Stable oxygen isotopes and Sr/Ca-ratios in modern *Diploria strigosa* corals from different sites in the Caribbean Sea – evaluation of a new climate archive for the tropical Atlantic

Stabile Sauerstoffisotope und Sr/Ca-Elementverteilung in rezenten *Diploria strigosa* Korallen von verschiedenen Lokationen in der Karibik – Evaluierung eines neuen Klimaarchives für den tropischen Atlantik

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EIDESSTATTLICHE ERKLÄRUNG

Hiermit erkläre ich an Eides statt, dass die vorliegende Abhandlung - abgesehen von der Beratung durch meinen akademischen Lehrer - in Inhalt und Form meine eigene Arbeit darstellt. Ferner habe ich weder diese noch eine ähnliche Arbeit an einer anderen Hochschule im Rahmen eines Prüfungsverfahrens vorgelegt.

Steffen Hetzinger

ABSTRACT

Instrumental climate data are limited in length and only available with low spatial coverage before the middle of the 20th century. This is too short to reliably determine and interpret decadal and longer scale climate variability and to understand the underlying mechanisms with sufficient accuracy. A proper knowledge of past variability of the climate system is needed to assess the anthropogenic impact on climate and ecosystems, and also important with regard to long-range climate forecasting. Highly-resolved records of past climate variations that extend beyond pre-industrial times can significantly help to understand long-term climate changes and trends.
Indirect information on past environmental and climatic conditions can be deduced from climate-sensitive proxies. Large colonies of massive growing tropical reef corals have been proven to sensitively monitor changes in ambient seawater. Rapid skeletal growth, typically ranging between several millimeters to centimeters per year, allows the development of proxy records at sub-seasonal resolution. Stable oxygen isotopic composition and trace elemental ratios incorporated in the aragonitic coral skeleton can reveal a detailed history of past environmental conditions, e.g., sea surface temperature (SST). In general, coral-based reconstructions from the tropical Atlantic region have lagged behind the extensive work published using coral records from the Indian and Pacific Oceans. Difficulties in the analysis of previously utilized coral archives from the Atlantic, typically corals of the genera *Montastrea* and *Siderastrea*, have so far exacerbated the production of long-term high-resolution proxy records.
The objective of this study is the evaluation of massive fast-growing corals of the species *Diploria strigosa* as a new marine archive for climate reconstructions from the tropical Atlantic region. For this purpose, coral records from two study sites in the eastern Caribbean Sea (Guadeloupe, Lesser Antilles; and Archipelago Los Roques, Venezuela) were examined.

At Guadeloupe, a century-long monthly resolved multi-proxy coral record was generated. Results present the first $\delta^{18}O$ (Sr/Ca)-SST calibration equations for the Atlantic braincoral *Diploria strigosa*, that are robust and consistent with previously published values using other coral species from different regions. Both proxies reflect local variability of SST on a sub-seasonal scale, which is a precondition for studying seasonally phase-locked climate variations, as well as track variability on a larger spatial scale (i.e., in the Caribbean and tropical North Atlantic). Coral Sr/Ca reliably records local annual to interannual temperature variations and is higher correlated to *in-situ* air temperature than to grid-SST. The warming calculated from coral Sr/Ca is concurrent with the strong surface temperature increase at the study site during the past decades. Proxy data show a close relationship to major climate signals from the tropical Pacific and North Atlantic (the El Niño Southern Oscillation (ENSO) and the North Atlantic Oscillation (NAO)) affecting the seasonal cycle of SST in the North Tropical Atlantic (NTA). Coral oxygen isotopes are also influenced by seawater $\delta^{18}O$ ($\delta^{18}O_{sw}$) which is linked to the hydrological cycle, and capture large-scale climate variability in the NTA region better than Sr/Ca. Results from a quantitative comparison between extreme events in the two most prominent modes of external forcing, namely the ENSO and NAO, and respective events recorded in seasonal coral $\delta^{18}O$ imply that SST variability at the study site is highly linked to Pacific and North Atlantic variability, by this means supporting the assumptions of observational- and model-based studies which suggest a strong impact of ENSO and NAO forcings onto the NTA region through a modulation of trade wind strength in winter. Results from different spectral analysis tools suggest that interannual climate variability recorded by the coral proxies is

largely dictated by Pacific ENSO forcing, whereas at decadal and longer timescales the influence of the NAO is dominant.

The Archipelago Los Roques is situated in the southeastern Caribbean Sea, north of the Venezuelan coast. Year-to-year variations in monthly resolved coral $\delta^{18}O$ of a near-century-long *Diploria strigosa* record are significantly correlated with SST and show pronounced multidecadal variations. About half of the variance in coral $\delta^{18}O$ can be explained by variations in seawater $\delta^{18}O$, which can be estimated by calculating the $\delta^{18}O_{residual}$ via subtracting the SST component from measured coral $\delta^{18}O$. The $\delta^{18}O_{residual}$ and a regional precipitation index are highly correlated at low frequencies, suggesting that $\delta^{18}O_{sw}$ variations are primarily atmospheric-driven. Warmer SSTs at Los Roques broadly coincide with higher precipitation in the southeastern Caribbean at multidecadal time scales, effectively strengthening the climate signal in the coral $\delta^{18}O$ record. The Los Roques coral $\delta^{18}O$ record displays a strong and statistically significant relationship to different indices of hurricane activity during the peak of the Atlantic hurricane season in boreal summer and is a particularly good indicator of decadal-multidecadal swings in the latter indices. In general, the detection of long-term changes and trends in Atlantic hurricane activity is hampered due to the limited length of the reliable instrumental record and the known inhomogeneity in the observational databases which result from changes in observing practice and technology over the years. The results suggest that coral-derived proxy data from Los Roques can be used to infer changes in past hurricane activity on timescales that extend well beyond the reliable record. In addition, the coral record exhibits a clear negative trend superimposed on the decadal to multidecadal cycles, indicating a significant warming and freshening of surface waters in the genesis region of tropical cyclones during the past decades. The presented coral $\delta^{18}O$ time series provides the first and, so far, longest continuous coral-based record of hurricane activity. It appears that the combination of both signals (SST and $\delta^{18}O_{sw}$) in coral $\delta^{18}O$ leads to an amplification of large-scale climate signals in the record, and makes coral $\delta^{18}O$ even a better proxy for hurricane activity than SST alone.
Atlantic hurricane activity naturally exhibits strong multidecadal variations that are associated with the Atlantic Multidecadal Oscillation (AMO), the major mode of low-frequency variability in the North Atlantic Ocean. However, the mechanisms underlying this multidecadal variability remain controversial, primarily because of the limited instrumental record. The Los Roques coral $\delta^{18}O$ displays strong multidecadal variability with a period of approximately 60 years that is closely related to the AMO, making the Archipelago Los Roques a very sensitive location for studying low-frequency climate variability in the Atlantic Ocean.

In summary, the coral records presented in this thesis capture different key climate variables in the north tropical Atlantic region very well, indicating that fast-growing *Diploria strigosa* corals represent a promising marine archive for further proxy-based reconstructions of past climate variability on a range of time scales.

ZUSAMMENFASSUNG

Instrumentell aufgezeichnete Klimadaten sind in der Länge begrenzt und vor der Mitte des 20. Jahrhunderts in ihrer räumlichen Verfügbarkeit stark eingeschränkt. Diese Daten sind zu kurz um dekadische und längerskalige Klimavariabilität sowohl verlässlich bestimmen und interpretieren zu können, als auch die zugrundeliegenden Mechanismen mit hinlänglicher Genauigkeit zu verstehen. Eine angemessene Kenntnis vergangener Klimavariabilität ist von eminenter Wichtigkeit um den anthropogenen Einfluss auf Klima und Ökosysteme verlässlich zu beurteilen, sowie maßgebend um langfristige Klimavorhersagen treffen zu können. Aus diesem Grund können hochaufgelöste Aufzeichnungen vergangener Klimavariabilität, welche sich bis ins vorindustrielle Zeitalter erstrecken, sehr hilfreich sein um langfristige Klimaänderungen und Trends besser zu verstehen. Indirekte Informationen über in der Vergangenheit vorherrschende Umwelt- und Klimabedingungen können von Klima-sensitiven Proxies abgeleitet werden. Große Kolonien tropischer Korallen massiver Wuchsform sind dafür bekannt Veränderungen im sie umgebenden Meerwasser mit hoher Genauigkeit aufzuzeichnen. Das schnelle Wachstum des Korallenskeletts, welches im Bereich von einigen Millimetern bis zu wenigen Zentimetern pro Jahr liegt, erlaubt die Entwicklung von sogenannten Proxy-Zeitserien die saisonale und höhere zeitliche Auflösung aufweisen. Im aragonitischen Korallenskelett eingebaute stabile Sauerstoffisotopen und Spurenelemente können ein detailliertes Bild über die Abfolge vergangener Änderungen in den Umweltbedingungen (z.B. der Temperatur an der Wasseroberfläche, SST) liefern. Die Anzahl der auf Korallen aus dem tropischen Atlantik basierenden Rekonstruktionen vergangener Klimabedingungen ist gering im Vergleich zu den zahlreichen Studien die auf Korallen aus dem Indischen und Pazifischen Ozean gründen. Bislang wurde die Herstellung von hochaufgelösten Langzeit-Proxyzeitserien vor allem durch Schwierigkeiten in der Beprobung und Analyse der im tropischen Atlantik vorrangig verwendeten Korallengattungen *Montastrea* und *Siderastrea* erschwert.
Das Ziel dieser Studie ist die Evaluierung von schnellwachsenden Korallen massiver Wuchsform der Art *Diploria strigosa* als neues marines Archiv für Klimarekonstruktionen aus dem tropischen Atlantik. Zu diesem Zweck wurden neue Korallen-Zeitreihen von zwei Lokationen in der östlichen Karibik (Guadeloupe, Kleine Antillen; und Archipel Los Roques, Venezuela) entwickelt und untersucht.

Im Arbeitsgebiet Guadeloupe wurde eine das letzte Jahrhundert umspannende Multi-Proxy Korallen-Zeitserie hergestellt, die monatliche Auflösung bietet. Die Ergebnisse der Studie repräsentieren die ersten Kalibrationsgleichungen zwischen Sauerstoffisotopen, Spurenelementen (Sr/Ca) und der Wassertemperatur (SST) für die aus dem Atlantik stammende Korallenart *Diploria strigosa*. Die berechneten Kalibrationen sind robust und stimmen gut mit den bekannten Werten anderer Korallenarten aus verschiedenen Regionen weltweit überein. Beide verwendeten Proxies spiegeln die lokale Variabilität der Oberflächen-Wassertemperatur mit hoher zeitlicher Auflösung wider, was wiederum eine wichtige Voraussetzung für die Untersuchung von stark saisonal geprägten Klimasignalen darstellt. Ferner zeichnen beide Proxies die weiträumigere SST-Variabilität auf, d.h. in der Karibik und in Teilen des tropischen Nordatlantiks. Das Korallen-Sr/Ca stellt einen zuverlässigen Proxy für lokale annuelle bis interannuelle Temperaturschwankungen dar, der höher mit lokal gemessener Lufttemperatur korreliert als mit gemittelter SST. Die aus Korallen-Sr/Ca errechnete Erwärmung stimmt mit der im Arbeitsgebiet beobachteten starken Erwärmung der Oberflächentemperatur während der letzten Jahrzehnte überein. Die Proxydaten zeigen eine enge Verbindung zu bedeutenden Klimasignalen aus dem tropischen Pazifik und Nordatlantik (die El Niño-Südhemisphären Oszillation (ENSO),

sowie die Nordatlantische Oszillation (NAO)), welche den Jahresgang der SST im nordtropischen Atlantik (NTA) beeinflussen.
Am Aragonit von Korallen gemessene Sauerstoffisotopen werden außerdem vom Meerwasser $\delta^{18}O$ ($\delta^{18}O_{Meerwasser}$) beeinflusst, das wiederum vom hydrologischen Kreislauf abhängig ist, und zeichnen großskalige Klimavariabilität im nordtropischen Atlantik besser auf als Sr/Ca, welches vor allem lokale Temperaturschwankungen reflektiert. Ein quantitativer Vergleich zwischen Extremereignissen in externen Klimasignalen, welche den tropischen Atlantik beeinflussen können (ENSO und die NAO), und im saisonalen Korallen-$\delta^{18}O$ aufgezeichneten Ereignissen zeigt, dass die Temperaturvariabilität im Arbeitsgebiet mit der Variabilität im tropischen Pazifik und Nordatlantik in Verbindung steht. Diese Ergebnisse unterstützen wiederum die auf instrumentellen Daten und Klimasimulationen basierenden Resultate, welche einen starken Einfluß der ENSO und der NAO auf den nordtropischen Atlantik durch die Regulierung der Passatwind-Stärke vermuten lassen. Die Ergebnisse aus der Untersuchung der Proxy-Zeitserien mit verschiedenen Methoden der Spektralanalyse deuten darauf hin, dass die von der Koralle aufgezeichnete interannuelle Klimavariabilität vor allem durch den pazifischen Einfluss (ENSO) bestimmt wird, wohingegen der Einfluss der NAO auf dekadischen und längeren Zeitskalen zu dominieren scheint.

Das Archipel Los Roques liegt in der südöstlichen Karibik, nördlich der Küste Venezuelas. Die auf einer rezenten *Diploria strigosa* Koralle basierende monatlich aufgelöste Sauerstoffisotopen-Zeitserie deckt nahezu das gesamte letzte Jahrhundert ab und weist eine hohe Korrelation zur Wassertemperatur auf, außerdem zeigt der Rekord sowohl jahreszeitliche Schwankungen als auch deutliche Variabilität auf multidekadischen Zeitskalen. Etwa die Hälfte der Varianz des Korallen-$\delta^{18}O$ kann dabei durch Schwankungen im $\delta^{18}O_{Meerwasser}$ erklärt werden, welches durch die Berechnung des $\delta^{18}O_{residual}$ abgeschätzt werden kann indem man die Temperatur-Komponente (hier: SST) vom gemessenen Korallen-$\delta^{18}O$ subtrahiert. Das $\delta^{18}O_{residual}$ und ein regionaler Niederschlagsindex zeigen eine starke Verbindung auf niedrigen Frequenzen, was auf eine Steuerung der Variabilität des $\delta^{18}O_{residual}$ durch die Atmosphäre hindeutet. Im Allgemeinen gehen, auf multidekadischen Zeitskalen betrachtet, hohe Wassertemperaturen im Arbeitsgebiet mit starkem Niederschlag in der südöstlichen Karibik einher. Dadurch wird das Klimasignal im Korallen-$\delta^{18}O$ verstärkt. Ferner weist der Korallen-$\delta^{18}O$ Rekord während des borealen Sommers eine statistisch signifikante Beziehung zu verschiedenen Indizes auf, welche die Aktivität atlantischer Hurrikane messen. Die Proxy-Zeitreihe bildet vor allem Schwankungen der Indizes auf dekadischen bis multidekadischen Zeitskalen ab. Die verfügbaren instrumentellen Messdaten zur Hurrikanaktivität sind zeitlich stark eingeschränkt und weisen große Unterschiede auf, welche vor allem auf die über die Jahre erfolgten Umstellungen in Messmethodik und –technik zurückzuführen sind. Jedoch erschwert dies die Erkennung und Interpretation langfristiger Schwankungen und Trends in der Atlantischen Hurrikanaktivität. Die hier vorgestellten Ergebnisse legen nahe, dass die auf Korallen vom Los Roques Archipel basierenden Proxydaten wichtige Erkenntnisse über vergangene Schwankungen in der Hurrikanaktivität liefern können, und zwar auf Zeitskalen welche sich bis vor die verlässlichen instrumentellen Aufzeichnungen erstrecken. Im Korallen-Rekord ist außerdem ein negativer Trend zu erkennen, der die dekadische bis multidekadische Variabilität überlagert und auf eine Erwärmung sowie einen möglichen Rückgang der Oberflächenwassersalinität im Entstehungsgebiet tropischer Zyklone während der letzten Jahrzehnte hindeutet. Die Korallen-$\delta^{18}O$ Zeitreihe stellt den ersten, und bis jetzt längsten, auf Korallen basierenden kontinuierlichen Rekord für Hurrikanaktivität dar. Die Ergebnisse deuten darauf hin das die Kombination des Temperatursignals mit dem $\delta^{18}O_{Meerwasser}$-Signal im Korallen-$\delta^{18}O$ zu einer Verstärkung

großräumiger Klimasignale führt, was wiederum Korallen-$\delta^{18}O$ zu einem besseren Indikator für Hurrikanaktivität machen würde als SST allein betrachtet.
Die Atlantische Hurrikanaktivität weist natürliche multidekadische Schwankungen auf, welche mit der bedeutendsten niederfrequenten Variabilität im Nordatlantik, der Atlantischen Multidekadischen Oszillation (AMO), assoziiert werden. Diesem Klimasignal zugrundeliegende Mechanismen sind jedoch weitestgehend ungeklärt, hauptsächlich bedingt durch die zeitlich begrenzten instrumentellen Daten. Der Korallen-$\delta^{18}O$ Rekord weist ein deutliches multidekadisches Signal mit einer Periode von etwa 60 Jahren auf, dass in enger Verbindung zur AMO steht. Wiederum deutet dies darauf hin, dass das Archipel Los Roques eine besonders sensitive Lokation für die Erfassung und Rekonstruktion niederfrequenter atlantischer Klimavariabilität darstellt.

Zusammenfassend lässt sich feststellen, dass die in dieser Arbeit vorgestellten Korallen-Rekords verschiedene, im nordtropischen Atlantik entscheidende, Klimaparameter mit hoher Zuverlässigkeit aufzeichnen. Dies impliziert, dass schnellwachsende *Diploria strigosa* Korallen ein vielversprechendes marines Archiv darstellen, welches erhebliches Potential für zukünftige Proxy-basierte Rekonstruktionen vergangener Klimavariabilität auf verschiedenen Zeitskalen aufweist.

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CHAPTER 1 - INTRODUCTION

1.1 Corals as archives of paleoclimatic variability

A better understanding of decadal to centennial climate variations is crucial in order to shed light onto ocean-atmosphere processes in the tropics that are known to impact climate variability worldwide. In this context, enhanced knowledge about past natural climate variability over a wide range of time scales is of highest relevance to present socio-economic and political concerns. State-of-the-art climate models, that can be used to predict future climate scenarios, are based only on the observational data available from the past several decades. However, these records are too short to examine important low-frequency climate variability and to understand its underlying mechanisms with sufficient accuracy. For example, instrumental observations of surface seawater parameters in the tropical oceans are temporally and spatially limited, and therewith hamper the detection and investigation of statistically significant relationships between different climate parameters over extended time periods. Generally, observational records of environmental parameters become sparser and are spatiotemporally incomplete before 1950, and especially prior to the past century observational data coverage (e.g., for sea surface temperature, SST) decreases rapidly (Smith and Reynolds, 2003). These circumstances hinder the understanding of tropical ocean-atmosphere dynamics on time scales prior to the instrumental period.

Proxy data provide indirect information on past climate conditions and can help to complement and significantly extend the records back in space and time (Jones et al., 2001). Continental climate proxies such as tree rings and stalagmites, which are commonly used to provide reconstructions of precipitation, droughts and land air temperature, exhibit annual or lower resolution, the temporal resolution of laminated marine sediments is even coarser. However, in order to successfully resolve climate variability that very often displays a strong seasonality highly resolved proxy records are a prerequisite. Tropical corals represent a very promising tool to extend records of ocean-atmosphere variability to pre-industrial times, since geochemical proxy records obtained from coral skeletons can function as indicators of climate variability with sub-seasonal resolution. Due to their long lifetime (up to several centuries) and widely abundance in the tropical marine realm, corals are an ideal archive for the reconstruction of seasonal to multidecadal variability of environmental variables in the tropical surface oceans. In numerous studies, coral skeletons from massive scleractinian reef corals have provided valuable insights on environmental and climatic changes over the past several centuries in many regions of the tropics (e.g., Cole et al., 1993; Gagan et al., 1998; McCulloch et al., 1994). For example, geochemical coral proxy records from equatorial and near-equatorial Pacific sites have been used to reconstruct past ENSO variability (e.g., Cobb et al., 2003; Cole and Fairbanks, 1990; Cole et al., 1993; Dunbar et al., 1994; Evans et al., 1999; Linsley et al., 2000; Tudhope et al., 2001; Urban et al., 2000).

Large colonies of massive growing reef corals represent excellent resources of past climate fluctuations since they provide archives that offer both high temporal resolution and up to multi-century record length. The annual density bands found in coral skeletons provide a chronological control at sub-seasonal resolution. Most massive growing species produce annual density bands that present time markers for the development of long chronologies. Typical growth rates of tropical corals range from about 5 to 20 mm per year. Taxonomically, corals belong to the phylum Cnidaria and the class Anthozoa. Modern tropical coral reefs are dominated by colonies of hermatypic (reef-building) corals that belong to the order of scleractinians (stony corals) and contain endosymbiotic algae (unicellular dinoflagellates), the zooxanthellae. They typically live at water depths <20 m, where sufficient light is available for the photosynthetic activity of the endosymbiotic algae. The development of coral reefs is restricted to locations with warm water temperatures, i.e., where mean annual SSTs are not below 24°C and/or mean winter minimum temperatures are not below ~18°C. This restricts the spatial distribution of coral reefs to a band located roughly equatorwards of 23-24° latitude.

The aragonitic skeleton of hermatypic corals carries a diverse suite of chemical and isotopic indicators (so-called "geochemical proxies") that are a function of environmental changes in the ambient seawater, such as surface water temperature and salinity, as well as site specific features (e.g., turbidity, runoff, upwelling intensity). Therefore, corals can serve as archives of various components of the climate system, including sea surface temperatures (Beck et al., 1992; Dunbar and Wellington, 1981; Dunbar et al., 1994; Fairbanks and Dodge, 1979; Weber and Woodhead, 1972), and the precipitation-evaporation balance (e.g., Cole and Fairbanks, 1990; Cole et al., 1993; Gagan et al., 2000; Kilbourne et al., 2004). However, only few coral records have been calibrated with multi-year *in-situ* monitoring data. Hence, investigators usually rely on gridded data sets of SST, SSS, and rainfall for calibration of the coral-derived geochemical proxy records, or standardized indices of major climate phenomena.

The incorporation of isotopes and certain elements in coral skeletal aragonite is governed by thermodynamic properties, albeit modified by physiological processes. The most widely used coral-based climate proxies are stable isotopes ($\delta^{18}O$, $\delta^{13}C$) and trace elemental ratios (Sr/Ca, Mg/Ca). Most coral-based climate studies have relied on oxygen isotopic ($\delta^{18}O$) measurements because they are easy to obtain and relatively straightforward to interpret. The stable oxygen isotopic content of the aragonitic coral skeleton therefore provides a useful instrument to reconstruct past environmental changes. Coral $\delta^{18}O$ records SST variability (e.g., Weber and Woodhead, 1972) at the time of carbonate precipitation, or, when seawater $\delta^{18}O$ ($\delta^{18}O_{sw}$) is variable due to changes in the hydrological cycle (precipitation-evaporation balance and runoff), this component is also incorporated in the coral skeletal $\delta^{18}O$ (e.g., Cole and Fairbanks, 1990; Gagan et al., 1994; Linsley et al., 1994) and variations in the freshwater balance can be reconstructed (Cole et al., 1993; Hendy et al., 2002; Linsley et al., 1994). In oceanic settings where the $\delta^{18}O_{sw}$ co-varies with salinity, coral $\delta^{18}O$ records these changes (Dunbar and Wellington, 1981; Gagan et al., 1994) and can be used to reconstruct salinity variations (Gagan et al., 1998; Linsley et al., 1994; McCulloch et al., 1994). The Sr/Ca ratio is perhaps the best characterized and most widely used trace elemental indicator in coral studies, and appears to be a robust thermometer in reef corals (e.g., Alibert and McCulloch, 1997; Beck et al., 1992; de Villiers et al., 1994; Gagan et al., 1998; Marshall and McCulloch, 2002; Shen et al., 1996).

During recent decades, a number of studies have provided new information on environmental changes in surface ocean conditions spanning over the past several centuries in many regions of the tropics using massive scleractinian reef corals. Worldwide, about a dozen coral-based climate records exist that extend back beyond 1850 with at least seasonal or higher resolution (Fig. 1-1).

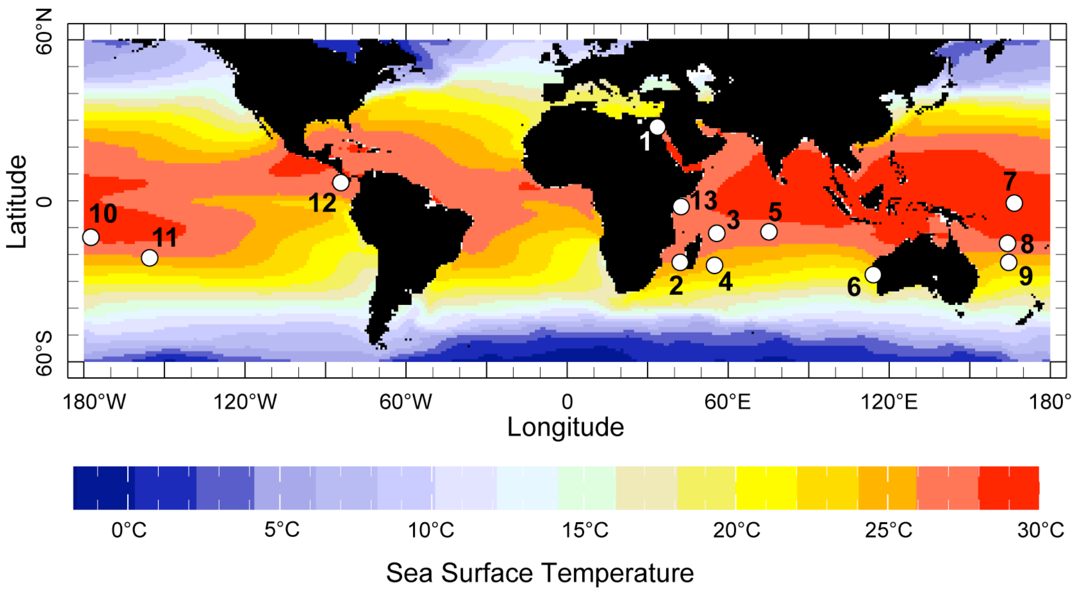


Figure 1-1. NOAA NCEP SST climatology based on January-December average SST from the 1° by 1° resolved Optimum Interpolation Sea Surface Temperature analysis data set (version 2) (Reynolds et al., 2002). Circles represent the locations of published coral-derived climate records that extend beyond 1850 and exhibit at least seasonal resolution: 1) Ras Umm Sid (Felis et al., 2000), and Aquaba (Heiss, 1994); 2) Ifaty (Madagascar) (Zinke et al., 2004); 3) Seychelles (Charles et al., 1997; Pfeiffer and Dullo, 2006); 4) La Reunion (Pfeiffer et al., 2004b); 5) Chagos Archipelago (Pfeiffer et al., 2004a); 6) Houtman Abrolhos Island (Australia) (Kuhnert et al., 1999); 7) Maiana (Kiribati Atoll) (Urban et al., 2000); 8) Espiritu Santo (Vanuatu) (Quinn et al., 1996); 9) Amedee Lighthouse (New Caledonia) (Quinn et al., 1998); 10) Fiji (Linsley et al., 2004); 11) Rarotonga (Cook Islands) (Linsley et al., 2000); 12) Secas Island (Panama) (Linsley et al., 1994); 13) Malindi (Kenya) (Cole et al., 2000).

The tropical Pacific has been in the focus of many coral paleoclimate studies due to the importance of the ENSO system in global climate variability and the presence of long-lived coral heads (Fig. 1-1) (e.g., Cobb et al., 2003; Cobb et al., 2001; Cole and Fairbanks, 1990; Cole et al., 1993; Dunbar et al., 1994; Evans et al., 1999; Linsley et al., 1994; Linsley et al., 2006; Quinn and Taylor, 2006;

Quinn et al., 2006; Shen et al., 2005; Shen et al., 1996; Tudhope et al., 1995; Wellington et al., 1996). Outside the Pacific Ocean, long-term records have been published from the Indian Ocean that reflect large-scale variability (e.g., Charles et al., 2003; Charles et al., 1997; Pfeiffer and Dullo, 2006; Pfeiffer et al., 2004a; Pfeiffer et al., 2004b; Zinke et al., 2004). However, studies on corals from the Atlantic region have lagged behind the extensive work published using corals records from the Indo-Pacific Oceans. So far, no continuous long-term high-resolution record is available from this region (Fig. 1-1).

