2007

Interdecadal-Decadal Climate Variability from Multi-Coral Oxygen Isotope Records in the South Pacific Convergence Zone Region Since 1650AD

Peipei Zhang
University at Albany, State University of New York

Recommended Citation

Zhang, Peipei, "Interdecadal-Decadal Climate Variability from Multi-Coral Oxygen Isotope Records in the South Pacific Convergence Zone Region Since 1650AD" (2007). *Geology Theses and Dissertations*. 102.
http://scholarsarchive.library.albany.edu/cas_daes_geology_etd/102

Interdecadal-Decadal Climate Variability from Multi-Coral Oxygen Isotope Records in the South Pacific Convergence Zone Region Since 1650AD

A thesis presented to the Faculty

of the University at Albany, State University of New York

in partial fulfillment of the requirements

for the degree of

Master of Science

College of Arts & Sciences

Department of Earth and Atmospheric Sciences

Peipei Zhang

2007

ABSTRACT

Annual average oxygen isotope ($\delta^{18}O$) time series from five coral cores collected from Fiji and Tonga are used to construct a Fiji-Tonga Interdecadal-Decadal Pacific Oscillation (F-T IDPO) index of low frequency (>9yr and <55yr) climate variability in this area back to 1650 A.D. Presently, both Fiji and Tonga are located in the South Pacific Convergence Zone (SPCZ) salinity front region where the Interdecadal Pacific Oscillation (IPO) variation is most pronounced. We first demonstrate the consistency between this F-T IDPO index and a MSL pressure-based SPCZ Position Index (SPI) (1891-2000), thus verifying the ability of coral $\delta^{18}O$ to record past interdecadal-decadal climatic variations in this region back to 1891. The F-T IDPO index is then shown to be synchronous with the IPO index (1856-2000), suggesting that this coral-based index effectively represents the interdecadal-decadal scale climate variance back to 1650. The consistently anti-phase spectrums of the F-T five-coral composite and the interdecadal-decadal components in equatorial Pacific coral $\delta^{18}O$ series from Maiana [*Urban et al., 2000*] and Palmyra [*Cobb et al., 2001*] suggest that the simultaneous eastern expansion (western contraction) of the eastern salinity front of Western Pacific Warm Pool (WPWP) occurs at the same time as the northeast (southwest) movement of the SPCZ during a positive IPO (negative IPO) phase.

ACKNOWLEGEMENTS

I would like to express my gratitude to all those who helped me complete this thesis. I am deeply indebted to my supervisor Dr. Braddock Linsley. Brad inculcated in me a taste for the field of climatological research with his inspiration and the great efforts to explain things clearly and simply. This work would not have been possible without his help, stimulating suggestions and encouragement throughout this research and during the writing of this thesis. It has been a pleasure to be one of his team.

I gratefully acknowledge the other two committee members who monitored my work and took effort in reading and providing me with valuable comments on earlier versions of this thesis: Dr. John Arnason and Dr. Alexey Kaplan. I would also like to thank Steve S. Howe for assistant with the isotopic analysis, who was always available when I needed his advises. Many thanks to Alexa Stolorow, who sampled coral core TNI2 which is an essential part of my argument.

My special thanks are due to some other professors for their dedication in teaching and excellent skills. They are Dr. John Delano and Dr. William Kidd from Department of Earth and Atmospheric Sciences and Dr. Malcolm Sherman from Department of Mathematics.

Lastly, and I wish to thank my parents, Nengwei Zhang and Ningbai Lee. They bore me, raised me, supported me, taught me, and loved me. To them I dedicate this thesis.

TABLE OF CONTENTS

ABSTRACT

APPENDIX

LIST OF FIGURES

LIST OF TABLES

1. Introduction

The South Pacific Convergence Zone (SPCZ) is a reverse-oriented monsoon low-pressure trough stretching from the Intertropical Convergence Zone (ITCZ) near the Solomon Islands to Fiji, Samoa, Tonga and further southeast to French Polynesia. This region features a large sea surface temperature (SST) gradient and active low-level convergence. The low-level convergence of moisture leads to a persistent cloud band as well as showers and thunderstorms. Precipitation and convection within the band is seasonally dependent. Its equatorial portion, where it is connected to the ITCZ, is most active in the Southern Hemisphere summer, and the more southeasterly portion is most active during transition seasons of fall and spring. At the southeastern edge of the SPCZ, oceanic circulation around the feature creates a salinity gradient in the ocean, with fresher and warmer waters of the western Pacific lying to the west of the salinity front and cooler, saltier waters lying to the east. [*Gouriou and Deleroix, 2002*]. The salinity front shifts northwestward (southeastward) during El Niño (La Niña) events [*Gouriou and Deleroix, 2002; Juillet-Leclerc et al., 2006; Linsley et al., 2006*]. On interdecadal time-scales the SPCZ and associated salinity front migrate southwestward (northeastward) during the negative (positive) phase of the Interdecadal Pacific Oscillation (IPO), e.g., during the late-1940s to mid-1970s and after the mid-1970s, respectively [*Delcroix et al., 2007*]. While the interannual-scale SPCZ displacement is relatively well known, the low-frequency displacement is less well understood due to the lack of long-term instrumental records. Folland et al. [*2002*] have developed a SPCZ position index (SPI) from the monthly instrumental mean sea level (MSL) pressure differences between Suva, Fiji (18°9'S, 178°26'E) and Apia, Samoa (13°48'S, 171°47'W) from November to April during the period 1891-2000. The SPI was found to be closely correlated with the phase of the IPO, with the SPCZ displaced towards Fiji during negative phases of the IPO and towards Samoa during positive phases of the IPO [*Folland et al., 2002*]. At lower frequencies, Linsley et a., [*2006*] have interpreted the secular trends in replicated coral oxygen isotope (δ^{18}O) records from Fiji and Rarotonga as evidence that the SPCZ has been expanding since the mid-1800's.

In many studies $\delta^{18}O$ series in corals have been shown to provide a unique record of past climatic variability due both to: 1.) the precise dating provided by annual growth rings combined with $\delta^{18}O$ annual cycles and 2.) the ability of corals to record environmental changes in the geochemistry of their skeletons. However, limitations of using the coral $\delta^{18}O$ proxy include uncertainties in the combined effects of sea surface temperature and the $\delta^{18}O$ of seawater, and effect of poorly-understood potential biological artifacts such as inconsistent annual skeletal extension rates and calcification rates. The climatic significance of interdecadal-decadal modes in coral $\delta^{18}O$ time-series is still under debate [*Jones et al., 1998; Crowley et al., 1999; Evans et al., 2000*]. To verify the reliability of the coral-based $\delta^{18}O$ proxy to reconstruct climate variability in the past, we isolated and examined the interdecadal-decadal modes in five coral $\delta^{18}O$ time-series (two from Fiji and three from Tonga). Both island chains are from an area of the South Pacific where the IPO is most pronounced (Figure 1). Folland et al. [*2002*] demonstrated the equivalence of the IPO and the North Pacific derived Pacific Decadal Oscillation (PDO) index. The IPO appears to be of similar magnitude in the South Pacific to the El Niño Southern Oscillation (ENSO). Although large uncertainties remain regarding the temporal and spatial coherence of this interdecadal-decadal variability prior to ~1950 when the instrumental data had less dense coverage and is generally thought to be less reliable. Here we will show that the correspondence between interdecadal-decadal modes extracted from the $\delta^{18}O$ series of multiple corals from Fiji and Tonga and their correlation with the SPI and IPO indices demonstrates the reliability of coral $\delta^{18}O$ as a proxy for climate changes at these frequencies and establishes that a five-coral $\delta^{18}O$ composite Interdecadal-Decadal Pacific Oscillation (IDPO) Index back to 1650AD documents past interdecadal-decadal climate oscillations.

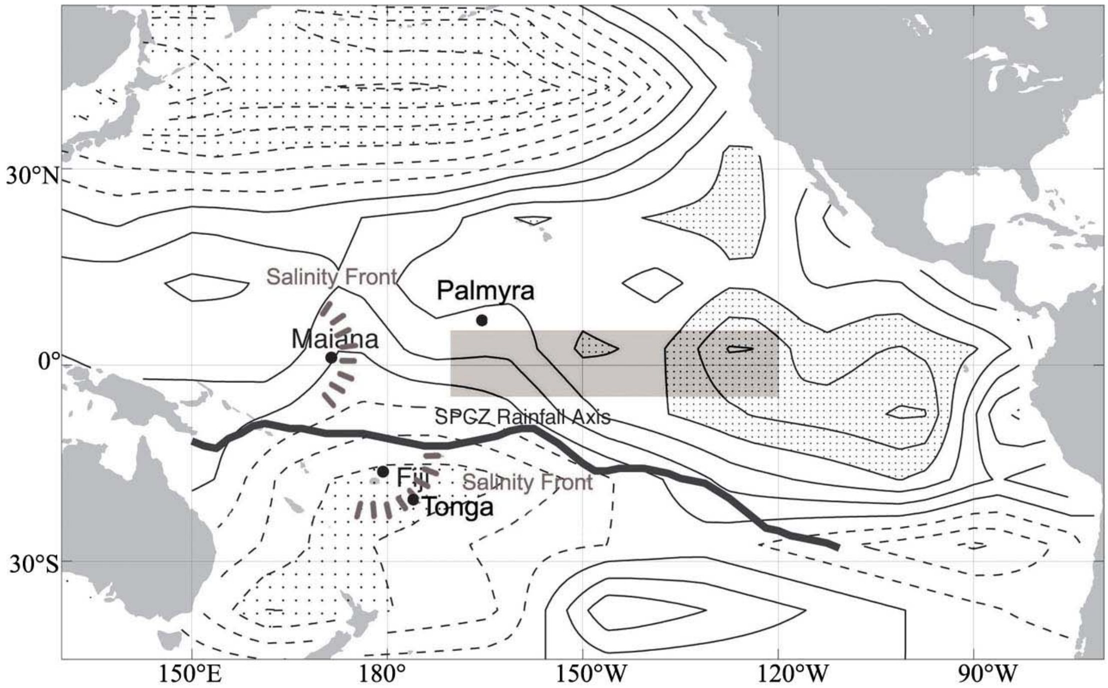


Figure 1. Location of Fiji, Tonga, Maiana, Palmyra and the Nino 3.4 area (shaded box, 5°N-5°S, 120°-170°W) in relation to the South Pacific Convergence Zone salinity front near Fiji and Tonga, the West Pacific Warm Pool salinity front near Maiana and the spatial pattern of the IPO [*Folland et al., 2002*]. Background contours show the IPO as a covariance map of the 3rd EOF of low-pass filtered SST anomalies for 1911-1995. The contour interval is 0.04°C, negative contours are dashed, values < -0.12°C lightly stippled and those > +0.12°C heavily stippled. The rainfall maximum axis of the SPCZ for 1958-1998 is also shown as a thick black line. Figure modified from Folland et al. [*2002*].

2. Methods

2.1 Sampling and Chronology

In November 2004 three *Porites lutea* coral colonies were drilled at Tonga on the islands of Ha'afera, Malinoa and Nomuka Iki. At Ha'fera (19°56'S, 174°43'W) a large colony with a dead flat top but with live sides was cored. The colony was ~4.5 m high with ~1 m of water covering the top at low tide. Two coral cores TH1 Hole 4 (TH1-H4 hereafter) and TH1 Hole 5 (TH1-H5 hereafter) were collected. The 4.2m-long core TH1-H4 was drilled from the dead top of the colony and the 67cm-long TH1-H5 was collected from the live side of the colony. As discussed below, TH1-H4 and TH1-H5 were spliced together using the timing of known El Niño events. At Malinoa (21°02'S, 175°08'W), north of Nuku'alofa, a 1.63 m core (TM1) was collected from a living colony in 6 m of water. At Nomuka Iki (20°16'S; 174°49'W) two useable cores were collected from a large living colony in 3.5 m of water (TNI2-H1 and TNI2-H3). Due to a bio-eroded zone from ~1m to 1.68 m in TNI2-H1, TNI2-H3 was drilled to allow sampling around the bio-eroded zone by splicing the $\delta^{18}O$ record from H3 onto H1. The $\delta^{18}O$ data from the two Fiji cores (Fiji 1F and Fiji AB) used in this study were originally discussed in Linsley et al. [*2004, 2006*]. It should be noted that subsequent to publishing the Fiji core AB chronology in Linsley et al. [*2006*], we determined that a 2-year gap existed in this core (missing years 1727 and 1728) at a core break. For this current work we have inserted two years by calculating the average of each decade on either side of the gap.

Core ID	Years	$\delta^{18}O$ Sampling	Water Depth	Location	Latitude and Longitude
1F	1997-1780	Millimeter-scale	10 m	Savusavu Bay, Fiji	16°49'S 179°14'E
AB	2001-1617	Millimeter-scale	10 m	Savusavu Bay, Fiji	16°49'S 179°14'E
TH1	2004-1794	Millimeter-scale and annually	1 m	Ha'afera, Tonga	19°56'S 174°43'W
TNI2	2004-1650	Millimeter-scale and annually	3.5 m	Nomuka Iki, Tonga	20°16'S 174°49'W
TM1	2004-1837	Millimeter-scale and annually	6 m	Malinoa, Tonga	21°02'S 175°08'W

Table 1. List of five *Porites Lutea* coral cores used to develop the composite Interdecadal-decadal Pacific Oscillation (IDPO) index. Description of Fiji cores (designated 1F and AB) were given by Linsley et al. [*2004*] and Linsley et al. [*2006*].

All of the coral cores were cut into ~7 mm thick slabs in the laboratory with a modified tile saw, cleaned and air-dried. The slabs were X-rayed (35kV for 90 seconds) to reveal the density bands. X-radiographs of TH1-H5, TH1-H4 and TM1 are shown in Appendix 1. All of the slabs were then cleaned with a high-energy (500W, 20kHz) probe sonicator in a deionized water bath for approximately 6 minutes and air-dried. Dry slabs were sampled with a low-speed micro-drill with a 1-mm-diameter diamond drill bit parallel to corallite traces along growth axes (as identified in the X-radiographs). Each core was sampled at 1 mm intervals through the top ~30 years, by excavating a 4-5-mm-wide (perpendicular to the growth axis) and 2-3-mm-deep groove in the coral slabs. Below this a technique of annual-scale sampling technique was used (described below). Between some slab sections, the sampling track jumped from one growing axis to another to bypass possible gaps caused by breakage of the slabs. In these cases, all of the jumps were made along a distinct density band to avoid any temporal hiatus in our data.

Approximately 100μg of coral powder in each sample was dissolved in 100% H_3PO_4 at 90°C in a MultiPrep sample preparation device and the generated CO_2 gas was analyzed by a Micromass Optima gas-source triple-collector mass spectrometer at the University at Albany, State University of New York Stable Isotope Ratio Mass Spectrometer (SIRMS) Laboratory. Table 2 lists the number of samples analyzed from each Tonga core, the average difference between replicate samples, and the average isotopic compositions and precision in the analysis of international standard NBS-19. Approximately 10% of the 3,300 Tonga coral samples were analyzed in duplicate. All data are expressed in the conventional delta notation as per mil deviations relative to Vienna Peedee Belemnite (VPDB).

Core ID	Dates of Analysis	Number of Samples Analyzed	Average Difference of Replicates	Average $\delta^{18}O$ Composition and Precision of NBS-19 (n=number analyzed)
TH1-H4	12/06-1/07	522	0.036	-2.199±0.031
TH1-H5	10/06-10/06	192	0.039	-2.199±0.031 (n=135)
TM1	11/06-1/07	391	0.037	-2.195±0.030 (n=76)
TNI2-H1	1/06-6/06	889	0.056	-2.206±0.034 (n=152)
TNI2-H3	8/05-2/06	1306	0.047	-2.200±0.038 (n=218)

Table 2. The isotope analysis statistics.

For the last three decades of cores TH1-H4, TH1-H5, TM1, and TNI2-H3, the chronologies are based on the reconstructed annual cycle in millimeter-scale $\delta^{13}C$ and $\delta^{18}O$ data with two age control points per year. The 1977-78 El Niño, 1974-1975 La Niña, 1971-72 La Niña, 1964-1965 El Niño and 1955-57 La Niña events were set as control points to determine the age of TH1-H4 (the same colony as TH1-H5, but dead on the top). Figure 2 shows the mm-scale $\delta^{18}O$ results from cores TH1-H4, TH1-H5 and TNI2-H3 to illustrate the match of the interannual $\delta^{18}O$ changes with known ENSO events. We added TH1-H5 atop of TH1-H4 (the overlapping part was averaged) and named the combined time series dataset spanning 1794-2004 TH1.

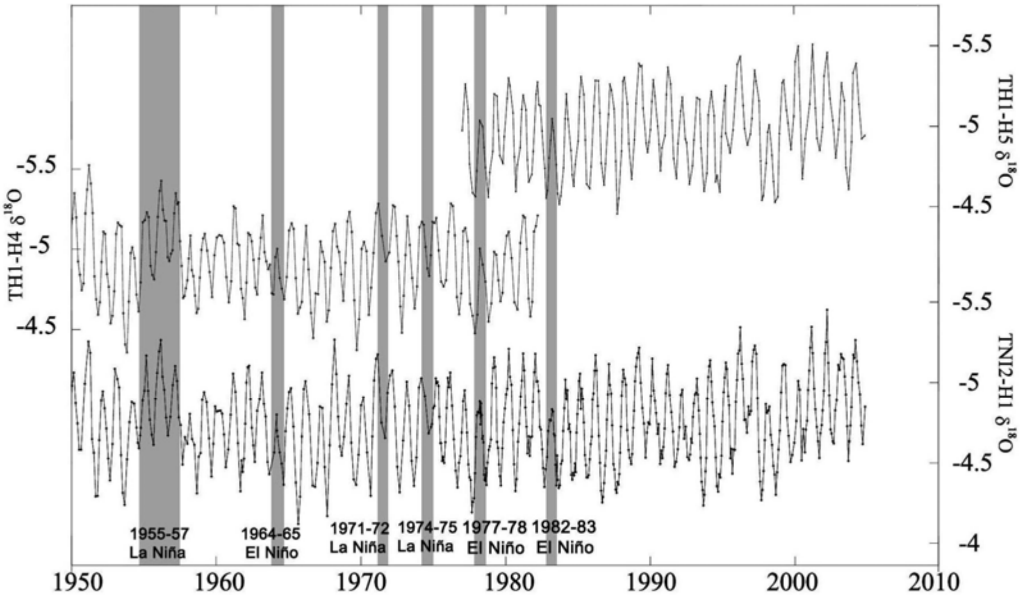


Figure 2 The plots of TH1-H5(top), TH1-H4(middle) and TNI2-H1(bottom) over the period of 1950-2004 to illustrate the match of the annual cycles during the ENSO events. The top of the TH1-H5 was added later on top of TH1-H4 and was assigned the name TH1.

Below the millimeter-scale sampling, we have utilized an annual-average sampling method which is based on the annual density cycles identified by using X-ray photos and ultraviolet light. Sampling was done along the maximum growth axis as with the mm-scale sampling, but only one continuous sample was drilled through each density band (~8-17 mm long, depending on the coral extension rates). Powder from each annual accretion drilling was well mixed and its $\delta^{18}O$ value was taken as a one-year average value of the corresponding year. Millimeter sampling was applied in intervals where the density bands were not clear enough to identify the annual growth increments.

Unlike the millimeter-scale sampled Fiji cores, (Fiji 1F [*Linsley et al., 2004*] and Fiji AB [*Linsley et al., 2006*]), whose annual average δ^{18}O values were derived from all the data points between the two most negative δ^{18}O values of each year, the annual average δ^{18}O values from the annual-scale drilling of the Tonga cores are not necessarily 12-month averages. In the Tonga cores, although most of the dense bands appear right before the warmest time in each cycle, there are exceptions that cause differences in time spans of some years. Instead of an integrated one-year cycle, several months could be missed and added to the year before or after. However, since as will be discussed below, the fact that the resulting modes in different frequencies are similar among the five coral cores confirms the practical reliability of our sampling technique.

