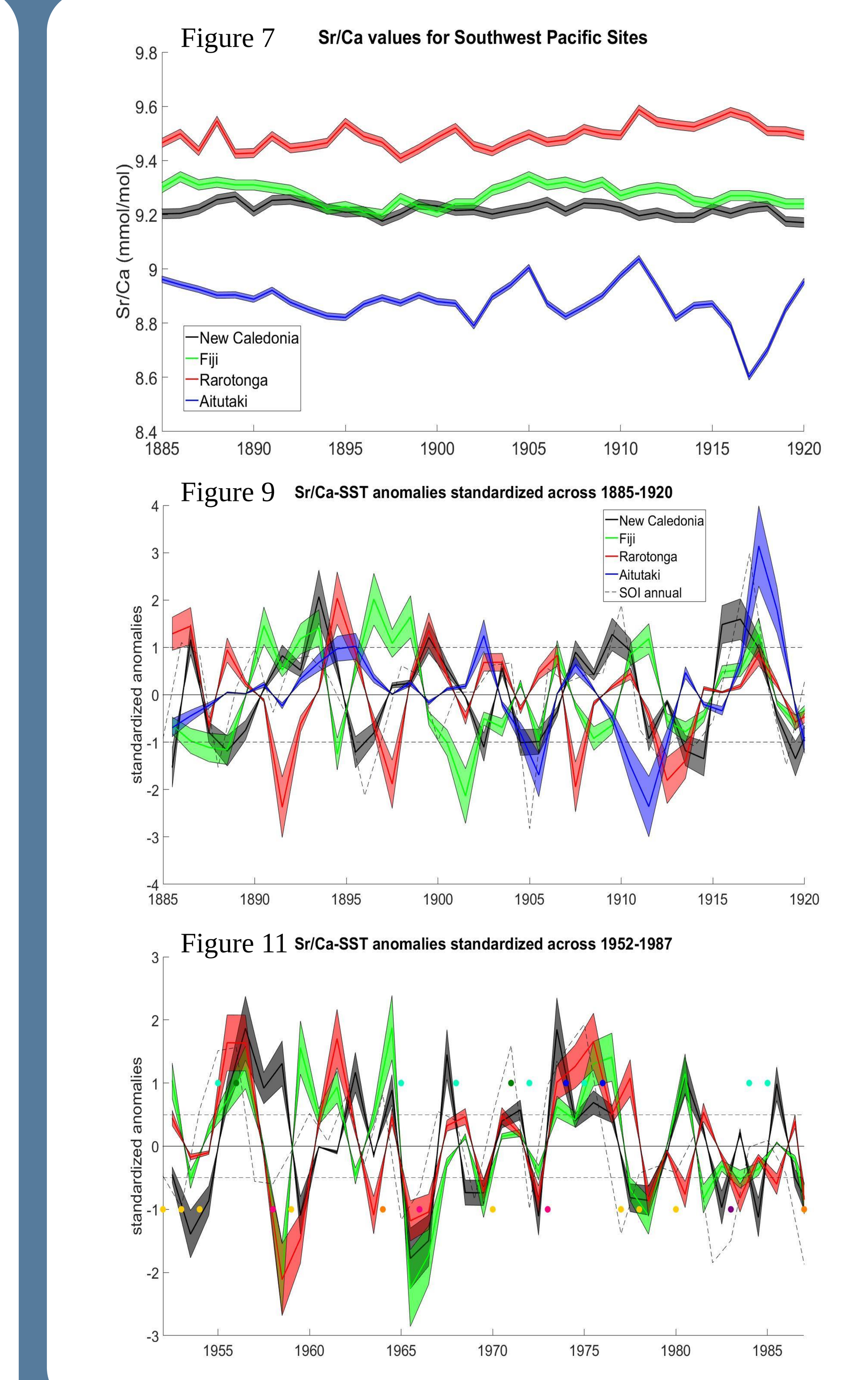
Figures 1-6 show the change in the frequency and period with their corresponding linear trends for the times that fell above (solid line) and below (dashed line) zero during a unique 30 year period for a site. **The uncertainty within the frequency is ± 1 and within the period ± .5 years.**