Most of the published coral records exhibit strong correlations to local environmental and climatic parameters and, in addition, provide information about large-scale climate variability as well. Records obtained from modern corals usually span the past century to a maximum of about 500 years. Exceptionally long records have become important paleoclimatic archives of climate change in the tropics and have been incorporated into historical climate records used to investigate global warming in the past century (Crowley, 2000; Mann et al., 1998). Fossil corals have been used for longer reconstructions of climate variability, spanning throughout the last millennium and beyond (e.g., Cobb et al., 2003; Hughen et al., 1999; Tudhope et al., 2001). Although the complications of using fossil corals as paleoclimate archives are greater than using modern corals (e.g., often potential diagenetic changes have to be taken into consideration), the paleoclimatic information to be gained is of great importance, since it applies to climate systems under different boundary conditions (Tudhope et al., 2001).

1.2 Isotope partitioning between coral aragonite and seawater

The partitioning of isotopes between reef carbonates and seawater has been investigated extensively during the recent decades, and reviews of this relationship can be found for example in Swart (1983) and Swart et al. (1996), Aharon (1991), and Leder et al. (1996). A concise summary of the major characteristics of the partitioning is given in the below paragraph.

The isotope fractionation factor between any two compounds "a" and "b" (e.g., $CaCO_3$ and H_2O) is defined as:

$$\alpha_{a\text{-}b} = R_a / R_b$$

with R being the ratio of heavy/light isotopes (e.g., $^{18}O/^{16}O$; $^{13}C/^{12}C$, etc.). The fractionation factor α can be expressed as the difference in the delta-values (δ) of the two compounds a and b as long as the difference between these values is relatively small (< 10‰):

$$1000 \ln \alpha_{a\text{-}b} \cong \delta_a - \delta_b$$

The isotopic composition of the two compounds a and b are reported routinely in delta (δ) notation as deviations in ‰ (parts per thousand or per mil) from a reference standard (Craig, 1957):

$$\delta_a\ (‰) = [(R_a/R_{standard}) - 1] \times 10^3$$
$$\delta_b\ (‰) = [R_b/R_{standard}) - 1] \times 10^3$$

The isotopic compositions of slowly precipitated carbonates are governed by the temperature-dependent thermodynamic isotope fractionation factors (McCrea, 1950) and the isotopic composition of the fluid. Experimental equilibrium isotope fractionations have been compared with isotope determinations from reef skeletal material deposited over the temperature range of 20 to 30°C (Fig. 1-2) to determine "isotope offsets". It has been indicated that non-equilibrium isotope partitioning occurs during the formation of reef skeletal material (e.g., Weber and Woodhead (1972) using a large collection of modern hermatypic coral genera).

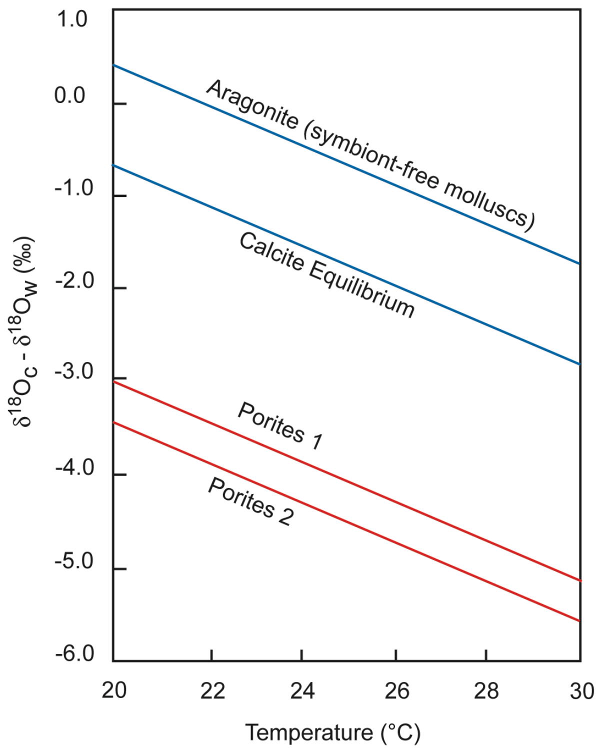


Figure 1-2. Temperature dependency of oxygen isotope fractionation over the temperature range from 20 to 30°C for selected biogenic aragonites and equilibrium calcite. Shown coral δ^{18}O offsets occur between coral specimens from the same genus (*Porites*). Redrawn from Aharon (1991).

The oxygen isotopic composition of coral aragonite is invariably depleted relative to equilibrium by ~ 1-6‰, presumably because of the different biochemical mechanisms of precipitation as well as the influence of symbiotic zooxanthellae. The δ^{18}O composition is offset below the values predicted for equilibrium precipitation at any given temperature (Fig. 1-2). McConnaughey (1989a;

1989b) identified kinetic and metabolic factors as the causes that lead to isotopic disequilibria during biological calcification.

Simultaneous depletion of ^{18}O and ^{13}C isotopes are ascribed to kinetic isotope effects believed to result primarily from slower reaction kinetics for molecules containing the heavy isotopes ^{18}O and ^{13}C during CO_2 hydration and hydroxylation which are important processes in biological calcification (Aharon, 1991). Strong disequilibrium behavior often appears to be associated with rapid calcification in both photosynthetic and non-photosynthetic organisms. Hence, kinetic isotope disequilibria tend to be constant in the rapidly growing portions of the skeletons of photosynthetic corals (Fig. 1-3), and time dependent variations are controlled by thermodynamic laws and therefore reflect changes in environmental variables. The $\delta^{18}O$ of coral skeletal aragonite is related to the equilibrium isotope partitioning according to the following relation:

$$\delta^{18}O_{coral} = \delta^{18}O_{equ} + \delta^{18}O_{offset}$$

where the "offset" term is constant for individual coral colonies within the experimental uncertainties with respect to temperature, but varies even between colonies belonging to the same genus (Fig. 1-2) and among different coral taxa (Aharon, 1991; Suzuki et al., 2005; Weber and Woodhead, 1972). In the slower growing portions of the coral skeleton (Fig. 1-3), the isotopic composition may gradually approach equilibrium. Hence, large variations in skeletal extension rate may bias environmental signals.

Although researchers recognize that vital effects can offset coral $\delta^{18}O$ to varying degrees (McConnaughey, 1989a, b), this offset appears to be stable over time in many different settings (Gagan et al., 2000), and hence a well calibrated oxygen isotope paleotemperature equation is available for corals. The slope of the calibrations appears to be nearly constant at ~ -0.2‰ per °C (slopes obtained for *Porites* corals from the Indo-Pacific range between -0.18 and -0.22‰ per 1°C (Gagan et al., 1994; Juillet-Leclerc and Schmidt, 2001; Weber and Woodhead, 1972; Wellington et al., 1996)). This is in general agreement with the slope of inorganic experiments. The $\delta^{18}O$ of calcium carbonate precipitated in equilibrium with seawater decreases by ~ 0.22‰ per 1°C rise in water temperature (Epstein et al., 1953).

According to McConnaughey (1989b), similar ^{18}O depletions have been found in both photosynthetic and non-photosynthetic corals, and therefore ^{18}O fractionation between seawater and coral aragonite is not affected by photosynthesis. In contrast, deviations of $\delta^{13}C$ compositions from equilibrium values that are not associated with $\delta^{18}O$ offsets are attributed to metabolic isotope effects resulting from modifications of the dissolved inorganic carbon (DIC) by photosynthesis and respiration (Aharon, 1991; McConnaughey, 1989a, b).

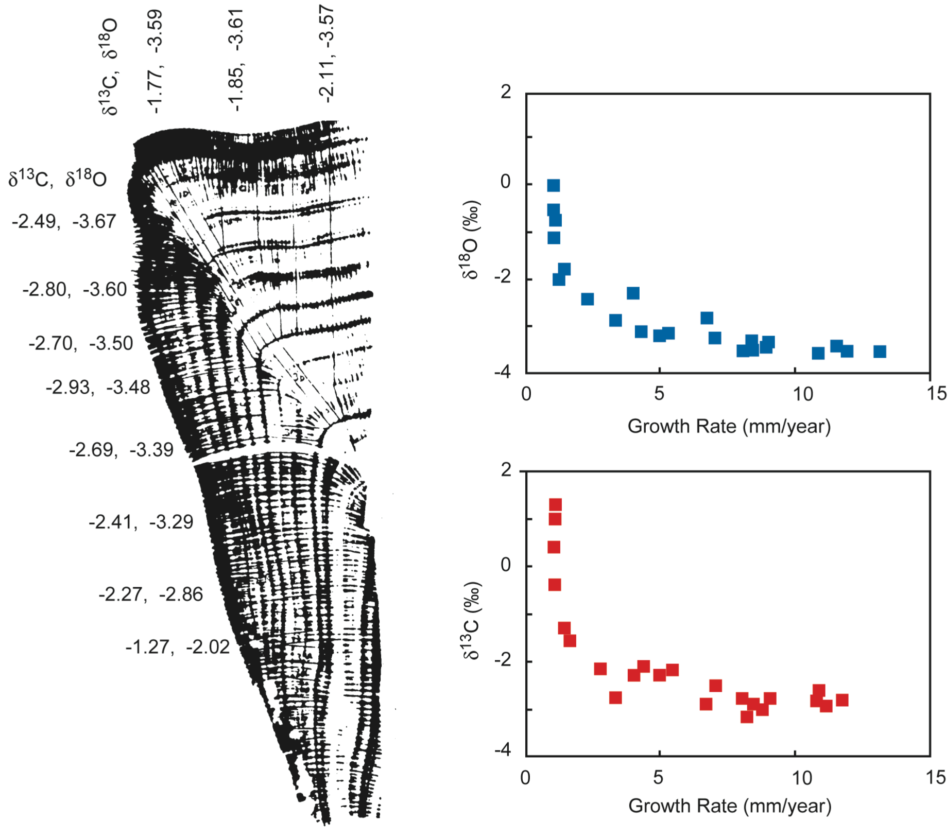


Figure 1-3. Left: X-radiography and skeletal isotopic composition of a portion of a horizontally sampled *Pavona clavus* coral head retrieved off Punta Pitt, San Cristobal Island (Galápagos). Each pair of numbers represents the carbon/oxygen isotopic ratio ($\delta^{13}C$, $\delta^{18}O$) for skeletal material deposited over the interval 1979-1982. The upper surface of the coral head received more sunshine than the lateral surfaces, hence grew faster, and was relatively depleted in ^{18}O. Right: Correlations between skeletal $\delta^{18}O$ (top) and $\delta^{13}C$ (bottom) and skeletal extension (growth) rate for horizontally sampled *Pavona clavus* heads. Redrawn and slightly modified from McConnaughey (1989a).

Because of these "metabolic" isotope effects, time-dependent variations in the $\delta^{13}C$ of photosynthetic corals are not reproducible even between adjacent colonies of the same coral genus (e.g., Guilderson and Schrag, 1999) and, hence, impede the successful interpretation of this proxy.

1.3 Oxygen isotopes in seawater

The strong relationship between the $\delta^{18}O$ of seawater ($\delta^{18}O_{sw}$) and sea surface salinity (SSS) is an important factor in paleoclimate studies. $\delta^{18}O_{sw}$ and SSS covary in the surface waters of the oceans on a global scale. Both parameters are largely related to the hydrological cycle, with higher SSS and $\delta^{18}O_{sw}$ values observed in areas where evaporation exceeds precipitation, and with lower values in areas characterized by high precipitation and runoff. Additionally, SSS and the $\delta^{18}O_{sw}$ of surface waters are influenced by oceanic advection and diffusion processes. The relationship between SSS and $\delta^{18}O_{sw}$ has been extensively studied in the past decades (Craig and Gordon, 1965; Delaygue et al., 2000; Östlund et al., 1987; Schmidt, 1998; Schmidt, 1999), but there are still significant gaps in the spatial coverage, as shown in the NASA/GISS Global Seawater Oxygen Isotope Database (http://data.giss.nasa.gov/o18data/ (Bigg and Rohling, 2000; Schmidt et al., 2000)). It is well known that atmospheric forcing (i.e., precipitation-evaporation (E-P)) leads to strong latitudal gradients in the $\delta^{18}O_{sw}$ and SSS of surface waters (Fig. 1-4a). Also, the isotopic composition of rainfall and river water is not constant. For example, in the subtropics, where evaporation exceeds precipitation, the values are enriched, whereas waters of the higher latitudes are depleted. The western equatorial Pacific and the equatorial Indian Ocean exhibit intermediate values due to the large amount of precipitation associated with the seasonal movement of the ITCZ.

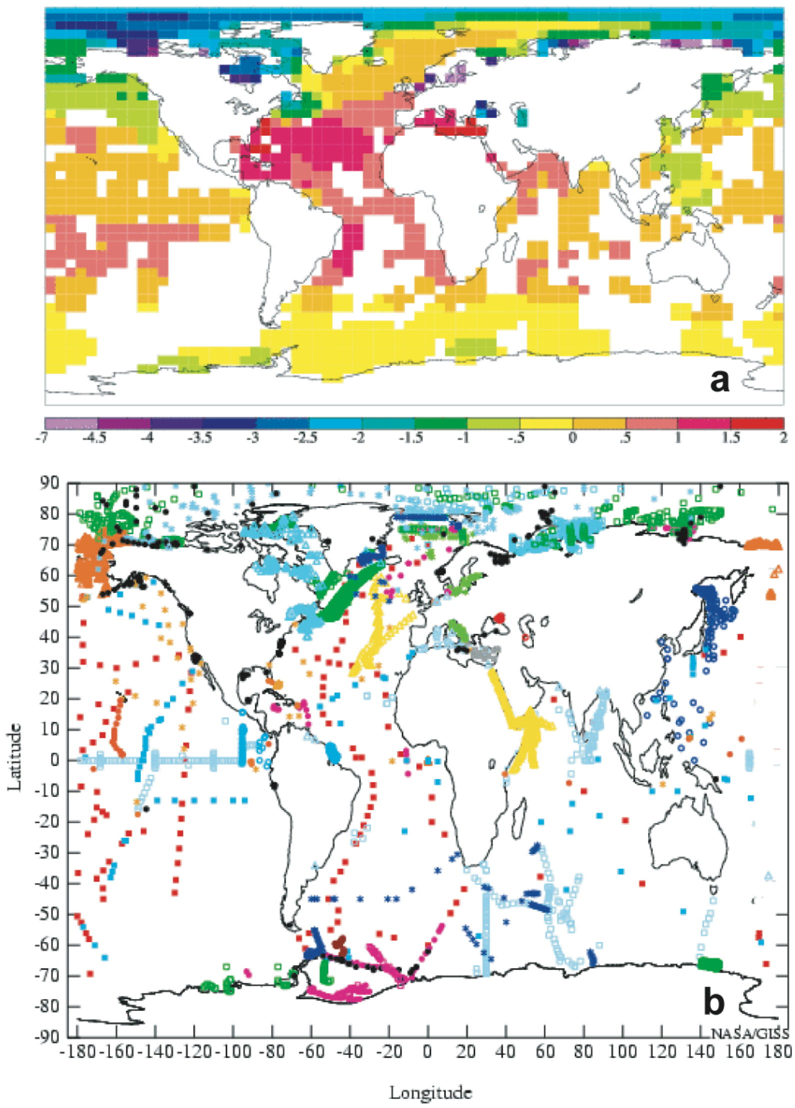


Figure 1-4. (a) Seawater $\delta^{18}O$ ($\delta^{18}O_{sw}$) of surface waters from Global Seawater Oxygen-18 Database (Bigg and Rohling, 2000; Schmidt et al., 2000). The database is a collection of over 22,000 seawater ^{18}O measurements made since about 1950. All surface delta values are reported with respect to V-SMOW and have been interpolated on a 4° x 5° grid; (b) shows measurement points and transects of the respective observations incorporated into the database.

In contrast, the Atlantic is characterized by much higher values than the other two ocean basins (Fig. 1-4a). This difference corresponds to a net atmospheric freshwater export form the Atlantic to the Pacific basin via Central America (Delaygue et al., 2000; Zaucker and Broecker, 1992). The spatial relationship between $\delta^{18}O_{sw}$ and SSS is linear (Craig and Gordon, 1965), but the slope of the relationship is determined by the local hydrological balance and oceanic advection (Delaygue et al., 2000). Hence, there is not a single $\delta^{18}O_{sw}$-SSS relationship in the oceans, but rather multiple relationships depending on the variable atmospheric fluxes at certain latitudes and ocean basins considered (Bigg and Rohling, 2000).

Generally, an increase in the slope with latitude is observable (Craig and Gordon, 1965). Low slope values for the $\delta^{18}O_{sw}$-SSS relationship in the surface waters were observed in the tropics and subtropics (~0.1 - 0.5), and higher values in the extratropical latitudes (~0.5 – 0.8) (Delaygue et al., 2000). The range of the $\delta^{18}O_{sw}$-SSS gradient is known to be limited by ocean dynamics. For example in the North Atlantic basin, the net transport of surface waters originating in the Caribbean and Gulf of Mexico leads to an enrichment in $\delta^{18}O_{sw}$ and SSS, which is then transported polewards of 60°N by the North Atlantic drift. Like SST, SSS is an important physical parameter in climate studies. Together with temperature, salinity is the driving force of the thermohaline circulation and also plays a crucial role in the generation of major climate phenomena, for example ENSO events (Delcroix et al., 1998).

Coral $\delta^{18}O$ is dependent upon both SST and $\delta^{18}O_{sw}$. Hence, in theory, it is possible to assess past changes in SSS from coral $\delta^{18}O$ providing the local $\delta^{18}O_{sw}$-SSS relationship is known, and the SST component of the coral $\delta^{18}O$ signal is either known or negligible. Different approaches have been brought forward to reconstruct paleo-SSS using corals. For example, the coupling of coral Sr/Ca and $\delta^{18}O$ measurements as a potential paleo-salinometer has been discussed in several studies (Gagan et al., 1998; Hendy et al., 2002; Kilbourne et al., 2004; Linsley et al., 2004; McCulloch et al., 1994; Ren et al., 2002). Combined measurements of $\delta^{18}O$ and Sr/Ca in coral skeletons can provide information on $\delta^{18}O_{sw}$ as well as temperature variability of surface water through removing the temperature component of the $\delta^{18}O$ variations which is derived from the Sr/Ca time series. Provided that the relationship between $\delta^{18}O_{sw}$ and SSS is constant over time, the coupled approach using combined $\delta^{18}O$ and Sr/Ca measurements in corals can potentially be used to reconstruct past variability in SSS. These studies have shown that major changes in surface hydrology (and hence salinity) can be documented, although the reconstruction of absolute SSS values is not possible.

However, reconstructions of past SSS variability based on oxygen isotope ratios in biological carbonates are, in general, based on the assumption that the long-term temporal gradient between SSS and $\delta^{18}O_{sw}$ in the ocean at a fixed point in the past is equal to the spatial gradient today. It has been shown that due to the influence of external sources and sinks not related to the local hydrological cycle (Rohling and Bigg, 1998), the temporal relationship between SSS and $\delta^{18}O_{sw}$ is not linear in any specific area. Relative or absolute changes in the flux rate or isotopic signal of any external source or sink would result in non-linear temporal behavior (Rohling and Bigg, 1998). Additionally, little is known about the seasonal and long-term behavior in $\delta^{18}O_{sw}$ due to the lack of measurements. Large areas of the oceans are utterly devoid of observations (Fig. 1-4b). Longer time series of $\delta^{18}O_{sw}$ measurements are needed to approve and validate modelling studies. At this stage, a better knowledge of the $\delta^{18}O_{sw}$-SSS relationship and of its potential variability through time is crucial before precise estimates of paleo-SSS can be extracted from corals (Corrège, 2006).

1.4 Sr/Ca as trace elemental indicator in corals

Stoichiometric trace elemental ratios within the aragonitic skeletons of hermatypic corals are known to have temperature dependent seawater/coral partition coefficients that can provide a proxy for estimating sea surface temperature (e.g., Marshall and McCulloch, 2002). In terms of environmental controls, perhaps the best characterized is the behavior of Sr in coral aragonite. Through the secretion of aragonitic coral skeletons, both Sr and Ca are incorporated into the skeletal structure. Sr^{2+} mainly substitutes for Ca^{2+} in the crystal lattice (Kinsman and Holland, 1969). Since the chemistry of Sr^{2+} is very similar to Ca^{2+}, their behavior is very similar. Hermatypic scleractinian corals generally contain about 7500 ± 500 ppm Sr in their aragonitic skeleton, although due to vital effects there can be distinct differences between genera (Weber, 1973). Apart from these vital effects, the ratio of Sr to Ca in the coral is believed to be controlled predominantly by two factors: a) the Sr/Ca activity ratio of seawater, and b), the Sr/Ca distribution coefficient between aragonite and seawater (Smith et al., 1979). When a compatible trace elemental component substitutes for calcium in the aragonitic crystal lattice, the concentration of that trace element can be predicted by its distribution coefficient (D_{Sr}):

$$D_{Sr} = (Sr/Ca)_{coral} / (Sr/Ca)_{seawater}$$

Because of the long residence times of Sr and Ca in the oceans (5.1×10^6 yr for Sr and 1.1×10^6 yr for Ca (Broecker and Peng, 1982)), it has generally been assumed that the Sr/Ca activity ratio has remained essentially constant over the past 100,000 years or so. The aragonitic skeletons of corals have a preference for Sr rather than Mg, and in general, aragonite will accommodate more Sr than calcite. The higher uptake of Sr into aragonite rather than calcite is a function of the higher distribution coefficient for Sr (Marshall and McCulloch, 2002). The distribution coefficient for corals is considered to be close to unity (Weber, 1973), whereas for inorganically precipitated aragonite it is about 1.15 (Kinsman and Holland, 1969). Several studies have confirmed that the value of the distribution coefficient for Sr has remained constant (Marshall and McCulloch, 2002; Shen et al., 1996; Weber, 1973). Hence, the distribution coefficient, and therewith the Sr/Ca ratio in coral aragonite, strongly depends on the ambient water temperature at which the precipitation of skeletal aragonite occurs (Kinsman and Holland, 1969; Smith et al., 1979).

The breakthrough study for coral skeletal Sr/Ca, led by Beck and co-workers (1992), utilized isotope dilution thermal ionization mass spectrometric (ID-TIMS) determinations to establish a relationship between coral Sr/Ca and temperature with high precision, sufficient for key climate questions. Their calibration data indicated a 0.6% decrease in Sr/Ca per 1 °C, a relationship similar to the calibration by Smith et al. (1979), but with greater precision. However, a note of caution was introduced by de Villiers et al. (1995; 1994), who found that Sr/Ca ratios were lower in the faster growing coral portions and suggested that interspecies differences, variable calcification and extension rates, and variability in the Sr/Ca composition of seawater could introduce significant errors (1-2 °C) in the use of the Sr/Ca method. Evidence of biological control has been refuted and a number of studies have concluded that calcification and linear extension has little effect on coral Sr/Ca as long as sampling is confined to the main axis of coral growth (Alibert and McCulloch, 1997; Allison and Finch, 2004; Corrège et al., 2004; Gagan et al., 1998; McCulloch et al., 1994; Mitsuguchi et al., 1996; Shen et al., 1996; Swart et al., 2002), whereas sampling outside this axis can result in higher Sr/Ca values. Such "off axis" sampling could account for the variable results of the de Villiers et al. (1995) study. Shen et al. (1996) showed that species differences and variations in growth rate did not appear to affect the relationship between Sr/Ca and SST. Another major step forward in the application of the Sr/Ca paleothermometer came with the development of a new high-precision method of Sr/Ca determination via inductively coupled plasma atomic emission spectroscopy (ICP-AES), that frequently compares sample values to a reference solution and has greatly increased sample throughput (Schrag, 1999). This technique allows to generate large data sets required for long high-resolution climate records. The relationship between coral Sr/Ca and SST is parametrized as a linear function of the form:

$$Sr/Ca_{coral}\ (\mathrm{mmol\ mol^{-1}}) = b + m(\mathrm{SST})$$

Calibrations are available for a number of coral species, but mostly for the genus *Porites* from the Indo-Pacific Oceans (e.g., Beck et al., 1992; Cohen et al., 2001; Cohen et al., 2002; de Villiers et al., 1994; Gagan et al., 1998; Marshall and McCulloch, 2002; Mitsuguchi et al., 1996; Shen et al., 1996; Smith et al., 1979), although some calibrations exist for other coral species, e.g., slow-growing *Diploria labyrinthiformis* corals from Bermuda (slope values range between -0.036 and -0.084 mmol/mol/°C) (Cardinal et al., 2001; Cohen et al., 2004; Goodkin et al., 2005); and *Montastrea* sp. corals from Florida (slope values range between -0.023 and -0.047 mmol/mol/°C) (Smith et al., 2006; Swart et al., 2002). Generally, for Atlantic corals, the slope values of the Sr/Ca-SST relationship lie at the lower end of the published range for corals (mainly *Porites*) from the Indo-Pacific (-0.04 to -0.08 mmol/mol per 1°C; Marshall and McCulloch (2002)). Overall, there are large differences between slope values for coral Sr/Ca-SST relationships between different studies. The variability in the slope, and hence the lack of a "universal" calibration equation for the Sr/Ca ratio with SST is a critical value for coral strontium paleothermometry.

These differences can at least partly be attributed to the different analytical methods used (ID-TIMS, ICP AES, ICP MS, etc.), and to the lack of a common measurement standard between different laboratories, as well as to the quality of the different SST products used for calibration. Ideally, the comparison between the coral Sr/Ca ratio and an *in-situ* instrumental SST record from the same time period from the same reef is the best method. In reality, due to the lack in availability of such data, only a few studies exist (Alibert and McCulloch, 1997; Crowley et al., 1999) that use *in-situ* SST data, and even in this situation the calibrations can be nonuniform. Most studies must rely on data from either SST stations that are remote to the coral site, or gridded SST datasets that are based on measurements from satellites and ships-of-opportunity (Gagan et al., 2000). This is considered to be a significant uncertainty in deriving accurate Sr/Ca-SST relationships. However, it is still not fully understood how coral growth and environmental factors affect the uptake of Sr into the microstructure of skeletal aragonite. Also, the mode of Sr incorporation in coral aragonite is controversial (e.g., Cohen et al., 2001; Cohen and McConnaughey, 2003; Cohen et al., 2002; Ferrier-Pages et al., 2002; Reynaud et al., 2004; Sinclair et al., 2006). The work of Allison and Finch (2004) and Allison et al. (2005) has shown that the large small-scale heterogenity of Sr/Ca, whatever its cause is, can be potentially smoothed out in favour of the SST factor when the sampling resolution is decreased, hence providing an explanation for the good consistency between calibration curves produced over the years. An extensive review of this topic can be found in Corrège (2006).

1.5 Geographic, climatic and oceanographic setting

Geographic setting

The Lesser Antilles are a group of islands lying in an 800 kilometer long arc, stretching from the Anegada Passage (Fig. 1-5) due east of the Virgin Islands, southwards to Grenada which lies close to the South American continental shelf. These islands form the eastern margin of the Caribbean Sea. Geographically, the Lesser Antilles can be divided into the Windward Islands in the south and the Leeward Islands in the north. The Leeward Antilles are the southern Lesser Antilles just north of Venezuela (Fig. 1-5). The deep waters of the Puerto Rico Trench, which is the result of the subduction of the Atlantic plate under the Caribbean plate, lie to the north and northeast (Spalding et al., 2001). Convergent, compressional and collisional tectonic activity caused primarily from the eastward movement of the Caribbean Plate in relation to the North American and South American

Plates is responsible for zones of subduction in the region, the formation of island arcs and the evolution of particular volcanic centers on the overlying plate. These active geo-dynamic processes have created the Lesser Antilles Islands Arc, an arc of small islands with 19 active volcanoes characterized by both effusive and explosive activity. Geologically, the islands are quite varied, but are dominated by two types, older sedimentary islands and more recent volcanic islands.