2.2 Statistical Analysis

Following the approach of Vautard and Ghil [*1989*] and Vautard et al. [*1992*] we performed Singular Spectrum Analysis (SSA) of the annually averaged coral δ^{18}O time-series. SSA decomposes time series into several significant frequency components. The resulting modes of variability, defined as SSA eigenvectors, are linear combinations of the individual data records so that the sums are uncorrelated with each other. The sampled time series X of length N is used in to fill a (N-M+1)×M matrix by taking as state vectors the consecutive sequences $Z_n = (X_n, X_{n+1} \ldots X_{n+m-1})$ from n=1 to N-M+1. Variable M is called the embedding dimension or window width. Frequency separation increases as M increases, whereas statistical significance of correlations decreases. An M value of N/3 should not be exceeded [*Vautard et al., 1992*]. Varying window widths were applied over a reasonable range to the annually averaged δ^{18}O time series data of each core. The stable features of the eigenvectors were evaluated and a window dimension (M) was selected to resolve the IPO band (~9-55 years) which was the focus of this research. Since the time series are of different lengths, M varied between cores. The SSA results presented here are based on the following M setting: Fiji 1F with M=40 (N=216), Fiji AB with M=55 (N=384), Tonga TH1 with M=30 (N=212), TNI2 with M=50 (N=355) and TM1 with M=40 (N=168).

3. Results

As previously observed for other coral records [*Tudhope et. al, 1995; Linsley et al., 1999, 2004, 2006; Cobb et al., 2003*], an offset in mean $\delta^{18}O$ value exists in some of the five corals and could be attributed to differences in disequilibrium "vital" effect between coral colonies. The 20th century mean values for annually averaged $\delta^{18}O$ are -4.64‰ for core AB, -5.06‰ for core 1F, -4.88‰ for core TH1, -4.70‰ for core TNI2 and -4.43‰ for core TM1. In the three Tonga corals, the offsets are relatively small and could be due to mean SST or SSS differences between sites TH1, TNI2 and TM1. In the case of the two Fiji cores, the offset is 0.42‰. These *Porites* colonies are growing in the same setting within 200m of each other in Savusavu Bay and this difference in mean $\delta^{18}O$ is probably due to a difference in the disequilibrium $\delta^{18}O$ offset. Given the uncertainty of the significance of this $\delta^{18}O$ offset we have subtracted the twentieth century mean $\delta^{18}O$ value of each core in order to compare the $\delta^{18}O$ time series. Centered $\delta^{18}O$ series for the five cores are shown in Figure 3. Since all five colonies are composed of the same species of coral and are from a relatively small area, we expected that they would contain common variance due to regional climatic variability. The consistency of the timing of interannual, decadal and interdecadal components is remarkable in our record. For example, the 1982-83 El Niño event (marked by arrows on figure 3) is shown by simultaneous decreases in coral $\delta^{18}O$ in all five corals. However, some variability in the response of the various coral colonies to certain single climatic events e.g. an individual El Niño event, is likely due to local environmental SST or sea surface salinity (SSS) changes, while some is probably due to biological effects. This can be seen for the 1982-83 El Niño which resulted in a decrease of about 0.15‰ in $\delta^{18}O$ in the Tonga cores TH1 and TNI2, and in the Fiji cores 1F and AB, but the same event resulted in a more pronounced 0.5‰ decrease in Tonga core TM1.

Four out of the five corals show a gradual trend toward warmer and fresher conditions since the early 1900's (figure 3), which probably indicates a southeastward expansion of the SPCZ [*Linsley et al., 2006*]. The only exception is TNI2 which records an abrupt 0.32‰ decrease in $\delta^{18}O$ between 1915 and 1916. We believe this "jump" is the result of an unknown biological, digenetic effects and/or possible tectonic shifting of water depth at the coral site (active Tonga trench is nearby) since the synchronous $\delta^{13}C$ values are normal and there did not exist any known climatic event that could change the temperature and/or salinity comparable to a 0.32‰ drop in $\delta^{18}O$ value.

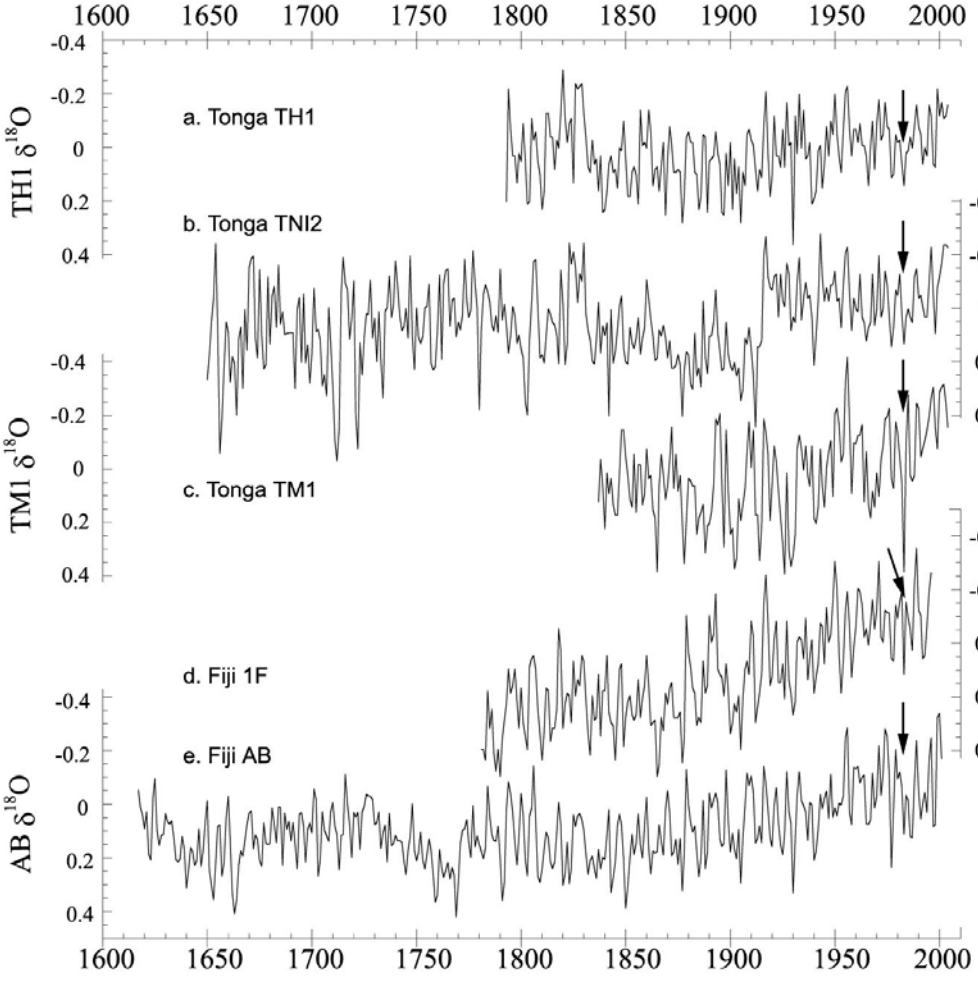


Figure 3. The annually averaged $\delta^{18}O$ data of the five corals from Fiji and Tonga with twentieth century mean values removed. The black arrows show the 1982-83 El Niño event. All five coral data were plotted on the same $\delta^{18}O$ (‰) scale.

As a well-established proxy, coralline $\delta^{18}O$ is known to track both water temperature and the seawater $\delta^{18}O$ value ($\delta^{18}O_{seawater}$). At both Tonga and Fiji, the ~1.0‰ annual amplitude of the millimeter-scale (near-monthly) analysis fits well with the annual 4°C-5°C instrumental SST range from the NCEP SST database [*Reynolds and Smith, 1994*]. This suggests that seasonal water temperature change is the dominant influence on sub-annual changes in Fiji and Tonga coral $\delta^{18}O$ in accord with Linsley et al [2006]. The weak, irregular seasonal SSS cycle in the 2°-10° latitude-longitude gridded SSS data [*Gouriou and Delcroix, 2002*] is in marked contract to the strong annual sea surface temperature cycles. On interannual time-scales, SSS variability of 1-1.2 p.s.u (~1 p.s.u. in Tonga and ~1.2 p.s.u. in Fiji) appears to be the dominant factor affecting coral δ^{18}O at these sites compared with ~1°C interannual SST variance in the region. This effect was previously discussed for Fiji cores 1F and AB [*Linsley et al., 2006*].

Figure 4 compares Tonga cores TH1, TNI2, and TM1 and Fiji cores 1F and AB annual-averaged δ^{18}O data to annual-averaged sea surface salinity (SSS) from Gouriou and Delcroix [*2002*] and annual SST anomaly from the Hadley Center Sea Ice and Sea Surface temperature database (HadISST1). Correlation coefficients (R value) between annual-averaged coral δ^{18}O and SSS over the interval from 1976 and 2000 are 0.61 for core TH1, 0.52 for core TNI2, 0.62 for core TM1, 0.66 for core 1F and 0.71 for core AB. Correlation coefficients between annual averaged δ^{18}O and local SST during 1870 and 1996 are -0.44 for core TH1, -0.46 for core TNI2, -0.41 for core TM1, -0.54 for core 1F and -0.64 for core AB.

Assuming that the relationship between coral δ^{18}O and SST is -0.21‰/°C (-0.17 to -0.23‰/°C is the common range of coral δ^{18}O-SST calibrations [*Epstein et al., 1953; Dunbar et al., 1994; Wellington et al., 1996*]) and the factors influencing coral δ^{18}O are independent from each other, the 1°C interannual range of annual SST of both Tonga and Fiji from the HadISST1 during 1976-2000 contributes ~0.21‰ to the change in coral δ^{18}O in this time interval. Subtracting this 0.21‰ SST portion from the total coral δ^{18}O range (~0.5‰) during the same period of time results in a residual of ~0.29‰. The magnitude of this "residual" is in accord with the 1-1.2 p.s.u. change (annually averaged) [*Gouriou and Delcroix, 2002*] based on the 0.27‰/p.s.u. between $\delta^{18}O_{seawater}$ and SSS found by Fairbanks et al. [*1997*] for the equatorial Pacific. SST and $\delta^{18}O_{seawater}$ (linearly related to SSS) drive the coral δ^{18}O in the same direction for a single ENSO event. During El Niño events and/or positive phases of the IPO and PDO indices, locally cooler and saltier conditions drive the coral δ^{18}O composition at Fiji-Tonga toward more positive values. The opposite occurs during

La Niña events or negative IPO/PDO intervals. Since greater precipitation amounts and warmer temperatures (or drier conditions with cooler temperatures) occur together in the study area [*Folland et al., 2002*], we take coral $\delta^{18}O$ as an index of ENSO or IPO/PDO without disentangling the effects of SST and SSS.

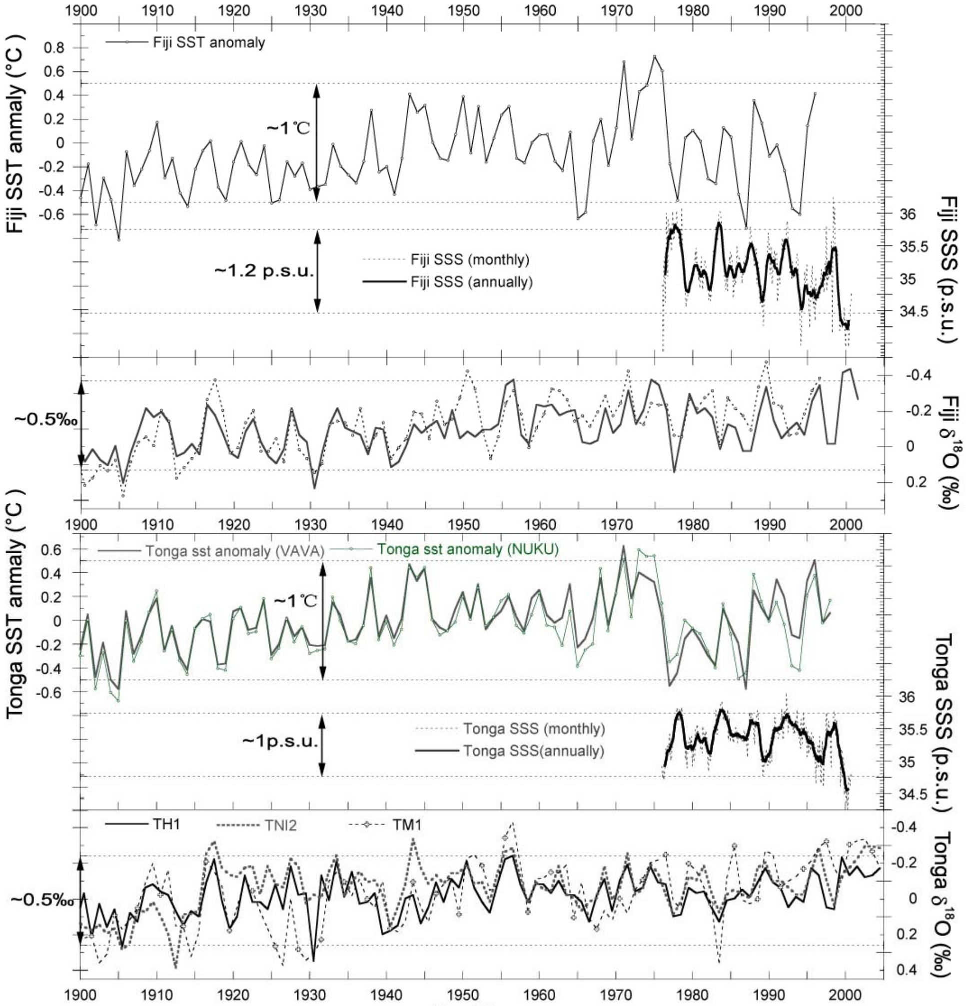


Figure 4. The relative contribution of SST and SSS changes to the coralline $\delta^{18}O$ variance in Fiji (top) and Tonga (bottom). The annual SST data back to 1900 is from the HadISST1. Note that there are two stations (VAVA and NUKU) in Tonga and we plotted them together in the figure. Local SSS data back to 1976 is from Gouriou and Delcroix [*2002*]. The SST (°C) and $\delta^{18}O$ (‰) were plotted on a 0.2‰/°C scale and the SSS (p.s.u) and $\delta^{18}O$ (‰) were plotted on a 0.29‰/p.s.u. scale.

We performed SSA to quantify the variance in the annual-averaged coral $\delta^{18}O$ time series from each core. SSA decomposes time series data into trends and significant oscillatory components in different frequencies. For the coral $\delta^{18}O$ series analyzed in this study, we separated the oscillatory components into two groups, an ENSO band with frequencies ranging between 3-8 years and an interdecadal-decadal band with mean periods between ~9 and ~55 years. Below, we will refer to this band as the interdecadal-decadal Pacific Oscillation (IDPO). This frequency cut-off for ENSO has been widely applied and is based on the recurrence interval of recent El Niño events. The SSA results for Core TH1 also show the biennial components that we did not included in the ENSO band. All other oscillations with mean frequencies >55 years are reported as secular trend components. We note that in the 5 coral $\delta^{18}O$ time series no oscillatory components have periods that fall between 55-75 years, thus 55 years appears to be logical frequency cutoff to separate the interdecadal variability from the secular trend. The resulting peak frequencies of SSA components are listed in the Table 1 in Appendix 2.

SSA of the Tonga and Fiji coral $\delta^{18}O$ records indicates that between 13%-38% of the variance in each annual-averaged time series is in the IDPO with mean periods between ~9 and ~55 years. The percent variance of IDPO or ENSO varies in each core with core TM1 having the most pronounced IDPO variance at 38.4%, which is about twice as large as other cores. Besides the exceptionally large variance, the IDPO of TM1 exhibits a perceptibly different amplitude pattern from the other four cores. A possible explanation is that TM1 (near Nuku'alofa, in southern Tonga) lies at the boundary between two climate regions [*Salinger et al., 1995*] and is not only influenced by southeast trades winds but also by southern westerlies in the anticyclonic belt, while the four other corals are mainly controlled by southeast trade winds.

4. Discussion

4．1 Fiji-Tonga Interdecadal-Decadal Pacific Oscillation Index

Although these five coral cores were collected from a relatively small area (5°- 6° latitude -longitude) along the salinity front at the southeast boundary of SPCZ, the colonies grew in water of different depths in different lagoon/fore-reef settings. TH1 was collected in an isolated lagoon in 1 m water. TNI2 was collected from a colony in 3.5 m of water in a well flushed passage. TM1 grew more slowly (~4-12 mm/yr) than the other cores (~7-15 mm/yr) and contained residue pigments along the density bands from fungal growth. Fiji Core AB [*Linsley et al., 2006*] and Fiji core 1F [*Linsley et al., 2004*] were collected at 10 m depth within 200 m of each other in Savusavu Bay.

Although various biological effects in these diverse settings could potentially influence the skeletal δ^{18}O, we find that once the δ^{18}O series are corrected for differences in disequilibrium offset (as in *Linsley et al., 1999*), the annually averaged δ^{18}O series contain variability that can be explained as due predominately to climate variability. The IDPO variance (periods between ~9 and ~55 years) isolated from the δ^{18}O data of these five corals by SSA align reasonably well with each other back to 1650 (Figure 5). We argue that the reproducibility of the timing of the summed interdecadal and decadal components in the multi-coral δ^{18}O series demonstrates a locally consistent, environmental origin for this mode of δ^{18}O variability despite the variations in amplitude observed in some intervals. The five-coral Fiji-Tonga δ^{18}O series are from a region with a common climatic forcing related to the SPCZ and associated changes in SST and SSS (e.g. *Salinger et al., 1995; Folland et al., 2002*). Folland et al. [*2002*] identified this region of the southwest Pacific as a “center of action” for the PDO/IPO. This observation motivated us to develop a Tonga-Fiji IDPO index from the five-coral δ^{18}O series we have generated. To develop the index we averaged the IDPOs isolated from the five δ^{18}O series and assigned it the name Fiji-Tonga Interdecadal-Decadal Pacific Oscillation (F-T IDPO) Index. The correlation coefficients of the IDPO’s for all of the five cores are listed in Table 3. TM1 is least correlated with other cores. This could be due its more southerly location between two different climatic zones [*Salinger et al., 1995*] as previously mentioned and may mean that TM1 contains climatic information from both regions. We note that removing TM1 from the index does not modify our F-T IDPO significantly (see Appendix Figure 4). A 15-year running averaged correlation coefficient highlights intervals when the IDPO temporally aligns in each coral series and when they do not. Positive r-values indicate positive linear regressions.

Correlation Coefficient	TNI2	TM1	1F	AB
TH1	0.67	0.35	0.47	0.55
TNI2		0.23	0.49	0.37
TM1			0.24	0.53
1F				0.45

Table 3. The correlation coefficients (R value) between the Fiji and Tonga coral δ^{18}O IDPO indices. The low correlation between TNI2 and AB may be due to their inconsistency during ~1750-1760 and ~1700-1720.