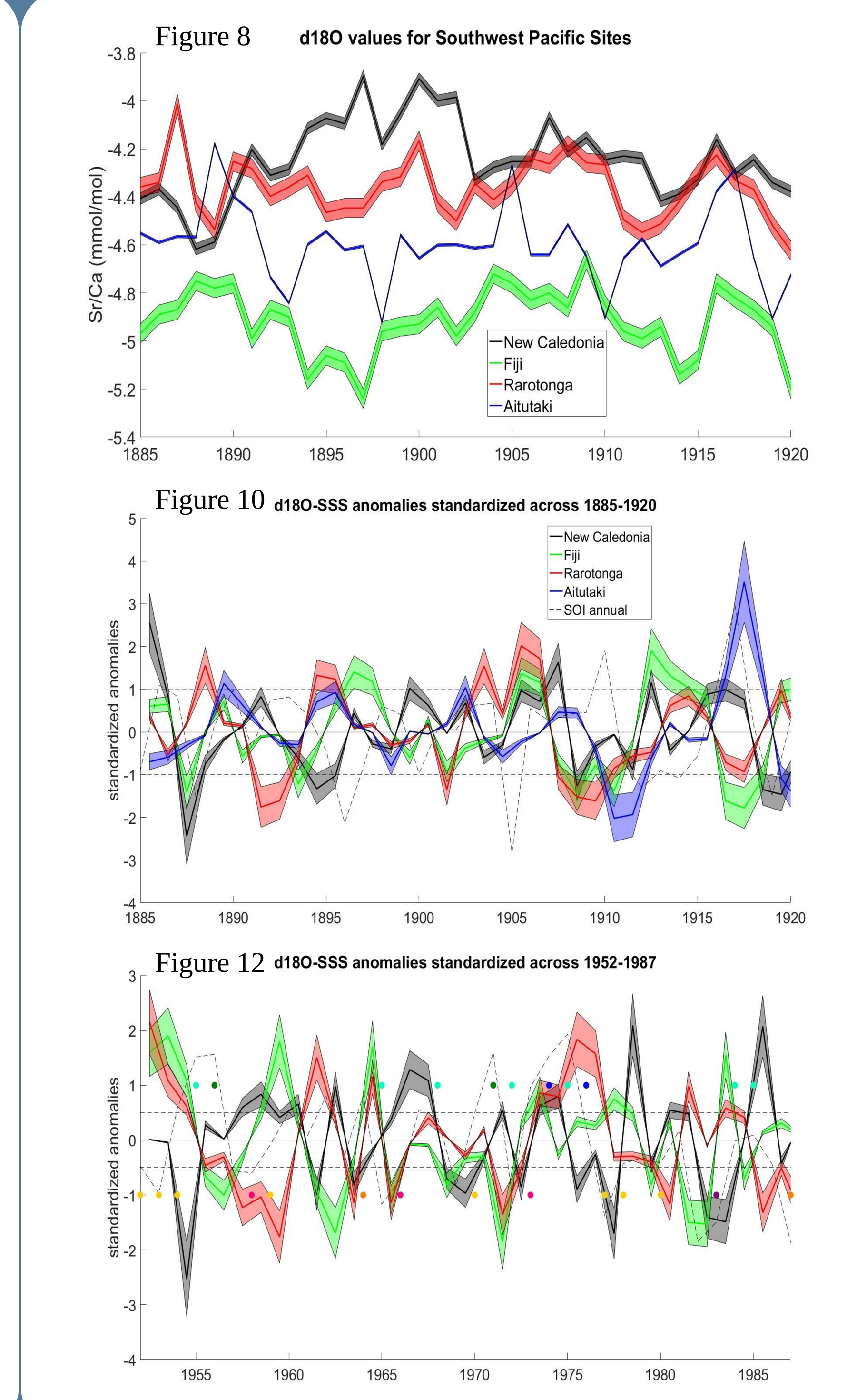
Key Results

1. **Regarding hypothesis 1**: there is no significant difference (p-value < 0.05 significance level) between averages taken for 1885-1920 CE and 1952-1987 CE for Sr/Ca and $\delta^{18}O$ (figure 7 and 8).
2. **ENSO frequency**: There is a larger range in $\delta^{18}O$-SSS frequency for: Fiji entire series, Rarotonga entire series, and the beginning of New Caledonia series (figure 4-6 a). Little change in the Sr/Ca-SST frequency for Fiji, but for New Caledonia and Rarotonga, there appears to be a slight increase in frequency (figure 1-3 a).
3. **ENSO period**: There is a significant decrease in the average period from 1744-1840 CE and 1840-1976 CE for Rarotonga Sr/Ca-SST above zero scenario and $\delta^{18}O$-SSS below zero scenario (figure 3 and 6 b).
4. **Standardized Sr/Ca-SST anomalies**: Most sites Sr/Ca-SST are significantly correlated to one another and to SOI (p-values > .05 significance level). Aitutaki Sr/Ca-SST anomalies were the exception, with poor correlation to other sites and SOI (figure 9 and 11). The Sr/Ca-SST peaks of New Caledonia, Fiji and Rarotonga may be used to identify ENSO events, falling with 1 year of SOI identified events.
5. **Standardized $\delta^{18}O$-SSS anomalies:** Most sites $\delta^{18}O$-SSS correlated significantly with one another and SOI (p-values > .05 significance level). Aitutaki $\delta^{18}O$-SSS anomalies were the exception, with poor correlation to other sites and SOI (figure 8 and 10). When $\delta^{18}O$-SSS anomalies were examined for ENSO events identified using Sr/Ca-SST anomalies, there was no significant, consistent behavior in $\delta^{18}O$-SSS for either ENSO phase or any site.

Key Conclusions

1. **Regarding hypothesis 1**: The tropics experience less warming than higher latitudes, corresponding to the lack of significant change in mean Sr/Ca and $\delta^{18}O$ from southwest Pacific sites between 1885-1920 CE and 1952-1987 CE. However, the general decrease in Sr/Ca mean may be indicative that warming is still occurring.