Study area: Guadeloupe

The Guadeloupe archipelago is located at the eastern boundary of the Caribbean Sea and is part of the Lesser Antilles Islands Arc (Leeward Islands), which separates the Caribbean Sea from the Atlantic Ocean. Guadeloupe is an overseas territory of France that covers an area of ~1821 sq. km (15.95° – 16.5°N, 61.2° – 61.8°W, Fig. 1-5a) and consists of two principal main islands, Grande Terre and Guadeloupe or Basse Terre, which are separated by the Rivière Salée.

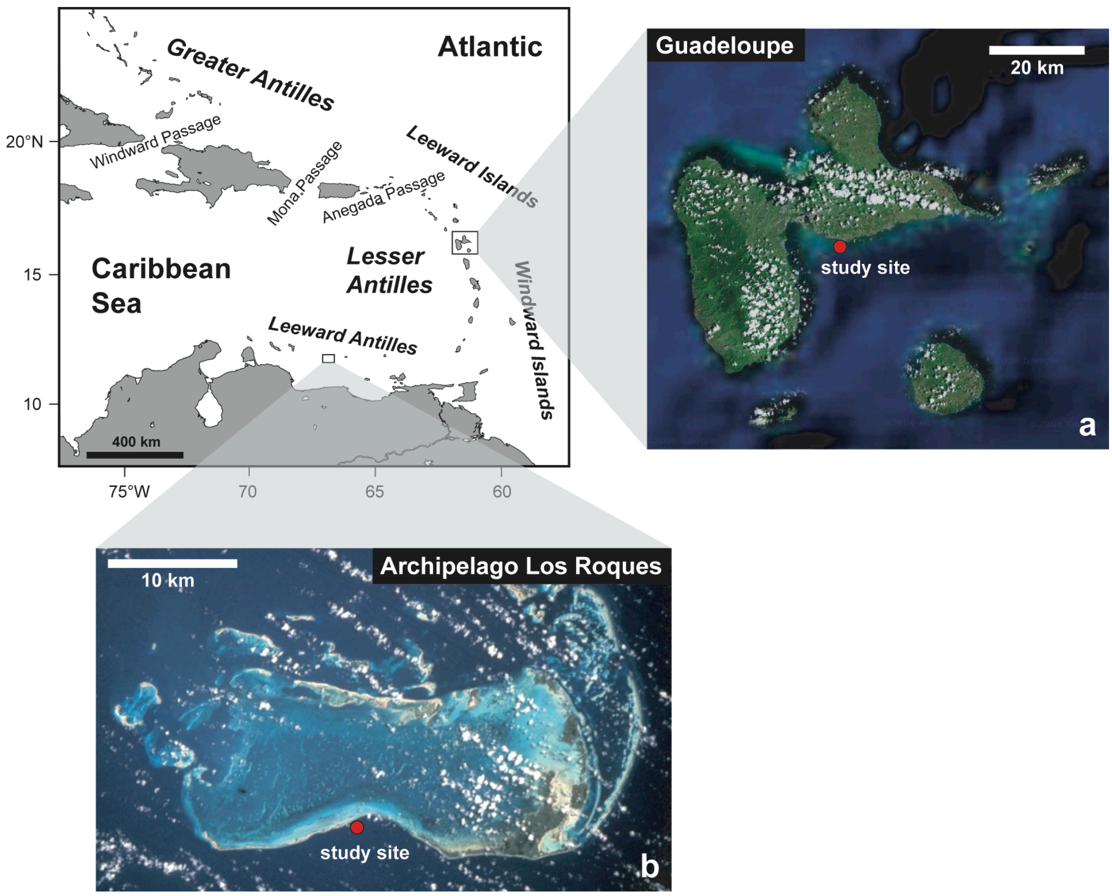


Figure 1-5. Map of the eastern Caribbean Sea with the location of both study areas: (a) the Guadeloupe archipelago; and (b) the Archipelago Los Roques, Venezuela. Sampling localities are marked by red circles. The inlet-image in (a) was obtained using the freely available Google-Earth software; the image shown in (b) was obtained at http://eol.jsc.nasa.gov and is courtesy of the Earth Sciences and Image Analysis Laboratory, NASA Johnson Space Center.

North of Dominica the Lesser Antilles arc divides into two, with the active volcanic arc lying to the west in Basse Terre of Guadeloupe and the extinct Limestone Caribbee arc lying to the east in Marie Galante and Grande Terre of Guadeloupe. The island of Grande Terre is flat (110m maximum altitude) and calcareous. In contrast, Basse Terre is mountainous and volcanic, it rises 1484 m (Mt. Soufrière) above sea level. Particularly on the southern side of Grande Terre, fringing and bank barrier reef structures can be found (Wells, 1988). The marine environment between Pte de Chateaux and Gosier is characterized by mostly narrow and sometimes localized coral reefs of the fringing type (Spalding et al., 2001). The study site "Isle de Gosier" is situated approximately 0.8 km south of Grande Terre (Fig. 1-5a).

Study area: Archipelago Los Roques

The Los Roques Archipelago is located about 140 km north of the central coast of Venezuelas continental territory and is part of the Leeward Antilles (Fig. 1-5). Since 1972 the marine ecosystem of the archipelago is protected and has been declared as a national park. The Los Roques National Park is located between 11°58`36"N and 11°44`26"N, and 66°57`26"W and 66°36`25"W, and is part of the Federal Dependencies of Venezuelas insular territory. In 1996, Los Roques was declared as a Ramsar site because of its importance as a biodiversity and food-source reservoir. The large reef complex rests on a flat submarine mountain (guyot) surrounded by deep waters (>1,000 m). It is an elongated complex that spans 36.6 km east to west and 24.4 km north to south, covering an area of 894 km^2, with a large central lagoon, and has been characterized as an atoll (Williams-Trujillo, 1980) or as a „semi-atoll" (Mendez, 1978). El Gran Roque is the inhabited main island and the only one with exposed igneous and sedimentary rocks (Weil, 2003), it rises 130 meters above sea level at its highest point.

The archipelago and reef complex is formed by about 52 islands, over 200 reef banks, hundreds of small patch and pinnacle reefs, and fringing mangrove forests and islands (Weil, 2003). The extensive coral reefs cover an area of about 221,120 ha. Most islands around the lagoon have well-developed fringing reefs on their exposed side. The wide, shallow central lagoon covers an area of approximately 300 km^2 with an average depth of 4 m. Long fringing reef systems limit the atoll complex on the east and south. The southern fringing reef runs almost continuously for about 24 km from east to west, it is narrow with a steep drop-off in many areas (see Figure 1-5b for study site). Extensive areas of the reef present a steep, wall-like slope that can drop 25-30 m from the edge of the reef to a sandy bottom platform that starts at around 50 m depth and has a gentle slope down to the edge of the guyot. The origin of the coral reef systems is very recent (about 10,000 to 15,000 years ago). The igneous and metamorphic rock formations that sustain the reefs originated during the Upper Cretaceous (Mendez, 1978). Calcareous sediments accumulated on these rock foundations. After the last ice age, the rising sea level allowed the formation of the north and south barriers, that enabled the formation of keys and the inner lagoon (Mendez, 1978).

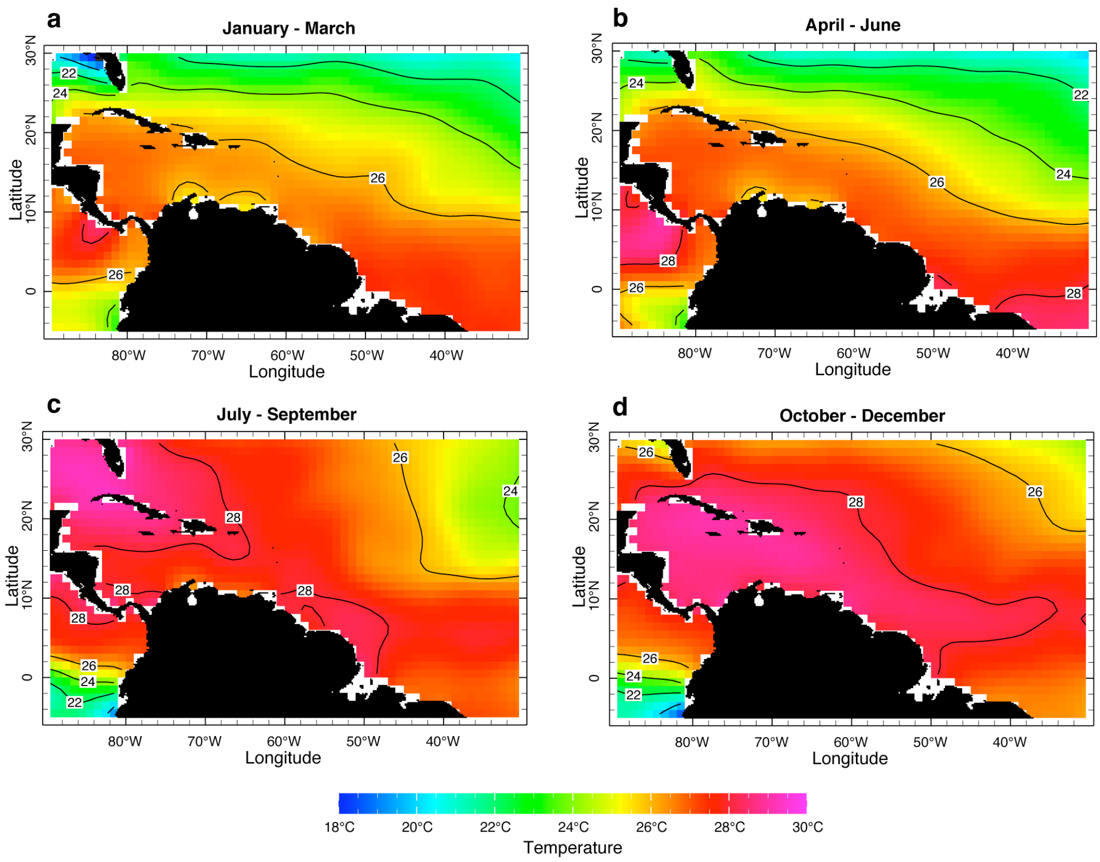
Climate

a) Annual cycle

The climate in the Caribbean Sea and tropical North Atlantic is primarily forced by the covarying pattern of trade wind convergence (e.g., Hastenrath, 1976; Hastenrath, 1984; Peterson et al., 1991), the seasonally migration of the Intertropical Convergence Zone (ITCZ), and the underlying cross-equatorial SST gradient (Carton et al., 1996). The ITCZ is an equatorial zone of atmospheric convection driven by the Hadley Cells. The ITCZ and associated rainfall migrate seasonally northward and southward over tropical South America. The seasonal fluctuation of the ITCZ occurs along a gradient from the Amazon River basin across the Orinoco River basin and into the central Caribbean (Corredor and Morell, 2001). In accordance with the shift of the thermal equator to the south during the northern winter, the ITCZ is located south of the Caribbean at ca. 0° to 5°S. After spring equinox, the thermal equator shifts to the north and the ITCZ migrates off the equator towards the Caribbean to about 6° to 10°N. It reaches its northernmost position at the height of boreal summer (Curtis and Hastenrath, 1995). Due to feedback mechanisms between the converging trade winds and SST, it maintains north of the equator through the fall equinox (Giannini et al., 2000). At that time, the Caribbean hydrography is characterized by enhanced precipitation and fluvial freshwater supply.

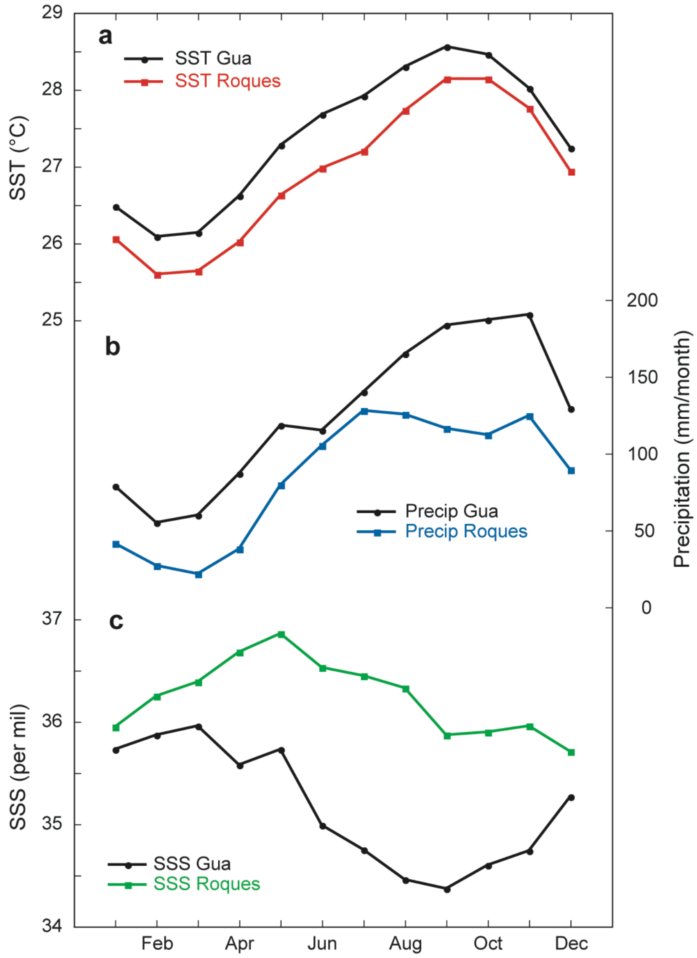
In the eastern Caribbean, average maximum SST values occur in September (28.6°C at Guadeloupe, Figs. 1-6 and 1-7a; and 28.1°C at the Archipelago Los Roques on average) and average minimum SST values in February (26.1°C at Guadeloupe; and 25.6°C at Los Roques) based on gridded SST observations of the ERSST.v2 data compilation (Smith and Reynolds, 2004). Mean annual SST for the grid box surrounding Guadeloupe is 27.4°C and 26.9°C at the Archipelago Los Roques study site, the average seasonal SST cycle is similar at both study sites and amounts to approximately 2.5°C.

The mean Caribbean rainy season (also warm season) runs from May-October with two distinct peaks during May-June, and September-October, and a relative minimum in July-August. Related to geography, three different rainfall regimes can be differentiated according to a study by Giannini et al. (2000): rainfall from *May to October* is typical for Central America and South America, whereas northwestern South America (including the Venezuelan coast) and the southern coast of Jamaica and Hispaniola are characterized by a pronounced *midsummer break* in rainfall accumulations (Fig. 1-7b). The rainfall regime in Puerto Rico, as well as the northern coasts of Jamaica and Hispaniola, and the Lesser Antilles (including Guadeloupe Island) is characterized by a *late-fall-peak*, and a smaller rainfall peak during May-June (Fig. 1-7b).



<u>Figure 1-6.</u> Sea surface temperature (SST) from the Levitus and Boyer (1994) climatology averaged over three months: (a) January-March; (b) April-June; (c) July-September; and (d) October-December.

Massive freshwater inputs to the eastern Caribbean occur during, or shortly after the peak of the rainy season, which result from direct precipitation and continental runoff. Tropical rivers directly or indirectly drain into the Caribbean Sea and, thus, influence the hydrography and chemistry of surface waters year-round. The most important Caribbean freshwater sources are the Amazon and the Orinoco Rivers (Milliman and Meade, 1983). However, the influence of the Orinoco in the eastern Caribbean may be more important than that of the Amazon (Müller-Karger et al., 1989), since most of the Orinoco waters travel in a north-northwest direction into the eastern Caribbean (Bonilla et al., 1993).



<u>Figure 1-7.</u> Seasonal climatology of environmental parameters at the study sites Guadeloupe and Archipelago Los Roques: (a) Instrumental sea surface temperature (SST) in a 2° by 2° grid box centered on the respective study sites (ERSSTv.2 data set (Smith and Reynolds, 2004)): Black line represents seasonal SST cycle at Guadeloupe, red line displays SST at Archipelago Los Roques. (b) Precipitation climatology from the DEKLIM Variability Analysis of Surface Climate Observations (VASClimO) project (Beck et al., 2005) centered on the study site Guadeloupe (black curve) and Los Roques (blue curve) averaged over the 1951-2000 time period. (c) Sea surface salinity (SSS) from Levitus et al. (1994) for the study site Guadeloupe (black line) and Los Roques (green line).

The seasonal change between high and low precipitation, related to the ITCZ movement, propels seasonally varying fluvial supply, which is reflected in seasonal surface salinity depressions (Fig. 1-8) and varying nutrient concentrations in the eastern Caribbean in the fall of each year (Froelich et al., 1978; Morrison and Nowlin, 1982). According to climatological data from Levitus et al. (1994), the seasonal cycle of surface salinity near Guadeloupe is around 1.6‰ (Fig. 1-7c). Maximum salinities of 36‰ occur during the winter (March), and minimum salinities of 34.4‰ occur during the summer season (September). Maximum salinities at the Archipelago Los Roques of around 36.9‰ occur in May, and minimum salinities of 35.7‰ occur during the winter season (December, Fig. 1-7c). The seasonal cycle of surface salinity at Los Roques (1.2‰) is smaller compared to the Guadeloupe study site.

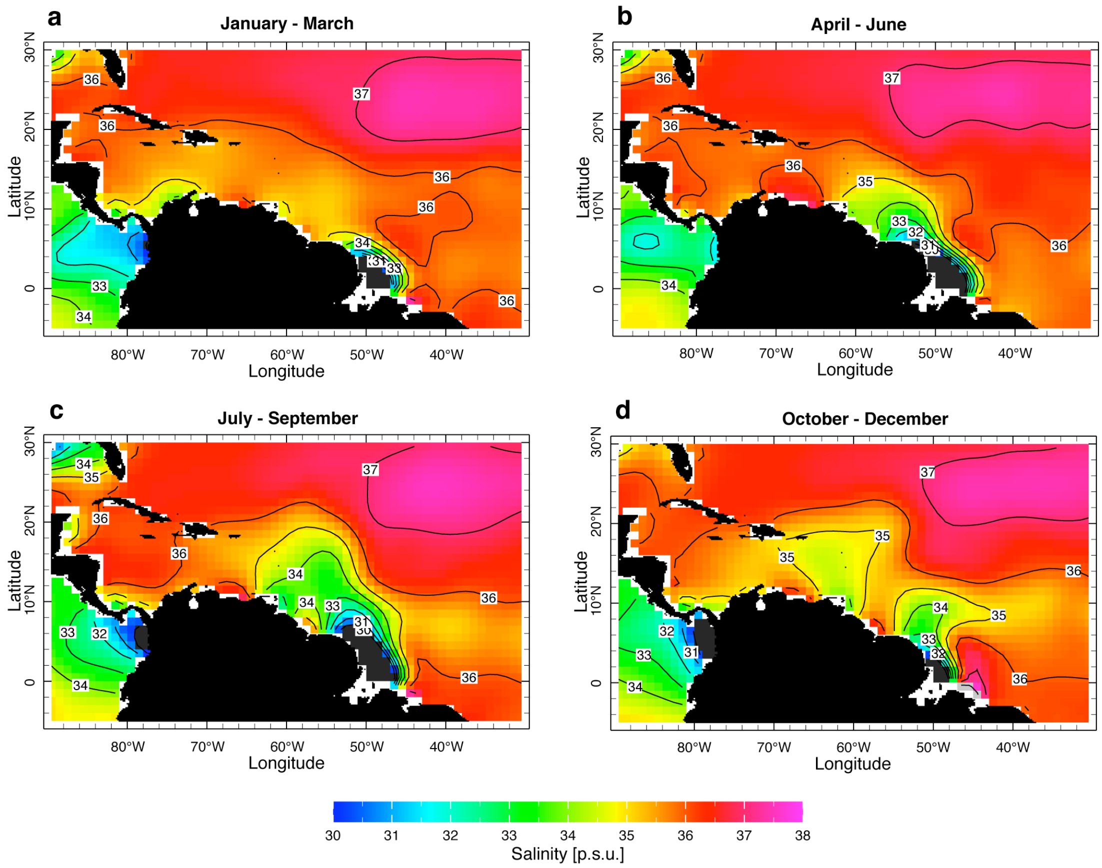


Figure 1-8. Sea surface salinity (SSS) from the Levitus et al. (1994) climatology averaged over three months: (a) January-March; (b) April-June; (c) July-September; and (d) October-December.

b) Interannual to decadal variability

In contrast to the tropical Pacific, where climate variability on seasonal-to-decadal timescales is dominated by a single mode, the El Niño Southern Oscillation (ENSO), climate variability in the tropical Atlantic region is more complex (Handoh et al., 2006; Marshall et al., 2001), and rather subject to multiple competing influences of comparable importance (Sutton et al., 2000). These interacting influences can arise from local (internal) processes, as well as originate from regions remote from the tropical Atlantic. On interannual to decadal time scales, the Caribbean climate is known to be influenced by both the tropical Pacific and the tropical North Atlantic variability (Taylor et al., 2002). SST over the north tropical Atlantic (NTA) exhibits substantial interannual to decadal variability, and is arguably one of the most important climatic parameters on these time scales. Several mechanisms have been proposed to explain the origins of this variability. These mechanisms include both local coupled ocean-atmospheric interaction, and remote forcing from ENSO and the NAO (in depth reviews can be found in Marshall et al. (2001) and Xie and Carton (2004)). Previous studies on climate variability in the NTA and Caribbean region have emphasized the remote influences from both the Pacific El Niño-Southern Oscillation (ENSO) (e.g., Curtis and Hastenrath, 1995; Czaja et al., 2002; Enfield and Mayer, 1997; Giannini et al., 2000; Hastenrath, 1976; Mestas-Nunez and Enfield, 1999; Saravanan and Chang, 2000) and the extratropical North Atlantic (e.g., Czaja et al., 2002; Nobre and Shukla, 1996; Wu and Liu, 2002; Xie and Tanimoto, 1998). Enfield and Mayer (1997) have noted that ENSO represents the dominant mode of interannual temperature variability in the Caribbean and tropical Atlantic. SSTs in this region act in concert with SSTs in the eastern tropical Pacific, albeit lagged in time (Saravanan and Chang, 2000).

The El Niño-Southern Oscillation is a system of interactions between the equatorial Pacific Ocean and the atmosphere above it (Philander, 1990; Rasmusson and Carpenter, 1982). El Niño and La Niña events represent the opposite states of the ENSO system. In general, the term El Niño is associated with significantly warmer temperatures than average in the equatorial Pacific, whereas the term La Niña is associated with significantly cooler temperatures than average (Fig. 1-9). The term Southern Oscillation refers to the differences in atmospheric pressure between the East and West Pacific associated with these anomalies in temperature. This gradient is captured by an index that is based on the sea level pressure (SLP) difference between Darwin (Australia) and Tahiti (French Polynesia) and is known as the Southern Oscillation Index (SOI).
During an El Niño event, sea level pressure tends to be lower in the eastern Pacific and higher in the western Pacific (negative SOI) while the opposite scenario tends to occur during a La Niña (positive SOI). Once an El Niño or La Niña event develops, it persists for about twelve months. The periodicity of successive El Niño events is irregular but they typically occur every 3 to 7 years. A La Niña event often, but not always, follows an El Niño and vice versa. El Niño (La Niña) events are typically characterized by warmer (cooler) than average sea surface temperatures in the tropical Pacific, but they are also associated with changes in wind, pressure, and rainfall patterns (Fig. 1-9).
The Pacific ENSO system influences seasonal climate variability (such as rainfall and temperature) on a global scale (Philander, 1990). That means, depending on the region and season, certain climate conditions are more likely to happen during El Niño events or during La Niña events than at other times. These climatic anomalies, which occur in response to remote forcing, are called teleconnections. For example, during El Niño events flooding often occurs along the Pacific coast of South America due to increased precipitation, and fish stocks suddenly disappear as ocean upwelling, containing cold high-nutrient water, diminishes. A comprehensive review of the El Niño phenomenon and the Southern Oscillation can be found in the studies of Trenberth (1997) and Cane (2005).
The ENSO system is known to influence also wind stress, rainfall, and the occurrence of hurricanes in the Caribbean (Enfield and Mayer, 1997; Giannini et al., 2000; Gray, 1984; Tang and Neelin, 2004). Enfield and Alfaro (1999) have shown evidence that the strongest response in rainfall is generated when SSTs in the equatorial Pacific and northern tropical Atlantic are of opposite sign.

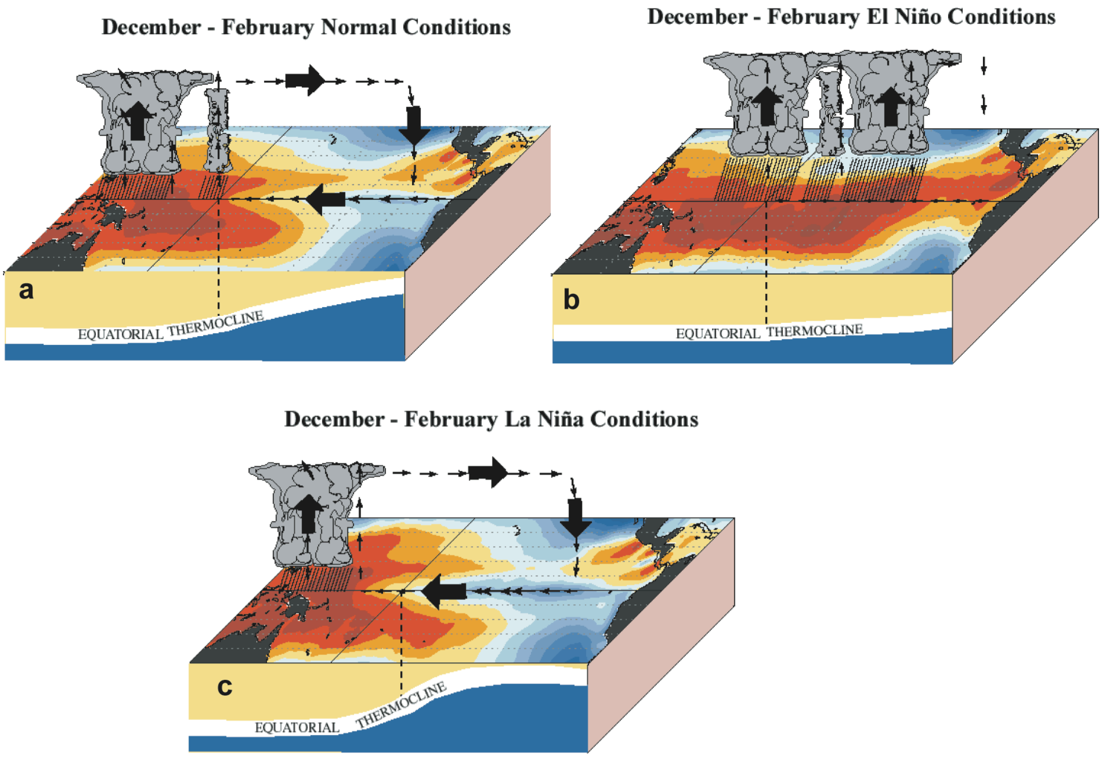


Figure 1-9. Schematics of normal conditions, El Niño and La Niña conditions in the equatorial Pacific Ocean and the atmosphere above it: (a) During normal conditions, the warmest water and greatest rainfall is found in the western Pacific. The trade winds provide a westward wind stress over the equatorial Pacific. The thermocline is near the surface in the east and temperatures there are cold. The stronger winds pull the thermocline up and increase upwelling; the stronger east-west SST gradient creates a stronger east-west sea level pressure (SLP) gradient (manifested by a more positive Southern Oscillation) that drives stronger winds. (b) During El Niño events, the equatorial trade winds relax, the thermocline deepens in the east and warmer than average sea surface temperatures extend eastward into the central and eastern tropical Pacific; the region of strongest rainfall moves eastward. The SST and SLP gradients decrease, weakening the trade winds, and the warm state is reinforced. (c) La Niña conditions can be thought of as an enhancement of normal conditions. During these events, the equatorial trade winds strengthen, colder than average ocean water extends westward to the central Pacific, leading to above average SSTs in the western Pacific. The plots are based on data from the NOAA Climate Prediction Center (http://www.cpc.noaa.gov/).