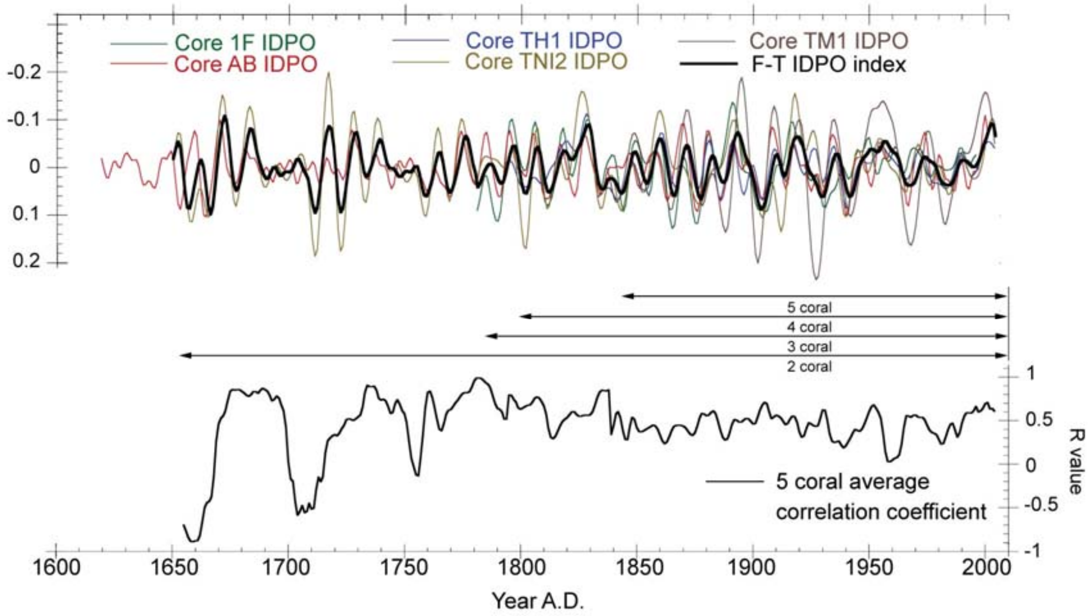


Figure 5. (Top) IDPO signals filtered by SSA of the five coral δ^{18}O series from Fiji and Tonga (thin colored lines), from which the average F-T IDPO index was created (thick black line).
(Bottom) The 15-year window running average correlation coefficients.

Potential chronological errors (1-2 years) in the δ^{18}O series may reduce the alignment (R values), but chronological error is not likely to happen in all five cores in the same period of time and would not modify the five-coral composite greatly. Furthermore, ENSO-band (~3-8 years) variability in each coral δ^{18}O series was used to double check the accuracy of the chronologies (see Appendix 3) and the alignment of the ENSO-band between the five corals supports the reliability of our chronologies back to at least 1715AD. We do note an ENSO-band offset between Fiji AB and Tonga TNI2 from 1715 to 1700AD and from 1650-1660AD which probably is interannual-scale chronology related. One motivation for developing a Fiji-Tonga IDPO index from multiple coral cores is to minimize the potential chronological errors and to reduce potential biological artifacts that affect individual δ^{18}O series, e.g., the variations in disequilibrium effect over time between coral colonies [*Juillet-Leclerc et al., 2005*]. We suggest the F-T IDPO index is more representative of interdecadal-decadal climatic variability in this region than any one of the five δ^{18}O series.

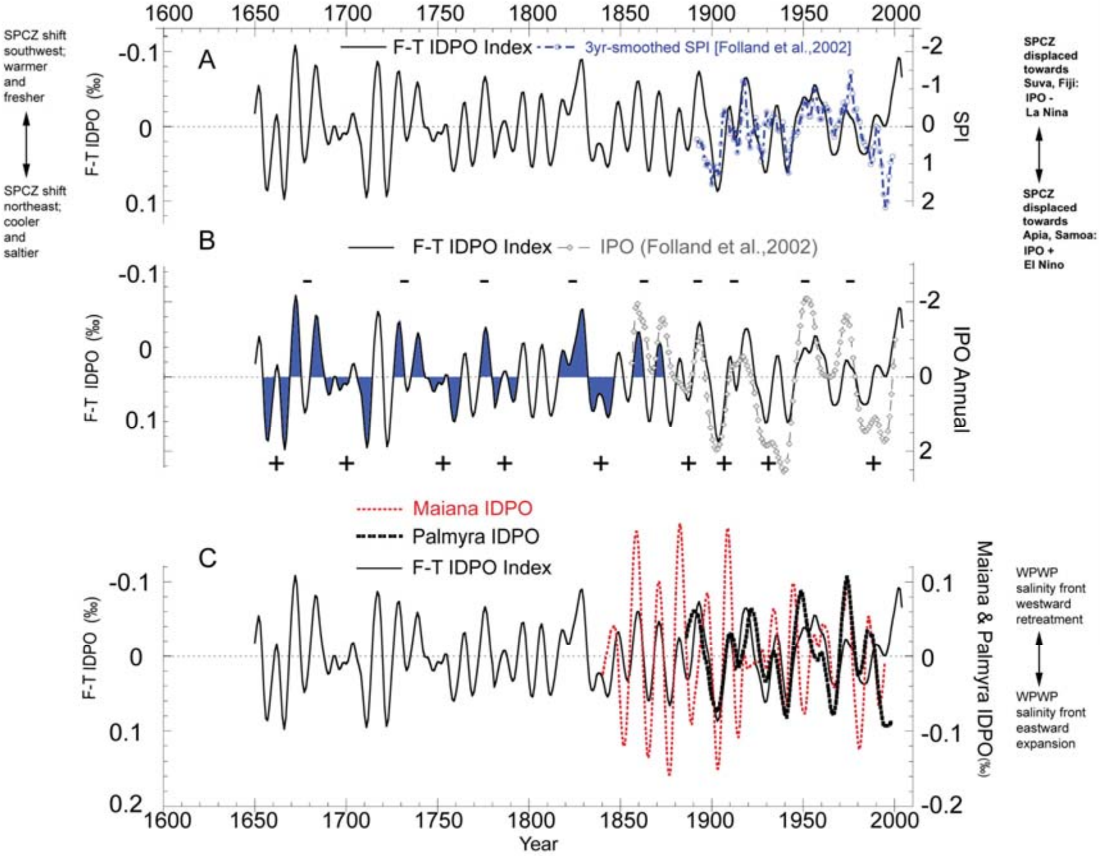


Figure 6. **A.)** The alignment between the F-T IDPO index and SPI [*Folland et al.,2002*]. **B.)** The F-T IDPO index compared with the IPO Index [*Folland et al, 2002*]. The colored areas show the IPO phases revealed by the F-T IDPO index back to 1650AD. "+" indicates positive IPO phases and "-" indicates negative IPO phases. After 1860, the IDPO phase changes are well recognized by instrumentally derived indices such as the IPO, PDO and SPI. **C.)** F-T IDPO with 2 coral δ^{18}O series from the equatorial Pacific, both filtered by SSA to isolate the IDPO band. Note that the scale of the right-hand Y-axis of the Maiana [Urban et al., 2000] and Palmyra [Cobb et al., 2001] δ^{18}O series have been reversed for an easier comparison with the left-hand Y-scale of the F-T IDPO index.

The coherence between this five-coral δ^{18}O IDOP composite and the SPI [*Folland et al., 2002*] supports the reliability of this coral $\delta^{18}O$ -based IDPO index and the method of SSA de-convolution to reconstruct interdecadal to decadal-scale climate changes in this region (Figure 6A). The correlation coefficient between the 3-year smoothed SPI and F-T IDPO is 0.39. Note that SPI combines both ENSO and IDPO variances [*Folland et al., 2002*]. The anti-phase correlation in the last 10 years may be due to the two intense El Niño events in this time period (personal communication with J. Salinger). The low R value may be caused by the ENSO component in the SPI that is excluded from the F-T IDPO index. Positive SPI values indicate a northeast displacement of SPCZ towards Apia creating cooler and saltier conditions in the study area (Fiji and Tonga), which accords with times of more positive coral $\delta^{18}O$ in the F-T IDPO index. The consistency between the two indices, one oceanic and one atmospheric, confirms the climatic origin of the IDPO signal isolated in our five-coral composite index and the synchronous IDPO-scale oceanic and atmospheric changes in this area.

To evaluate the five-coral composite IDPO index further, we also compare it with the IPO index by Folland et al. [*2002*], which is defined as the third Empirical Orthogonal Function (EOF) of 13-year low-pass filtered Pacific SST over the period 1911-1995. The IPO is highly correlated with the PDO Index for the North Pacific, and Folland et al. [*2002*] suggested that the IPO could be regarded as the Pacific-wife manifestation of the PDO. The consistency between F-T IDPO index and IPO (Figure 6B) indicates that the interdecadal to decadal-scale displacement of SPCZ shown by F-T IDPO is also related to the IPO.

The interdecadal-decadal Pacific climate oscillation is relatively well recognized after 1860AD. However, prior to this time, little is known about interdecadal-decadal scale variability [e.g. *Mantua et al., 1997; Power et al., 1999; Hare and Mantua, 2000*]. Before 1860AD, our F-T IDPO index shows a regular progression of positive and negative IPO phases. From the ~1850 to mid-1830s the IPO was in a positive phase (warmer equatorial Pacific-cooler and saltier SPCZ region) following a pronounced negative IPO period (cooler equatorial Pacific-warmer and fresher SPCZ region) during the mid-1810s to 1830. In 1780s to mid-1790s the IPO was positive and from mid-1760s to 1780 negative. From the mid-1740s to the mid-1760s, a positive IPO existed, after a negative IPO phase from mid-1720s to mid-1740s. A prolonged positive IPO phase lasted for ~ 30 years from the mid-1680s to the mid 1710s and is proceeded by a pronounced negative IPO signal during ~1670-1680. The earliest IDPO phase in the F-T IDPO index is a positive phase from ~1650 to ~1670. It is interesting that the IDPO oscillation appears to have been muted during ~1740 to mid-1750s and also during mid-1680s to mid-1700s. These amplitude changes are observed in both of the coral records that span these intervals (AB and TNI2) (Figure 5) and were abrupt with pronounced IDPO variation before and after each period.

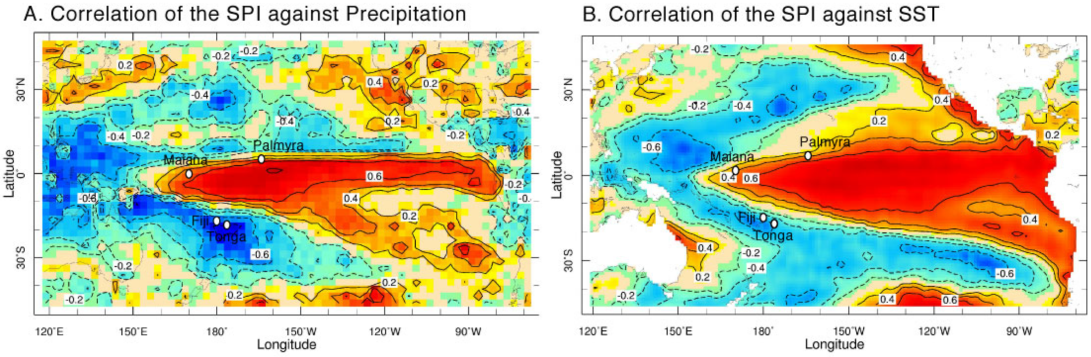
This coral δ^{18}O-based IDPO index extends the existing instrumentally derived interdecadal-decadal oscillation indices, e.g. IPO and PDO, back to 1650AD, providing a reliable reference for the future study of lower frequency climatic oscillations.

4.2 F-T IDPO in-phase in SPCZ and WPWP

Comparison of the IDPO signal at Fiji and Tonga with the IDPO signal in two equatorial coral δ^{18}O records at Palmyra [*Cobb et al., 2001*] and Maiana [*Urban et al., 2000*], yields a high anti-phase correlation (R= -0.51 between Palmyra and F-T IDPO; R= -0.41 between Maiana and F-T IDPO). This anti-phase correlation is expected because Palmyra and Maiana are both located in an area were SST variability positively correlated to the IPO while SST in the Fiji and Tonga region is negatively correlated with the IPO (Figure 1) [*Folland et al., 2002*]. Palmyra (5.9°N, 162.1°W) is located in the center of the tropical Pacific but outside of the WPWP and 1° north of the Nino 3.4 region (shaded box in Figure 1), where the ENSO has a larger amplitude than the interdecadal-decadal oscillation [*Cobb et al., 2001*]. If the coral δ^{18}O changes at Palmyra are interpreted strictly as temperature (using a range of published coral temperature-δ^{18}O regressions (0.17-0.23‰/°C) [*Reynolds and Smith, 1984; Gagan et al., 1994*]), the total range of the Palmyra IDPO (~0.2‰) during 1998-1886 corresponds to ~1°C. This is the same order of magnitude as the IDPO variability derived from Nino 3.4 SST anomalies [*Kaplan et al., 1998*]. This match suggests that the SST variability is the dominant factor affecting the coral δ^{18}O values in Palmyra over interdecadal-decadal time scales. In other words, warmer and fresher conditions in Tonga and Fiji

(SPCZ positioned further south-west) happen simultaneously with cooler conditions in the central equatorial Pacific on IDPO time-scales.

In contrast to Palmyra, the $\delta^{18}O$ signal in Maiana records both SST and the $\delta^{18}O_{seawater}$ (linearly related to salinity) [*Urban et al., 2000*]. Maiana (01°N, 173°E) is located 25° west of Palmyra and is near the position of the salinity front on the eastern edge of West Pacific Warm Pool (WPWP)[Picaut et al., 1996]. Maiana $\delta^{18}O$ IDPO contains a similar pattern as Palmyra and in an opposite phase with F-T IDPO. When a south-west shift of SPCZ creates locally warmer and fresher conditions (more negative $\delta^{18}O$ value) at Fiji and Tonga, it is accompanied by cooler and saltier conditions at Maiana caused by less rainfall and/or a westward retreat of the WPWP.


A. Correlation of the SPI against Precipitation

B. Correlation of the SPI against SST

Figure 7. **A.**) Correlation of SPCZ position index (SPI) [*from Folland et al., 2002*] against precipitation over the interval from 1979 to 2000 (R-values). Note that the SPI is based on the air pressure difference between Apia (Samoa) and Suva (Fiji). **B.**) Correlation of SPCZ position index (SPI)[*from Folland et al., 2002*] against SST over interval from 1981 to 2000 (r-values). August to July annual means of precipitation and SST are computed from monthly analyses by Xie and Arkin [*1996*] and Reynolds et al [*2001*], respectively. Note the location of our other study sites at Fiji, Tonga and coral-climate study sites at Maiana [*Urban et al., 2002*] and Palmyra [*Cobb et al., 2001*].

The eastward (westward) migration of the warm pool during the El Niño (La Niña) phase of ENSO is well characterized by instrumental data [*Picaut et al., 1996; Delcroix and McPhaden, 200;*]. Due to the scarcity of long-term instrumental data, the interdecadal-decadal scale displacement of the WPWP eastern salinity front is less well understood. Recently, Delcroix et al. *[2007]* observed the presence of a PDO-like SSS signal in the WPWP, the SPCZ and the Equatorial Cold Tongue during 1970-2003. Figure 7 shows the regression pattern (R values) of the precipitation over the interval from 1979 to 2000 [*Xie et al., 1996*] and SST over the interval from 1981 to 2000

[*Reynolds et al, 2001*] on the SPCZ position index (SPI) [*Folland et al., 2002*]. Negative correlations (dashed contours) in Figure 7 reflect below average precipitation and SST during positive SPI and positive correlations (thin solid contours) indicate above average precipitation and SST during positive SPI. From the figure, it is clear that precipitation and SST regimes in the Fiji-Tonga (SPCZ) area are reversed from those within Maiana-Palmyra area of the central equatorial Pacific. This observation agrees with the negative correlation between the five-coral composite F-T IDPO index and Maiana-Palmyra, as discussed above.

The precipitation changes in a positive SPI are of the same magnitude in Maiana and Palmyra (Figure 7). In other words, the SSS variance due to precipitation is comparable in these two places. This is interesting since variability in coralline δ^{18}O in Maiana is due to both SST and SSS while at Palmyra it is due mostly to SST [*Urban et al. 2000; Cobb et al., 2001*]. Presently, Maiana is located on the WPWP eastern salinity front while Palmyra is in the center of the equatorial Pacific in a region without a pronounced east-west SSS gradient and away from the WPWP. The migration of the WPWP salinity front will modify SSS near Maiana, but not at Palmyra. An implication of this is that the SSS changes at Maiana are mainly the result of the salinity front displacement, and not precipitation. There is evidence that the excess or deficit of rainfall in the past could cause considerable local SSS variance [*Delcroix et al., 2007*], but this can be compensated for by other factors such as evaporation (enhanced convection will bring greater-than-average rainfall but at the same time the increased temperature will accelerate evaporation) and the possible horizontal and vertical advection caused by thermocline displacement. We argue that the SSS variance observed in coral δ^{18}O in Fiji-Tonga and Maiana is largely the result of shifts in the SPCZ-related and WPWP-related salinity fronts, respectively. The coherent δ^{18}O IDPO indices from Maiana and Fiji-Tonga coral δ^{18}O suggest that significant interdecadal-decadal changes in the eastern salinity front of WPWP are in-phase with SPCZ shifts and SPCZ salinity front movement in the Tonga and Fiji region. In a positive IPO phase, the SPCZ shifts northeast creating a cooler and saltier conditions locally and simultaneously the WPWP salinity front expands eastward with warm and fresher conditions in the middle equatorial Pacific.

5. Summary

We have developed a coral $\delta^{18}O$ Fiji-Tonga Interdecadal-decadal Pacific Oscillation (F-T IDPO) index based on annually averaged $\delta^{18}O$ time series from five corals from Fiji and Tonga (16°49'S-21°02'S; 179°14'E-174°43'W). The F-T IDPO index spans the period 1650-2004 AD and has been shown to closely track the IPO and SPI indices. Thus, this index effectively extends our knowledge of interdecadal-decadal ocean-climate variability for 250 years prior to the instrumental record. We note that during ~1740 to mid-1750s and during mid-1680s to mid-1700s the amplitude of the IDPO variability diminished sharply. We also observe an anti-correlation with coral $\delta^{18}O$ IDPO components isolated from other equatorial Pacific coral records at Maiana and Palmyra. This suggests the simultaneous but opposite behavior between the SPCZ and western equatorial Pacific regions. By examining the pattern of precipitation response in Maiana and Palmyra to a PDO positive phase, we conclude that at interdecadal-decadal time-scales, it is the displacement of a salinity front at the eastern WPWP, instead of the precipitation change, that contributes to the SSS variance recorded by coralline $\delta^{18}O$ series at Maiana. This observation suggests that the anti-phase IDPO variations between the equatorial Pacific and the SPCZ region can be interpreted as salinity fronts shifting in opposing directions in the eastern WPWP and the SPCZ. In other words, the interdecadal-decadal eastward expansion (westward contraction) of the WPWP salinity front occurs at the same time as the northeast (southwest) shift of the SPCZ salinity front.

References

Carton, J. A.: A simple ocean data assimilation analysis of the global upper ocean 1950-95. Part 1: Methodology. *Journal of Physical Oceanography,* 30, p. 294-309, 2000a.

Carton, J. A.:A simple ocean data assimilation analysis of the global upper ocean 1950-95. Part 2: Results. *Journal of Physical Oceanography,* 30, p. 311-326, 2000b.

Cobb, K. M.; Charles; C. D. and Hunter, D. E.: A central tropical Pacific coral demonstrates Pacific, Indian, and Atlantic decadal climate connections, *Geophysical Research Letters,* 28, No. 11, p.2209-2212, 2001.

Cobb, K. M.; Charles, C. D.; Cheng, H. and Edwards R. L., El Niño/Southern Oscillation and tropical Pacific climate during the last millennium, *Nature,* 424, No. 6946, p. 271-276, 2003.

Crowley, T. J.; Quinn, T. M. and Hyde, W. T.: Validation of coral temperature calibrations, *Paleoceanography,* 14, Issue 5, p. 605-615, 1999.

Delcroix, T. and McPhaden M. J.: Interannual sea surface salinity and temperature changes in the western Pacific warm pool during 1992-2000, *Journal of Geophysical Research.*, 107(C12), 8002, doi: 10.1029/2001JC000862, 2002.

Delcroix, T.; McPhaden M. J.; Dessier A. and Gouriou Y.: Time and space scales for sea surface salinity in the tropical oceans, *Deep-sea research. Part I.* 52(5), p. 787-813, 2005.

Delcroix, T.; Cravatte S. and McPhaden, M. J.: Decadal variations and trends in tropical Pacific sea surface salinity since 1970, *Journal of Geophysical Research,* 112, C03012, doi:10.1029/2006JC003801, 2007.