2. **ENSO frequency**: Because Fiji sits more directly in the path of the SPCZ, Fiji's large range and low variance in interannual Sr/Ca-SST frequency may indicate that the SPCZ's interaction with ENSO has a predictable pattern. The change from a large to a smaller range in frequency for New Caledonia appears to indicate that the SPCZ has shifted eastward.
3. **ENSO period**: For Rarotonga, a decrease in the period of the Sr/Ca-SST above threshold scenario and the $\delta^{18}O$-SSS below threshold scenario could indicate conditions, that were at one time anomalously warm or wet, are becoming the new norm. This suggests an eastward shift of the SPCZ's high rainfall and the West Pacific's warm waters.
4. **Standardized anomalies**: Southwest Pacific Sr/Ca-SST anomalies appear to be a good indicators of an ENSO event. The $\delta^{18}O$-SSS should be further examined for inter-site relationships which correspond to the position of the SPCZ and ENSO.
5. **Aitutaki:** One likely cause for poor correlation between Aitutaki and other southwest Pacific sites is its location. Aitutaki sits on the boundary between the SPCZ and a high pressure zone, a wet verses dry region. With further analysis, this node may be useful in determining the phase and strength of ENSO.





Figures 7-8 show the original Sr/Ca and $\delta^{18}O$ data for all four southwest Pacific sites for 1885-1920. Figures 9-12 display the detrended, standardized reconstructed Sr/Ca-SST and $\delta^{18}O$-SSS annual anomalies for 1885-1920 and 1952-1987 for all sites. New Caledonia (black), Rarotonga (red), Fiji (green), and Aitutaki (blue) data series are the solid lines and the uncertainty is the shaded area surrounding the line. For figures 9-12, the uncertainty is measurements is ± 27%. In figures 11-12, the multi-color dots correspond to ENSO phases of varying strength (legend to the right).

New Caledonia
Fiji
Rarotonga
SOI annual
Warm: weak
Warm: moderate
Warm: strong
Warm: very strong
Cold: weak
Cold:moderate
Cold: strong