Atlantic tropical cyclone activity is known to be negatively correlated with SST indices of ENSO (Gray, 1984). In general, the frequency of Atlantic hurricanes in an El Niño year is reduced, while in a La Niña year, there are more Atlantic hurricanes (Saunders et al., 2000). One hypothesized mechanism is suppression by wind shear (e.g., Goldenberg and Shapiro, 1996; Gray, 1984). ENSO events alter the global circulation and change the upper level winds over the Atlantic (Arkin, 1982). During an El Niño year, the difference between upper and lower level winds (i.e., wind shear) is larger in most of the tropical Atlantic, which inhibits the formation of hurricanes, while the opposite happens in a La Niña year. However, hurricanes are complex phenomena and ENSO is only one factor influencing Atlantic hurricane activity. Other important environmental factors are, for example, SSTs in the Atlantic (Landsea et al., 1999), the stratospheric Quasi-biennial oscillation (Gray, 1984), the NAO (Elsner et al., 2000b), African Easterly Waves and large-scale atmospheric circulation (moisture variability and atmospheric stability) (Gray, 1968).

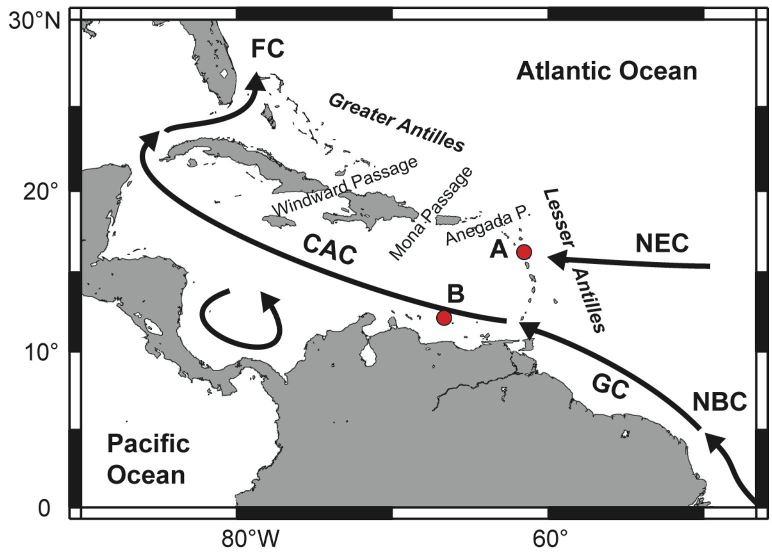
Recent modeling studies (Sutton et al., 2000; Visbeck et al., 1998) suggest that fluctuations in the winter NTA trade winds are correlated with variability of higher latitude westerlies and might be viewed as a low latitude manifestation of the NAO. For example, a study by George and Saunders (2001) has demonstrated that the wintertime NAO affects the precipitation over the Caribbean in the following year, suggesting that this forcing is a result of SST anomalies set up by the winter trade winds. The NAO is defined as the normalized sea-level pressure difference between the Azores and Iceland (Jones et al., 1997). This gradient affects the strength of the tropical North Atlantic trade winds (George and Saunders, 2001), and the extent of the western hemisphere warm pool in the Caribbean Sea (Wang and Enfield, 2001). On decadal timescales the NAO influences climate in the North Atlantic basin and the surrounding continents. NAO-related impacts on winter climate extend from Florida to Greenland, from northwestern Africa to Europe, and as far as into northern Asia (Visbeck et al., 2001). A detailed review of the North Atlantic Oscillation can be found in (Hurrell et al., 2003).

c) *Low-frequency variability*

Low-frequency climate variability in the tropical Atlantic region appears to be closely linked to decadal to interdecadal fluctuations in tropical Atlantic SST (e.g., Marshall et al., 2001). Several observational- and model-based approaches have observed significant decadal-interdecadal scale variability (with a period of around 8-20 years) in tropical Atlantic SST, precipitation, and the frequency of tropical cyclones (Carton et al., 1996; Chang et al., 1997; Elsner et al., 2000a; Gray et al., 1997; Handoh et al., 2006; Joyce et al., 2000; Marshall et al., 2001). However, the mechanisms underlying the observed low-frequency climate phenomena in the Atlantic are complex and subject of intensive discussion (Carton et al., 1996; Dommenget and Latif, 2000; Enfield and Mayer, 1997; Huang et al., 2004; Hurrell, 1995; Hurrell and van Loon, 1997; Joyce et al., 2000; Kushnir et al., 2002; Marshall et al., 2001; Nobre and Shukla, 1996; Xie and Carton, 2004; Xie and Tanimoto, 1998). The leading large-scale pattern of multidecadal variability in SST centered in the North Atlantic Ocean (0°-70°N) exhibits a 65-80 year cycle (Enfield et al., 2001; Schlesinger and Ramankutty, 1994) over the last 150 years of instrumental observations with a temperature range of around 0.4°C (Enfield et al., 2001), and has been referred to as the Atlantic Multidecadal Oscillation (AMO) (Kerr, 2000). Its global impacts on climate and ecology are only recently becoming appreciated (Enfield and Cid-Serrano, 2006; Knight et al., 2006). For example, a clear link between AMO warm and cold phases and the frequency of Atlantic hurricanes has been established (Goldenberg et al., 2001). The mechanisms underlying this multidecadal signal remain controversial, primarily because of the limited instrumental record (Latif et al., 2006). Observation- and model-based studies imply that changes in the strength of the North Atlantic thermohaline circulation (THC) could drive the associated multidecadal variability in SST (Delworth and Mann, 2000; Folland et al., 1986; Knight et al., 2005; Latif et al., 2004).

Oceanography

The Caribbean Sea is a semi-enclosed basin in the western part of the North Atlantic Ocean. It is the source area of warm water masses leaving the low latitudes. The outflow from the Caribbean promotes the transequatorial heat transfer to higher latitudes (Sato and Rossby, 1995; Schmitz et al., 1993; Schmitz and McCartney, 1993) and acts as a starting point of the Gulf Stream (Hogg and Johns, 1995). Water masses entering the Caribbean originate from two nearly equal sources, the North Atlantic and the South Atlantic Ocean (Johns et al., 2002). The closely spaced chain of islands, banks, and sills of the Antilles Islands Arc act as a sieve for the inflow of Atlantic water (Andrade and Barton, 2000; Murphy et al., 1999), which enters to the eastern Caribbean Sea through passages within the Lesser Antilles (Stalcup and Metcalf, 1972; Wüst, 1964). The surface layer inflow is dominated by water entering through the Grenada, St. Vincent, and St. Lucia Passages (Johns et al., 2002). The surface circulation in the Caribbean, which consists of a generalized westward flow (Joyce, 2001), is determined by wind driven circulation and the strength of the thermohaline circulation (Johns et al., 2002). North of 15°N inflow water is primarily Gulf Stream water returning southwestward in the North Equatorial Current (NEC, Fig. 1-10), passing through the Leeward Islands of the Lesser Antilles, through the Windward Passage between Hispaniola and Cuba, and through the Mona Passage between Hispaniola and Puerto Rico (Richardson, 2005). The wind-driven subtropical gyre inflow to the Caribbean that enters through the passages north of Martinique at ~ 15°N is estimated to about 17 Sv (1 Sverdrup=$10^6 m^3/s$) (Johns et al., 2002). Results from numerical models suggests that the meridional overturning circulation adds about 11 Sv of waters that originate primarily of tropical and South Atlantic sources (Johns et al., 2002). This inflow mainly occurs through the southern Lesser Antilles passages (south of 15°N). South Atlantic waters cross the equator as North Brazil Current (NBC) and flow north along the northeastern continental margin of South America, near French Guyana part of it separates from the coast and retroflects to join the North Equatorial Counter Current (NECC). The rest of the NBC continues flowing northwestward to form the Guyana Current (GC), which is significantly influenced by freshwater discharges from the Amazon and Orinoco Rivers (Morrison and Smith, 1990). Overall, the thermohaline circulation combines with the wind-driven circulation from the subtropical gyre to form an inflow of about 28 Sv to the Caribbean (Johns et al., 2002; Schmitz and Richardson, 1991). The water then continues westward as the Caribbean Current, the main surface circulation in the Caribbean Sea (Gordon, 1967; Hernandez-Guerra and Joyce, 2000; Roemmich, 1981; Wüst, 1964). The Caribbean Current builds an important branch of the upper part of the northward-flowing meridional overturning circulation (MOC) (Schmitz and McCartney, 1993; Schmitz and Richardson, 1991), since this is the major route by which South Atlantic water flows into the Florida Current and Gulf Stream. The outflow of warm water masses from the Caribbean concentrates on the southern Florida Strait between Florida Keys and Cuba and the northern Florida Strait between the Bahama Bank and Florida (Fig. 1-10). The Gulf Stream system is of fundamental importance to the climatic evolution in high northern latitudes and, thus, to the living conditions in NW Europe.



<u>Figure 1-10.</u> Modern oceanographic setting of the Caribbean and western tropical Atlantic region schematically showing the major surface current systems. The study sites are marked by points: (A) Guadeloupe, (B) Archipelago Los Roques. Major surface currents are indicated based on data from Gordon (1967): CAC: Caribbean Current; FC: Florida Current; NBC: North Brazil Current; GC: Guyana Current; NEC: North Equatorial Current.

Surface current patterns and hydrography in the Caribbean are subject to seasonal fluctuations that are mainly controlled by the seasonally northward and southward migration of the ITCZ. During the northern summer, when the ITCZ reaches its northernmost position, the Caribbean hydrography is characterized by enhanced rainfall, and hence fluvial freshwater input. Also, the North Equatorial Counter Current establishes during that time, mainly driven by a combination of the southeast trade winds and the diverting Coriolis force, that forces equatorial Atlantic surface waters towards the east and leads to strengthened inflow into the Caribbean (Richardson and McKee, 1984). The uppermost layer of Caribbean seawater (~ upper 80 m), which was termed Caribbean Surface Water by Wüst (1964), is thought to be a mixture of freshwater from both the Amazon and Orinoco Rivers and tropical Atlantic surface waters, which flow to the Caribbean as the Guyana Current (Fig. 1-10). It has a potential temperature of about 28°C, due to the influence of riverine freshwater salinity values of the Caribbean Surface Water (CSW) are relatively low (around 35.5 psu; (Hernandez-Guerra and Joyce, 2000)). According to Schmitz and Richardson (1991), about 80% of the CSW originates from South Atlantic water, while the remainder has a North Atlantic source. Highest surface velocities of the Caribbean Sea are found near the southern boundary along the coast of Venezuela and the Netherlands Antilles (Centurioni and Niiler, 2003; Fratantoni, 2001). Hernandez-Guerra and Joyce (2000) conducted a meridional hydrographic section at 66°W starting at the coast of Venezuela in August-September 1997. They found different water masses in two sections: from Venezuela to about 13°N and from 14°N to Puerto Rico. From Venezuela to 13°N they found a low-salinity water mass with its source in the tropics and South Atlantic. Within the southernmost portion of this area, two different flow patterns were observed. At the surface, there was an intensified westward jet with velocities of 130 cm/s in midbasin. Underneath this flow, there was an eastward flow with a subsurface maximum near the Venezuelan coast and slope. From 14°N to Puerto Rico, Hernandez-Guerra and Joyce (2000) found Caribbean Surface Water and Subtropcial UnderWater (SUW), as previously observed by Wüst (1964), Kinard et al. (1974), and Metcalf (1976). SUW is found deeper, at about 80-200 m and it is more saline (salinity of 36.5 psu or higher) and cooler (temperature of 22-23°C) than CSW (Morrison and Nowlin, 1982; Schmitz and McCartney, 1993). This water mass originates in the central tropical Atlantic, where evaporation exceeds precipitation, and forms the permanent upper thermocline in the Caribbean (Wüst, 1964).

1.6 Atlantic and Caribbean coral records

Coral-based reconstructions of climate variability in the Atlantic region in general, and in the Caribbean region specifically, have lagged behind the extensive work published using coral records from the Indian and Pacific Oceans. In the tropical Atlantic region, primarily *Montastrea* sp. corals have been used for paleoclimatic studies (e.g., Emiliani et al., 1978; Guilderson et al., 2001; Leder et al., 1996; Nyberg, 2002; Swart et al., 2002; Swart et al., 1996; Watanabe and Oba, 1999; Watanabe et al., 2001; 2002; Winter et al., 2000; 2003), which are the dominant reef-building corals in the Atlantic and are long-lived and fast-growing. Previous workers have used these corals to develop records of temperature and insolation (e.g., Fairbanks and Dodge, 1979; Gischler and Oschmann, 2005; Swart et al., 2002), upwelling (Guilderson et al., 2005; Reuer et al., 2003), and ocean circulation (Druffel and Suess, 1983). Paired measurements of geochemical proxies (Mg/Ca, $\delta^{18}O$) have been employed over short time windows to assess possible changes in temperature and salinity in the Caribbean region during the Little Ice Age (Watanabe et al., 2001).
However, several studies have shown that laborious high resolution sampling techniques (>20-50 samples/year) are necessary in order to resolve the full seasonal temperature cycle using *Montastrea* sp. (Leder et al., 1996; Watanabe et al., 2001; 2002). As a result, published records either span a couple of decades in high-resolution, or extend back further in time but exhibit only low temporal resolution.

Other studies have demonstrated that slower growing massive corals of the genus *Siderastrea* (e.g., Gischler and Oschmann, 2005; Moses et al., 2006) and the species *Diploria labyrinthiformis* (e.g., Cohen et al., 2004; Draschba et al., 2000; Goodkin et al., 2007; Goodkin et al., 2005; Kuhnert et al., 2005; Kuhnert et al., 2002), which are also abundant in the tropical and subtropical Atlantic, exhibit annual growth rates on the order of approximately 1.5-4 mm, and are particularly of interest as potential recorders of environmental data since they can be found in environments with extreme temperature, salinity, and river runoff/sediment input variations, where no fast-growing corals are available for reconstructions. However, the slow growth rates are causing problems, because microsampling in aragonitic coral skeletons becomes more difficult with decreasing annual coral growth (e.g., Moses et al., 2006). For example, the restriction of microsampling to a single structure of the coral skeleton for geochemical analysis, which should be the preferable sampling method in order to obtain optimal unbiased results (Leder et al., 1996), is difficult and sometimes not possible using slow-growing corals. Hence, it is difficult to capture the full amplitude of the annual SST cycle using conventional coarse sampling for slow-growing coral species, and therefore, the application of tedious high-resolution sampling techniques is necessary.

In spite of previous work, there is currently no continuous multi-decadal or longer coral record available for the tropical Atlantic resolving climate variability of the 20th century with a high temporal resolution. In contrast, more than a dozen century- to multi-century-long coral records of $\delta^{18}O$ and/or Sr/Ca variability do exist from the Indo-Pacific region (Gagan et al., 2000).

1.7 Aims and Objectives

Motivation

Multidecadal to century-long records of past sea surface parameters from the tropical oceans are essential for the understanding of past and future climate variations. Especially, highly-resolved long-term proxy records of past sea surface conditions are required as input data for the calibration and validation of numerical climate models, which have the objective to enhance our understanding of internal variability in the coupled ocean-atmosphere system (e.g., the Northern Hemisphere ocean circulation, including the Caribbean Current, the Gulf Stream system, and the North Atlantic thermohaline circulation (THC) (Latif, 2001; Latif et al., 2000; Vellinga and Wu, 2004)). A proper knowledge of past variability of the climate system is also important with regard to long-range climate forecasting (Delworth and Mann, 2000), and to assess the anthropogenic impact on climate and ecosystems.

Especially in the tropics, the availability of instrumental climate data is relatively scarce and only available with low spatial coverage before the middle of the 20^{th} century. Consequently, the interpretation of climate signals exhibiting decadal or longer scale variability is complicated. Moreover, difficulties in previously utilized coral archives from the Atlantic (see previous chapter) have, so far, exacerbated the production of long-term high-resolution proxy records in this region. Thus, the evaluation and development of new potential coral archives that can be used to develop high-resolution proxy data is highly needed in order to be able to establish new continuous long-term coral-based proxy records that can help to better understand interannual to centennial-scale climate variability in the tropical Atlantic, which is a key region in the Northern Hemisphere when it comes to the reconstruction of long-term climate variations. Moreover, model simulations and studies based on instrumental data demonstrate that the Caribbean is a prime area for the reconstruction and study of global temperature trends and variability (e.g., *Hoerling et al.* (2001)).

Objectives

The main objective of this dissertation is the evaluation of massive fast-growing corals (i.e., with annual growth rates of around 8 mm or higher) of the species *Diploria strigosa* (Dana, 1848) as a new marine archive for climate reconstructions from the tropical Atlantic region. For this purpose, coral records from two study sites in the eastern Caribbean Sea (Guadeloupe, Lesser Antilles; and Archipelago Los Roques, Venezuela) were examined. *Diploria strigosa* is a common reef-building coral and a potentially important environmental recorder because it forms massive colonies, is abundant throughout western Atlantic and Caribbean reefs, produces distinct annual density bands (Helmle et al., 2002), and can grow up to several hundred years of age. Corals of this species have, so far, not been used for reconstructions of past Atlantic climate variability. The general aim of this study concentrates on the development of highly-resolved geochemical proxy records from the aragonitic skeletons of massive fast-growing colonies of *Diploria strigosa* from the tropical Atlantic.

The first part of this thesis is aimed at the evaluation of fast-growing *Diploria strigosa* corals as new climate archive. For this task, the isotopic and trace elemental composition of the top part of a century-long coral record was examined. In order to assess the robustness of the measured geochemical proxies ($\delta^{18}O$, Sr/Ca), a calibration exercise was conducted using local environmental data when available (e.g., SST) to test proxy-temperature relationships and develop the first calibration equations for fast-growing *Diploria strigosa* corals. In a second step, the potential of geochemical proxy time series derived from *Diploria strigosa* corals to capture local environmental signals, as well as large-scale climate signals on interannual to multidecadal time scales, was assessed. This investigations were undertaken using coral cores derived from two study sites located in the southeastern Caribbean Sea. Both examined records span through the 20th century and display high-temporal sampling resolution.

1.8 Thesis structure

This thesis consists of six chapters, with **chapter 1** giving a basic introduction on the use of tropical corals as archives of past climatic variability. Then, the basic theory of geochemical proxies used in this study is discussed, followed by an overview of the geographic, climatic, and oceanographic setting of the study sites. At the end of chapter 1, previous coral-based studies from the Atlantic are summarized concisely, and finally the aims and objectives of this work are outlined. **Chapter 2** gives a detailed description of the materials used in this study, as well as the applied methods and the employed analytical and statistical procedures. Results presented in **chapter 3 to 5** are structurized in a format suitable for publication in peer-reviewed scientific journals. The following paragraphs give a short overview of the questions and the thematic content addressed in the respective chapters:

In **chapter 3**, the development of the first geochemical proxy time series from fast-growing corals of the species *Diploria strigosa* are described. A 41-year continuous multi-proxy ($\delta^{18}O$ and Sr/Ca) record is produced using a coral from the eastern Caribbean Sea. The potential of fast-growing corals of this species as a new and easily accessible oceanic archive is evaluated. Furthermore, the ability of the coral proxies to record large-scale SST variability in the tropical North Atlantic is examined.

In **chapter 4**, the calibrated records from chapter 3 are extended in time and the major climatic signals recorded in the century-long coral record, that are known to have strong influence on climate variability of the tropical Atlantic region on different time scales, are assessed. In this multi-proxy approach, the relationships of geochemical coral proxy data with SST are discussed, along with the feasibility of the coral proxies to track the impact of seasonally dependent remote forcings on north tropical Atlantic SST and climate variability. For this task, a quantitative comparison between coral proxies and the two primary modes of external forcing (ENSO and NAO) is conducted. In addition, different spectral analysis tools were applied to both coral proxy time series in order to identify and characterize the role of dominant climate signals in the records on interannual to decadal time scales.

With the prerequisites from the previous chapters, **chapter 5** functions as a case study using a coral record of the same coral species, but from another locality in the Caribbean. In this study, the climate signals recorded in the oxygen isotopic variations of a coral record from the Archipelago Los Roques (Venezuela) are examined. A particular focus lies on the connection between north tropical Atlantic SST and precipitation, recorded in the coral proxy time series, and the activity of Atlantic hurricanes. The potential of the coral proxy record as an archive for past hurricane activity is assessed, and the implications from the multidecadal signal captured by the coral for the reconstruction of past low-frequency climate variability in the Atlantic sector are discussed.

Chapter 6 summarizes the major implications of chapters 3 to 5 and points out the main conclusions of this thesis.

CHAPTER 2 - MATERIALS, METHODS AND ANALYTICAL PROCEDURES

In this chapter a comprehensive summary of the materials, methods and analytical procedures used in this study is presented, and an overview of the applied statistical analysis tools is given. Some parts may be repeated in the following chapters which have been written in a format suitable for publication.

2.1 Collection of coral cores

All coral cores used in this thesis were drilled underwater using SCUBA and a hand held pneumatic drill gun. The drill was air-powered by a compressor or SCUBA tanks. The core barrel used was a diamond-tipped steel tube with an inner core barrel diameter of 36 mm and 30 cm length. Through the use of extension rods, the collection of longer coral cores (in 30 cm-segments) was enabled. After drilling, the cores were rinsed with freshwater and air dried. All cores were drilled vertically, in parallel orientation to the dominant axis of coral growth, to the bottom of the coral colony.

The coral cores used in this study were collected in the framework of a field campaign to the eastern Caribbean Sea in 2000 (Guadeloupe), and during a 2004 field expedition to Venezuela (Archipelago Los Roques). A 1.26 m long coral core was drilled in April 2000 on the southern edge of Isle de Gosier (16.20°N, 61.49°W), which is located approximately 0.8 km south of Grande Terre, Guadeloupe (Fig. 1-5a). Core Gua1 was retrieved from a hemispherical *Diploria strigosa* coral colony (1.5 m in diameter) growing in a water depth of 1.7 m. In December 2004 a hemispherical *Diploria strigosa* colony was sampled live at 2 m water depth off Cayo Sal (11.77°N, 66.75°W), at the southernmost rim of the Los Roques Archipelago, Venezuela (Fig. 1-5b). A 1.15 m long coral core (Roq6) was retrieved.

2.2 Coral growth and microstructure

Diploria strigosa colonies (Fig. 2-1a) are massive (especially in shallow water) and show a meandroid growth form, which is also known under the term “brain coral”, with an even surface (sinuous valleys 6-9 mm wide; Fig. 2-1a). Linear series of polyps are separated by a solid skeletal wall called a theca (Fig. 2-1c). Adjacent rows of polyps share a common theca, and therefore, no exothecal structures are present. The thinner vertical inner walls are called septa (Fig. 2-1c). Opposing rows of septa anastomose, or join, to form a spongy structure that is called the columella. During growth of the coral colony, the polyps lift their basal surface and secrete new basal floors (dissepiments) (Helmle et al., 2002).

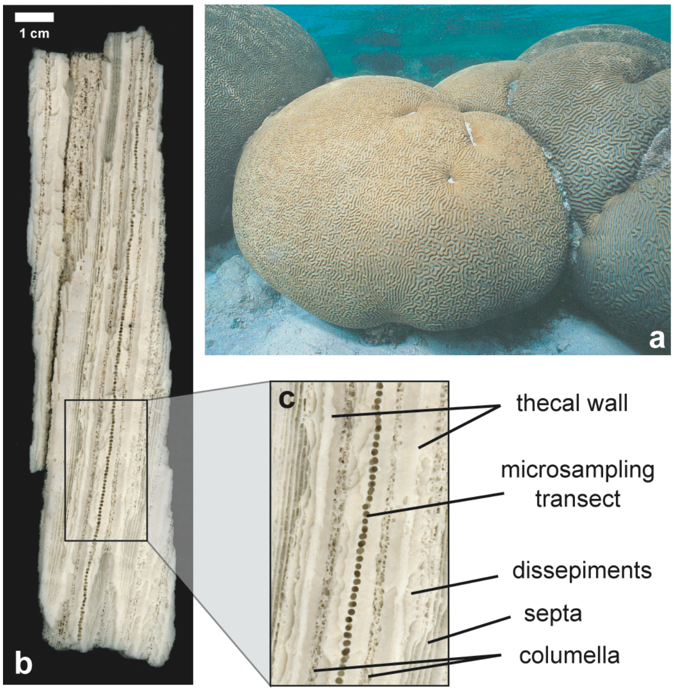
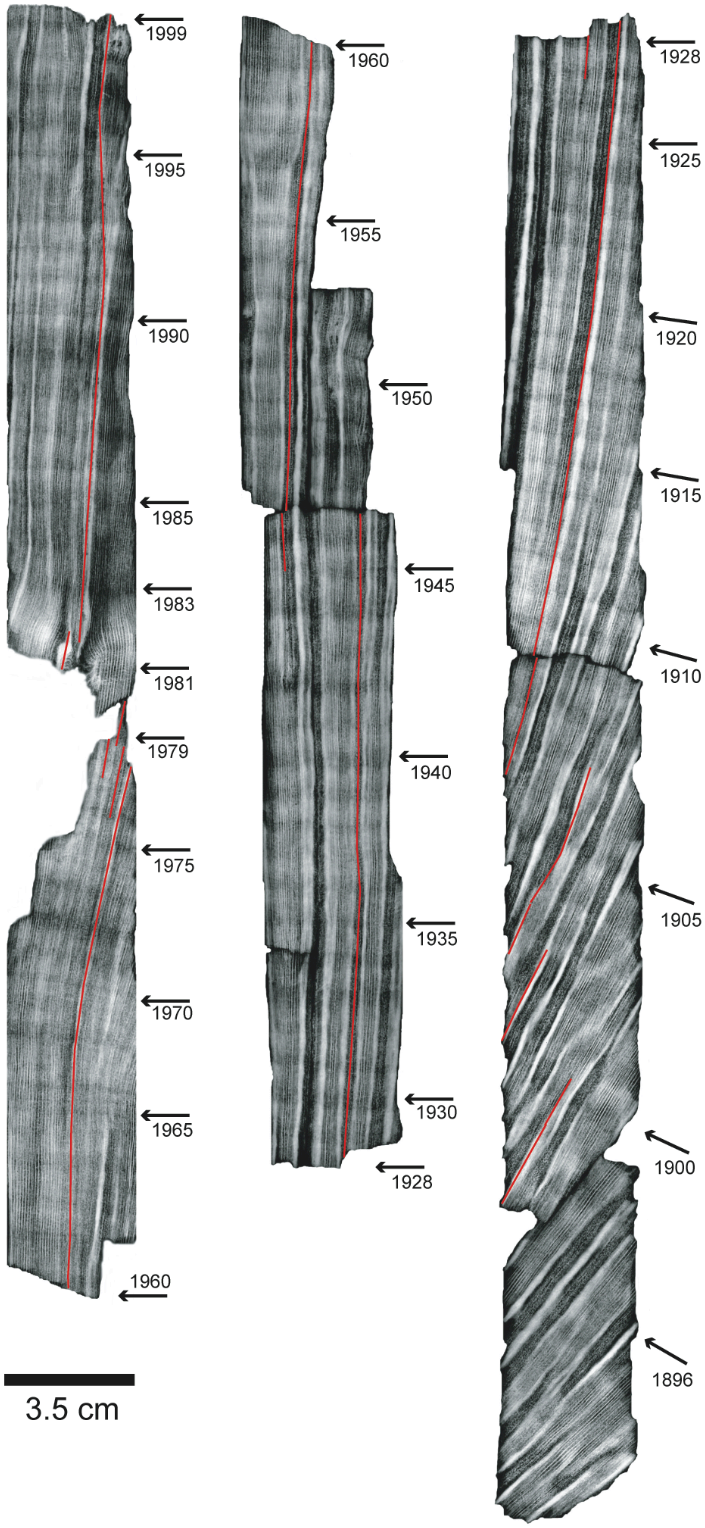


Figure 2-1. (a) Massive *Diploria strigosa* colony growing in shallow water (diameter approximately 1 m). (b) Sectioned coral slab from a Guadeloupe *Diploria strigosa* core. (c) Enlarged section: Major elements of the coral skeleton are indicated; row of small holes observable from upper right to lower left corner represents the microsampling transect (also observable in (b)).