Dunbar, R. B.; Wellington, G. M.; Colgan, M. W.; Glynn, P. W.: Eastern Pacific sea surface temperature since 1600 A.D.: The δ^{18}O record or climate variability in Galápagos corals, *Paleoceanography,* 9, Issue 2, p. 291-316, 1994.

Epstein, S.; Buchsbaum, R.; Lowenstam, H. and Urey, H.C.: Revised Carbonate-Water Isotopic Temperature Scale, *Bulletin of the Geologcal Society of America*, 64, p. 1315-1326, 1953.

Evans, M. N.; Kaplan, A. and Cane, M. A.: Intercomparison of coral oxygen isotope data and historical sea surface temperature (SST): Potential for coral-based SST field reconstructions, *Paleoceanography,* 15, Issue 5, p. 551-564, 2000.

Fairbanks, R.G.; Evans, M. N; Rubenstone, J. L.; Broad, K.; Moore M.D. and Charles C.D.: Evaluating climate indices and their geochemical proxies measured in corals, *Coral Reefs,* 16, p.93-100, 1997.

Folland, C. K.; Renwick, J. A.; Salinger, M. J. and Mullan A. B.: Relative influences of the Interdecadal Pacific Oscillation and ENSO on the South Pacific Convergence Zone, *Geophysical Research Letters*, 29. No.13, 10.1029/2001GL014201, 2002.

Gagan, M. K.; Chivas, A. R.; Isdale, P. J., High-resolution isotopic records from corals using ocean temperature and mass-spawning chronometers, *Earth and Planetary Science Letters*, 121, no. 3/4, p. 549-558, 1994

Guilderson, T. P. and Schrag D.P.: Reliability of coral isotope records from the western Pacific warm pool: A comparison using age-optimized records, *Paleoceanography,* 14, 457-464, 1999.

Gouriou, Y. and Delcroix T.: Seasonal and ENSO variations of sea surface salinity and temperature in the South Pacific Convergence Zone during 1976-20000, *Journal of Geophysical Research*, 107(C12), 3185, doi: 110.1029/2001JC000830, 2002.

Hare, S. and Mantua N.: Empirical evidence for North Pacific regime shifts in 1977 and 1989, *Prog. Oceanography*, 47, p. 103–146, 2000.

Jones, P. D.; Briffa, K.R.; Barnett, T.P.; Tett, S.F.B.: High-resolution palaeoclimatic records for the last millennium: interpretation, integration and comparison with General Circulation Model control-run temperatures, *The Holocene*, 8, No.4, p. 455-471(17), 1998.

Juillet-Leclerc, A.; Reynaud, S.; Rollion-Bard, C.; Cuif, J.P.; Dauphin, Y.; Blamart, D.; Ferrier-Pages, C. and Allemand, D., The relative impact of vital effect and environmental factors on the coral skeleton oxygen isotope ratio. *Geophysical Research Abstracts*, 7, 06587, 1607-7962/gra/ EGU05-A-06587, 2005.

Juillet-Leclerc, A.; Thiria, S.; Naveau, P.; Delcroix, T.; Le Bec, N.; Blamart, D. and Corrège, T., SPCZ migration and ENSO events during the 20th century as revealed by climate proxies from a Fiji coral, *Geophysical Research Letters,* 33, Issue 17, CiteID L17710, 2006.

Kaplan, A.; Cane, M.; Kushnir, Y.; Clement, A.; Blumenthal, M. and Rajagopalan, B.: Analyses of global sea surface temperature 1856-1991, *Journal of Geophysical Research,* 103, 18,567-589,1998.

Linsley,B. K.; Messier, R. G. and Dunbar, R. B.: Assessing between-colony oxygen isotope variability in the coral *Porites lobata* at Clipperton Atoll, *Coral Reefs,* 18(1), p. 13-27, 1999.

Linsley, B. K.; Wellington, G. M. and Schrag, D. P.: Decadal sea surface temperature variability in the subtropical Pacific from 1726 to 1997 A. D., *Science*, 290, p. 1145-1148, 2000.

Linsley, B. K.; Wellington, G. M.; Schrag, D. P.; Ren, L.; Salinger, M. J. and Tudhope, A. W., Geochemical evidence from corals for changes in the amplitude and spatial pattern of South Pacific interdecadal climate variability over the last 300 years, *Climate Dynamics,* 22, p. 1-11, 2004.

Linsley, B. K.; Kaplan, A.; Gouriou, Y.; Salinger, J.; deMenocal, P. B.; Wellington, G. M. and Howe, S. S: Tracking the extent of the South Pacific Convergence Zone since the early 1600s, *Geochemistry Geophysics Geosystems,* 7, Issue 5, CiteID Q05003, 2006.

Mantua, N.; Hare, S.; Zhang, Y.; Wallace, J. and Francis, R.: A Pacific interdecadal climate oscillation with impacts on salmon productions, *Bulletin of the American Meteorological Society,* 78, p. 1069– 1079, 1997.

North,G.R.; Bell,T.L.; Cahalan, R.F. and Moeng, F.J.:Sampling Errors in the Estimation of Empirical Orthogonal Functions, *Monthly Weather Review*, 110, Issue 7, p. 699–706, 1982.

Picaut J.; Ioualalen, M.; Menkes, C.; Delcroix, T. and McPhaden, M.: Mechanism of the zonal displacements of the Pacific Warm Pool, implications for ENSO, *Science, 274*, p. 1486-1489, 1996.

Power, S.; Casey, T.; Folland, C.; Coleman, A. and Metha, V.: Interdecadal modulation of the impact of ENSO on Australia, *Climate Dynamics,* 15, p. 319–324, 1999.

Rayner, N. A.; Parker, D. E.; Horton, E. B.; Folland, C.K.; Alexander, L.V.; Rowell, D. P.; Kent, E. C. and Kaplan, A.: Global analyses of sea surface temperature, sea ice, and night marine air temperature since the late nineteenth century. *Journal of Geophysical Research,* 108, 4407 10.1029/2002JD002670, 2002.

Reynolds, R.W. and Smith, T. M.: Improved global sea surface temperature analyses using optimum interpolation, *Journal of Climate*, 7, p. 929-948, 1994.

Reynolds, R.W.; Rayner, N.A.; Smith, T.M.; Stokes, D.C. and Wang W.: An Improved in-situ and Satellite SST Analysis for climate, *Journal of Climate,* 15, p. 1609-1625, 2001.

Salinger, M. J.; Basher, R.E.; Fitzharris, B. B.; Hay, J. E.; Jones, P. D.; Macvergh, J. P. and Schmidely-Leleu, I.: Climate trends in the South-west Pacific, *International Journal of Climatology,* 15(3), p. 285-302, 1995.

Tudhope, A.W.; Shimmield, G..B.; Chilcott, C.P.; Jebb, M.; Fallick, A.E. and Dalgleish, A.N.: Recent changes in climate in the far western equatorial Pacific and their relationship to the Southern Oscillation: Oxygen isotope records from massive corals, Papua New Quinea, *Earth and Planetary Science letter,* 136, p. 575-590, 1995.

Tudhope, A. W.; Chilcott, C. P.; McCulloch, M. T.; Cook E. R.; Chappell, J.; Ellam, R. M.; Lea D. W.; Lough J. M. and Shimmield, G. B.: Variability in the El Niño Southern Oscillation Through a Glacial-Interglacial Cycle, *Science*, 291, p. 1511-1517, 2001.

Urban, F. E.; Cole, J. E. and Overpeck, J. T.: Influence of mean climate change on climate variability from a 155-year tropical Pacific coral record. *Nature*, 407, p. 989-993. 2000.

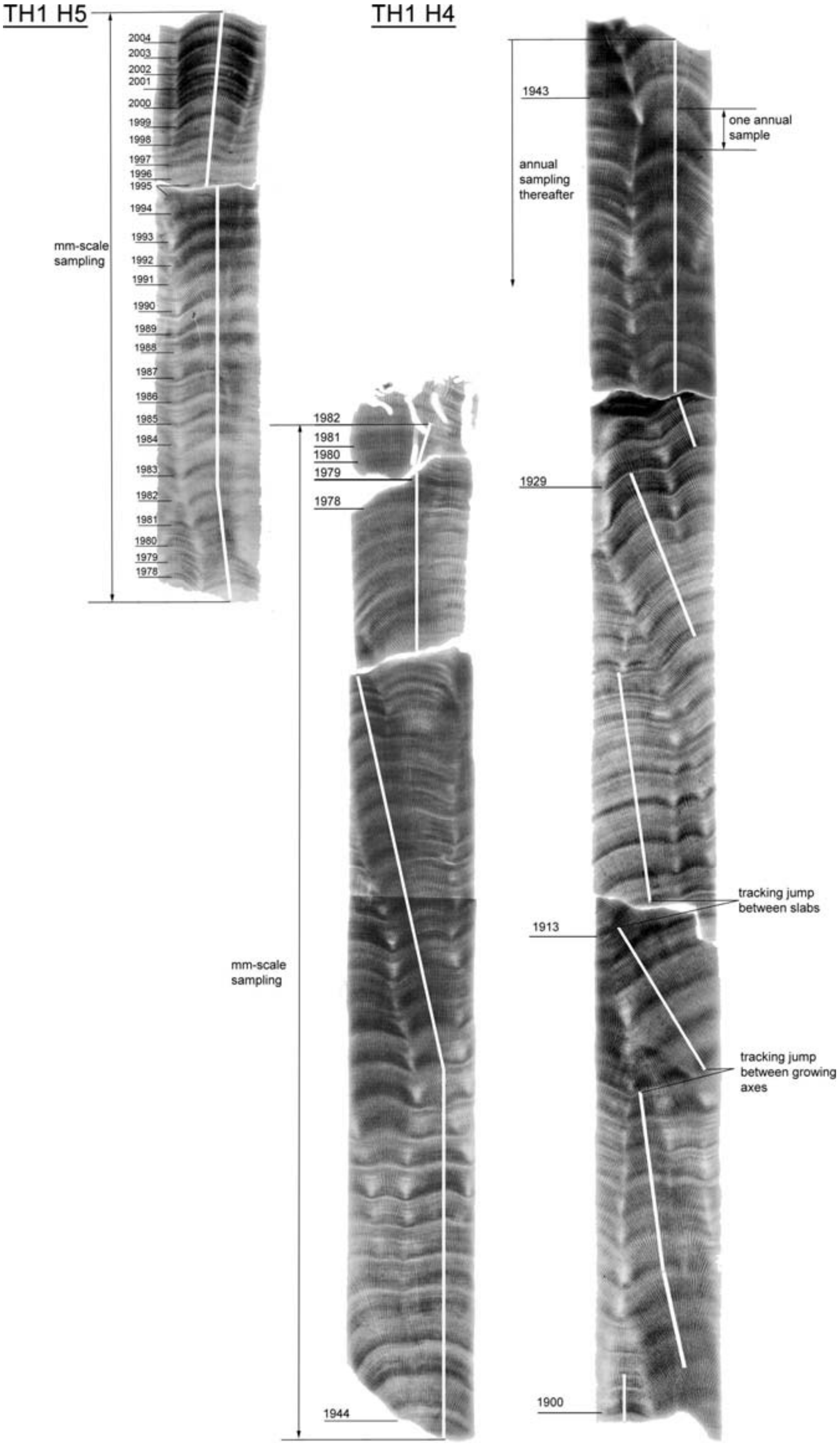
Vautard R. and Ghil, M.: Singular spectrum analysis in nonlinear dynamics, with applications to paleoclimatic time series, *Physica D*: p. 395-424, 1989.

Vautard, R.; Yiou, P. and Ghil, M.: Singular-spectrum analysis: a toolkit for short, noisy chaotic signals', *Physica D*, 58, p. 95-126, 1992.

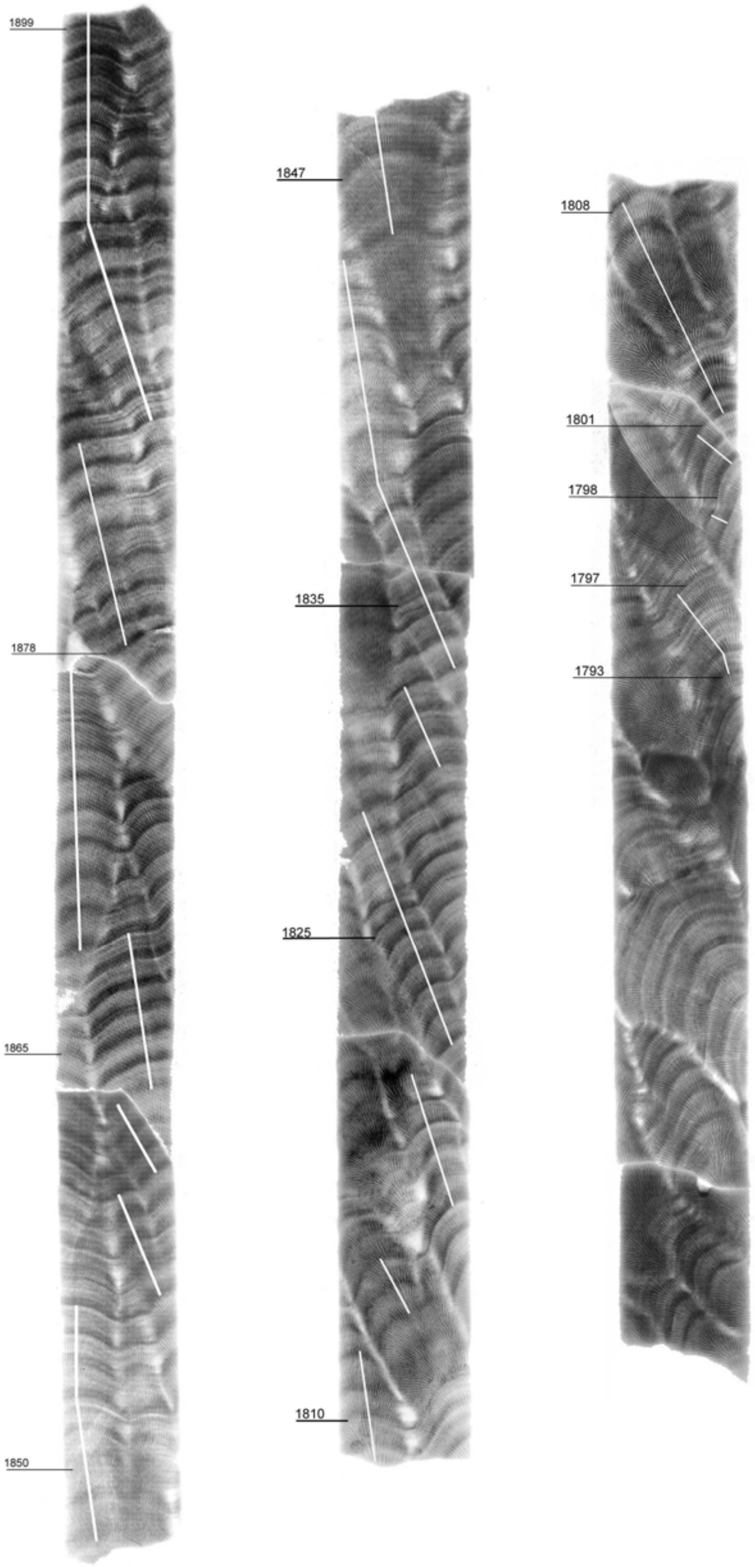
Wellington, G.M.; Dunbar, R. B. and Merlen, G.: Calibration of stable oxygen isotope signatures in Galapagos corals, *Paleoceanography* 11, p. 467-480, 1996.

Xie, P. and Arkin, P. A.: Analyses of global monthly precipitation using gauge observations, satellite estimates and numerical model predictions, *Journal of Climate*, 9, p. 840-858, 1996.

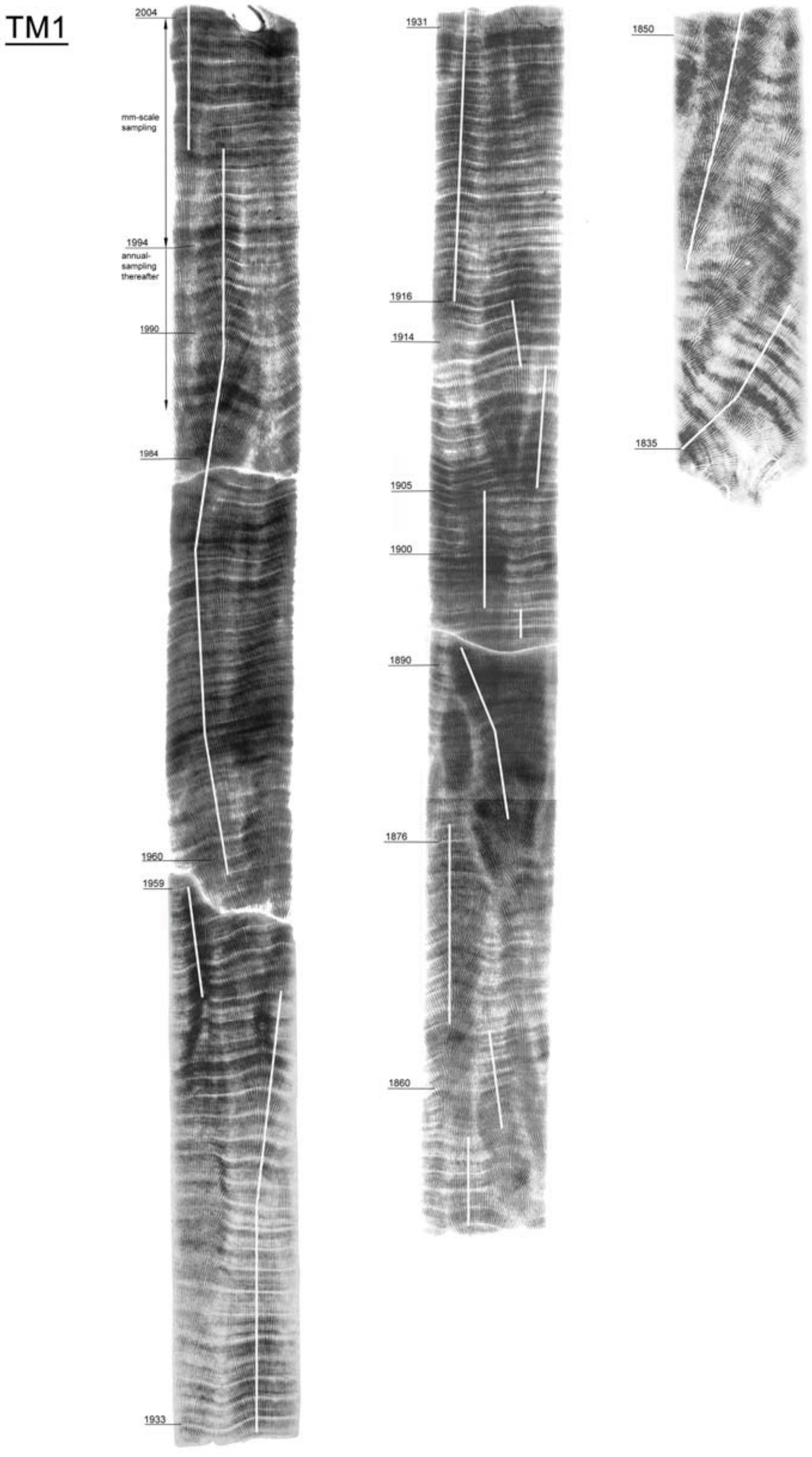
Appendix 1 Sampling Techniques



Appendix Figure 1. The X-ray photos of TH1-H5, TH1-H4 and TM1



Appendix Figure 1 (continued). The X-ray photos of TH1-H5, TH1-H4 and TM1



Appendix Figure 1 (continued). The X-ray photos of TH1-H5, TH1-H4 and TM1

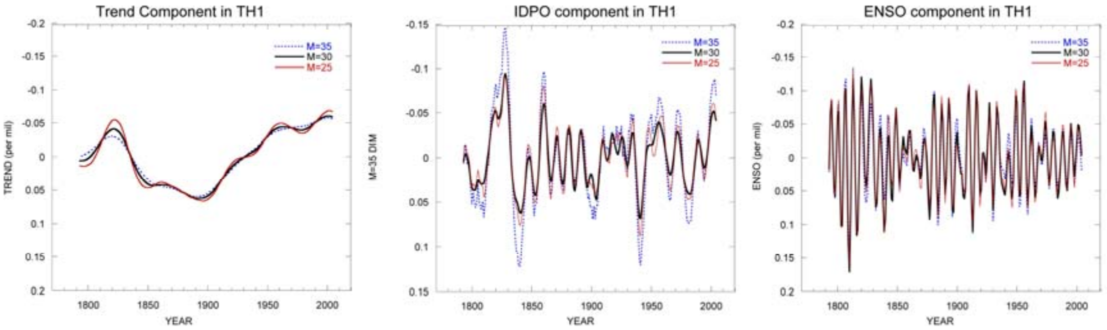
Sampling track jumps on coral slabs were made in two situations, (1) to keep the sampling along the growth axis or (2) to avoid overlaps between the slab breaks. In both situations, the sampling track jump from one growing axis to another was made along the same density band. In this way, no obvious data gap at track jumps occurred.