2.3 Technical sample preparation for geochemical analysis

After rinsing in freshwater, the coral cores were sectioned longitudinally into 7 mm thick slabs. The coral slabs were then cleaned in an ultrasonic bath with deionized water to remove saw cuttings and were oven dried at 50°C for 24 hours. Afterwards the slabs were X-rayed at 35 kV and 5 mA (exposure time: 12-15 minutes, Figs. 2-2 and 2-3) in order to expose annual density couplets. Chronologies were generated by counting the well-developed annual density banding observable on the X-radiographs, assuming that each high- and low-density (HD, LD) band couplet represents one year of growth (Knutson et al., 1972). These density variations result from changing coral calcification and/or linear extension rates and allow the counting of annual band pairs backwards from the top of the coral colony in order to assign calendric years to certain skeletal layers. The x-radiographs were also used to measure mean annual skeletal extension rates and to determine optimal sampling transects for following collection of microsamples.



<u>Figure 2-2.</u> X-radiographs of slabs from coral core Gua1 (*Diploria strigosa*). Alternating high (light) and low density (dark) bands can be observed clearly and banding is in a near perpendicular orientation with respect to the axis of the coral core. In the skeletal density banding pattern, one year of coral growth is represented by one high- and low-density band couplet. Years indicate coral chronology. Sampling transects are indicated by red solid vertical lines on each slab.

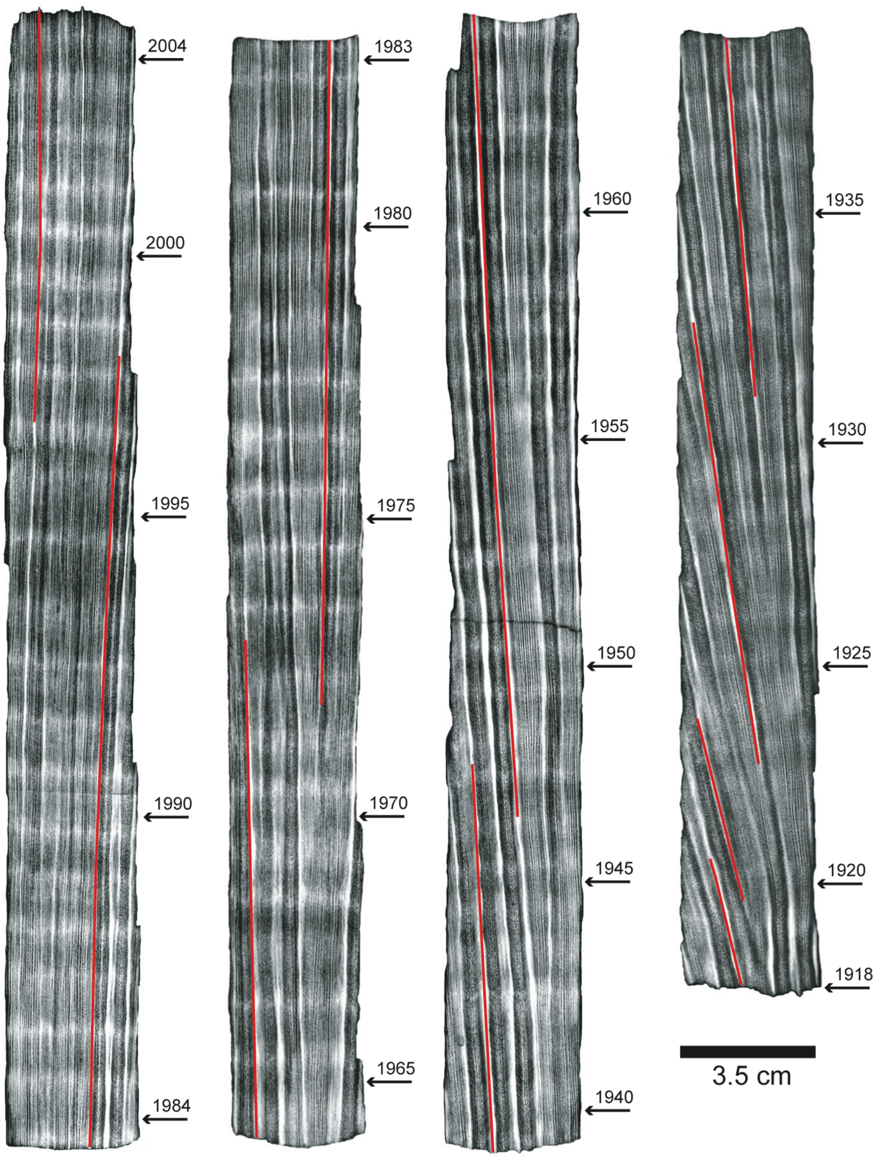


Figure 2-3. X-radiographs of slabs from coral core Roq6 (*Diploria strigosa*). Sampling transects are indicated by red solid vertical lines on each slab. Year dates show approximate markers of coral skeleton precipitation. Note the goodness of fit between individual slabs.

Samples for stable isotope and trace element analysis were collected using a low-speed micro drill (mounted on a Proxxon drill table) with a 0.5/0.7 mm diameter drill bit. The slabs were sampled along the corallite walls (theca), in order to avoid mixing of sample powder from different skeletal elements (Fig. 2-1c). A study by Helmle et al. (2002), who analyzed the complex skeletal architecture and density banding of the same coral species using X-ray computed tomography (Fig. 2-4), approved that the thecal wall of this species is not influenced by secondary thickening processes, which could dampen the annual signal in the proxy time series (e.g., as observed in slow-growing specimens of *Diploria labyrinthiformis* from Bermuda by Cohen et al. (2004)). Consequently, we confined sampling to this specific part of the coral skeleton. This has significantly improved the results compared to bulk sampling.

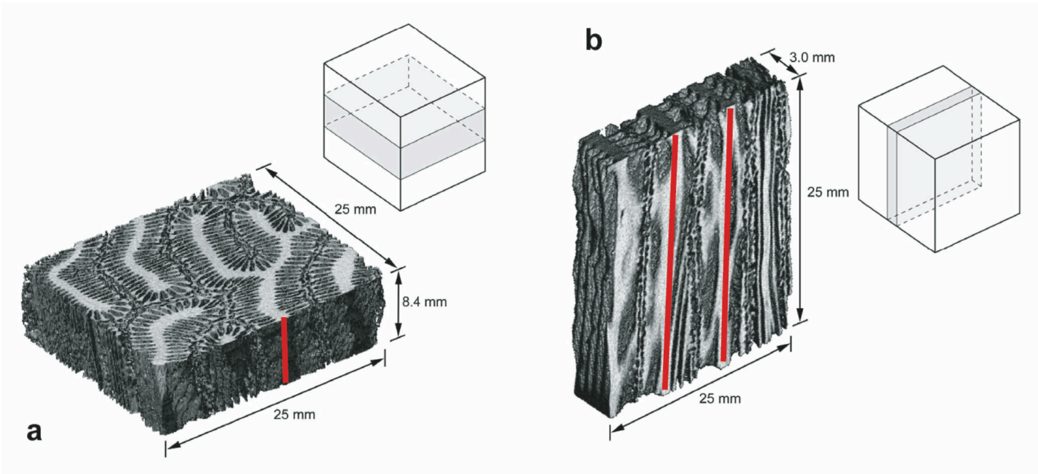


Figure 2-4. **Three-dimensional skeletal reconstructions of X-ray computed tomography (CT) images and their relative positions within a diagram of a 25x25x25 mm coral cube from a *Diploria strigosa* colony retrieved off Florida. (a) plan-view image, and (b) longitudinal-view image. Coral cube diagrams are oriented with the growth trajectory running vertically. From Helmle et al. (2002), slightly modified. Red lines schematically indicate the position of thecal walls used for microsampling within the skeletal framework.**

Microsamples were retrieved continuously at approximately 0.5 to 1.0 mm intervals along transects following the axis of maximum growth (Fig. 2-2 and 2-3), yielding on average 10-12 samples per year of growth, to facilitate calibration with monthly resolved SST data. Physical sample spacing was chosen depending on the skeletal extension rates. As a next step, the sample material was splitted into separate aliquots for stable isotope ($\delta^{18}O$ and $\delta^{13}C$) and trace element (Sr/Ca and Mg/Ca) analysis, respectively. Only the records of $\delta^{18}O$ and Sr/Ca ratios will be discussed herein.

2.4 Oxygen isotope analysis

The stable oxygen isotopic content of coral skeletal aragonite is expressed as delta^{18}O ($\delta^{18}O$) values in parts per thousand (‰). Quantitative results are obtained by comparing the isotopic ratio ($^{18}O/^{16}O$) in the carbonate of a given sample to an international reference standard:

$$\delta^{18}O\ (‰) = [(R_{sample} - R_{standard}) / R_{standard}] \times 10^3$$

with R_{sample} referring to the $^{18}O/^{16}O$ ratio in the sample, and $R_{standard}$ referring to the $^{18}O/^{16}O$ ratio in the standard, respectively (e.g., Emiliani, 1955; Shackleton and Opdyke, 1973). The conventional reference standard for carbonates is the PDB standard, which is defined from the rostrum of a Cretaceous belemnite *Belemnitella americana* (B-1) from the Pee Dee Formation in South Carolina (Epstein et al., 1953).

Technical preparation and analysis

Oxygen isotope measurements were performed at IFM-GEOMAR using a Themo Finnigan MAT Deltaplus Gasbench II connected to an autosampler for the analysis of the $\delta^{18}O$ composition of coral samples. The powdered samples were reacted with 100% phosphoric acid (H_3PO_4) at 70°C and the resulting carbon dioxide (CO_2) gas was analyzed in the mass spectrometer. The stable isotopes of oxygen and carbon are determined by mass spectrometric analysis of the mass ratios of CO_2 obtained from the carbonate sample, with reference to a standard carbon dioxide gas of known composition. The CO_2 is produced by the reaction of carbonate with H_3PO_4:

$$CaCO_3 + H_3PO_4 \Leftrightarrow CaHPO_4 + CO_2 + H_2O$$

The standard deviation of multiple measurements of the international reference standard NBS-19 was ±0.06‰ for $\delta^{18}O$. All samples are reported in ‰ relative to the Vienna Pee Dee Belemnite (VPDB) by assigning an $\delta^{18}O$ value of –2.20‰ to NBS-19.

2.5 Trace elemental analysis

Trace elements (Sr/Ca ratios) were measured in an inductively coupled plasma optical emission spectro-photometer (ICP-OES) at the Geological Institute of the University of Kiel following a combination of the techniques described in detail by Schrag (1999) and de Villiers (2002). Sr and Ca intensity lines used are 407 nm and 317 nm, respectively. The intensities of Sr and Ca were then converted into Sr and Ca ratios in mmol/mol. An in-house coral-based reference standard was used for drift-correction of the measured Sr/Ca ratios.

Technical preparation and analysis

The sample solution was prepared by dissolving 0.5 mg coral powder in 1 ml of 2% HNO_3. The working solutions were prepared by a serial dilution of the sample solution with 2% HNO_3 to obtain a concentration of about 8 ppm Ca. The in-house reference standard solution was prepared by dilution of 1 ml from a stock solution (0.52 g of coral powder from a Mayotte coral sample dissolved in 250 ml 2% HNO_3). Analytical precision on Sr/Ca determinations is about ±0.15% relative standard deviation (RSD) or 0.01 mmol/mol (1σ) (e.g., n=989 for core Gua1; 1 standard measured after every 6 samples). The reproducibility of Sr/Ca ratios from multiple measurements on the same day and on consecutive days is about 0.09% RSD (1σ).

2.6 Chronology - Age model development

Coral oxygen iostope and trace elemental records were measured in the depth domain (i.e., distance from core top) and have to be converted to the time domain (i.e. samples per time unit) in order to facilitate a comparison with instrumental climate data (e.g., SST). This is commonly done by first assigning a calendar year to each density band couplet, which comprehends one low and one high density band (observed in the x-radiographs as dark and light colored bands, Figs. 2-2 and 2-3), and is defined as one year of coral growth. Then, in a second step, the initial age model was refined using the pronounced seasonal cycle in the Sr/Ca record. It is assumed that the minimum (maximum) Sr/Ca in coral aragonite corresponds to the maximum (minimum) SST. Therefore, the measured skeletal Sr/Ca minimum (maximum) was assigned to the month which represents the average seasonal SST maximum (minimum) at a given site based on climatological data.

The same anchor points as for Sr/Ca were used for the interpolation of coral $\delta^{18}O$. The coral $\delta^{18}O$ and Sr/Ca time series were linearly interpolated between these anchor points using the Analyseries software (Paillard et al., 1996). To obtain equidistant time series (i.e., 12 points per year, a monthly time series), a second interpolation was performed. A visual comparison between the geochemical years and density band years confirmed the accuracy of the age conversion. This approach introduces a non-cumulative error of ±1 or 2 months in any given year. However, this is the most objective method (Charles et al., 1997), and the resulting proxy time series is independent of instrumental climate data.

Because coral growth is variable (e.g., in core Gua1 growth rate averages to 9.3 mm/year (± 1.39 mm)), we recognise that it is not completely accurate to refer to the sampling resolution as monthly. Annual variations in coral growth rate may result in a resolution of approximately 10 to 14 samples per year based on the used sampling method. However, this problem was taken into consideration and addressed during microsampling by using drill tips with different diameters and through the adjustment of sampling increments to the observed density banding, respectively. Variations of coral growth rate on subannual scale may potentially lead to an under-representation of coral skeletal aragonite formed during periods of slow growth (i.e., during cool season) relative to skeletal material formed during periods of faster growth (i.e., during warm season). This could result in an over-representation of environmental signals recorded during the warm season (e.g., Fallon et al., 1999; Kuhnert et al., 2002). However, this phenomenon is particularly pronounced in corals from higher latitudes, where winter SSTs are relatively cool.

2.7 Statistical analysis of time series

Statistical analyses of proxy time series and spectral analyses were performed using several programs and tools developed for the analysis of paleoclimatological data. The software packages used herein can be accessed freely via the internet. A more detailed description of the used programs and methods can be found in the references cited.

The **AnalySeries software package** (Paillard et al., 1996) is available freely at http://ngdc.noaa.gov/paleo/softlib/softlib.html (World Data Center for Paleoclimatology). AnalySeries is a graphically oriented, menu-driven Macintosh application, that was designed specifically to facilitate the study of paleoclimatic records using the approach and some of the methods defined by the SPECMAP group (Martinson et al., 1987). It addresses two main problems: transforming "data versus depth" records into "data versus age" records, and spectral analysis of the paleoclimatic records for studying their relationships with other climatic parameters in the frequency domain.

In order to characterize the spectral features in a given data set and to ensure the robustness and stability of the observed features, it is necessary to use different methods of time series analysis (Yiou et al., 1996). We therefore used four independent techniques for this task: standard wavelet analysis, wavelet cross coherency analysis, the multitaper method (MTM), and cross-spectral analysis. The latter was performed following the method of Blackman and Tukey (1958) using the Analyseries software package (Paillard et al., 1996). The Blackman-Tukey method represents the classical method for spectral analysis and is known to be very robust, unlikely to present spurious spectral features. The used algorithm computes first the autocovariance of the data, and then applies a window (here a Tukey window), and finally transforms the covariance functions to compute the power spectrum by using Fourier transforms (Paillard et al., 1996).

Wavelet software was provided by C. Torrence and G. Compo, and is available at http://paos.colorado.edu/research/wavelets. The wavelet analysis technique (Torrence and Compo, 1998) is a useful tool for analyzing non-stationary spectral features and localized variations of power within a time series. The wavelet power spectrum gives a measure of the time series variance at each period and at each depth (time). The software provides a method for calculating the significance levels of the wavelet moduli based on Monte-Carlo methods. The Morlet wavelet was used, and the transform is performed in Fourier space via the method described extensively in Torrence and Compo (1998). Significance levels were calculated against a red noise spectrum. Prior to wavelet power spectrum analysis the sample intervals were interpolated to monthly resolution, equivalent to the mean sampling resolution.

Software for **wavelet cross coherency analysis** for MatLab was provided by Grinsted et al. (2004). The wavelet coherency spectrum can be used to identify significant coherency between two time series even when their common power is low. The MatLab wavelet coherency software package can be downloaded at http://www.pol.ac.uk/home/research/waveletcoherence/.

For spectral analysis of coral data the **SSA-MTM-Toolkit** (Ghil et al., 2002) was used. Prior to spectral analysis, the time series were normalized to unit variance and detrended by removing the linear trend using the Analyseries software package (Paillard et al., 1996). The **Multitaper Method** (MTM) was applied, that provides useful tools for spectral estimation (Thomson, 1982) and signal reconstruction with high spectral resolution and significance tests. The significance tests are independent of the spectral power, therefore even oscillations with small-amplitudes can be identified with a high significance level in a time series whose spectrum may contain both broadband and line components (Ghil et al., 2002). Using the MTM, a small set of data tapers, or data windows, is applied to the data in the time domain to reduce the variance of spectral estimates before Fourier transformation (Thomson, 1982). This method has been widely applied to problems in geophysical signal analysis, for example analyses of instrumental data on the atmosphere and ocean (Mann et al., 1995), and paleoclimate proxy data (Berger et al., 1991; Mann and Lees, 1996; Thomson, 1990). A detailed description of this method can be found in Ghil et al. (2002).

Various statistical analyses, e.g., the calculation of running correlations etc., were performed using the web-based application „**Climate Explorer**" developed by G.J. van Oldenborgh (van Oldenborgh and Burgers, 2005) (Royal Netherlands Meteorological Institute (KNMI)), accessible at http://climexp.knmi.nl.

CHAPTER 3

Sr/Ca and $\delta^{18}O$ in a fast-growing *Diploria strigosa* coral: Evaluation of a new climate archive for the tropical Atlantic

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ABSTRACT

This study provides the first monthly resolved, 41-year record of geochemical variations ($\delta^{18}O$ and Sr/Ca) in a fast-growing *Diploria strigosa* braincoral from Guadeloupe, Caribbean Sea. Linear regression yields a significant correlation of coral Sr/Ca ($\delta^{18}O$) with instrumental SST on both monthly and mean annual scales (e.g., r = -0.59 for correlation between SODA SST and Sr/Ca; and r = -0.66 for $\delta^{18}O$; mean annual scale, p<0.0001). The generated coral Sr/Ca ($\delta^{18}O$)-SST calibration equations are consistent with each other and with published equations using other coral species from different regions. Moreover, a high correlation of coral Sr/Ca and $\delta^{18}O$ with local air temperature on a mean annual scale (r = -0.78 for Sr/Ca; r = -0.73 for $\delta^{18}O$; p<0.0001) demonstrates the applicability of geochemical proxies measured from *Diploria strigosa* corals as reliable recorders for interannual temperature variability.

Both coral proxies are highly correlated with annual and seasonal mean time series of major SST indices in the northern tropical Atlantic (e.g., r = -0.71 for correlation between the index of North Tropical Atlantic SST anomaly and Sr/Ca, and r = -0.70 for $\delta^{18}O$; mean annual scale, p<0.001). Furthermore, the coral proxies capture the impact of the El Niño-Southern Oscillation on the northern tropical Atlantic during boreal spring. Thus, fast-growing *Diploria strigosa* corals are a promising new archive for the Atlantic Ocean.

INTRODUCTION

The reconstruction of long-term climate variability in the tropical Atlantic sector is crucial in order to understand and predict important climate changes, such as rainfall over sub-Saharan West Africa, the nordeste Brazil and the Caribbean/Central American region (Marshall et al., 2001, references therein), and to capture the competing impacts of El Niño-Southern Oscillation (ENSO) and North Atlantic Oscillation (NAO) in the north tropical Atlantic region. Sea surface temperature (SST) is arguably one of the most important climatic parameters on interannual to decadal time scales. The dominant pattern of SST variability over the tropical Atlantic is characterized by anomalous SSTs in the north tropical Atlantic (NTA), between 5°-25°N and 60°-20°W (Czaja et al., 2002). NTA variability is most pronounced in boreal spring when the impact of remote forcing due to the ENSO and the NAO is strongest (Czaja, 2004; Czaja et al., 2002). ENSO and the NAO influence the trade winds over the northern tropical Atlantic, which in turn drive SST anomalies (Carton et al., 1996). Both observational and modeling studies rely on the accuracy of available observational data. However, observations of tropical Atlantic SST are limited in quality and particularly in length. The available SST data are rather short to study variability on decadal and longer scales (Dommenget and Latif, 2000). Therefore multidecadal to century-long proxy-based reconstructions of past sea surface temperatures from the Atlantic region are greatly needed in order to: (a) extend the temporally limited datasets into the past, (b) enhance useful predictability of tropical Atlantic SST anomalies (Penland and Matrosova, 1998), and (c) as calibration and validation data for numerical climate models.

A large number of studies have shown that SSTs can be reconstructed by measuring geochemical parameters ($\delta^{18}O$ and Sr/Ca) on carbonate samples extracted from reef coral skeletons (Cole et al., 1993; Marshall and McCulloch, 2002; Zinke et al., 2004). Relative variations of coral $\delta^{18}O$ (Sr/Ca) follow thermodynamic properties and are influenced by temperature and the $\delta^{18}O$ (Sr/Ca) of seawater. Over the past several hundred years, seawater Sr/Ca changes are negligible (Gagan et al., 2000) and several studies have used the Sr/Ca-ratios to develop paleothermometers for the reconstruction of SSTs (Marshall and McCulloch, 2002). At sites where seawater $\delta^{18}O$ variations are small and negligible, coral $\delta^{18}O$ also records SST variations (e.g., Pfeiffer and Dullo, 2006). Many coral $\delta^{18}O$ records were shown to recover large-scale climate phenomena which are related to local SST and/or SST covariant changes in seawater $\delta^{18}O$ (Evans et al., 2000). However, the majority of coral-based reconstructions of climate variability have been done using massive growing corals of the genus *Porites*, which are abundant in the tropical Indo-Pacific ocean (Cole et al., 2000; Cole et al., 1993; Pfeiffer et al., 2004; Quinn et al., 1998). In the tropical Atlantic, there is currently no continuous multi-decadal or longer coral record available with monthly temporal resolution. In the Atlantic, primarily *Montastrea* sp. corals have been used for climate reconstructions (e.g., Swart et al., 2002; 1996; Winter et al., 2000). However, laborious high resolution sampling techniques (>20-50 samples/year) are necessary in order to resolve the full annual temperature cycle using *Montastrea* sp. (Leder et al., 1996; Watanabe et al., 2001; 2002). Recent studies have demonstrated that corals of the species *Diploria labyrinthiformis* from Bermuda are also eligible for reconstructions of oceanic parameters in the northern Atlantic (Cohen et al., 2004; Goodkin et al., 2005; Kuhnert et al., 2005), although the low growth rates of Bermuda corals (~ 3-4 mm/year) are causing problems. For example, Goodkin et al. (2005) proposed a growth-dependent Sr/Ca-SST calibration that includes the effect of varying skeletal extension rates and thereby reduces biases in the coral SST reconstruction.

With the objective to evaluate a new and easily accessible oceanic archive, we have developed proxy records using the widely distributed, but so far under-utilized coral species *Diploria strigosa*. The coral stems from the eastern Caribbean Sea (Guadeloupe). This paper presents a continuous multi-proxy ($\delta^{18}O$ and Sr/Ca) timeseries extending from 1958 to 1999. In order to assess the robustness of our proxies, we have correlated each proxy with a local air temperature record, and with local SST data from global gridded SST products to derive proxy-temperature calibrations. Finally, the ability of the coral proxies to record large-scale SST variability in the tropical North Atlantic is evaluated.

DATA AND METHODS

Sampling

The Guadeloupe archipelago, which is part of the Lesser Antilles (Leeward Islands), covers an area of ~1821 sq. km (15.95° – 16.5°N, 61.2° – 61.8°W) and consists of two principal main islands, Grande Terre and Guadeloupe or Basse Terre. Core Gua1 was recovered in April 2000 from a hemispherical *Diploria strigosa* colony growing in a fringing reef located south of Grand Terre near Isle de Gosier (16.20°N, 61.49°W). The colony exhibited a diameter of 1.5 m and grew in a water depth of 1.7 m. Core Gua1 was drilled vertically. The core is 1.26 m long and has a diameter of 36 mm. The core was sectioned longitudinally into 7 mm thick slabs. The coral slabs were x-rayed in order to expose annual density band couplets. A chronology was generated by counting the well-developed annual density bands. Core Gua1 extends continuously from 1895 to 1999. The skeletal extension rate estimated from the annual density bands averages 9.2 mm/year (± 1.39 mm).

Coral $\delta^{18}O$ and Sr/Ca

The upper 41 years of Gua1 were sampled for stable isotope and trace element analysis. Powdered samples were collected using a low-speed micro drill with a 0.7 mm diameter diamond drill bit. The slabs were sampled continuously along the corallite walls (theca), in order to avoid mixing of sample powder from different skeletal elements. Samples were retrieved at approximately 0.8 mm intervals, yielding on average 10-12 samples per year. The powdered samples were split into separate aliquots for stable oxygen isotope ($\delta^{18}O$) and trace element (Sr/Ca) analysis. Sr/Ca was measured with an ICP-OES at the University of Kiel following the techniques described by Schrag (1999) and de Villiers et al. (2002). Analytical precision on Sr/Ca determinations is 0.15% RSD or 0.01 mmol/mol (1σ) (n=367; 1 standard after every 6 samples). The reproducibility of Sr/Ca ratios from multiple measurements on the same day and on consecutive days is 0.09% RSD (1σ). The $\delta^{18}O$ was analyzed using a Thermo Finnigan Gasbench II Deltaplus at IFM-GEOMAR. The isotopic ratios are reported in ‰ VPDB relative to NBS 19, and the analytical uncertainty is less than 0.06‰ (1σ) (n=367; 2 standards after every 10 samples). The overlapping parts of sampling transects along different thecal walls were compared for proxy validation. The reproducibility is excellent (RSD is 0.36% for Sr/Ca, and 1.88% for $\delta^{18}O$; n=24).

Coral Chronology

The age model was established based on the pronounced seasonal cycle in the Sr/Ca record. The maximum (minimum) Sr/Ca was tied to March (September), which is on average the coolest (warmest) month in the study area. The coral $\delta^{18}O$ and Sr/Ca timeseries were linearly interpolated between these anchor points using the Analyseries software (Paillard et al., 1996) to obtain monthly proxy timeseries. The uncertainty of the age model is approximately 1-2 months in any given year. The $\delta^{18}O$ and Sr/Ca records presented here extend from January 1958 to March 1999. Core Gua1 exhibits a gap of three years from October 1978 to October 1981, because a small piece from the 2nd core section broke off during drilling, and the remaining parts of the core do not contain any thecal walls suitable for sampling. However, the gap did not affect the development of the chronology, since the core sections could be fit together based on the density bands on the X-radiographs.

Instrumental Data

Monthly mean air temperatures were recorded at Pointe-à-Pitre airport (16.27N, 61.53W; WMO station 78897, 11 m altitude) between 1951 and 2000. Pointe-à-Pitre airport is located approximately 8 km to the northwest of the coral sampling site. The data is available online at http://climexp.knmi.nl (van Oldenborgh and Burgers, 2005). The Simple Ocean Data Assimilation (SODA) dataset (version 1.4.2) is a model-based reanalysis of oceanic parameters and covers a 44-year period from 1958-2001. The data is available at monthly temporal and 0.5° by 0.5° spatial resolution (Carton and Giese, 2005). We have extracted SST data from the grid-box centered at 16°N, 61°W. Additionally, monthly SSTs for the 2° latitude by 2° longitude box including the coral site (centered at 16°N, 62°W) were extracted from the Improved Extended Reconstruction of SST (ERSST.v2) compilation for the same time period (Smith and Reynolds, 2004). The ERSST uses statistical methods to fill in gaps in the instrumental data base (Smith and Reynolds, 2004). The SODA and ERSSTv.2 datasets are highly correlated on monthly ($r = 0.96$, $p<0.0001$) and annual mean scales ($r = 0.94$, $p<0.0001$). Table 3-1 summarizes basic statistics of the temperature products. The Pointe-à-Pitre air temperature record also correlates strongly with grid-SST ($r = 0.75$, $p<0.0001$ with SODA SST; $r = 0.74$, $p<0.0001$ with ERSSTv.2).

	seasonal cycle						
Dataset	**summer**	**winter**	**average**	**Max**	**Min**	**range**	**STD AnnM**
SODA SST	28.73	26.29	27.60	29.43	25.03	4.40	0.317
ERSST	28.67	26.29	27.55	29.46	25.34	4.12	0.273
Air Temp	27.40	24.20	25.90	28.80	22.30	6.50	0.634

Table 3-1. Basic statistics of the temperature datasets for the 1958-1999 time period (in °C; n=458; STD AnnM=standard deviation of mean annual values).

RESULTS AND DISCUSSION

Calibration of the coral proxy data

The coral $\delta^{18}O$ and Sr/Ca records display clear seasonal cycles, and the records are well correlated over the entire time period on monthly ($r = 0.72$, $p<0.001$) and on mean annual scales ($r = 0.77$, $p<0.001$). The correlation between annual mean coral growth rates and annual mean $\delta^{18}O$ (Sr/Ca) is low, r = 0.17 (r = 0.03) and not significant. To assess the reliability of coral $\delta^{18}O$ and Sr/Ca as recorders of local temperature variability, we calibrated both coral proxies with the local air temperature record from Pointe-à-Pitre airport and with the local grid-SST extracted from the SODA and ERSST products. Table 3-2 compares the calibration equations for monthly, annual mean and seasonal extreme values (maxima/minima) of the proxy records.

Dataset	Resolution	Slope	SE-sl	Intercept	SE-int	R^2	R	p-value	SE (s)
Sr/Ca									
SODA SST									
1958-1999	monthly	**-0.041**	0.002	**9.986**	0.058	0.45	**-0.67**	< 0.0001	0.042
1958-1999	extreme values	**-0.049**	0.004	**10.226**	0.109	0.68	**-0.82**	< 0.0001	0.043
1958-1998	annual mean	**-0.074**	0.017	**10.902**	0.476	0.35	**-0.59**	< 0.0001	0.033
ERSSTv.2									
1958-1999	monthly	**-0.042**	0.002	**10.013**	0.063	0.42	**-0.65**	< 0.0001	0.043
1958-1999	extreme values	**-0.050**	0.004	**10.258**	0.112	0.68	**-0.82**	< 0.0001	0.043
1958-1998	annual mean	**-0.066**	0.022	**10.696**	0.617	0.21	**-0.45**	< 0.005	0.036
Pointe-a-Pitre (air temperature)									
1958-1999	monthly	**-0.027**	0.001	**9.578**	0.039	0.43	**-0.65**	< 0.0001	0.043
1958-1998	annual mean	**-0.048**	0.006	**10.106**	0.169	0.61	**-0.78**	< 0.0001	0.025
δ18O									
SODA SST									
1958-1999	monthly	**-0.184**	0.007	**0.952**	0.189	0.61	**-0.78**	< 0.0001	0.138
1958-1999	extreme values	**-0.202**	0.012	**1.456**	0.321	0.80	**-0.90**	< 0.0001	0.126
1958-1998	annual mean	**-0.198**	0.039	**1.341**	1.063	0.44	**-0.66**	< 0.0001	0.073
ERSSTv.2									
1958-1999	monthly	**-0.196**	0.007	**1.282**	0.199	0.62	**-0.79**	< 0.0001	0.136
1958-1999	extreme values	**-0.209**	0.011	**1.635**	0.316	0.82	**-0.90**	< 0.0001	0.121
1958-1998	annual mean	**-0.196**	0.050	**1.276**	1.378	0.31	**-0.56**	< 0.0004	0.081
Pointe-a-Pitre (air temperature)									
1958-1999	monthly	**-0.113**	0.005	**-1.170**	0.142	0.49	**-0.70**	< 0.0001	0.158
1958-1998	annual mean	**-0.107**	0.017	**-1.334**	0.443	0.54	**-0.73**	< 0.0001	0.066

Table 3-2. Regression equations between coral $\delta^{18}O$ (Sr/Ca-ratios) and several instrumental temperature datasets. All equations are computed using ordinary least squares (OLS) regression with zero-lag, 95% confidence limits for slope and intercept are given (SE=standard error). Equations are in the form: $\delta^{18}O$ = m*SST + b; and Sr/Ca = m*SST + b.

The correlation between local air temperature and coral Sr/Ca is high (r = -0.65 for monthly, and r = -0.78 for annual means; p<0.0001, Table 3-2). Coral Sr/Ca also correlates significantly with grid-SST extracted from the SODA (Fig. 3-1) and ERSST.v2 datasets. The slope of the monthly Sr/Ca-SST calibration ranges from -0.041 to -0.042 mmol/mol/°C for SODA and ERSST.v2, respectively. A linear regression using only the minimum/maximum values in any given year (March/September) confirms the Sr/Ca-SST slope values obtained using the monthly data (Table 3-2). The correlation between coral Sr/Ca and instrumental SST remains high on an annual mean scale (Table 3-2). However, the slope values of the annual mean Sr/Ca-SST regression are larger than those of the monthly regression. With SODA, we obtain –0.074 mmol/mol per 1°C, and with the ERSST we obtain -0.066 mmol/mol per 1°C. Taking into account the statistical uncertainties of the estimated slope values (Table 3-2), only the annual mean Sr/Ca-SODA SST relationship is significantly different from the monthly and extreme value calibration.

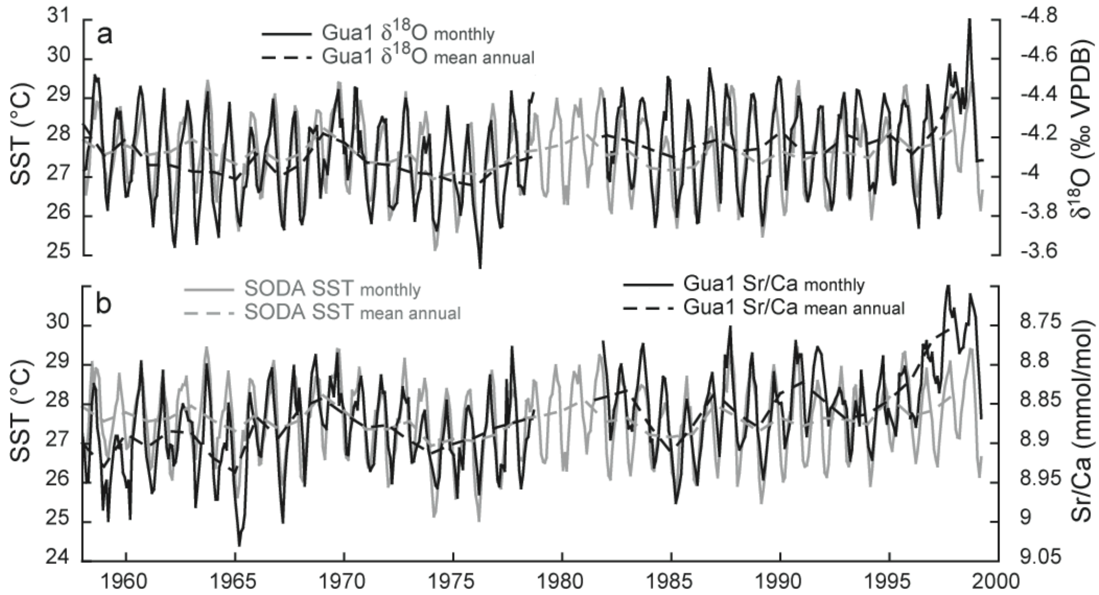

Figure 3-1. Calibration of monthly resolved coral (a) oxygen isotope data and (b) Sr/Ca elemental ratios (solid black lines) with instrumental SST (solid grey line) from the SODA reanalysis dataset (Carton and Giese, 2005) for the 1958-1999 period. Dashed lines are mean annual values. Note: The years 1998/99 represent the uppermost part of the coral core (core-top), where living organic coral tissue is still present. This organic layer is also clearly observable in the upper part of the analyzed coral slab, and most likely the cause for the observed deviation in coral proxies, though the Sr/Ca elemental ratios seems to be affected stronger than oxygen isotopes.

At present, there are less than a handful of published coral Sr/Ca-temperature calibrations from the tropical Atlantic Ocean. Published Sr/Ca-SST slope values range between -0.036 and -0.084 mmol/mol per 1°C for *Diploria labyrinthiformis* corals from Bermuda (Cardinal et al., 2001; Cohen et al., 2004; Goodkin et al., 2005) and between -0.023 and -0.047 mmol/mol per 1°C for *Montastrea* sp. corals from Florida (Smith et al., 2006; Swart et al., 2002). The Sr/Ca-SST slope values obtained in this study for a fast-growing *Diploria strigosa* coral lie well within the range of published Sr/Ca-SST slope values of other Atlantic corals. For all Atlantic corals, the Sr/Ca-SST relationship lies at the lower end of the published range of corals (mainly *Porites*) from the Indo-Pacific (-0.04 to -0.08 mmol/mol per 1°C; Marshall and McCulloch (2002)).

Over the period of 1958-1999, the coral $\delta^{18}O$ record also correlates strongly with local air temperature, and with grid-SST from the SODA (Fig. 3-1) and ERSST.v2 datasets (Table 3-2). The $\delta^{18}O$-SST slopes of the monthly and annual calibration are not significantly different, and range between -0.18 and -0.21 per mil per 1°C (Table 3-2). These values are consistent with the $\delta^{18}O$-

SST slopes obtained for *Porites* corals from the Indo-Pacific, that range between -0.18 and -0.22 per mil per 1°C (Gagan et al., 1994; Juillet-Leclerc and Schmidt, 2001; Weber and Woodhead, 1972; Wellington et al., 1996). Overall, the proxy-SST calibrations presented in Table 3-2 confirm that both coral $\delta^{18}O$ and Sr/Ca record the local temperature variability at Guadeloupe.

Correlation with SST anomaly indices

In order to evaluate the ability of our coral proxies to track the annual to interannual variability of SST over a wider region, we correlated our coral proxy timeseries against SST anomaly indices available for the Caribbean (CAR index, Caribbean Sea SST anomaly) and the North Tropical Atlantic region (NTA index, North Tropical Atlantic SST anomaly) provided by Penland and Matrosova (1998) (Fig. 3-2 and 3-3).

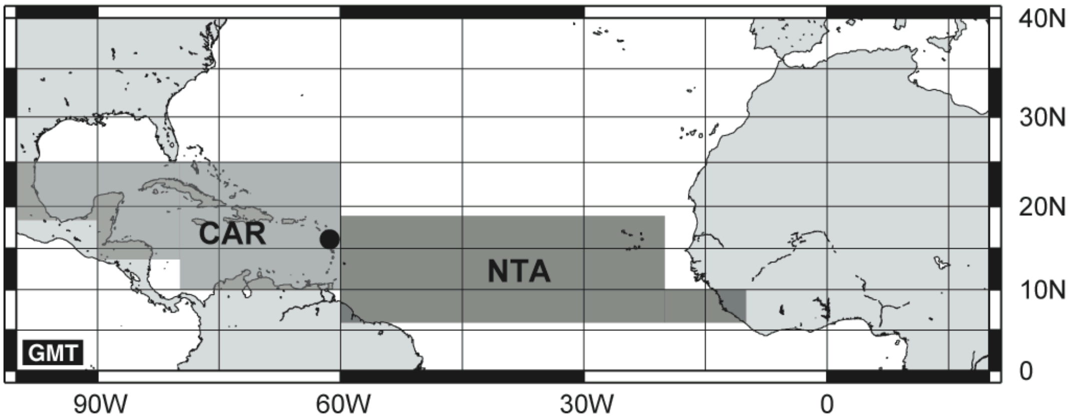

Figure 3-2. Overview map showing regions over which the SST has been averaged for the Caribbean Sea SSTa index (CAR) and the North Tropical Atlantic SSTa index (NTA). Both indices are available at the NOAA-CIRES Climate Diagnostics Center (http://www.cdc.noaa.gov/Climate Indices). Black dot marks study site.

These indices, which are based on the COADS dataset, capture the large-scale variability in the tropical North Atlantic. Figure 3-3 (a, b) shows that both the $\delta^{18}O$ and Sr/Ca record of Gua1 are highly correlated with CAR and NTA SST anomalies on an annual mean scale. The correlation of annual mean coral $\delta^{18}O$ with CAR and NTA is $r = -0.73$ ($p<0.001$) and $r = -0.70$ ($p<0.001$), respectively. For coral Sr/Ca, the correlation coefficient with CAR and NTA is $r = -0.56$ ($p<0.001$) and $r = -0.71$ ($p<0.001$), respectively. Thus, both proxy records are robust recorders of large-scale climate variability in the tropical North Atlantic.

Unlike the tropical Pacific, climate in the tropical Atlantic is not dominated by any single mode of variability (e.g., Sutton et al., 2000). Rather, the region is subject to multiple competing influences. The importance of these signals varies with season (Czaja, 2004; Sutton et al., 2000). In March-May (MAM), the Pacific ENSO and the NAO influence NTA SST anomalies (Czaja, 2004; Sutton et al., 2000). Warm ENSO years tend to be associated with warm SST anomalies in the northern tropical Atlantic, while negative NAO events also lead to an anomalous warming (Czaja et al., 2002). ENSO and NAO related anomalies may add constructively to create SST anomalies in the northern tropical Atlantic, but they may also cancel each other out (Czaja et al., 2002). Equatorial Atlantic SST anomalies ("Atlantic ENSO") contribute most to NTA SST variability in July-October (JASO) (Sutton et al., 2000). Thus, given the seasonal dependence of the dominant modes of climate variability in the northern tropical Atlantic, it is crucial that the coral proxies do not only capture the annual, but also the seasonal mean SST variability in the region.

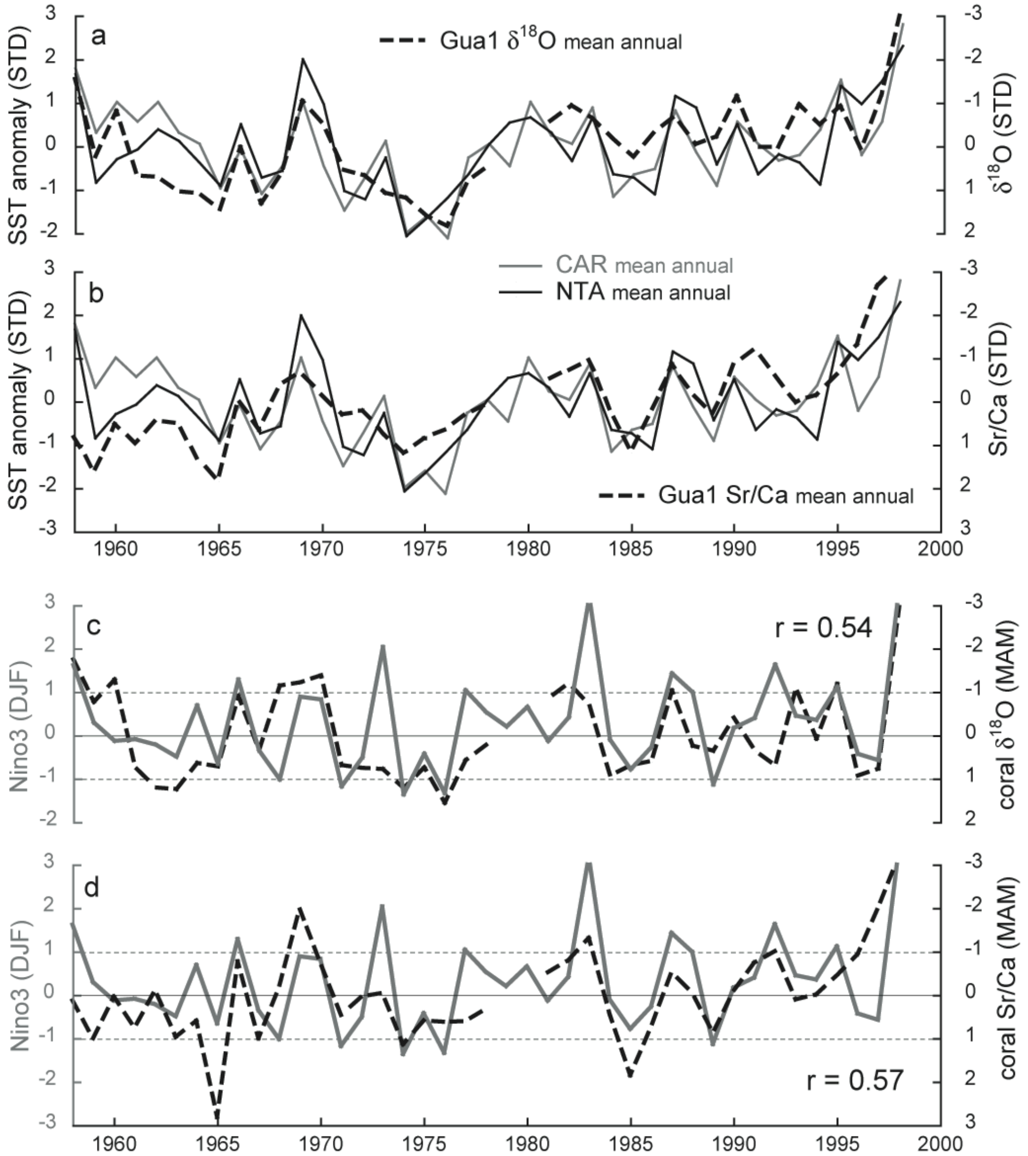

Figure 3-3. Coral (a) $\delta^{18}O$ and (b) Sr/Ca time series (dashed lines) with SST anomaly indices: CAR (solid grey line) and NTA (solid black line). Data shown are mean annual values. Nino3 SST index (5°S-5°N, 90°-150°W; from NCDC, Smith and Reynolds (2004)) in winter (DJF) with coral $\delta^{18}O$ (c) and Sr/Ca (d) proxy data for boreal spring (MAM). All data shown are normalized to unit variance and linearly detrended (STD=standard deviation). Correlation coefficients are indicated in the panel ($p<0.001$ for all correlations).

We have therefore correlated the mean MAM and JASO $\delta^{18}O$ and Sr/Ca records with the NTA index (not shown). The correlations are high ($\delta^{18}O$: r = -0.58 for MAM and r = -0.55 for JASO; Sr/Ca: r = -0.71 for MAM and r = -0.62 for JASO) and statistically significant ($p<0.001$). These results suggest that *Diploria strigosa* proxy records may be used to examine the relative importance of the various climate modes affecting the tropical North Atlantic on decadal to centennial time scales.

Year-to-year variations of NTA SST are largest in boreal spring (MAM), when ENSO and the NAO exert maximum influence (Czaja, 2004; Sutton et al., 2000). Figure 3-3 (c, d) compares the boreal winter Nino3 index (DJF) with MAM coral $\delta^{18}O$ and Sr/Ca of our *Diploria strigosa* coral. The linear correlation between the coral proxies and Nino3 is high (Fig. 3-3 c, d), attesting to the strength of the ENSO-NTA teleconnection. Warm and cold ENSO phases (+/- 1 standard deviation) are clearly identifiable in the coral $\delta^{18}O$ (Sr/Ca) time series (e.g., the ENSO warm phases of 1966, 1987 and 1997/98 and the ENSO cold phases of 1974 and 1976). However, the large El Niño events of 1972/73 and 1982/83 are not or only weakly recorded by the coral proxies. During these years, the impact of ENSO on NTA SST is reduced due to the positive NAO phases in the preceding boreal winter (Czaja et al. (2002), their Fig. 1; also compare Fig. 3-3 a-d).

CONCLUSIONS

We have presented the first monthly resolved $\delta^{18}O$ and Sr/Ca calibration of the Atlantic braincoral *Diploria strigosa*. Both geochemical proxies show a significant correlation with instrumental SST over a 41-year time period on both monthly and mean annual scales. We obtained proxy-SST calibrations that are consistent with previously published studies using other coral species from different regions.

A comparison between the coral proxies and SST anomaly indices available for the northern tropical Atlantic and Caribbean region yielded significant correlations on mean annual scales. This testifies the ability of *Diploria strigosa* to track the year-to-year variability of SST over a wide region. Moreover, the coral proxy records are able to resolve the seasonal-scale variability in the NTA, and thus can be used to detect the seasonal dependence of remote forcing on NTA SST, e.g., by Pacific ENSO events.

Therefore, we are optimistic that fast-growing *Diploria strigosa* corals, which can be up to 200 years old, represent a highly feasible new archive for future paleoclimatic reconstructions. The tropical North Atlantic is a key region of Northern Hemisphere climate variability and at present there is not a single century-long coral proxy record from this region. In the future, the obtained proxy-SST calibrations from our modern coral specimen can also be used as a basis for the interpretation of fossil *Diploria strigosa* corals in order to develop long-term reconstructions of environmental variables that extend over multiple centuries.

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CHAPTER 4

Impact of remote climate forcings on the eastern Caribbean Sea as captured by a monthly resolved coral proxy record from Guadeloupe covering the entire 20th century

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ABSTRACT

We have generated 104-year-long (1895-1999) monthly oxygen isotopic and trace elemental ratio (Sr/Ca) time series by analyzing a coral core from a fast-growing *Diploria strigosa* colony drilled off Guadeloupe Island, Lesser Antilles. Both coral proxies display robust relationships to sea surface temperature (SST) that are consistent with previously published calibrations. Coral Sr/Ca reliably records local annual to interannual temperature variations and is even higher correlated to *in-situ* air temperature than to grid-SST data. Using coral Sr/Ca, we calculated a warming of approximately 1.1-2°C since the mid-1970s, concurrent with the strong surface temperature increase at the study site. The seawater $\delta^{18}O$ ($\delta^{18}O_{sw}$) contribution to coral $\delta^{18}O$ is estimated by calculating the $\delta^{18}O_{residual(Sr/Ca)}$, which is found to be correlated to regional precipitation at low frequencies until around 1950.

Geochemical proxy data show a close relationship to major climate signals affecting the seasonal cycle of SST in the north tropical Atlantic (NTA) region. Results from a quantitative comparison between extreme events in the respective indices (Nino3 and NAO) and events recorded in seasonal coral $\delta^{18}O$ imply that interannual SST variability at the study site is highly linked to Pacific and North Atlantic variability, by this means supporting the assumptions of observational- and model-based studies which suggest a strong impact of El Niño Southern Oscillation (ENSO) and North Atlantic Oscillation (NAO) forcings onto the NTA region through a modulation of trade wind strength in winter. Results from different spectral analysis tools suggest that interannual climate variability recorded by the coral proxies is largely dictated by Pacific ENSO forcing, whereas at decadal and longer timescales the influence of the NAO is dominant.

INTRODUCTION

Climate variability in the tropical Atlantic region is known to have major socio-economic effects on surrounding continents, for example, agriculture in NE-Brazil (the Nordeste region) and in subSaharan Africa (the Sahel region) is strongly affected by rainfall anomalies that are linked to SST anomalies in the tropical Atlantic (e.g., Folland et al., 1986; Hastenrath, 1978, 1984; Hastenrath and Greischar, 1993; Moura and Shukla, 1981; Nobre and Shukla, 1996). The same climatic factors have also been linked to rainfall anomalies in the Caribbean/Central American region (Enfield and Alfaro, 1999; Giannini et al., 2000). It is also suggested that the intensity of tropical cyclones in the Atlantic is related to multidecadal fluctuations of North Atlantic SST (e.g., Gray, 1990; Latif et al., 2007).

In contrast to the tropical Pacific, where climate variability on seasonal-to-decadal timescales is dominated by a single mode, the El Niño Southern Oscillation, climate variability in the tropical Atlantic region is more complex (Handoh et al., 2006; Marshall et al., 2001), and rather subject to

multiple competing influences of comparable importance (Sutton et al., 2000). These interacting influences can arise from local (internal) processes, as well as originate from regions remote from the tropical Atlantic. A number of publications have been concerned with climate variability in the northern tropical Atlantic and/or the Caribbean region and its linkage to Pacific or Atlantic variability (e.g., Enfield and Mayer, 1997; George and Saunders, 2001; Giannini et al., 2001a; Taylor et al., 2002). Results from observational studies suggest that tropical Atlantic SSTs and wind fields are regularly affected by Pacific ENSO on an interannual time scale (e.g., Hastenrath et al., 1987; Nobre and Shukla, 1996). According to a recent study by Liu et al. (2004), the combined remote impact from the tropical Pacific and North Atlantic sea surface temperature anomaly (SSTA) is able to drive approximately half of the variance of tropical Atlantic SST variability on interannual and decadal timescales. ENSO and the North Atlantic Oscillation appear to be the major drivers of north tropical Atlantic (NTA) climate variability on interannual timescales (e.g., Covey and Hastenrath, 1978; Curtis and Hastenrath, 1995; Czaja et al., 2002; Enfield and Mayer, 1997). For instance, distinct warm events (e.g., in the year 1984, 1998, (Curtis et al., 2001; Elliott et al., 2001)) observed in the tropical Atlantic can be related to preceding El Niño events in the Pacific Ocean. It has been observed that these ENSO-induced Atlantic SST events tend to be locked to the annual cycle, with strongest activity of ENSO occurring during boreal autumn and winter, and the tropical Atlantic SSTs peaking in the following spring lagging their Pacific counterparts by 4-5 months (Enfield and Mayer, 1997; Sutton et al., 2000). The origin of this lag is not fully understood, but it is argued that the El Niño warming signal is communicated to the tropical Atlantic via a reduction in surface latent heat flux associated with a reduction of trade winds (Klein et al., 1999). Recent analyses have successfully isolated the ENSO-related response of the tropical Atlantic in their models (Saravanan and Chang, 2000; Sutton et al., 2000).
Some studies suggest that the involvement of local ocean-atmosphere coupled feedback is critical for the full development of variability in the tropical Atlantic (Chang et al., 1997; Wu and Liu, 2002), whereas results from a recent study suggest that north tropical Atlantic climate variability is largely a response to remote NAO and ENSO forcing without the need to invoke local air-sea coupling and oceanic dynamics (Czaja et al., 2002). However, in spite of the above studies the influence of these remote forcings on climate variability in the north tropical Atlantic and Caribbean region still needs to be better understood on longer time scales (Liu et al., 2004).

Multidecadal to century-long records of past sea surface parameters are essential for the understanding of past and future climate variations in the Atlantic region. Especially, highly-resolved long-term records of past sea surface conditions are required as input data for the calibration and validation of numerical climate models, which have the objective to enhance our understanding of internal variability in the coupled ocean-atmosphere system (e.g., the Northern Hemisphere ocean circulation, including the Caribbean Current, the Gulf Stream system, and the

North Atlantic thermohaline circulation (THC) (Latif, 2001; Latif et al., 2000; Vellinga and Wu, 2004)). A proper knowledge of past variability of the climate system is also important in regard to long-range climate forecasting (Delworth and Mann, 2000), and to assess the anthropogenic impact on climate and ecosystems.

Generally, the lack of long-term SST and climate records has hampered the detection and investigation of statistically significant relationships between different climate parameters over extended time periods. Observational records of environmental parameters become sparser and are spatiotemporally incomplete before 1950, and especially prior to the past century observational data coverage (e.g., for SST) decreases rapidly (Smith and Reynolds, 2003). Proxy data can help to complement and significantly extend such records back in space and time (Jones et al., 2001). However, it has to be noted that highly resolved proxy records are a prerequisite in order to successfully resolve climate variability that displays very often a strong seasonal behaviour. Continental climate proxies such as tree rings and stalagmites, which are commonly used to provide reconstructions of precipitation, droughts and land air temperature, exhibit annual or lower resolution, the temporal resolution of laminated marine sediments is even coarser. In contrast, due to their long lifetime (up to several centuries) and widely abundance in the tropical marine realm, corals are an ideal archive for the reconstruction of seasonal to multidecadal variability of environmental variables in the tropical surface oceans. The annual density bands found in coral skeletons provide a chronological control at subseasonal resolution. A number of studies have shown that past climatic conditions can be reconstructed by measuring geochemical parameters on carbonate samples extracted from reef coral skeletons (Cole et al., 1993; Gagan et al., 1998; McCulloch et al., 1994). The geochemical composition of coral skeletal carbonate from scleractinian corals contains valuable information about the environmental conditions that prevailed during coral growth. Therefore, corals can serve as proxy archives of various components of the climate system, including sea surface temperatures (Beck et al., 1992; Dunbar and Wellington, 1981; Dunbar et al., 1994; Fairbanks and Dodge, 1979; Weber and Woodhead, 1972), and the precipitation-evaporation balance (e.g., Cole and Fairbanks, 1990; Cole et al., 1993; Gagan et al., 2000; Kilbourne et al., 2004; Pfeiffer et al., 2006). Geochemical coral proxy records from equatorial and near-equatorial Pacific sites have been used to reconstruct past ENSO variability (e.g., Charles et al., 1997; Cobb et al., 2003; Cole and Fairbanks, 1990; Cole et al., 1993; Dunbar et al., 1994; Evans et al., 1999; Linsley et al., 2000; Tudhope et al., 2001; Urban et al., 2000).