In most cores, density bands are not distinct throughout the entire core. In the sections where the density bands were not clear enough to parse the coral growth annually by the naked eye or with an ultraviolet lamp, we adopted a mm-scale sampling approach and used the oxygen isotope ($\delta^{18}O$) annual cycle to determine the annual increments and to calculate a $\delta^{18}O$ annual-average value for those years.

The annual sampling and the alternate sampling between annual-scale and mm-scale may cause chronological problems, if the denser bands are not always deposited at the same time of year, In the modern sections of the Fiji and Tonga corals examined, the dense bands are accreted in January-February during the warmest time of the year. For example, if a dense band was deposited in January of a certain year and the following dense band was deposited in March of the next year, the time span of the first year would be 14 months and the annual average value of this year would come from 14 months of growth instead of from 12 months of growth. This small potential chronology issue should not be a problem, since we are interested in oscillations with frequencies ~9-55 years and the deviation caused by annual sampling is less than one year. Furthermore, the density bands appear to be deposited at roughly the same time of the year based on their fairly even distribution through time. Given these observations, we treated the averaged $\delta^{18}O$ values as 12-month averaged values in this research. From the coherence between the interdecadal-decadal indices (SPI, IPO) and our five-coral IDPO index, this annual-sampling method appears to be reliable.

Appendix 2 SSA Analysis

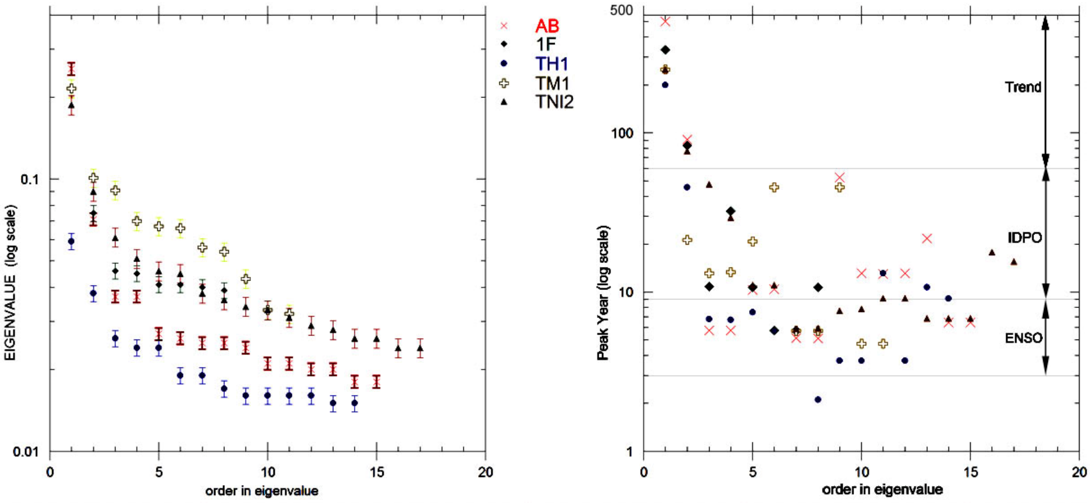
2.1 The Choice of Window Width



Appendix Figure 2. Trend, IDPO and ENSO component plots of TH1 with different window widths (M=25yrs, 30yrs and 35yrs).

In SSA, the choice of window width (M) is a tradeoff between resolution and significance. If M is too small, the coarse resolution may cause several neighboring peaks in the spectrum to combine and merge into one peak (with high statistical confidence). On the contrary, if there is an intermittent oscillation, reflected by a broad spectral peak, a large M (high resolution) will split the peak into several components with neighboring frequencies. Due to the different temporal lengths of the five corals, we adopted a different M for each coral. Generally, the longer the time record, the larger the M is set. We used different window widths over a reasonable range to evaluate the stable features of the eigensets. Figure 2 gives an example of the output component series of core TH1 with M=25, 30 and 35 years. As M increases, the number of the resulting eigen-values increases from 10 (M=25), to 14(M=30) to 16 (M=35) because some of the intermittent oscillations are split into more than one peak. After we categorized these peaks into trend, IDPO and ENSO components, the component series do not differ much from M=25 to M=35, despite the number of the eigen-values. Other cores show similar results. We concluded that within a reasonable range, the output analysis by SSA is statistically stable and the choice of window width does not affect our arguments.

2.2 SSA Output result



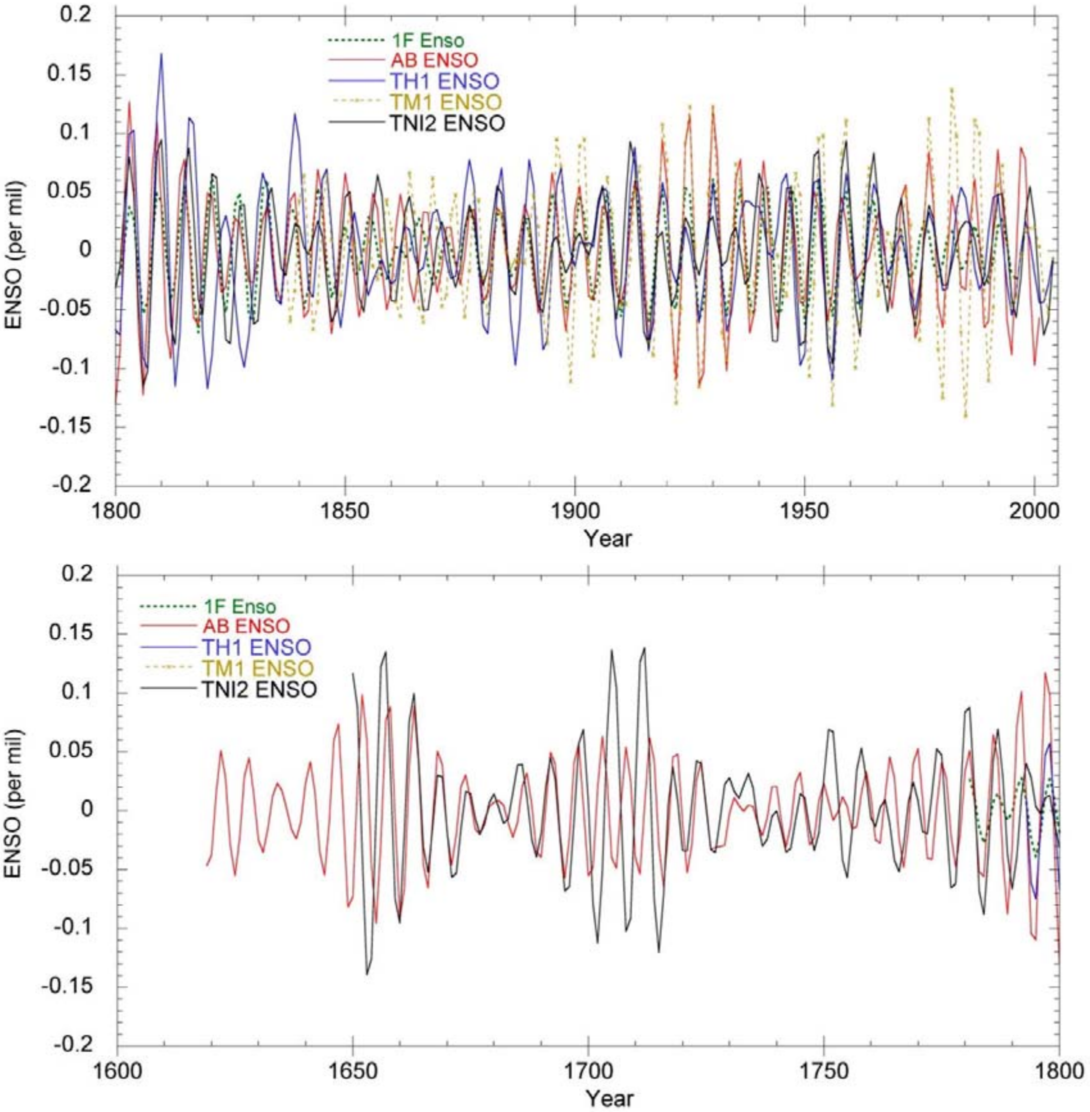
Appendix Figure 3. (Left) SSA eigenvalue spectra for the five-coral oxygen isotope series, with 95% confidence limits based on the criterion of *North et al. (1982)*. (Right) The output result in peak frequencies of SSA components. The larger the order in eigenvalues, the less significant the signal is in the total variance of each stable isotope series. The slowly decreasing ramp in every series corresponds to the white-noise dominated components *[Vautard et al., 1992]* (decreasing significance in the total variance of each series). The tails of the spectra are not flat, due to the finiteness of the data.

Core		Peak Frequencies of SSA components (signal strength: strong↔weak)						Variance
TH1	Trend							13.5%
	IDPO	45yr	13yr	11yr	9yr			**19.0%**
	ENSO	7yr	6yr	4yr				25.8%
TNI2	Trend	250	76					23.6%
	IDPO	48yr	30yr	18yr	16yr	11yr	9yr	**26.5%**
	ENSO	8yr	7yr	6yr				18.9%
TM1	Trend							18.9%
	IDPO	45yr	21yr	12yr				**38.4%**
	ENSO	6yr	5yr					15.3%
1F	Trend							52.1%
	IDPO	32yr	11yr					**13.1%**
	ENSO	6yr						6.2%
AB	Trend							35.5%
	IDPO	53yr	22yr	13yr	10yr			**17. 3%**
	ENSO	6yr						17.3%
Maiana	Trend							40.0%
	IDPO	13yr						**15.2%**
	ENSO	7yr	6yr	4yr	3yr			26.2%
Palmyra	Trend							23.5%
	IDPO	33yr	13yr					**13.4%**
	ENSO							23.1%

Appendix Table 1. List of Peak Frequencies of SSA components.

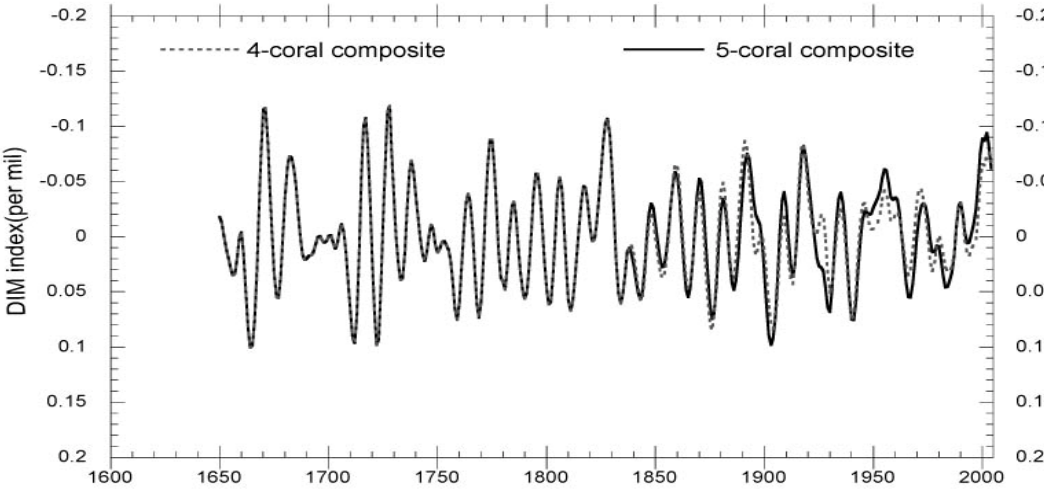
We divided the resulting peak frequencies into three groups: trend, IDPO and ENSO. ENSO is set to be ~3-8 years. The biennial ENSO effect has a fingerprint on the core TH1 with a ~8% variance. As TH1 is the only core that shows the biennial signal, we did not include it in the ENSO component. Since our research is on the interdecadal-decadal oscillations, this exclusion will not influence our conclusions. Interdecadal-decadal variance at about the same level of significance as ENSO is retained in the ~9-55 years band width. The mechanism of this low frequency component is still under debate and its frequency range is not well defined. Folland et al. *[2002]* argues the equivalence of the IPO and PDO in describing Pacific-wide variations in ocean climate. Following this idea, we included all of the signals between ENSO and secular trends in our analysis without separating the decadal and interdecadal signals. The secular trend is the largest component in all the cores with a peak frequency >~75 years.

Appendix 3. The ENSO-band Plots of the Five Corals



Appendix Figure 4. ENSO band plot of five Fiji-Tonga cores separated by SSA used to double check the chronologies of the coral cores. (Top) 1800-2005 (Bottom) 1617-1800.

Appendix 4. Comparison Between Five-coral Composite and Four-coral Composite



Appendix Figure 5. The four-coral composite (dashed line) and five-coral composite (solid line) were calculated using the same procedure from the same dataset, though the four-coral composite does not include core TM1. The two indices do not differ significantly either in amplitude or frequency (TM1 spans 2004-1836, so the two are identical before 1836). Given that, we adopt the five-coral composite to avoid artificial selection of the coral series composing constituting the F-T IDPO index.

Appendix 5. δ^{13}C and δ^{18}O data of Tonga cores TH1-H5, TH1 H4 and TM1

δ^{13}C and δ^{18}O data of Tonga cores TH1-H5

Depth (mm)	Year A.D.	δ^{13}C	δ^{18}O
1	2004.808	-2.06	-4.94
3	2004.608	-1.79	-4.92
5	2004.408	-2.16	-5.14
7	2004.208	-1.50	-5.39
9	2004.042	-0.76	-5.33
11	2003.875	-2.19	-4.90
13	2003.708	-2.26	-4.61
15	2003.542	-2.31	-4.74
17	2003.375	-2.03	-5.16
19	2003.208	-0.99	-5.25
21	2003.208	-1.09	-5.27
23	2003.008	-2.40	-4.98
25	2002.808	-2.42	-4.80
27	2002.608	-2.46	-5.04
29	2002.408	-2.03	-5.17
31	2002.208	-2.24	-5.46
33	2002.042	-1.12	-5.31
35	2001.875	-2.04	-4.99
37	2001.708	-2.19	-4.85
39	2001.542	-2.15	-4.93
41	2001.375	-2.85	-5.11
43	2001.208	-1.51	-5.51
45	2000.958	-1.77	-5.14
47	2000.708	-1.93	-4.92
49	2000.458	-1.01	-4.67
51	2000.208	-2.39	-5.50
53	2000.042	-1.69	-5.40
55	1999.875	-2.45	-5.06
57	1999.708	-2.58	-4.86
59	1999.542	-2.58	-5.02
61	1999.375	-2.25	-5.10
63	1999.208	-2.01	-5.29
65	1999.065	-1.58	-5.27
67	1998.923	-2.34	-4.95
69	1998.780	-2.53	-4.56
71	1998.637	-2.81	-4.52
73	1998.494	-2.72	-4.66
75	1998.351	-2.53	-4.82
77	1998.208	-2.08	-5.01
79	1998.083	-1.45	-4.96
81	1997.958	-2.18	-4.77
83	1997.833	-2.56	-4.57
85	1997.708	-2.98	-4.54
87	1997.583	-2.64	-4.78
89	1997.458	-2.17	-5.16
91	1997.333	-1.37	-5.28
93	1997.208	-1.27	-5.35
95	1997.042	-2.03	-5.05
97	1996.875	-2.53	-4.95
99	1996.708	-2.38	-4.88
101	1996.542	-2.43	-4.99
103	1996.375	-2.49	-5.13
105	1996.208	-1.84	-5.44
107	1996.042	-1.14	-5.39
109	1995.875	-1.78	-5.23
111	1995.708	-2.38	-4.98
113	1995.542	-2.51	-4.83
115	1995.375	-2.68	-4.88
117	1995.208	-2.64	-4.96
119	1995.208	-1.99	-5.25
121	1995.065	-1.75	-5.16
123	1994.923	-2.18	-4.94
125	1994.780	-2.69	-4.59
127	1994.637	-2.36	-4.70
129	1994.494	-2.37	-4.66
131	1994.351	-2.01	-5.07
133	1994.208	-1.30	-5.22
135	1994.042	-1.24	-5.07

137	1993.875	-2.41	-4.71
139	1993.708	-2.62	-4.60
141	1993.542	-2.42	-4.86
143	1993.375	-1.86	-5.17
145	1993.208	-1.52	-5.18
147	1993.042	-2.03	-4.92
149	1992.875	-2.39	-4.75
151	1992.708	-2.42	-4.64
153	1992.542	-2.44	-4.90
155	1992.375	-2.06	-4.92
157	1992.208	-1.39	-5.18
159	1992.065	-1.34	-5.09
161	1991.923	-2.21	-4.89
163	1991.780	-2.43	-4.68
165	1991.637	-2.48	-4.80
167	1991.494	-2.39	-5.04
169	1991.351	-1.99	-5.26
171	1991.208	-1.44	-5.37
173	1991.083	-1.94	-5.20
175	1990.958	-2.37	-4.94
177	1990.833	-2.60	-4.87
179	1990.708	-2.44	-4.72
181	1990.583	-2.61	-4.89
183	1990.458	-2.54	-5.00
185	1990.333	-1.97	-5.19
187	1990.208	-1.50	-5.29
189	1990.097	-1.87	-5.15
191	1989.986	-2.21	-4.98
193	1989.875	-2.51	-4.90
195	1989.764	-2.57	-4.84
197	1989.653	-2.68	-4.90
199	1989.542	-2.59	-5.11
201	1989.431	-2.01	-5.38
203	1989.319	-1.54	-5.37
205	1989.208	-1.73	-5.39
207	1989.042	-1.94	-5.14
209	1988.875	-2.45	-4.92
211	1988.708	-2.29	-4.67
213	1988.542	-2.28	-4.89
215	1988.375	-2.22	-5.14
217	1988.208	-2.35	-5.31
219	1988.083	-1.18	-5.28
221	1987.958	-1.87	-4.85
223	1987.833	-2.32	-4.55
225	1987.708	-2.48	-4.45
227	1987.583	-2.69	-4.78
229	1987.458	-2.17	-5.11
231	1987.333	-1.98	-5.23
233	1987.208	-1.45	-5.26
235	1987.065	-1.29	-5.07
237	1986.923	-2.11	-4.77
239	1986.780	-2.26	-4.63
241	1986.637	-2.33	-4.77
243	1986.494	-2.16	-5.08
245	1986.351	-1.83	-5.28
247	1986.208	-1.41	-5.29
249	1986.065	-1.46	-5.13
251	1985.923	-2.31	-4.75
253	1985.780	-2.31	-4.61
255	1985.637	-2.57	-4.64
257	1985.494	-2.18	-4.92
259	1985.351	-1.69	-5.20
261	1985.208	-1.14	-5.31
263	1985.083	-1.12	-5.18
265	1984.958	-1.82	-4.91
267	1984.833	-2.31	-4.76
269	1984.708	-2.13	-4.63
271	1984.583	-2.01	-4.70
273	1984.458	-2.01	-4.85
275	1984.333	-1.74	-5.04
277	1984.208	-1.38	-5.20
279	1984.083	-1.75	-5.05
281	1983.958	-2.41	-4.74
283	1983.833	-2.39	-4.57
285	1983.708	-2.48	-4.51
287	1983.583	-2.65	-4.58
289	1983.458	-2.53	-4.76
291	1983.333	-2.06	-4.97
293	1983.208	-1.52	-5.05
295	1983.097	-1.56	-4.91
297	1982.986	-1.81	-4.80
299	1982.875	-2.07	-4.60