The two most commonly used geochemical parameters measured on coral aragonite are stable oxygen isotopes ($\delta^{18}O$) and Sr/Ca-ratios. Relative variations of coral proxies ($\delta^{18}O$ and Sr/Ca-ratios) follow thermodynamic laws and are influenced by temperature and the $\delta^{18}O$ (Sr/Ca) of seawater. However, biological growth effects are able to alter the absolute values of coral proxy data (McConnaughey, 1989b). Coral $\delta^{18}O$ is known to reflect both temperature and the oxygen isotopic composition of seawater ($\delta^{18}O_{sw}$) at the time of carbonate precipitation (e.g., McConnaughey, 1989a; Weber and Woodhead, 1972). In oceanic settings where the $\delta^{18}O_{sw}$ co-varies with salinity, coral $\delta^{18}O$ records these changes (Gagan et al., 1994) and can be used to reconstruct salinity variations (Gagan et al., 1998; Linsley et al., 1994; McCulloch et al., 1994; Zinke et al., 2004). At sites where $\delta^{18}O_{sw}$ variations are small and negligible, coral $\delta^{18}O$ also records SST variations (e.g., Pfeiffer and Dullo, 2006). The Sr/Ca-elemental-ratios in coral skeletons have been shown to be temperature dependent because Sr/Ca seawater changes are negligible on short timescales (Gagan et al., 2000) and several studies have used the Sr/Ca-ratios to develop paleothermometers for reconstruction of SSTs (e.g., Alibert and McCulloch, 1997; Beck et al., 1992; de Villiers et al., 1994; Gagan et al., 2000; Marshall and McCulloch, 2002). Despite these approaches, there is no single Sr/Ca-SST relationship, which is universally accepted. Paired measurements of coral proxies ($\delta^{18}O$ and Sr/Ca) can facilitate the reconstruction of the oxygen isotopic composition of seawater and sea surface salinity (SSS) (Gagan et al., 1998; McCulloch et al., 1994).

The tropical Pacific has been in the focus of many coral paleoclimate studies due to the importance of the ENSO system in global climate variability and the presence of long-lived coral heads (Cobb et al., 2003; Cobb et al., 2001; Cole and Fairbanks, 1990; Cole et al., 1993; Dunbar et al., 1994; Evans et al., 1999; Tudhope et al., 1995). The majority of coral-based reconstructions of climate variability have been conducted using massive growing *Porites* corals, which are widely distributed in the Indo-Pacific ocean (Cole et al., 2000; 1993; Gagan et al., 2000; Gagan et al., 1998; McCulloch et al., 1994; Pfeiffer and Dullo, 2006; Pfeiffer et al., 2006; Pfeiffer et al., 2004; Quinn et al., 1998; Zinke et al., 2004). However, coral-based studies of climate variability in the Atlantic and Caribbean region have lagged behind the extensive work published using coral records from the Indo-Pacific Oceans. Hence, the development of continuous long-term coral-based proxy records is highly necessary for a better understanding of interannual to centennial-scale climate variability in the tropical Atlantic, which is a key region in the Northern Hemisphere when it comes to the reconstruction of long-term climate variations.

In the tropical Atlantic, primarily *Montastrea* sp. corals have been used for paleoclimatic studies (e.g., Leder et al., 1996; Swart et al., 2002; Swart et al., 1996; Watanabe and Oba, 1999; Watanabe et al., 2001; 2002; Winter et al., 2000; 2003), because they are abundant, long-lived and fast-growing. However, several studies have shown that laborious high resolution sampling techniques (>20-50 samples/year) are necessary in order to resolve the full seasonal temperature cycle using *Montastrea* sp. (Leder et al., 1996; Watanabe et al., 2001; 2002). Other studies have focused on slower growing massive corals of the genus *Siderastrea* (e.g., Gischler and Oschmann, 2005; Moses et al., 2006a; Moses et al., 2006b) and the species *Diploria labyrinthiformis* (e.g., Cohen et al., 2004; Goodkin et al., 2005; Kuhnert et al., 2005), which are abundant in the Atlantic region, exhibit annual growth rates on the order of approximately 1.5-4 mm, and are particularly of interest as potential recorders of environmental data since they can be found in environments with extreme temperature, salinity, and sediment input variations, where no fast-growing corals are available for reconstructions. However, the slow growth rates are causing problems, because microsampling in aragonitic coral skeletons becomes more difficult with decreasing annual coral growth (e.g., Moses et al., 2006a). For example, the restriction of microsampling to a single structure of the coral skeleton for geochemical analysis, which should be the preferable sampling method in order to obtain optimal unbiased results (Leder et al., 1996), is difficult and sometimes not possible using slow-growing corals. Therefore, it is difficult to capture the full amplitude of the annual SST cycle using conventional coarse sampling for these coral species.

Consequently, there is currently no continuous multi-decadal or longer coral record available for the tropical Atlantic resolving climate variability of the 20th century with a high temporal resolution. In contrast, more than a dozen century- to multi-century-long coral records of δ^{18}O and/or Sr/Ca variability do exist from the Indo-Pacific region (Gagan et al., 2000). For the first time, a recent study (Hetzinger et al., 2006) has shown that fast-growing corals of the species *Diploria strigosa* can be utilized as a highly feasible archive for the reconstruction of past environmental parameters in the tropical Atlantic. Moreover, it has been shown that corals of this species can be utilized to capture large-scale interannual climate variability in the Caribbean and tropical North Atlantic on decadal to multidecadal timescales (e.g., the remote forcing on NTA SST by Pacific ENSO events).

Here we present results from studying a modern 104-year (1895-1999) monthly resolved coral record developed from a fast-growing *Diploria strigosa* colony drilled off the south coast of Guadeloupe, Lesser Antilles, Caribbean Sea. In this study, we compare geochemical variations in the coral record with observational data and climate indices to address several fundamental questions:

First, we conducted stable oxygen isotope and Sr/Ca-ratio analyses to determine how well the records reflect SST variability at the study site. Therefore, the time series were calibrated with different SST data and compared to local air temperature. We then investigate in a separate chapter the trends underlying the coral proxy data and discuss the implications. Results from spectral analysis of the Guadeloupe coral record are discussed in detail thereafter, along with the relationships of the geochemical coral proxy data with major climate signals. In the following chapter, the remote impact on north tropical Atlantic SST/climate variability by the two primary modes of external forcing (ENSO and NAO) is assessed by quantitatively comparing positive/negative events in the seasonally averaged coral record to high and low years/events of the

Nino3 and the NAO indices over the entire period of record. Finally, different statistical analysis tools were applied to both coral proxy time series in order to identify and characterize the role of dominant climate signals in the record on interannual to interdecadal time scales.

Regional setting of the study site

The study site is located at the eastern boundary of the Caribbean Sea. Guadeloupe is part of the Antilles Islands Arc (Leeward Islands), which separates the Caribbean Sea from the Atlantic Ocean. The Guadeloupe archipelago consists of two principal main islands, Grande Terre and Guadeloupe or Basse Terre (15.95°–16.5°N, 61.2°–61.8°W), which are separated by the Rivière Salée. The island of Grande Terre rises more than 110 m, Basse Terre more than 1450 m above sea level. Particularly on the southern side of Grande Terre, fringing and bank barrier reef structures can be found (Wells, 1988). The study site "Isle de Gosier" is situated approximately 0.8 km south of Grande Terre (Fig. 4-1). Near Isle de Gosier the marine environment is characterized by mostly narrow and sometimes localized coral reefs of the fringing type (Spalding et al., 2001).

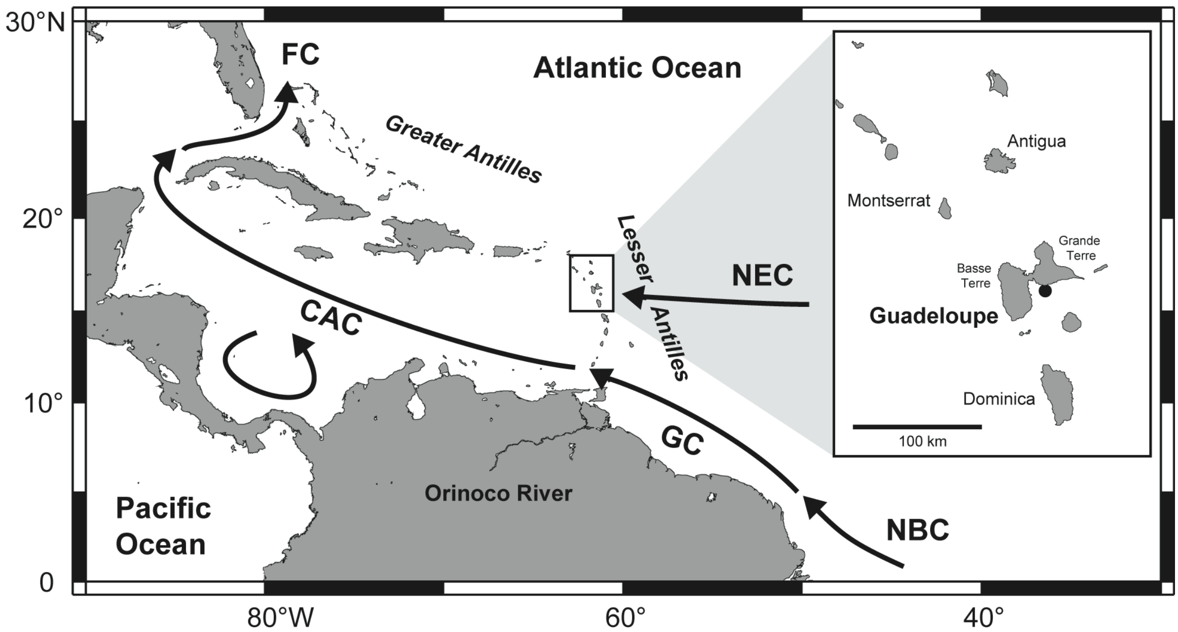


Figure 4-1. Oceanographic setting of the western tropical Atlantic and Caribbean region showing major surface currents. The small box indicates the location of the study site. The inlet shows the location map of the Guadeloupe archipelago. The sampling locality „Isle de Gosier", south of Guadeloupe Island, is marked by a spot. Major surface currents are indicated based on data from Gordon (1967): CAC: Caribbean Current; FC: Florida Current; NBC: North Brazil Current; GC: Guyana Current; NEC: North Equatorial Current.

Oceanography and Climate

Climate, surface current pattern and hydrography of the tropical North Atlantic and Caribbean are subject to seasonal fluctuations, which are mainly controlled by the covarying pattern of trade wind convergence (Hastenrath, 1976, 1984), the seasonally northward and southward migration of the Intertropical Convergence Zone (ITCZ), and the underlying cross-equatorial SST gradient (Carton et al., 1996). The seasonal fluctuation of the ITCZ occurs along a gradient from the Amazon River basin across the Orinoco River basin and into the central Caribbean (Corredor and Morell, 2001). In accordance with the shift of the thermal equator to the south during late boreal winter (March-April), the ITCZ is located south of the Caribbean at ca. 0° to 5°S. After spring equinox, the thermal equator shifts to the north and the ITCZ migrates off the equator towards the Caribbean to about 6° to 10°N. It reaches its northernmost position at the height of boreal summer (Curtis and Hastenrath, 1995). Due to feedback mechanisms between the converging trade winds and SST, it maintains north of the equator through the fall equinox (Giannini et al., 2000). At that time, the Caribbean hydrography is characterized by enhanced precipitation and fluvial freshwater supply. The mean Caribbean rainy season (also warm season) runs from May-October with two distinct peaks during May-June and September-October, and a relative minimum in July-August. The rainfall regime in Puerto Rico, as well as the northern coasts of Jamaica and Hispaniola, and the Lesser Antilles (including Guadeloupe Island) is characterized by a *late-fall-peak* (Giannini et al., 2000).

Massive freshwater inputs to the eastern Caribbean occur during, or shortly after the peak of the rainy season, which result from direct precipitation and continental runoff. Tropical rivers directly or indirectly drain into the Caribbean Sea and, thus, influence the hydrography and chemistry of surface waters year-round. The seasonal change between high and low precipitation propels seasonally varying fluvial supply, which is reflected in seasonally varying salinity and nutrient concentrations (Froelich et al., 1978; Morrison and Nowlin, 1982). In general, the annual cycle of surface salinity in the eastern Caribbean is dominated by fluvial freshwater input through the Amazon and Orinoco Rivers. Given the temporal displacement of the ITCZ, peak flows of the Orinoco River occur in the months of August-September, while flow of the Amazon River peaks around June-July (Boyer and Levitus, 2002). However, the influence of the Orinoco River in the eastern Caribbean may be more important than that of the Amazon (Müller-Karger et al., 1989), since most of the Orinoco waters travel in a north-northwest direction into the eastern Caribbean (Bonilla et al., 1993). Recurrent seasonal surface salinity depressions in the eastern Caribbean in the fall of each year are attributed to the influence of riverine freshwater (Froelich et al., 1978), and SSS in this region shows close correlation to average rainfall over the Orinoco River basin with 3-4 months offset due to travel time (Corredor and Morell, 2001). Water masses entering the Caribbean originate from two nearly equal sources, the North Atlantic and the South Atlantic Ocean (Johns et al., 2002). The closely spaced chain of islands, banks, and sills of the Antilles Islands Arc act as a sieve for the inflow of Atlantic water (Andrade and Barton, 2000; Murphy et al., 1999), which enters to the eastern Caribbean Sea through passages within the Lesser Antilles (Stalcup and Metcalf, 1972; Wüst, 1964) (Fig. 4-1).

The uppermost layer of Caribbean seawater (50-100 m), which was termed “Caribbean Surface Water” (CSW) by Wüst (1964), is thought to be a mixture of freshwater from both the Amazon and Orinoco Rivers and tropical Atlantic surface waters, which flow to the Caribbean as the Guyana Current (Fig. 4-1). The water then continues westward as the Caribbean Current, the main surface circulation in the Caribbean Sea (Gordon, 1967; Hernandez-Guerra and Joyce, 2000; Wüst, 1964). The Caribbean Current builds an important branch of the upper part of the northward-flowing meridional overturning circulation (MOC) (Schmitz and McCartney, 1993; Schmitz and Richardson, 1991), since this is the major route by which South Atlantic water flows into the Florida Current and Gulf Stream.

Seasonal climatology

Based on grid-SST observations (ERSST.v2 (Smith and Reynolds, 2004)), mean annual SST for the grid box surrounding Guadeloupe is 27.4°C (1896-1999). Average maximum SST values occur in September (28.6°C) and average minimum SST values (26.1°C) in February. Seasonal SST extremes produce an average annual SST cycle of 2.5°C at the study site (Fig. 4-2a). Mean air temperatures were recorded at Pointe-à-Pitre Le Raizet Aéroport International (16.27N, 61.53W; WMO station 78897, 11 m altitude) on a monthly basis between 1951 and 2000. Pointe-à-Pitre airport is located about 8 km to the northwest of the coral sampling site. The data is available online at http://climexp.knmi.nl (van Oldenborgh and Burgers, 2005). Air temperatures recorded at this station show a mean seasonal cycle of 2.1°C, with a mean annual air temperature of 26°C. Average maximum temperature occurs in July/August (27.4°C) and average minimum air temperature (24.2°C) in January. The rainfall regime in Guadeloupe exhibits a characteristic late-fall-peak with the maximum rainfall occurring in September-October (Giannini et al., 2000) (Fig. 4-2a), and a smaller rainfall peak during May-June. According to climatological data from Levitus et al. (1994), the seasonal cycle of surface salinity near Guadeloupe is around 1.6‰ (Fig. 4-2a). Maximum salinities of 36‰ occur during the winter (March), and minimum salinities of 34.4‰ occur during the summer season (September) (Levitus et al., 1994). This is supported by recent observations that include station and mooring data (S. Grodsky, pers. comm.), which indicate a seasonal range of 1.5‰ (Fig. 4-2a) in surface waters averaged over a grid-box including Guadeloupe (15°-17°N, 59°-63°W).

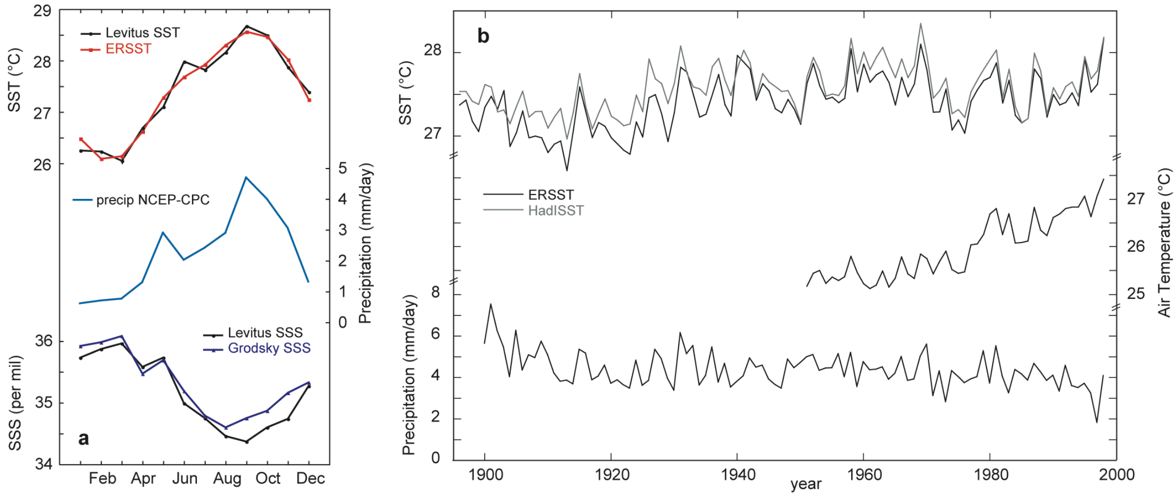


Figure 4-2. (a) Seasonal climatology of environmental parameters at the study site Guadeloupe. SST: Red line - Instrumental sea surface temperature (SST) in a 2° by 2° grid box centered on the study site (ERSSTv.2 data set (Smith and Reynolds, 2004)); Black line - SST from a 1° by 1° grid-box including the study site (Levitus and Boyer, 1994) (1896-1998). Precipitation is derived from NOAA NCEP CPC-merged analysis (1979-2005) (Xie and Arkin, 1996). Sea surface salinity (SSS): Black line – SSS from Levitus et al. (1994); Blue line - SSS averaged over a grid-box including Guadeloupe (15°-17°N, 59°-63°W), based on station/mooring data (S. Grodsky, pers. comm., (Grodsky et al., 2006)). (b) Mean annual variations of sea surface temperature (ERSST.v2 (Smith and Reynolds, 2004), and HadISSTv.1.1 (Rayner et al., 2003)), air temperature (data from Pointe-à-Pitre monitoring station), and precipitation at the study site. The precipitation record is an average of station data from the box 15° to 20°N and 55° to 65°W and was obtained from the CRU analysis land precipitation data set accessible via http://climexp.knmi.nl.

MATERIALS AND METHODS

Coral core collection and preparation

A coral core was drilled in April 2000 from a fringing reef located at the southern edge of Isle de Gosier (16.20°N, 61.49°W, Fig. 4-1). Core Gua1 (1,26 m in length) was retrieved from a hemispherical growing coral colony of the species *Diploria strigosa* using an underwater pneumatic drill. The colony exhibited a diameter of 1.5 m and grew in a water depth of 1.7 m. The core was drilled vertically, in parallel orientation to the dominant axis of coral growth, to the bottom of the coral colony. The core with a diameter of 36 mm was rinsed in freshwater, air dried and sectioned longitudinally into 7 mm thick slabs. The coral slabs were then cleaned in an ultrasonic bath with deionized water to remove saw cuttings and were oven dried at 50°C for 24 hours. Afterwards the slabs were X-rayed in order to expose annual density couplets. First chronologies were generated by counting the well-developed annual density banding observable on the X-radiographs (Fig. 4-3), assuming that each high- and low-density (HD, LD) band couplet represents one year of growth (Knutson et al., 1972). Core Gua1 exhibits continuous growth between 1895 and 1999 (based on counting of annual density couplets), the skeletal extension rate estimated from the annual density bands averages to 9.3 mm/year (± 1.39 mm). The upper part of this coral core (1958-1999) has already been used in a calibration exercise (Hetzinger et al., 2006), and results have shown that fast-growing corals of the species *Diploria strigosa* accurately record the variability of ambient environmental conditions in their aragonitic skeleton.

Microsampling and geochemical analysis (Coral $\delta^{18}O$ and Sr/Ca)

Samples for stable isotope and trace element analysis were collected from coral slabs using a low-speed micro-drill with a 0.7 mm diameter drill bit. The slabs were sampled along the corallite walls (theca), in order to avoid mixing of sample powder from different skeletal elements. A study by Helmle et al. (2002), who analyzed the complex skeletal architecture and density banding of the same coral species using X-ray computed tomography, approved that the thecal wall of this species is not influenced by secondary thickening processes which could dampen the annual signal in the proxy time series (e.g., as observed in slow-growing specimens of *Diploria labyrinthiformis* from Bermuda by Cohen et al. (2004)). Consequently, we confined sampling to this specific part of the complex coral skeleton. This has significantly improved the results compared to bulk sampling.

For the *Diploria strigosa* record presented here, samples were retrieved continuously at approximately 0.8 mm intervals along transects following the axis of maximum growth, yielding on average 10-12 samples per year of growth, to facilitate calibration with monthly resolved SST data. As a next step, the sample material was splitted into separate aliquots for stable isotope ($\delta^{18}O$ and $\delta^{13}C$) and trace element (Sr/Ca and Mg/Ca) analysis, respectively. Only the records of $\delta^{18}O$ and Sr/Ca ratios will be discussed herein.

Trace elements were measured in an inductively coupled plasma optical emission spectrophotometer (ICP-OES) at the Geological Institute of the University of Kiel following a combination of the techniques described in detail by Schrag (1999) and de Villiers (2002). Sr and Ca intensity lines used are 407 nm and 317 nm, respectively. The intensities of Sr and Ca were then converted into Sr/Ca ratios in mmol/mol. An in-house reference standard was used for drift-correction of the measured Sr/Ca ratios. Analytical precision on Sr/Ca determinations is 0.15% RSD or 0.01 mmol/mol (1σ) (n=989; 1 standard after every 6 samples). The reproducibility of Sr/Ca ratios from multiple measurements on the same day and on consecutive days is about 0.09% RSD (1σ).

The composition of stable isotopes ($\delta^{18}O$ and $\delta^{13}C$) in coral aragonite was analyzed using a Thermo Finnigan Gasbench II Deltaplus mass spectrometer at IFM-GEOMAR. The isotopic ratios are reported in ‰ VPDB relative to NBS 19, analytical uncertainty is less than 0.06‰ (1σ) for $\delta^{18}O$ measurements (n=989; 2 standards after every 10 samples). Samples from different drilling transects were spliced using the overlapping parts of the transects. The overlapping parts of sampling transects along different thecal walls were compared for validation of proxies. The reproducibility is excellent (RSD is 0.31% for Sr/Ca, n=46; and 2.02% for $\delta^{18}O$; n=157).

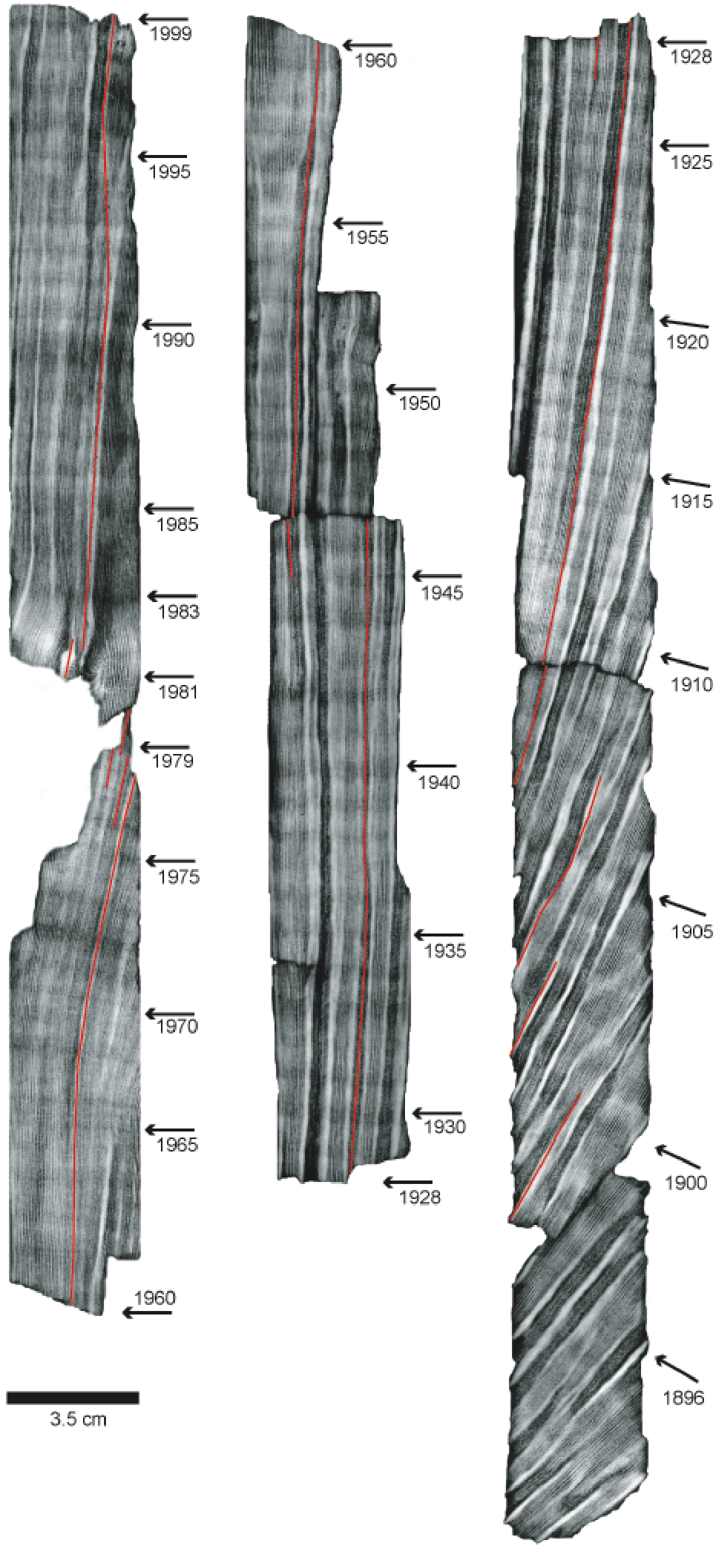


Figure 4-3. X-radiographs of slabs from coral core Gua1 (*Diploria strigosa*). Alternating high (light) and low density (dark) bands can be observed clearly and banding is in a near perpendicular orientation with respect to the axis of the coral core. In the skeletal density banding pattern, one year of coral growth is represented by a high- and low-density band couplet. Year dates show approximate markers of coral skeleton precipitation. Approximate sampling transects are indicated by red solid vertical lines on each coral section.

Coral Chronology

Chronologies were established using the pronounced seasonal cycle in the Sr/Ca record to build up the age model. We assume that the minimum (maximum) Sr/Ca in coral aragonite corresponds to the maximum (minimum) SST. The maximum (minimum) Sr/Ca was assigned to March (September), which represents the coolest (warmest) month at the study site based on climatological data (Fig. 4-2a (Levitus and Boyer, 1994; Smith and Reynolds, 2004)). The same anchor points as for Sr/Ca were used for the interpolation of coral $\delta^{18}O$. The coral $\delta^{18}O$ and Sr/Ca time series were linearly interpolated between these anchor points, and time was assigned to the depth series using the Analyseries software package (Paillard et al., 1996). To obtain equidistant time series, i.e., 12 points per year (a monthly time series), a second interpolation was performed. A visual comparison between the geochemical years and density band years confirmed the accuracy of the age conversion. The uncertainty of the age model is approximately 1-2 months in any given year. Based on the chronology and counting of annual density couplets, core Gua1 extends from September 1895 until March 1999 (Fig. 4-3) and was sampled continuously to produce 104-yr-long records of stable isotopes and trace elements. Geochemical time series of core Gua1 exhibit a gap of three years from October 1978 to October 1981, because a small piece from the top of core section B broke off during core drilling, and thus precluded geochemical sampling (Hetzinger et al., 2006), but core section A and B could be fitted together coherently using the X-radiographs. Thus, the gap did not affect the build-up of the age chronology.