301	1982.764	-2.09	-4.55
303	1982.653	-2.09	-4.74
305	1982.542	-2.11	-4.97
307	1982.431	-2.05	-5.13
309	1982.319	-1.77	-5.13
311	1982.208	-1.61	-5.28
313	1982.065	-1.52	-5.20
315	1981.923	-1.82	-4.84
317	1981.780	-2.04	-4.70
319	1981.637	-1.95	-4.65
321	1981.494	-1.95	-4.79
323	1981.351	-1.88	-5.10
325	1981.208	-1.25	-5.19
327	1981.083	-1.25	-5.11
329	1980.958	-1.74	-4.87
331	1980.833	-2.08	-4.76
333	1980.708	-2.63	-4.59
335	1980.583	-2.46	-4.81
337	1980.458	-1.97	-5.08
339	1980.333	-1.72	-5.25
341	1980.208	-1.62	-5.30
343	1980.065	-1.49	-5.17
345	1979.923	-1.87	-4.94
347	1979.780	-2.11	-4.77
349	1979.637	-2.08	-4.82
351	1979.494	-1.83	-4.97
353	1979.351	-1.39	-5.19
355	1979.208	-0.99	-5.20
357	1979.065	-1.61	-4.84
359	1978.923	-2.16	-4.71
361	1978.780	-2.23	-4.56
363	1978.637	-2.32	-4.74
365	1978.494	-2.31	-4.87
367	1978.351	-2.06	-5.00
369	1978.208	-1.70	-5.04
371	1978.042	-1.37	-4.72
373	1977.875	-1.85	-4.56
375	1977.708	-2.28	-4.59
377	1977.542	-2.42	-4.76
379	1977.375	-1.74	-5.11
381	1977.208	-1.08	-5.26
383	1977.042	-1.14	-4.97

δ^{13}C and δ^{18}O data of Tonga cores TH1-H4

Depth (mm)	Year A.D.	δ^{13}C	δ^{18}O
3	1982.208	-1.43	-5.21
5	1982.083	-0.74	-5.14
7	1981.958	-1.12	-5.11
9	1981.833	-1.40	-4.67
11	1981.708	-1.54	-4.58
13	1981.583	-1.78	-4.69
15	1981.458	-1.67	-5.00
17	1981.333	-1.37	-5.20
19	1981.208	-0.79	-5.21
21	1981.008	-0.99	-5.04
23	1980.808	-1.21	-4.62
25	1980.608	-1.88	-4.67
27	1980.408	-1.46	-4.95
29	1980.208	-1.06	-5.11
31	1980.065	-0.93	-5.08
33	1979.922	-1.39	-4.97
34	1979.779	-1.62	-4.73
35	1979.637	-1.77	-4.68
36	1979.494	-1.62	-4.81
37	1979.351	-1.21	-4.96
39	1979.208	-0.36	-4.98
41	1979.008	-1.16	-4.66
43	1978.808	-1.71	-4.55
45	1978.608	-1.75	-4.80
47	1978.408	-1.05	-4.90
49	1978.208	-0.82	-5.00
51	1978.042	-1.34	-4.59
53	1977.875	-1.92	-4.48
55	1977.708	-2.12	-4.59
57	1977.542	-2.03	-4.66

59	1977.375	-1.71	-5.05
61	1977.208	-1.20	-5.13
63	1977.065	-1.21	-5.11
65	1976.923	-1.14	-4.72
67	1976.780	-1.51	-4.60
69	1976.637	-1.82	-4.70
71	1976.494	-1.64	-5.09
73	1976.351	-1.16	-5.27
75	1976.208	-0.85	-5.28
77	1976.042	-0.64	-5.11
79	1975.875	-1.31	-4.81
81	1975.708	-1.58	-4.77
83	1975.542	-2.20	-4.80
85	1975.375	-1.71	-4.99
87	1975.208	-1.27	-5.19
89	1975.083	-1.10	-5.16
91	1974.958	-0.88	-5.17
93	1974.833	-1.14	-4.96
95	1974.708	-1.32	-4.83
97	1974.583	-1.52	-4.88
99	1974.458	-1.87	-5.01
101	1974.333	-1.63	-5.15
103	1974.208	-1.19	-5.17
105	1974.042	-1.15	-5.14
107	1973.875	-1.63	-4.77
109	1973.708	-1.80	-4.63
111	1973.542	-1.88	-4.82
113	1973.375	-1.67	-5.03
115	1973.208	-1.15	-5.21
117	1973.083	-1.13	-4.96
119	1972.958	-1.74	-4.71
121	1972.833	-2.05	-4.48
123	1972.708	-2.34	-4.64
125	1972.583	-2.31	-4.92
127	1972.458	-2.05	-5.08
129	1972.333	-1.03	-5.26
131	1972.208	-1.19	-5.27
133	1971.958	-1.52	-4.98
135	1971.708	-1.65	-4.92
137	1971.458	-1.51	-5.08
139	1971.208	-1.12	-5.28
141	1971.042	-0.73	-5.22
143	1970.875	-1.25	-4.98
145	1970.708	-1.66	-4.76
147	1970.542	-1.53	-4.59
149	1970.375	-1.51	-4.99
151	1970.208	-0.83	-5.05
153	1970.042	-0.85	-5.00
155	1969.875	-1.63	-4.56
157	1969.708	-1.92	-4.37
159	1969.542	-2.01	-4.68
161	1969.375	-1.61	-5.11
163	1969.208	-1.32	-5.23
165	1969.065	-1.03	-5.17
167	1968.923	-1.35	-4.92
169	1968.780	-1.46	-4.68
171	1968.637	-1.64	-4.84
173	1968.494	-1.65	-4.98
175	1968.351	-1.62	-5.02
177	1968.208	-1.27	-5.16
179	1968.065	-0.79	-5.11
181	1967.923	-1.46	-4.88
183	1967.780	-1.63	-4.62
185	1967.637	-2.05	-4.55
187	1967.494	-1.82	-4.92
189	1967.351	-1.30	-4.98
191	1967.208	-1.27	-5.05
193	1967.042	-1.63	-4.72
195	1966.875	-1.76	-4.73
197	1966.708	-2.08	-4.45
199	1966.542	-2.26	-4.60
201	1966.375	-1.67	-4.87
203	1966.208	-1.17	-5.15
205	1966.065	-1.06	-4.94
207	1965.923	-1.74	-4.67
209	1965.780	-1.91	-4.64
211	1965.637	-2.20	-4.60
213	1965.494	-2.26	-4.82
215	1965.351	-1.76	-5.13
217	1965.208	-1.24	-5.16
219	1965.042	-0.91	-5.12
221	1964.875	-1.36	-4.83
223	1964.708	-1.70	-4.69
225	1964.542	-1.96	-4.76
227	1964.375	-1.98	-4.82
229	1964.208	-1.34	-5.00

231	1964.083	-0.99	-4.95
233	1963.958	-1.52	-4.72
235	1963.833	-1.77	-4.73
237	1963.708	-1.88	-4.91
239	1963.583	-1.98	-4.88
241	1963.458	-2.09	-4.93
243	1963.333	-1.75	-4.98
245	1963.208	-1.40	-5.21
247	1963.083	-1.43	-5.07
249	1962.958	-1.47	-4.94
251	1962.833	-1.82	-4.72
253	1962.708	-2.06	-4.76
255	1962.583	-2.52	-4.93
257	1962.458	-1.83	-5.05
259	1962.333	-1.65	-5.09
261	1962.208	-1.27	-5.10
263	1962.083	-1.49	-4.79
265	1961.958	-1.47	-4.57
267	1961.833	-1.64	-4.70
269	1961.708	-2.20	-4.75
271	1961.583	-2.04	-5.03
273	1961.458	-2.00	-5.03
275	1961.333	-1.33	-5.25
277	1961.208	-1.14	-5.27
279	1961.042	-1.46	-4.80
281	1960.875	-1.98	-4.67
283	1960.708	-2.24	-4.83
285	1960.542	-2.14	-5.04
287	1960.375	-1.85	-5.08
289	1960.208	-1.59	-5.09
291	1960.042	-1.40	-5.07
293	1959.875	-1.50	-4.96
295	1959.708	-1.87	-4.70
297	1959.542	-1.98	-4.86
299	1959.375	-2.07	-4.99
301	1959.208	-1.74	-5.10
303	1959.097	-1.87	-5.07
305	1958.986	-1.42	-5.00
307	1958.875	-1.26	-4.82
309	1958.764	-1.69	-4.63
311	1958.653	-2.11	-4.60
313	1958.542	-2.53	-4.71
315	1958.431	-2.35	-4.83
317	1958.319	-1.86	-4.87
319	1958.208	-1.51	-5.09
321	1958.108	-1.52	-4.94
323	1958.008	-2.06	-4.81
325	1957.908	-2.31	-4.76
327	1957.808	-2.61	-4.71
329	1957.708	-2.77	-4.70
331	1957.608	-3.01	-4.90
333	1957.508	-2.59	-5.05
335	1957.408	-2.26	-5.29
337	1957.308	-1.73	-5.28
339	1957.208	-1.74	-5.35
341	1957.097	-1.58	-5.22
343	1956.986	-1.92	-4.99
345	1956.875	-2.10	-4.97
347	1956.764	-2.41	-4.93
349	1956.653	-2.73	-4.95
351	1956.542	-2.90	-5.18
353	1956.431	-2.82	-5.18
355	1956.319	-2.59	-5.25
357	1956.208	-2.30	-5.43
359	1956.083	-1.67	-5.37
361	1955.958	-1.28	-5.20
363	1955.833	-1.42	-4.98
365	1955.708	-2.02	-4.81
367	1955.583	-2.05	-4.84
369	1955.458	-2.06	-4.90
371	1955.333	-1.72	-5.20
373	1955.208	-1.37	-5.23
375	1955.065	-1.47	-5.18
377	1954.923	-1.34	-5.17
379	1954.780	-1.70	-4.79
381	1954.637	-2.12	-4.61
383	1954.494	-2.22	-4.72
385	1954.351	-1.63	-4.94
387	1954.208	-1.35	-5.01
389	1954.083	-0.92	-4.98
391	1953.958	-1.77	-4.67
393	1953.833	-2.17	-4.36
395	1953.708	-2.36	-4.41
397	1953.583	-2.39	-4.60
399	1953.458	-1.99	-5.14
401	1953.333	-1.37	-5.15

403	1953.208	-1.29	-5.17
405	1953.083	-1.28	-5.10
407	1952.958	-1.92	-4.74
409	1952.833	-2.12	-4.59
411	1952.708	-2.27	-4.54
413	1952.583	-2.50	-4.77
415	1952.458	-2.02	-4.85
417	1952.333	-1.37	-5.10
419	1952.208	-1.39	-5.11
421	1952.083	-1.55	-4.92
423	1951.958	-2.18	-4.67
425	1951.833	-2.33	-4.59
427	1951.708	-2.31	-4.69
429	1951.583	-2.21	-4.83
431	1951.458	-1.93	-5.22
433	1951.333	-1.83	-5.41
435	1951.208	-1.76	-5.52
437	1951.083	-1.03	-5.37
439	1950.958	-1.81	-5.22
441	1950.833	-2.12	-4.79
443	1950.708	-2.15	-4.74
445	1950.583	-2.22	-4.84
447	1950.458	-2.19	-4.92
449	1950.333	-1.82	-5.20
451	1950.208	-1.13	-5.35
453	1950.065	-1.35	-5.19
455	1949.923	-1.43	-5.05
457	1949.780	-1.97	-4.72
459	1949.637	-1.99	-4.54
461	1949.494	-2.18	-4.63
463	1949.351	-1.77	-5.02
465	1949.208	-1.31	-5.28
467	1949.097	-1.43	-5.22
469	1948.986	-1.36	-5.04
471	1948.875	-2.16	-4.93
473	1948.764	-2.10	-4.76
475	1948.653	-2.34	-4.75
477	1948.542	-2.43	-4.91
479	1948.431	-2.30	-4.98
481	1948.319	-1.62	-4.98
483	1948.208	-1.23	-5.10
485	1948.083	-1.33	-5.15
487	1947.958	-1.89	-4.81
489	1947.833	-2.30	-4.67
491	1947.708	-2.26	-4.53
493	1947.583	-2.40	-4.64
495	1947.458	-2.33	-4.83
497	1947.333	-2.41	-5.07
499	1947.208	-1.51	-5.23
501	1947.097	-1.09	-5.19
503	1946.986	-1.20	-5.21
505	1946.875	-1.93	-4.84
507	1946.764	-2.02	-4.71
509	1946.653	-2.15	-4.68
511	1946.542	-2.48	-4.66
513	1946.431	-2.13	-5.00
515	1946.319	-1.74	-5.09
517	1946.208	-1.44	-5.23
519	1946.083	-1.44	-5.22
521	1945.958	-1.52	-5.05
523	1945.833	-2.06	-4.65
525	1945.708	-2.23	-4.37
527	1945.583	-1.70	-4.54
529	1945.458	-2.31	-4.57
531	1945.333	-2.01	-4.97
533	1945.208	-1.15	-5.19
535	1944.875	-1.18	-5.15
537	1944.625	-1.55	-4.92
547.5	1943.708	-1.78	-4.89
564.5	1942.708	-1.83	-4.87
587	1941.708	-1.81	-4.72
605	1940.708	-1.77	-4.69
618	1939.708	-1.63	-4.67
632	1938.708	-1.55	-4.90
647.5	1937.708	-1.48	-4.85
666	1936.708	-1.44	-4.84
683	1935.708	-1.32	-5.02
695	1934.708	-1.15	-4.88
706	1933.708	-1.19	-5.08
713	1933.608	-1.56	-4.78
715	1933.508	-1.56	-4.84
717	1933.408	-1.22	-5.18
719	1933.308	-0.84	-5.37
721	1933.208	-0.86	-5.40

*723	1932.708	-0.88	-5.02
*725	1932.208	-1.37	-4.57
727	1931.708	-0.28	-4.54
729	1931.208	-0.57	-4.73
731	1930.875	-0.87	-4.56
733	1930.542	-1.61	-4.28
746	1929.708	-1.76	-4.90
764	1928.708	-1.33	-4.89
778	1927.708	-1.46	-5.05
792	1926.708	-1.56	-4.81
809	1925.708	-1.56	-4.95
825	1924.708	-1.77	-4.81
842	1923.708	-1.57	-4.85
858	1922.708	-1.19	-4.85
870	1921.708	-1.35	-5.00
882.5	1920.708	-1.41	-4.77
896.5	1919.708	-1.53	-4.70
912.5	1918.708	-1.45	-4.86
932	1917.708	-1.52	-5.09
951.5	1916.708	-1.58	-4.96
967.5	1915.708	-1.61	-4.77
975	1915.208	-1.81	-4.41
977	1915.097	-2.01	-4.54
979	1914.986	-1.87	-4.34
981	1914.875	-2.09	-4.34
983	1914.764	-1.89	-4.73
985	1914.653	-1.64	-4.91
987	1914.542	-1.75	-4.86
989	1914.431	-0.55	-5.15
991	1914.319	-0.76	-4.99
998.5	1913.708	-1.67	-4.72
1015	1912.708	-1.74	-4.80
1034.5	1911.708	-1.87	-4.89
1055	1910.708	-1.83	-4.91
1072.5	1909.708	-1.64	-4.95
1087.5	1908.708	-1.67	-4.93
1103	1907.708	-1.87	-4.74
1118.5	1906.708	-1.75	-4.79
1134	1905.708	-1.84	-4.60
1151	1904.708	-2.04	-4.81
1170	1903.708	-1.95	-4.71
1188.5	1902.708	-1.53	-4.84
1206	1901.708	-1.83	-4.65
1221.5	1900.708	-1.40	-4.90
1229	1900.042	-1.69	-4.71
1231	1899.875	-1.77	-4.32
1233	1899.708	-1.86	-4.50
1235	1899.542	-1.49	-4.65
1237	1899.375	-1.66	-5.01
1239	1899.208	-1.21	-5.20
1241	1899.042	-1.10	-5.12
1250	1898.708	-1.37	-4.86
1264.5	1897.708	-1.51	-4.63
1277.5	1896.708	-1.42	-4.64
1292.5	1895.708	-1.46	-4.82
1308.5	1894.708	-1.65	-4.86
1326	1893.708	-1.62	-4.94
1344.5	1892.708	-1.58	-4.85
1362	1891.708	-1.43	-4.84
1379	1890.708	-1.60	-4.83
1396	1889.708	-1.63	-4.64
1413	1888.708	-1.64	-4.92
1430	1887.708	-1.68	-4.93
1446	1886.708	-1.46	-4.70
1462.5	1885.708	-1.43	-4.65
1478	1884.708	-1.51	-4.78
1494.5	1883.708	-1.63	-4.79
1514	1882.708	-1.68	-4.90
1533.5	1881.708	-1.58	-4.90
1551	1880.708	-1.66	-4.94
1567.5	1879.708	-1.21	-4.92
1581.5	1878.708	-1.17	-4.70
1595	1877.708	-1.23	-4.60
1610	1876.708	-1.36	-4.79
1625	1875.708	-1.21	-4.80
1642	1874.708	-1.33	-4.79
1660	1873.708	-1.46	-4.79
1678	1872.708	-1.48	-4.89
1697.5	1871.708	-1.44	-4.96
1716.5	1870.708	-1.42	-4.84
1737	1869.708	-1.49	-4.63

1755	1868.708	-1.32	-4.90
1768.5	1867.708	-1.31	-4.81
1782.5	1866.708	-1.45	-4.72
1796	1865.708	-1.26	-4.81
1810.5	1864.708	-1.59	-4.80
1826	1863.708	-1.81	-4.74
1843	1862.708	-1.57	-4.94
1858	1861.708	-1.19	-5.02
1871	1860.708	-1.32	-4.88
1886	1859.708	-1.28	-4.90
1900	1858.708	-1.30	-4.89
1915.5	1857.708	-1.36	-5.02
1934.5	1856.708	-1.32	-4.67
1952	1855.708	-1.48	-4.78
1969	1854.708	-1.51	-4.81
1989	1853.708	-1.29	-4.79
2007.5	1852.708	-1.70	-4.70
2024	1851.708	-1.70	-4.70
2043.5	1850.708	-1.78	-4.84
2067	1849.708	-1.81	-4.98
2086	1848.708	-1.82	-4.87
2101	1847.708	-1.83	-4.88
2118	1846.708	-1.83	-4.73
2138.5	1845.708	-1.83	-4.80
2157.5	1844.708	-1.33	-4.79
2174	1843.708	-1.37	-4.85
2195	1842.708	-1.54	-4.82
2215	1841.708	-1.84	-4.72
2233.5	1840.708	-1.76	-4.65
2256	1839.708	-1.95	-4.64
2276.5	1838.708	-2.39	-4.85
2293	1837.708	-2.58	-4.72
2307.5	1836.708	-2.36	-4.84
2319.5	1835.708	-2.47	-4.82
2331.5	1834.708	-2.24	-4.91
2345	1833.708	-2.10	-4.79
2360	1832.708	-2.27	-4.81
2375.5	1831.708	-1.32	-4.92
2389.5	1830.708	-1.27	-5.01
2404	1829.708	-1.55	-5.12
2418	1828.708	-1.46	-5.11
2432.5	1827.708	-1.46	-5.10
2447	1826.708	-1.27	-5.12
2459	1825.708	-1.10	-4.75
2470	1824.708	-1.20	-4.99
2483.5	1823.708	-1.45	-4.97
2498	1822.708	-1.32	-4.90
2512	1821.708	-1.55	-4.99
2527	1820.708	-1.39	-5.17
2542	1819.708	-1.32	-5.01
2555.5	1818.708	-1.14	-4.88
2568	1817.708	-1.32	-4.91
2582	1816.708	-1.48	-4.80
2596.5	1815.708	-1.47	-4.92
2610	1814.708	-1.90	-4.92
2625.5	1813.708	-1.79	-5.01
2643	1812.708	-1.87	-5.01
2658	1811.708	-1.69	-4.72
2673	1810.708	-1.74	-4.65
2689	1809.708	-1.71	-4.78
2704.5	1808.708	-1.67	-4.83
2722	1807.708	-1.95	-4.94
2741.5	1806.708	-2.04	-4.91
2753	1806.208	-1.86	-5.27
2755	1806.108	-1.70	-5.18
2757	1806.008	-1.80	-5.09
2759	1805.908	-1.78	-5.01
2761	1805.808	-1.83	-5.02
2763	1805.708	-1.98	-4.94
2765	1805.608	-2.22	-4.84
2767	1805.508	-2.43	-4.81
2769	1805.408	-2.35	-4.75
2771	1805.308	-2.15	-4.98
2773	1805.208	-1.43	-5.04
2775	1805.041	-1.07	-4.85
2777	1804.875	-1.56	-4.53
2779	1804.708	-1.58	-4.27
2781	1804.541	-1.89	-4.48
2783	1804.375	-1.59	-4.91
2785	1804.208	-0.70	-4.95
2787	1804.041	-0.96	-4.70
2789	1803.875	-1.36	-4.35
2796	1802.708	-1.25	-4.83
2808.5	1801.708	-1.15	-4.97

2820	1800.708	-1.47	-4.83
2831	1799.708	-1.31	-4.86
2841.5	1798.708	-1.43	-4.75
2851.5	1797.708	-1.16	-4.85
2863	1796.708	-1.25	-4.85
2876.5	1795.708	-1.12	-4.95
2889	1794.708	-1.21	-5.10
2899	1793.708	-1.29	-4.68

* One year was inserted because of slab break.

δ^{13}C and δ^{18}O data of Tonga cores TM1

Depth (mm)	Year A.D.	δ^{13}C	δ^{18}O
1	2004.833	-1.32	-4.58
2	2004.708	-1.62	-4.57
3	2004.583	-1.86	-4.63
4	2004.458	-2.01	-4.74
5	2004.333	-1.67	-4.86
6	2004.208	-0.95	-4.92
7	2004.097	-0.29	-4.57
8	2003.986	-0.62	-4.42
9	2003.875	-1.03	-4.46
10	2003.764	-1.46	-4.28
11	2003.653	-1.72	-4.46
12	2003.542	-1.58	-4.62
13	2003.431	-1.42	-4.84
14	2003.319	-1.26	-4.91
15	2003.208	-1.10	-4.95
16	2003.117	-1.20	-4.83
17	2003.027	-1.42	-4.75
18	2002.936	-1.44	-4.61
19	2002.845	-1.59	-4.48
20	2002.754	-1.93	-4.46
21	2002.663	-2.14	-4.45
22	2002.572	-2.16	-4.54
23	2002.481	-2.00	-4.68
24	2002.390	-2.11	-4.91
25	2002.299	-2.11	-5.05
26	2002.208	-1.82	-5.21
27	2002.125	-1.27	-5.06
28	2002.042	-1.31	-4.83
29	2001.958	-1.57	-4.74
30	2001.875	-1.58	-4.66
31	2001.792	-1.67	-4.52
32	2001.708	-1.95	-4.53
33	2001.625	-2.17	-4.45
34	2001.542	-2.48	-4.57
35	2001.458	-2.62	-4.76
36	2001.375	-2.45	-4.86
37	2001.292	-2.19	-5.05
38	2001.208	-1.85	-5.13
39	2001.108	-1.35	-5.07
40	2001.008	-1.50	-4.88
41	2000.908	-1.77	-4.82
42	2000.808	-1.82	-4.66
43	2000.708	-1.81	-4.47
44	2000.608	-2.17	-4.52
45	2000.508	-2.46	-4.45
46	2000.408	-2.77	-4.64
47	2000.308	-2.73	-4.94
48	2000.208	-2.29	-5.15
49	2000.125	-1.86	-5.11
50	2000.042	-1.04	-4.97
51	1999.958	-1.23	-4.76
52	1999.875	-1.74	-4.61
53	1999.792	-1.82	-4.58
54	1999.708	-1.96	-4.45
55	1999.625	-2.14	-4.52
56	1999.542	-2.34	-4.58
57	1999.458	-2.56	-4.60
58	1999.375	-2.31	-4.69
59	1999.292	-2.05	-4.85
60	1999.208	-1.74	-4.91
61	1999.117	-1.46	-4.85
62	1999.027	-1.56	-4.57
63	1998.936	-1.68	-4.49
64	1998.845	-1.70	-4.32
65	1998.754	-1.73	-4.24
66	1998.663	-1.99	-4.28
67	1998.572	-2.23	-4.37
68	1998.481	-2.45	-4.51

69	1998.390	-2.31	-4.58
70	1998.299	-2.01	-4.70
71	1998.208	-1.71	-4.76
72	1998.125	-1.77	-4.72
73	1998.042	-1.57	-4.62
74	1997.958	-1.55	-4.60
75	1997.875	-1.60	-4.59
76	1997.792	-1.89	-4.48
77	1997.708	-2.10	-4.35
78	1997.625	-2.62	-4.38
79	1997.542	-2.54	-4.36
80	1997.458	-2.38	-4.65
81	1997.375	-2.26	-4.79
82	1997.292	-2.33	-4.99
83	1997.208	-1.66	-5.15
84	1997.125	-1.00	-4.97
85	1997.042	-1.13	-4.71
86	1996.958	-1.39	-4.71
87	1996.875	-1.41	-4.61
88	1996.792	-1.38	-4.66
89	1996.708	-1.63	-4.56
90	1996.625	-1.77	-4.60
91	1996.542	-2.45	-4.50
92	1996.458	-2.61	-4.67
93	1996.375	-2.16	-4.89
94	1996.292	-1.67	-5.03
95	1996.208	-1.44	-5.11
96	1996.131	-1.09	-5.05
97	1996.054	-1.22	-4.80
98	1995.978	-1.32	-4.77
99	1995.901	-1.45	-4.66
100	1995.824	-1.82	-4.45
101	1995.747	-2.11	-4.39
102	1995.670	-2.21	-4.49
103	1995.593	-2.42	-4.54
104	1995.516	-2.54	-4.58
105	1995.439	-2.45	-4.64
106	1995.362	-1.95	-4.93
107	1995.285	-1.61	-5.00
108	1995.208	-1.59	-5.07
109	1995.117	-1.31	-5.00
110	1995.027	-1.31	-4.85
111	1994.936	-1.64	-4.70
112	1994.845	-1.74	-4.57
113	1994.754	-1.95	-4.44
114	1994.663	-1.91	-4.25
115	1994.572	-2.20	-4.33
116	1994.481	-2.17	-4.50
117	1994.390	-2.08	-4.60
118	1994.299	-1.65	-4.81
119	1994.208	-1.30	-4.89
120	1994.042	-0.90	-4.75
121	1993.875	-1.08	-4.58
123	1993.708	-1.60	-4.19
128.5	1993.208	-1.70	-4.56
139.5	1992.208	-1.61	-4.53
151	1991.208	-1.60	-4.50
163	1990.208	-1.68	-4.68
170	1989.637	-1.75	-4.55
171	1989.494	-2.04	-4.60
173	1989.351	-2.40	-4.90
175	1989.208	-2.18	-5.03
177	1989.065	-1.67	-4.98
179	1988.923	-1.58	-4.68
181	1988.780	-1.81	-4.62
183	1988.637	-2.27	-4.40
185	1988.494	-2.44	-4.52
187	1988.351	-2.22	-4.69
189	1988.208	-1.16	-4.84
191	1988.408	-1.18	-4.38
193	1988.608	-1.46	-4.26
195	1988.808	-2.02	-4.17
197	1989.008	-1.80	-4.51
199	1987.208	-0.83	-4.59
201	1987.542	-1.10	-4.41
203	1987.875	-1.89	-4.22
205	1986.208	-1.97	-4.43
214	1985.208	-1.79	-4.73
227.5	1984.208	-1.22	-4.55
236	1983.208	-0.42	-4.07
244	1982.208	-0.73	-4.40
252.5	1981.208	-0.82	-4.50
260	1980.208	-0.76	-4.59

267	1979.208	-0.86	-4.63
274	1978.208	-1.12	-4.38
282.5	1977.208	-1.28	-4.42
292.5	1976.208	-1.35	-4.68
302	1975.208	-1.04	-4.65
311	1974.208	-0.93	-4.64
319.5	1973.208	-1.29	-4.54
328.5	1972.208	-0.89	-4.49
336.5	1971.208	0.13	-4.35
343.5	1970.208	-0.26	-4.44
351	1969.208	-0.02	-4.31
358.5	1968.208	0.11	-4.37
366.5	1967.208	-0.04	-4.27
373.5	1966.208	-0.07	-4.32
380.5	1965.208	-0.34	-4.52
388.5	1964.208	-0.18	-4.33
396	1963.208	-0.52	-4.62
404.5	1962.208	-0.99	-4.58
414.5	1961.208	-0.85	-4.58
424.5	1960.208	-0.66	-4.55
434	1959.208	-0.79	-4.55
443	1958.208	-1.03	-4.36
452	1957.208	-1.05	-4.63
462	1956.208	-1.13	-4.87
473.5	1955.208	-1.15	-4.78
484.5	1954.208	-1.01	-4.51
494	1953.208	-0.68	-4.48
504.5	1952.208	-1.23	-4.62
515.5	1951.208	-1.11	-4.68
525.5	1950.208	-0.79	-4.66
534.5	1949.208	-0.94	-4.35
545	1948.208	-0.96	-4.56
557	1947.208	-1.30	-4.52
570	1946.208	-1.27	-4.46
583	1945.208	-1.27	-4.31
595	1944.208	-1.13	-4.39
607	1943.208	-1.44	-4.53
618	1942.208	-1.17	-4.31
629	1941.208	-1.40	-4.25
640.5	1940.208	-1.17	-4.27
652.5	1939.208	-1.53	-4.54
664.5	1938.208	-1.57	-4.39
677	1937.208	-1.51	-4.43
689	1936.208	-1.21	-4.54
699.5	1935.208	-1.19	-4.45
709.5	1934.208	-1.02	-4.53
720	1933.208	-1.06	-4.58
730.5	1932.208	-1.25	-4.53
739	1931.208	-1.22	-4.21
743	1930.408	-2.25	-4.33
745	1930.208	-1.66	-4.57
747	1930.008	-0.76	-4.26
749	1929.808	-0.39	-4.05
751	1929.608	-1.00	-3.82
753	1929.408	-1.76	-3.94
755	1929.208	-0.64	-4.41
757	1928.958	-0.11	-3.97
759	1928.708	-0.42	-3.91
761	1928.458	-1.32	-4.07
763	1928.208	-0.97	-4.40
765	1928.042	-0.32	-4.23
767	1927.875	-0.08	-4.00
769	1927.708	-0.92	-3.97
771	1927.542	-1.42	-4.32
773	1927.375	-0.86	-4.52
777.5	1927.208	-0.57	-4.44
784.5	1926.208	-0.39	-4.06
791	1925.208	-0.39	-4.17
798	1924.208	-0.54	-4.27
805.5	1923.208	-0.75	-4.37
814	1922.208	-0.83	-4.48
823	1921.208	-0.87	-4.54
832	1920.208	-0.96	-4.39
841.5	1919.208	-0.87	-4.26
851	1918.208	-0.81	-4.51
861	1917.208	-0.77	-4.59
871	1916.208	-0.67	-4.64
879	1915.208	-0.62	-4.24
886	1914.208	-0.72	-4.11
893	1913.208	-0.80	-4.28
900.5	1912.208	-0.88	-4.28
909.5	1911.208	-0.99	-4.60
920.5	1910.208	-0.97	-4.46
931.5	1909.208	-0.97	-4.63

941.5	1908.208	-0.93	-4.52
950	1907.208	-0.77	-4.38
956.5	1906.208	-0.57	-4.32
962.5	1905.208	-0.44	-4.26
968.5	1904.208	-0.60	-4.34
975	1903.208	-0.04	-4.12
981	1902.208	0.13	-4.08
986.5	1901.208	0.16	-4.23
992.5	1900.208	-0.03	-4.21
999	1899.208	-0.04	-4.37
1006	1898.208	-0.61	-4.60
1012.5	1897.208	-0.19	-4.16
1018.5	1896.208	-0.31	-4.40
1025.5	1895.208	-0.46	-4.66
1034	1894.208	-0.58	-4.62
1044	1893.208	-0.56	-4.64
1052	1892.208	-0.26	-4.39
1056	1891.208	-0.12	-4.61
1057	1891.042	-0.17	-4.41
1058	1890.875	-0.19	-4.14
1059	1890.708	-0.31	-4.06
1060	1890.542	-0.19	-4.26
1061	1890.375	0.39	-4.25
1062	1890.208	0.30	-4.30
1063	1890.042	0.18	-4.19
1064	1889.875	0.00	-4.01
1065	1889.708	-0.37	-4.11
1066	1889.542	-0.34	-4.35
1067	1889.375	0.05	-4.53
1068	1889.208	0.01	-4.55
1069	1889.042	0.08	-4.30
1070	1888.875	-0.05	-4.24
1071	1888.708	-0.25	-4.08
1072	1888.542	-0.33	-4.01
1073	1888.375	-0.04	-4.25
1074	1888.208	0.13	-4.26
1075	1887.958	0.09	-4.15
1076	1887.708	0.12	-3.91
1077	1887.458	-0.29	-4.24
1078	1887.208	-0.03	-4.37
1079	1887.042	0.23	-4.28
1080	1886.875	0.11	-4.20
1081	1886.708	0.15	-4.06
1082	1886.542	-0.42	-4.32
1083	1886.375	-0.63	-4.66
1084	1886.208	-0.62	-4.75
1085	1886.065	-0.30	-4.52
1086	1885.923	-0.28	-4.52
1087	1885.780	-0.10	-4.38
1088	1885.637	-0.05	-4.12
1089	1885.494	-0.39	-3.88
1090	1885.351	-0.66	-3.90
1091	1885.208	-0.13	-4.10
1092	1885.065	0.37	-4.01
1093	1884.923	0.27	-3.73
1094	1884.780	-0.17	-3.58
1097	1885.208	-0.48	-4.27
1103	1883.708	-0.13	-4.21
1109.5	1882.708	-0.14	-4.39
1115.5	1881.708	-0.23	-4.39
1119	1881.663	-0.21	-4.14
1120	1881.572	-0.40	-4.14
1121	1881.481	-0.65	-4.22
1122	1881.390	-0.61	-4.51
1123	1881.299	-0.55	-4.70
1124	1881.208	-0.38	-4.71
1125	1881.065	-0.33	-4.54
1126	1880.923	-0.16	-4.34
1127	1880.780	-0.23	-4.04
1128	1880.637	-0.61	-4.24
1129	1880.494	-0.77	-4.38
1130	1880.351	-0.94	-4.60
1131	1880.208	-0.68	-4.73
1132	1880.097	-0.25	-4.69
1133	1879.986	-0.15	-4.46
1134	1879.875	-0.12	-4.33
1135	1879.764	-0.20	-4.23
1136	1879.653	-0.50	-4.15
1137	1879.542	-0.82	-4.18
1138	1879.431	-1.22	-4.42
1139	1879.319	-1.29	-4.61
1140	1879.208	-0.99	-4.79
1141	1879.097	-0.58	-4.59

1142	1878.986	-0.44	-4.53
1143	1878.875	-0.35	-4.26
1144	1878.764	-0.18	-4.07
1145	1878.653	-0.62	-3.92
1146	1878.542	-0.91	-3.95
1147	1878.431	-1.16	-4.09
1148	1878.319	-1.24	-4.17
1149	1878.208	-0.90	-4.27

1153.5	1877.708	-0.29	-4.10
1161.5	1876.708	-0.57	-4.25
1169.5	1875.708	-0.61	-4.43
1177	1874.708	-0.50	-4.37
1184	1873.708	-0.47	-4.51
1191.5	1872.708	-0.37	-4.38
1199	1871.708	-0.49	-4.61
1206	1870.708	-0.58	-4.49
1213.5	1869.708	-0.65	-4.39
1220.5	1868.708	-0.42	-4.34
1228.5	1867.708	-0.74	-4.43
1238.5	1866.708	-0.55	-4.51
1247	1865.708	-0.59	-4.39
1254	1864.708	0.14	-4.07
1261.5	1863.708	-0.04	-4.27
1269	1862.708	-0.24	-4.30
1276.5	1861.708	-0.42	-4.43
1284	1860.708	-0.17	-4.42
1291	1859.708	-0.31	-4.53
1298.5	1858.708	-0.30	-4.36
1306.5	1857.708	-0.06	-4.32
1314.5	1856.708	-0.47	-4.47
1323.5	1855.708	-0.75	-4.47
1332.5	1854.708	-0.64	-4.29
1341	1853.708	-0.82	-4.51

1346	1853.042	-0.56	-4.38
1347	1852.708	-0.79	-4.20
1348	1852.608	-1.06	-4.20
1349	1852.508	-1.10	-4.22
1350	1852.408	-1.11	-4.36
1351	1852.308	-0.93	-4.59
1352	1852.208	-0.72	-4.69
1353	1852.108	-0.35	-4.62
1354	1852.008	-0.51	-4.45
1355	1851.908	-0.44	-4.39
1356	1851.808	-0.40	-4.26
1357	1851.708	-0.68	-4.09
1358	1851.608	-0.74	-4.05
1359	1851.508	-0.88	-4.03
1360	1851.408	-1.23	-4.29
1361	1851.308	-0.78	-4.56
1362	1851.208	-0.47	-4.71
1363	1851.097	-0.34	-4.66
1364	1850.986	-0.29	-4.45
1365	1850.875	-0.31	-4.37
1366	1850.764	-0.22	-4.14
1367	1850.653	-0.47	-4.20
1368	1850.542	-0.75	-4.25
1369	1850.431	-0.78	-4.40
1370	1850.319	-0.77	-4.70
1371	1850.208	-0.54	-4.82

1377.5	1849.708	-0.88	-4.50
1390	1848.708	-0.64	-4.60
1401.5	1847.708	-0.88	-4.60
1412.5	1846.708	-0.78	-4.44
1425	1845.708	-1.11	-4.28
1436.5	1844.708	-0.71	-4.28
1447.5	1843.708	-1.00	-4.32
1459.5	1842.708	-0.98	-4.42
1470	1841.708	-0.37	-4.36
1480	1840.708	-0.45	-4.44
1489.5	1839.708	-0.62	-4.23
1499	1838.708	-0.96	-4.39
1510.5	1837.708	-0.98	-4.49
1521	1836.708	-1.65	-4.33

The space lines are the breaks between mm-samplings and annual samplings.

Appendix 6. Annually averaged $\delta^{18}O$ data of five Fiji Tonga Corals

Year A.D.	1F $\delta^{18}O$	AB $\delta^{18}O$	TH1 $\delta^{18}O$	TM1 $\delta^{18}O$	TNI2 $\delta^{18}O$
2004			-5.04	-4.74	-4.93
2003			-5.00	-4.61	-4.94
2002			-4.99	-4.70	-4.94
2001		-4.81	-5.05	-4.77	-4.87
2000		-4.98	-5.00	-4.76	-4.82
1999		-4.96	-5.10	-4.74	-4.78
1998		-4.56	-4.81	-4.53	-4.61
1997		-4.56	-4.82	-4.61	-4.75
1996	-5.32	-4.89	-5.00	-4.76	-4.93
1995	-5.25	-4.80	-5.04	-4.72	-4.80
1994	-5.12	-4.61	-4.85	-4.65	-4.67
1993	-5.01	-4.68	-4.88	-4.60	-4.67
1992	-5.00	-4.64	-4.82	-4.56	-4.71
1991	-5.16	-4.59	-4.93	-4.53	-4.75
1990	-5.18	-4.69	-4.96	-4.50	-4.74
1989	-5.41	-4.88	-5.04	-4.68	-4.85
1988	-5.27	-4.72	-4.96	-4.70	-4.82
1987	-5.03	-4.52	-4.88	-4.43	-4.65
1986	-5.11	-4.52	-4.92	-4.41	-4.67
1985	-5.15	-4.65	-4.87	-4.43	-4.70
1984	-5.21	-4.67	-4.86	-4.73	-4.67
1983	-4.94	-4.53	-4.74	-4.55	-4.57
1982	-5.25	-4.71	-4.82	-4.07	-4.68
1981	-5.21	-4.76	-4.91	-4.40	-4.83
1980	-5.15	-4.73	-4.90	-4.50	-4.75
1979	-5.20	-4.84	-4.93	-4.59	-4.77
1978	-4.99	-4.62	-4.78	-4.63	-4.63
1977	-5.00	-4.40	-4.77	-4.38	-4.56
1976	-5.17	-4.75	-4.95	-4.42	-4.67
1975	-5.17	-4.89	-4.96	-4.68	-4.79
1974	-5.18	-4.92	-5.05	-4.65	-4.84
1973	-5.06	-4.75	-4.93	-4.64	-4.70
1972	-5.08	-4.67	-4.91	-4.54	-4.67
1971	-5.36	-4.86	-5.06	-4.49	-4.90
1970	-5.18	-4.67	-4.97	-4.35	-4.70
1969	-5.11	-4.62	-4.80	-4.44	-4.64
1968	-5.22	-4.76	-4.98	-4.31	-4.83
1967	-5.13	-4.58	-4.89	-4.37	-4.65
1966	-5.05	-4.56	-4.74	-4.27	-4.63

Year A.D.	1F $\delta^{18}O$	AB $\delta^{18}O$	TH1 $\delta^{18}O$	TM1 $\delta^{18}O$	TNI2 $\delta^{18}O$
1965	-5.11	-4.57	-4.85	-4.32	-4.58
1964	-5.08	-4.75	-4.89	-4.52	-4.65
1963	-5.20	-4.74	-4.89	-4.33	-4.67
1962	-5.25	-4.72	-4.97	-4.62	-4.83
1961	-5.26	-4.78	-4.90	-4.58	-4.69
1960	-5.12	-4.77	-4.95	-4.58	-4.70
1959	-5.04	-4.78	-4.95	-4.55	-4.74
1958	-4.93	-4.56	-4.85	-4.55	-4.62
1957	-5.12	-4.61	-4.95	-4.36	-4.76
1956	-5.25	-4.92	-5.11	-4.63	-4.93
1955	-5.18	-4.89	-5.09	-4.87	-4.91
1954	-4.99	-4.67	-4.95	-4.78	-4.79
1953	-4.87	-4.64	-4.79	-4.51	-4.63
1952	-5.02	-4.64	-4.85	-4.48	-4.74
1951	-5.26	-4.60	-4.93	-4.62	-4.73
1950	-5.36	-4.63	-5.08	-4.68	-4.84
1949	-5.21	-4.59	-4.93	-4.66	-4.79
1948	-5.09	-4.75	-4.98	-4.35	-4.79
1947	-5.06	-4.59	-4.85	-4.56	-4.73
1946	-5.19	-4.69	-4.96	-4.52	-4.78
1945	-4.98	-4.66	-4.82	-4.46	-4.73
1944	-5.12	-4.62	-4.73	-4.31	-4.82
1943	-5.13	-4.67	-4.89	-4.39	-4.98
1942	-4.98	-4.55	-4.87	-4.53	-4.73
1941	-4.93	-4.46	-4.72	-4.31	-4.60
1940	-4.87	-4.43	-4.69	-4.25	-4.49
1939	-5.07	-4.64	-4.67	-4.27	-4.67
1938	-5.00	-4.65	-4.90	-4.54	-4.75
1937	-4.92	-4.50	-4.85	-4.39	-4.74
1936	-5.15	-4.61	-4.84	-4.43	-4.80
1935	-5.00	-4.63	-5.02	-4.54	-4.74
1934	-5.07	-4.65	-4.88	-4.45	-4.66
1933	-5.08	-4.76	-5.08	-4.53	-4.89
1932	-5.06	-4.67	-4.86	-4.58	-4.80
1931	-4.84	-4.51	-5.00	-4.53	-4.65
1930	-4.79	-4.31	-4.52	-4.21	-4.67
1929	-4.87	-4.57	-4.90	-4.13	-4.62
1928	-4.92	-4.61	-4.89	-4.09	-4.83
1927	-5.14	-4.76	-5.05	-4.15	-4.87
1926	-4.85	-4.53	-4.81	-4.44	-4.71
1925	-4.98	-4.45	-4.95	-4.06	-4.73
1924	-4.91	-4.49	-4.81	-4.17	-4.83
1923	-4.91	-4.57	-4.85	-4.27	-4.67
1922	-5.14	-4.70	-4.85	-4.37	-4.83

Year A.D.	1F $\delta^{18}O$	AB $\delta^{18}O$	TH1 $\delta^{18}O$	TM1 $\delta^{18}O$	TNI2 $\delta^{18}O$
1921	-5.07	-4.63	-5.00	-4.48	-4.82
1920	-4.93	-4.48	-4.77	-4.54	-4.77
1919	-4.90	-4.51	-4.70	-4.39	-4.78
1918	-5.14	-4.62	-4.86	-4.26	-4.82
1917	-5.31	-4.72	-5.09	-4.51	-4.97
1916	-5.20	-4.78	-4.96	-4.59	-4.90
1915	-4.94	-4.50	-4.77	-4.64	-4.58
1914	-4.87	-4.56	-4.80	-4.24	-4.56
1913	-4.82	-4.51	-4.72	-4.11	-4.56
1912	-4.76	-4.49	-4.80	-4.28	-4.26
1911	-5.08	-4.68	-4.89	-4.28	-4.45
1910	-5.14	-4.74	-4.91	-4.60	-4.55
1909	-4.94	-4.71	-4.95	-4.46	-4.63
1908	-4.99	-4.76	-4.93	-4.63	-4.57
1907	-4.96	-4.63	-4.74	-4.52	-4.59
1906	-4.85	-4.51	-4.79	-4.38	-4.40
1905	-4.66	-4.34	-4.60	-4.32	-4.36
1904	-4.86	-4.55	-4.81	-4.26	-4.48
1903	-4.80	-4.44	-4.71	-4.34	-4.45
1902	-4.83	-4.47	-4.84	-4.12	-4.50
1901	-4.76	-4.53	-4.65	-4.08	-4.47
1900	-4.72	-4.46	-4.90	-4.23	-4.49
1899	-4.88	-4.58	-4.74	-4.21	-4.53
1898	-4.98	-4.77	-4.86	-4.37	-4.65
1897	-4.86	-4.49	-4.63	-4.60	-4.48
1896	-4.93	-4.48	-4.64	-4.16	-4.47
1895	-4.94	-4.51	-4.82	-4.40	-4.54
1894	-4.96	-4.64	-4.86	-4.66	-4.61
1893	-5.24	-4.68	-4.94	-4.62	-4.77
1892	-5.09	-4.66	-4.85	-4.64	-4.65
1891	-5.06	-4.63	-4.84	-4.39	-4.60
1890	-5.16	-4.68	-4.83	-4.29	-4.60
1889	-4.90	-4.46	-4.64	-4.25	-4.46
1888	-4.87	-4.40	-4.92	-4.24	-4.52
1887	-4.99	-4.65	-4.93	-4.14	-4.73
1886	-4.76	-4.44	-4.70	-4.32	-4.41
1885	-4.78	-4.37	-4.65	-4.29	-4.48
1884	-4.75	-4.46	-4.78	-4.27	-4.45
1883	-4.87	-4.56	-4.79	-4.21	-4.61
1882	-4.89	-4.54	-4.90	-4.39	-4.40
1881	-4.97	-4.57	-4.90	-4.39	-4.42
1880	-5.02	-4.64	-4.94	-4.41	-4.53
1879	-5.16	-4.77	-4.92	-4.42	-4.54
1878	-4.70	-4.45	-4.70	-4.26	-4.47

Year A.D.	1F $\delta^{18}O$	AB $\delta^{18}O$	TH1 $\delta^{18}O$	TM1 $\delta^{18}O$	TNI2 $\delta^{18}O$
1877	-4.61	-4.32	-4.60	-4.10	-4.30
1876	-4.80	-4.51	-4.79	-4.25	-4.49
1875	-4.78	-4.41	-4.80	-4.43	-4.53
1874	-4.78	-4.51	-4.79	-4.37	-4.49
1873	-4.78	-4.46	-4.79	-4.51	-4.48
1872	-4.91	-4.45	-4.89	-4.38	-4.48
1871	-4.89	-4.61	-4.96	-4.61	-4.58
1870	-4.83	-4.69	-4.84	-4.49	-4.52
1869	-4.87	-4.62	-4.63	-4.39	-4.59
1868	-4.73	-4.45	-4.90	-4.34	-4.64
1867	-4.78	-4.50	-4.81	-4.43	-4.60
1866	-4.60	-4.56	-4.72	-4.51	-4.62
1865	-4.56	-4.46	-4.81	-4.39	-4.52
1864	-4.77	-4.46	-4.80	-4.07	-4.51
1863	-4.76	-4.46	-4.74	-4.27	-4.60
1862	-4.75	-4.38	-4.94	-4.30	-4.66
1861	-4.90	-4.48	-5.02	-4.43	-4.74
1860	-5.01	-4.67	-4.88	-4.42	-4.81
1859	-4.90	-4.56	-4.90	-4.53	-4.63
1858	-4.85	-4.44	-4.89	-4.36	-4.59
1857	-4.78	-4.49	-5.02	-4.32	-4.53
1856	-4.92	-4.60	-4.67	-4.47	-4.67
1855	-4.79	-4.49	-4.78	-4.47	-4.59
1854	-4.77	-4.45	-4.81	-4.29	-4.55
1853	-4.79	-4.53	-4.79	-4.51	-4.57
1852	-4.86	-4.44	-4.70	-4.31	-4.63
1851	-4.84	-4.33	-4.70	-4.34	-4.49
1850	-4.78	-4.25	-4.84	-4.43	-4.50
1849	-4.67	-4.44	-4.98	-4.50	-4.55
1848	-4.98	-4.56	-4.87	-4.60	-4.75
1847	-4.96	-4.60	-4.88	-4.60	-4.71
1846	-4.80	-4.56	-4.73	-4.44	-4.63
1845	-4.62	-4.42	-4.80	-4.28	-4.54
1844	-4.75	-4.36	-4.79	-4.28	-4.50
1843	-4.76	-4.31	-4.85	-4.32	-4.70
1842	-4.80	-4.62	-4.82	-4.42	-4.30
1841	-5.01	-4.53	-4.72	-4.36	-4.65
1840	-4.88	-4.43	-4.65	-4.44	-4.60
1839	-4.88	-4.44	-4.64	-4.23	-4.64
1838	-4.71	-4.40	-4.85	-4.39	-4.54
1837	-4.94	-4.47	-4.72	-4.49	-4.73
1836	-4.78	-4.36	-4.84	-4.33	-4.58
1835	-4.77	-4.40	-4.82		-4.49
1834	-4.86	-4.45	-4.91		-4.51

Year A.D.	1F $\delta^{18}O$	AB $\delta^{18}O$	TH1 $\delta^{18}O$	TM1 $\delta^{18}O$	TNI2 $\delta^{18}O$
1833	-4.64	-4.43	-4.79		-4.58
1832	-4.72	-4.38	-4.81		-4.62
1831	-4.85	-4.46	-4.92		-4.68
1830	-4.99	-4.54	-5.01		-4.95
1829	-5.01	-4.58	-5.12		-4.81
1828	-4.90	-4.60	-5.11		-4.83
1827	-4.92	-4.60	-5.10		-4.72
1826	-4.86	-4.56	-5.12		-4.86
1825	-4.99	-4.60	-4.75		-4.91
1824	-4.76	-4.40	-4.99		-4.87
1823	-4.86	-4.34	-4.97		-4.95
1822	-4.87	-4.50	-4.90		-4.57
1821	-4.83	-4.38	-4.99		-4.49
1820	-4.74	-4.34	-5.17		-4.72
1819	-5.03	-4.56	-5.01		-4.85
1818	-5.11	-4.65	-4.88		-4.50
1817	-4.81	-4.53	-4.91		-4.60
1816	-4.74	-4.42	-4.80		-4.64
1815	-4.74	-4.40	-4.92		-4.65
1814	-4.69	-4.42	-4.92		-4.68
1813	-4.88	-4.51	-5.01		-4.70
1812	-4.89	-4.54	-5.01		-4.60
1811	-4.73	-4.47	-4.72		-4.50
1810	-4.62	-4.40	-4.65		-4.53
1809	-4.72	-4.35	-4.78		-4.52
1808	-4.81	-4.37	-4.83		-4.71
1807	-4.96	-4.58	-4.94		-4.89
1806	-5.01	-4.78	-4.91		-4.88
1805	-5.00	-4.62	-4.99		-4.73
1804	-4.97	-4.59	-4.68		-4.59
1803	-4.66	-4.37	-4.67		-4.31
1802	-4.71	-4.43	-4.83		-4.35
1801	-4.76	-4.60	-4.97		-4.52
1800	-4.89	-4.68	-4.83		-4.55
1799	-4.74	-4.52	-4.86		-4.60
1798	-4.84	-4.41	-4.75		-4.57
1797	-4.96	-4.50	-4.85		-4.68
1796	-4.90	-4.61	-4.85		-4.71
1795	-4.87	-4.68	-4.95		-4.60
1794	-4.96	-4.72	-5.10		-4.54
1793	-4.83	-4.62	-4.68		-4.64
1792	-4.77	-4.35			-4.72
1791	-4.70	-4.28			-4.66
1790	-4.56	-4.44			-4.85

Year A.D.	1F $\delta^{18}O$	AB $\delta^{18}O$	TH1 $\delta^{18}O$	TM1 $\delta^{18}O$	TNI2 $\delta^{18}O$
1789	-4.66	-4.56			-4.61
1788	-4.58	-4.50			-4.68
1787	-4.65	-4.51			-4.62
1786	-4.81	-4.53			-4.64
1785	-4.74	-4.59			-4.73
1784	-4.88	-4.71			-4.76
1783	-4.62	-4.48			-4.79
1782	-4.66	-4.44			-4.76
1781	-4.66	-4.46			-4.63
1780		-4.49			-4.33
1779		-4.52			-4.70
1778		-4.48			-4.79
1777		-4.63			-4.92
1776		-4.44			-4.70
1775		-4.50			-4.67
1774		-4.58			-4.73
1773		-4.55			-4.89
1772		-4.54			-4.68
1771		-4.49			-4.62
1770		-4.35			-4.65
1769		-4.22			-4.60
1768		-4.37			-4.74
1767		-4.40			-4.73
1766		-4.36			-4.64
1765		-4.42			-4.85
1764		-4.39			-4.84
1763		-4.37			-4.79
1762		-4.40			-4.51
1761		-4.47			-4.83
1760		-4.30			-4.62
1759		-4.27			-4.49
1758		-4.38			-4.47
1757		-4.47			-4.50
1756		-4.51			-4.79
1755		-4.45			-4.71
1754		-4.40			-4.70
1753		-4.43			-4.60
1752		-4.54			-4.57
1751		-4.46			-4.60
1750		-4.43			-4.70
1749		-4.47			-4.47
1748		-4.64			-4.60
1747		-4.52			-4.90
1746		-4.47			-4.59

Year A.D.	1F $\delta^{18}O$	AB $\delta^{18}O$	TH1 $\delta^{18}O$	TM1 $\delta^{18}O$	TNI2 $\delta^{18}O$
1745		-4.38			-4.70
1744		-4.43			-4.63
1743		-4.50			-4.62
1742		-4.50			-4.67
1741		-4.50			-4.78
1740		-4.52			-4.88
1739		-4.49			-4.71
1738		-4.48			-4.67
1737		-4.61			-4.82
1736		-4.42			-4.70
1735		-4.56			-4.69
1734		-4.53			-4.37
1733		-4.48			-4.51
1732		-4.61			-4.69
1731		-4.57			-4.50
1730		-4.56			-4.66
1729		-4.66			-4.59
1728		-4.67			-4.81
1727		-4.67			-4.68
1726		-4.68			-4.68
1725		-4.63			-4.60
1724		-4.61			-4.45
1723		-4.47			-4.57
1722		-4.61			-4.18
1721		-4.59			-4.30
1720		-4.61			-4.81
1719		-4.44			-4.66
1718		-4.57			-4.59
1717		-4.64			-4.77
1716		-4.75			-4.80
1715		-4.53			-4.89
1714		-4.53			-4.77
1713		-4.40			-4.25
1712		-4.53			-4.13
1711		-4.56			-4.21
1710		-4.65			-4.41
1709		-4.61			-4.58
1708		-4.50			-4.71
1707		-4.52			-4.38
1706		-4.54			-4.45
1705		-4.61			-4.41
1704		-4.43			-4.59
1703		-4.37			-4.62
1702		-4.66			-4.62

Year A.D.	1F $\delta^{18}O$	AB $\delta^{18}O$	TH1 $\delta^{18}O$	TM1 $\delta^{18}O$	TNI2 $\delta^{18}O$
1701		-4.70			-4.78
1700		-4.53			-4.53
1699		-4.57			-4.42
1698		-4.54			-4.57
1697		-4.42			-4.50
1696		-4.56			-4.76
1695		-4.61			-4.50
1694		-4.60			-4.74
1693		-4.40			-4.70
1692		-4.49			-4.40
1691		-4.57			-4.61
1690		-4.50			-4.61
1689		-4.57			-4.61
1688		-4.55			-4.61
1687		-4.61			-4.61
1686		-4.41			-4.69
1685		-4.63			-4.64
1684		-4.63			-4.86
1683		-4.50			-4.63
1682		-4.56			-4.78
1681		-4.63			-4.75
1680		-4.49			-4.57
1679		-4.49			-4.82
1678		-4.49			-4.49
1677		-4.57			-4.48
1676		-4.41			-4.60
1675		-4.43			-4.85
1674		-4.51			-4.52
1673		-4.53			-4.59
1672		-4.47			-4.90
1671		-4.62			-4.89
1670		-4.61			-4.86
1669		-4.56			-4.55
1668		-4.50			-4.70
1667		-4.45			-4.40
1666		-4.47			-4.63
1665		-4.41			-4.59
1664		-4.28			-4.31
1663		-4.23			-4.50
1662		-4.31			-4.52
1661		-4.50			-4.43
1660		-4.67			-4.61
1659		-4.59			-4.65
1658		-4.42			-4.48

Year A.D.	1F $\delta^{18}O$	AB $\delta^{18}O$	TH1 $\delta^{18}O$	TM1 $\delta^{18}O$	TNI2 $\delta^{18}O$
1657		-4.37			-4.29
1656		-4.56			-4.16
1655		-4.56			-4.62
1654		-4.42			-4.94
1653		-4.28			-4.74
1652		-4.34			-4.66
1651		-4.39			-4.53
1650		-4.65			-4.44
1649		-4.57			
1648		-4.47			
1647		-4.41			
1646		-4.55			
1645		-4.43			
1644		-4.41			
1643		-4.46			
1642		-4.48			
1641		-4.40			
1640		-4.33			
1639		-4.47			
1638		-4.52			
1637		-4.43			
1636		-4.42			
1635		-4.43			
1634		-4.52			
1633		-4.58			
1632		-4.57			
1631		-4.57			
1630		-4.60			
1629		-4.53			
1628		-4.52			
1627		-4.49			
1626		-4.54			
1625		-4.74			
1624		-4.67			
1623		-4.43			
1622		-4.45			
1621		-4.61			
1620		-4.55			
1619		-4.60			
1618		-4.63			
1617		-4.69			