Statistical analysis of time series

It is necessary to use different methods of time series analysis in order to provide a more robust estimate of the spectral properties in a given data set, and hence be able to correctly characterize and interpret the spectral features observed. We used four independent techniques for this task: standard wavelet analysis, wavelet cross coherency analysis, the multitaper method (MTM), and cross-spectral analysis. The latter was performed following the method of Blackman and Tukey (1958) (BT) using the Analyseries software package (Paillard et al., 1996).

Wavelet software was provided by C. Torrence and G. Compo, and is available at http://atoc.colorado.edu/research/wavelets/. The wavelet analysis technique (Torrence and Compo, 1998) is a useful tool for analyzing non-stationary spectral features and localized variations of power within a time series. The wavelet power spectrum gives a measure of the time series variance at each period and at each depth (time). The software provides a method for calculating the significance levels of the wavelet moduli based on Monte-Carlo methods. The Morlet wavelet was used, and the transform is performed in Fourier space via the method described extensively in Torrence and Compo (1998). Significance levels were calculated against a red noise spectrum. Software for wavelet cross coherency analysis for MatLab was provided by Grinsted et al. (2004).

Wavelet coherency spectra can be used to identify significant coherency between two time series even when their common power is low. The MatLab wavelet coherency software package can be downloaded at http://www.pol.ac.uk/home/research/waveletcoherence/.

For spectral analysis of coral data the SSA-MTM-Toolkit (Ghil et al., 2002) was used. Prior to spectral analysis, the time series were normalized to unit variance and detrended by removing the linear trend using the Analyseries software package (Paillard et al., 1996). The Multitaper Method (MTM) was applied, that provides useful tools for spectral estimation (Thomson, 1982) and signal reconstruction with high spectral resolution and significance tests. The significance tests are independent of the spectral power, therefore even oscillations with small-amplitudes can be identified with a high significance level in a time series whose spectrum may contain both broadband and line components (Ghil et al., 2002). Using the MTM, a small set of data tapers, or data windows, is applied to the data in the time domain to reduce the variance of spectral estimates before Fourier transformation (Thomson, 1982). This method has been widely applied to problems in geophysical signal analysis, for example analyses of instrumental data on the atmosphere and ocean (Mann et al., 1995), and paleoclimate proxy data (Berger et al., 1991; Mann and Lees, 1996; Thomson, 1990). A detailed description of this method can be found in Ghil et al. (2002). Various statistical analyses (e.g., the calculation of running correlations) were performed using the web-based application „Climate Explorer“ developed by G.J. van Oldenborgh (van Oldenborgh and Burgers, 2005), accessible at http://climexp.knmi.nl.

Instrumental data

Local, *in-situ* records of SST are not available for the study site. Therefore, we have used monthly resolved SST data from different sources. For example, SST time series were extracted from the Improved Extended Reconstruction of SST (ERSST.v2) compilation (Smith and Reynolds, 2004) for a 2° latitude by 2° longitude grid box closest to the Guadeloupe study site (centered at 16°N, 62°W) dating back to 1895. SSTs from another gridded product (HadISSTv1.1; (Rayner et al., 2003)) extracted for the grid-point nearest to the study site (15.5°N, 61.5°W) agree well with the ERSST.v2 time series ($r = 0.98$ on monthly, and $r = 0.93$ on annual mean scale, 1895-1999) over the entire period of record (Fig. 4-2b). Both SST datasets are based on the Comprehensive Ocean Atmosphere Data Set (COADS), which consists of historical SST data collected primarily by ships-of-opportunity (Woodruff et al., 1998). Since the COADS data only contain historical SST measurements, large gaps in the data set are evident. Especially before around 1950 measurement data become sparser, and hence, reconstructed SST data are less reliable. The ERSST.v2 compilation uses different statistical methods to fill in gaps in the instrumental data base, that allows a stable reconstruction of SST in periods of sparse data. Basic statistics of temperature data products are summarized in Table 4-1.

Dataset	seasonal cycle summer	winter	average	range	Max	Min	total range	STD AnnM
ERSST	28.56	26.09	27.40	2.47	29.46	25.29	4.17	0.32
HadISST	28.68	26.26	27.58	2.42	29.36	25.39	3.97	0.29
Air temperature (1951-1998)	27.36	24.23	25.99	3.14	28.80	22.30	6.50	0.64

Table 4-1. Basic statistics of the temperature datasets for the 1896-1998 time period, and the 1951-1998 interval for air temperature (reported in °C; STD AnnM=standard deviation of mean annual values).

RESULTS AND DISCUSSION

Coral proxy data

Both geochemical proxy records ($\delta^{18}O$ and Sr/Ca) extend from 1999 to 1895 with monthly resolution and exhibit a strong seasonal cycle (Fig. 4-4a,b). The mean amplitude of the annual cycle is 0.52 per mil (0.12 mmol/mol) for the coral $\delta^{18}O$ (Sr/Ca) time series. The proxy time series are linearly correlated over the entire time period on monthly ($r = 0.71$, $p<0.0001$) and on mean annual scales ($r = 0.59$, $p<0.0001$). A running correlation analysis (Fig. 4-4c) between both geochemical coral proxy records indicates that the strength of the correlations changes over time and exhibits a variability on decadal-to-multidecadal time scales. For example, the results shown in Figure 4-4c indicate a decrease of correlation coefficients during the late 1930s, and an increase to significant levels beginning in the mid 1950s.

Geochemical relationships with temperature

Both proxy records of Gua1 were calibrated with local instrumental records of temperature (Table 4-2). For comparison, we used data from the ERSST.v2 (Smith and Reynolds, 2004) and HadISSTv1.1 (Rayner et al., 2003) global SST compilations. All correlations between instrumental temperature records and coral proxy time series were calculated using the standard ordinary least squares (OLS) regression method. Calibration of the monthly coral $\delta^{18}O$ (Sr/Ca) with local SST data reveals a SST-coral $\delta^{18}O$ (Sr/Ca) relationship of –0.195 ‰/°C (-0.043 mmol/mol/°C) for the 1895-1999 time period (Table 4-2). These values correspond very well to the results reported for the top part (1958-1999) of the same coral core in an earlier calibration exercise (Hetzinger et al., 2006). Due to the close correspondence between ERSST and HadISST gridded SST products, the regression equations between these data and coral proxy data are very similar on monthly and annual mean scale (Table 4-2). The coral $\delta^{18}O$-SST relationship is consistent with published equations using other coral species from different regions (e.g., Gagan et al., 1994; Juillet-Leclerc and Schmidt, 2001; Weber and Woodhead, 1972). Also, the Sr/Ca-SST calibration equation obtained in this study (Table 4-2) lies well within the range of Sr/Ca-SST relationships determined from other Atlantic corals (e.g., Cardinal et al., 2001; Cohen et al., 2004; Goodkin et al., 2005; Smith et al., 2006; Swart et al., 2002). Hence, we interpret our proxy-SST relationships to be reasonable.

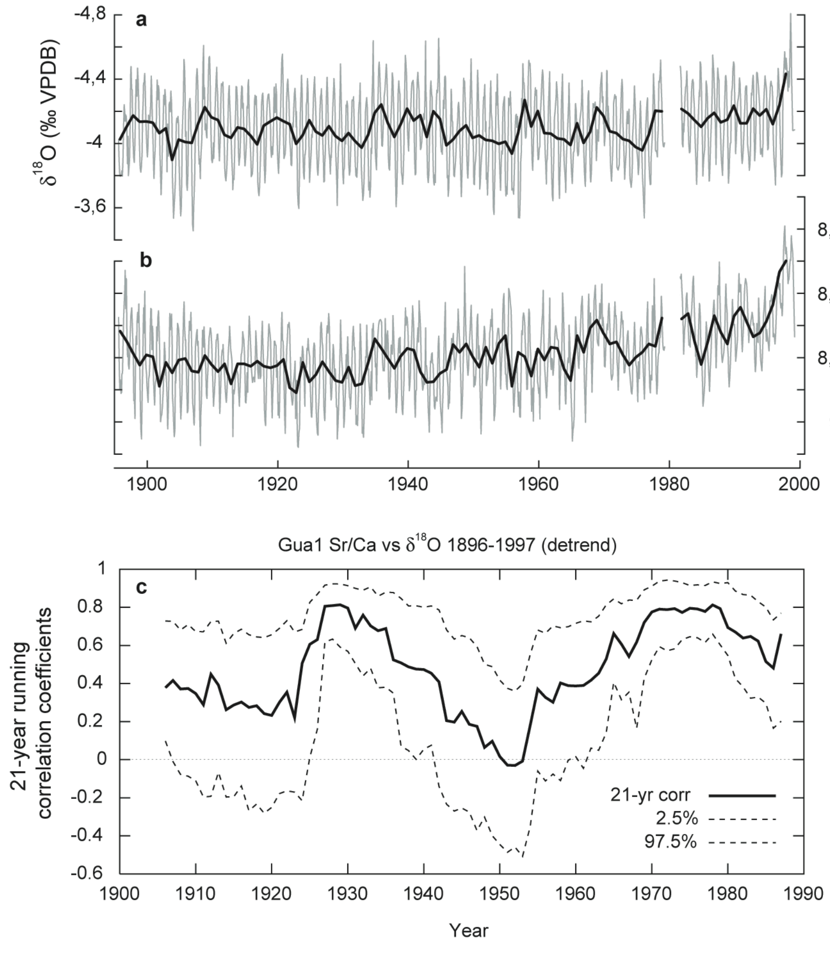


Figure 4-4. Monthly (grey lines) and annual mean (bold black lines) time series (1895-1999) of (a) coral $\delta^{18}O$, and (b) coral Sr/Ca from core Gua1. The gap in the geochemical time series extends from October 1978 to October 1981, where geochemical sampling of the coral core was not possible. (c) Running correlation coefficients between annual mean coral $\delta^{18}O$ and Sr/Ca. Correlations are computed using 21-year sliding windows. Confidence limits (dashed lines) on correlation coefficients were calculated with bootstrap methods (1000 sample Monte Carlo). Correlation coefficients are plotted at the midpoint of each 21-year window and were computed at http://climexp.knmi.nl/.

However, it has to be noted that strong relationships between monthly proxy and instrumental records can be misleading as a result of the influence that the extreme values of the seasonal cycle exert on the OLS regression technique (so-called autocorrelation). Usually, the analysis of annual mean values results in slightly lower correlation coefficients compared to the monthly mean calibration, but is a much better measure of the significance of the relationship between two variables (Quinn and Sampson, 2002). Both of our coral proxies ($\delta^{18}O$ and Sr/Ca) are significantly correlated with instrumental temperature on monthly and annual mean scale (Table 4-2).

Proxy	Temperature data	Resolution	Slope	SE-sl	Intercept	SE-int	R^2	R	p-value	SE (s)
	1895-1999 (n=1205)									
$\delta^{18}O$	ERSST	monthly	**-0.194**	0.004	**1.232**	0.118	0.630	**-0.794**	< 0.0001	0.139
$\delta^{18}O$	HadISST	monthly	**-0.196**	0.004	**1.303**	0.123	0.614	**-0.784**	< 0.0001	0.142
Sr/Ca	ERSST	monthly	**-0.043**	0.001	**10.081**	0.035	0.492	**-0.702**	< 0.0001	0.041
Sr/Ca	HadISST	monthly	**-0.043**	0.001	**10.074**	0.037	0.462	**-0.679**	< 0.0001	0.042
	1896-1998 (n=99)									
$\delta^{18}O$	ERSST	annual	**-0.096**	0.025	**-1.461**	0.692	0.130	**-0.360**	< 0.0002	0.080
$\delta^{18}O$	HadISST	annual	**-0.100**	0.029	**-1.348**	0.789	0.111	**-0.333**	0.0008	0.081
Sr/Ca	ERSST	annual	**-0.051**	0.010	**10.280**	0.278	0.203	**-0.451**	< 0.0001	0.032
Sr/Ca	HadISST	annual	**-0.048**	0.012	**10.211**	0.326	0.144	**-0.379**	< 0.0001	0.033
1896-1949 / 1950-1998										
	1896-1949 (n=53)									
$\delta^{18}O$	ERSST	annual	**-0.046**	0.031	**-2.845**	0.853	0.040	**-0.200**	0.150	0.071
	1950-1998 (n=45)									
$\delta^{18}O$	ERSST	annual	**-0.195**	0.050	**1.276**	1.370	0.264	**-0.514**	0.0003	0.086

Table 4-2. Linear regressions and correlation coefficients between geochemical coral proxies ($\delta^{18}O$ and Sr/Ca) and local grid-SST centered on the study site (16°N, 62°W for ERSST.v2; 15.5°N, 61.5°W for HadISSTv.1.1). Monthly calibrations are reported for 1895-1999, annual mean calibrations for the 1896-1998 time interval, respectively. All equations are computed using ordinary least squares (OLS) regression with zero-lag, 95% confidence limits for slope and intercept apply (SE=standard error). Equations are in the form: $\delta^{18}O$ = m*SST + b; and Sr/Ca = m*SST + b.

Despite the strong correlation on monthly scale, the correlation between mean annual values of coral $\delta^{18}O$ (Sr/Ca) and temperature is somewhat weaker, as expected, but significant for the 1896-1998 time interval (Table 4-2). On annual mean scale, we observed statistically significant correlations between coral proxies and both instrumental data sets. In order to test the stability of the coral $\delta^{18}O$ (Sr/Ca)-temperature relationships over the entire period of record, we compared the here obtained regression equations for the 1895-1999 time period to the previously calibrated, but shorter time interval (1958-1999) of the same coral core (Hetzinger et al., 2006). We have used SST data from the ERSST.v2 compilation for calibration with coral proxies. On monthly scale, the coral $\delta^{18}O$ (Sr/Ca)-SST relationships are very stable, and the regression slope estimates are practically identical for both time intervals ($\delta^{18}O$-SST (ERSST.v2): -0.196 ‰/°C for 1958-1999, -0.195 ‰/°C for 1895-1999; Sr/Ca-SST: -0.042 mmol/mol/°C for 1958-1999, -0.043 mmol/mol/°C for 1895-1999). On annual mean scale, the slope estimates of the Sr/Ca-SST relationship are not significantly different, varying between –0.066 mmol/mol/°C (1958-1999) and –0.051

mmol/mol/°C (1896-1998, ERSST.v2). However, the slope estimates for the coral $\delta^{18}O$-SST relationship decreases from -0.196 ‰/°C for 1958-1999, to –0.096 ‰/°C for 1896-1998.

With respect to the weaker correlations (Table 4-2) between mean annual values of the Gua1 coral proxies and local gridded SST, and the observed decrease in the $\delta^{18}O$-SST relationship in the first half of the 20th century, we investigate whether the strength of the correlation has changed over time. Figure 4-5 presents correlation coefficients calculated for 21-year running windows between annually averaged coral proxies and gridded ERSST. The results shown in Figure 4-5a suggest strong and highly significant correlations between coral $\delta^{18}O$ and SST from the top of the records backwards to the correlation windows centered during the 1930s. A strong decrease of the correlation coefficients between coral $\delta^{18}O$ and locally averaged ERSST is observed from approximately 1940 to 1930. No significant correlations are indicated during the late 1900s to early 1930s (Fig. 4-5a). This, however, could also be the reason for the observed decrease in the slope estimate of the $\delta^{18}O$-SST relationship.

In order to test this hypothesis, we have examined the variability of the $\delta^{18}O$-SST relationship in the time domain. Therefore, we have divided the record into two time intervals of near equal length, from 1896 to 1949 and from 1950 to 1998, and calculated the linear regressions for both time intervals separately. The calculations have shown clearly that the coral $\delta^{18}O$-SST relationship has changed with time. For the time interval 1896-1949, the correlation between $\delta^{18}O$ and SST is significantly reduced in comparison with the upper part of the record (1950-1998), as is the slope estimate (Table 4-2). In accordance with the decrease in correlation between coral $\delta^{18}O$ and SST prior to around 1950 (Fig. 4-5a) and the lack of correlation between both time series between the 1900s and the early 1930s, the slope estimate of the calibration equation has changed, too. The possible causes of the shift in correlations between SST and coral $\delta^{18}O$ will be assessed in one of the following chapters.

The results from a running correlation analysis between coral Sr/Ca and SST (Figure 4-5b) suggest a high multidecadal variability in the strength of the correlations. From the top of the records to the correlation windows centered during the 1960s, strong and highly significant correlation coefficients are observed, whereas no significant correlations are present from the mid 1950s to mid 1920s (Fig 4-5b). Blackman-Tukey cross spectral analysis between coral proxies and local grid-SST (ERSST) shows that both coral $\delta^{18}O$ and Sr/Ca are coherent with SST at interannual time scales (Fig. 4-5c,d), but not on decadal scales.

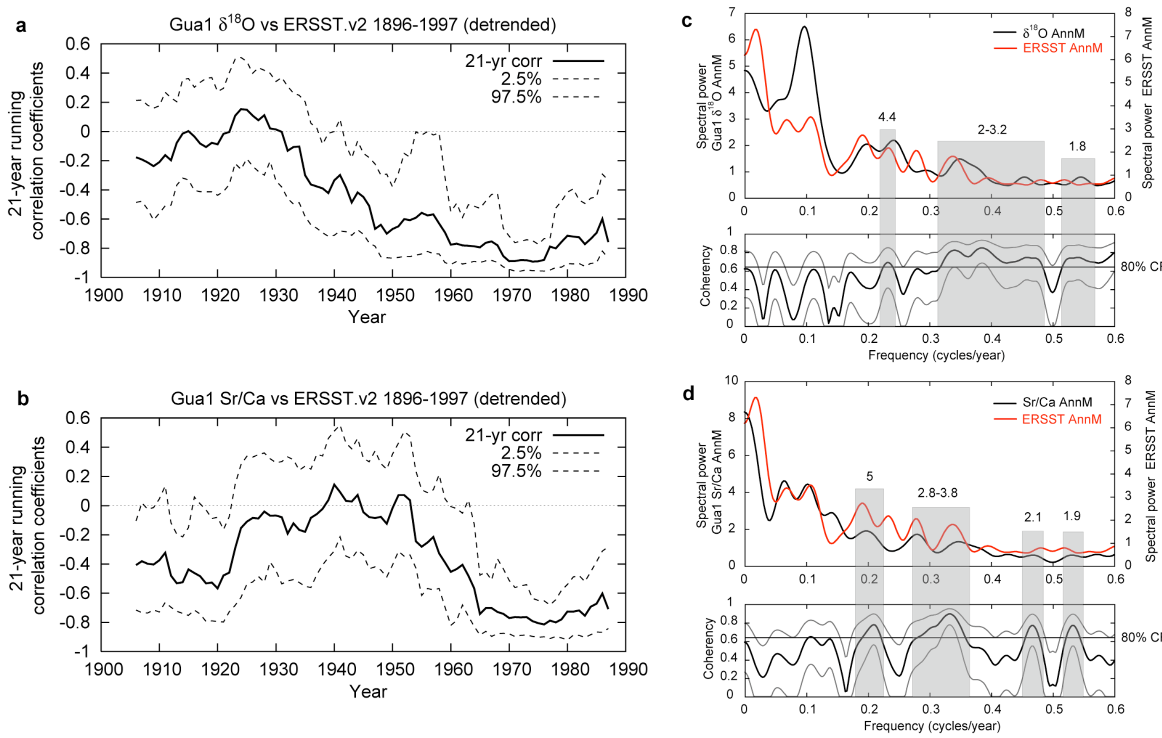


Figure 4-5. Running correlation coefficients between SST (ERSST.v2) and annual mean Guadeloupe (a) coral $\delta^{18}O$, and (b) coral Sr/Ca. Correlations are computed using 21-year sliding windows. Confidence limits on correlation coefficients (dashed lines) were calculated with bootstrap methods (1000 sample Monte Carlo). Correlation coefficients are plotted at the midpoint of each 21-year window and were computed at http://climexp.knmi.nl/ (van Oldenborgh and Burgers, 2005). Results of Blackman–Tukey cross-spectral analysis between annually averaged (c) coral $\delta^{18}O$ and ERSST, and (d) coral Sr/Ca and ERSST using a Bartlett window. The records were normalized and detrended prior to analysis. (c,d) Variance spectra (upper panels), and coherency (the correlation coefficient as a function of frequency) between both time series (lower panels, thick black line). Thin grey lines indicate the upper and lower coherency confidence intervals at the 80% level, i.e., over 64% (0.8^2) of the variance at these periods is linearly correlated between these time series. The periods (in years) at which the two time series are coherent at the 80% level are shown in the variance spectra as numbers. The criteria for this are that the variance peaks of both time series in the respective upper panel are in line and that the corresponding coherency (lower panel) exceeds the 80% confidence level (CL).

Comparison between proxies and local air temperature

A comparison between gridded SST data (ERSST.v2) and local air temperature from the Pointe-à-Pitre monitoring station has shown that both temperature data show similar variability. The air temperature record correlates strongly with ERSSTv.2 on monthly ($r = 0.82$, $p<0.0001$) and on mean annual scale ($r = 0.64$, $p<0.0001$) when the linear upward trend is removed from both time series, undetrended records display weaker correlations (Fig. 4-6a).

In addition to the calibration of coral proxies with SST, we compared our proxies to the local air temperature record, since we assume that air temperature variability could be, albeit somehow lagged, recorded in corals growing in shallow water. Highest correlation was obtained for coral Sr/Ca on mean annual scale ($r = -0.77$; $p<0.0001$, 1951-1998, Fig. 4-6b). The coral Sr/Ca record, which is believed to be controlled by temperature only, is able to reflect annual to interannual temperature variability at the study site very well (Fig. 4-6b).

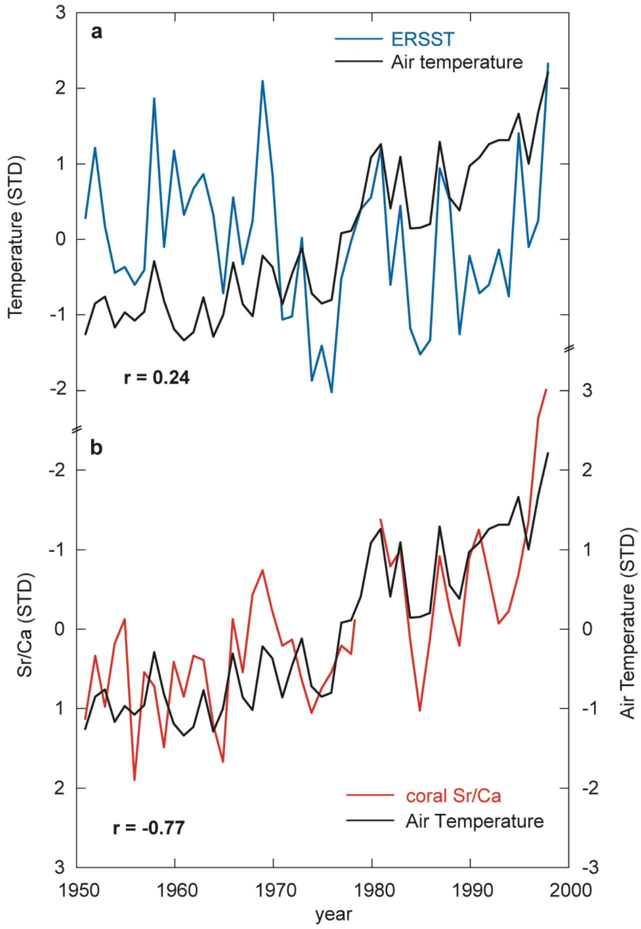


Figure 4-6. Comparison between air temperature from the Pointe-à-Pitre monitoring station located about 8 km to the northwest of the coral sampling site, SST derived from locally averaged grid data (ERSST.v2 (Smith and Reynolds, 2004)), and Guadeloupe coral Sr/Ca. (a) SST compared to local air temperature (r = 0.24; σ_{ERSST} = 0.26°C, $\sigma_{airTemp}$ = 0.65°C). Note that correlation between SST and air temperature is much higher when the linear trend is removed (r = 0.64, not shown). (b) Same air temperature record as shown in (a) compared to coral Sr/Ca (r = -0.77; $\sigma_{Sr/Ca}$ = 0.039 mmol/mol). All time series were standardized by subtracting the mean and dividing by the standard deviation prior to comparison.

Apparently, the correlation with air temperature is higher on mean annual scale than on monthly scale for both proxies (Sr/Ca: r = -0.66 for monthly, and r = -0.77 for annual means; $\delta^{18}O$: r = -0.72 for monthly, and r = -0.73 for annual means; 1951-1998, p<0.0001). This is most presumably due to the higher variability of air temperature on shorter timescales (daily to monthly) when compared to SST variability. The correlation with local air temperature yields even higher correlation coefficients on mean annual scale than with grid-SST for the same time period (Sr/Ca-ERSST: r = -0.37; p=0.016, 1951-1998). Thus, our calibration exercise corroborates the applicability of coral Sr/Ca as a reliable proxy for local temperature variability.

The close correspondence between coral proxies (particularly the Sr/Ca-ratios, Fig. 4-6b) and local *in-situ* air temperature is not surprising, since the coral core stems from a colony living in shallow water (1.7 m water depth). Water temperatures in shallow water areas are known to follow surface air temperature closely. This could explain why the coral proxies at this site are stronger correlated to local air temperature than to gridded SST, which generally consists of SST averages from much bigger areas of the ocean.

Long-term trends in instrumental data and coral proxies

Both SST data centered on Guadeloupe and the local air temperature record show a pronounced trend to warmer temperatures through the 20th century (Fig. 4-7). This is consistent with recent analyses of global surface temperature that indicate an increase of 0.56 to 0.92°C during the last century related to global warming (Intergovernmental Panel on Climate Change (IPCC), Fourth Assessment Report, 2007, Summary for Policy Makers, accessible via http://www.ipcc.ch/) and a linear warming trend over the past 50 years (0.10 to 0.16°C per decade) that is almost twice of that for the past 100 years. The magnitude of the upward trend in SST (ERSST.v2) centered on the study site is around 0.55°C between 1896 and 1998, with around 0.25°C of the increase alone since 1976. However, the air temperature record from Guadeloupe displays a much stronger upward trend than SST since the 1950s (Fig. 4-7a,b). The increase in local air temperature is approximately 1.9°C since 1951, from which the main part (around 1.25°C) occurred since 1976.

Recent studies indicate that the relationship between regional SST and large-scale atmospheric circulation in the tropical oceans has changed after the mid-1970s. Instrumental observations reveal a shift towards warmer and wetter conditions in the tropical Pacific since around 1976 and a number of studies have discussed the persistent widespread changes in Pacific basin climate (Mantua et al., 1997; Trenberth and Hurrell, 1994; 1997). This warming trend is also clearly documented in a number of coral records from the Pacific and Indian oceans (Cobb et al., 2001; Cole et al., 1993; Guilderson and Schrag, 1999; Kilbourne et al., 2004; Urban et al., 2000). However, so far, no evidence exists for a comparable trend in proxy records from Atlantic corals.

We observe a similar trend in the Guadeloupe coral proxy time series. Our record captures a decreasing trend in coral $\delta^{18}O$ and Sr/Ca, which is most pronounced since the mid-1970s (Fig. 4-7), in consistence with the increase in SST and air temperature at the study site. We have compared the magnitude of the trends for the 1950-1998 and the 1976-1998 time intervals. Figure 4-7 shows that the trend to lower values is pronounced much stronger in coral Sr/Ca than in the coral $\delta^{18}O$ record. Coral Sr/Ca-ratios are believed to be temperature-controlled. A comparison of the magnitudes of the decrease in coral Sr/Ca between both time intervals has shown that the strongest decrease in coral Sr/Ca occurred from 1976 upwards with a magnitude of around 0.087 mmol/mol, which would represent a SST warming of approximately 1.1-2°C, assuming Sr/Ca-SST relationships between -0.04 and -0.08 mmol/mol per 1°C (Marshall and McCulloch, 2002). This is consistent with the increase in observed air temperature and indicates that coral Sr/Ca reliably records the strong surface temperature increase at the study site (compare also Figs. 4-7b,e).

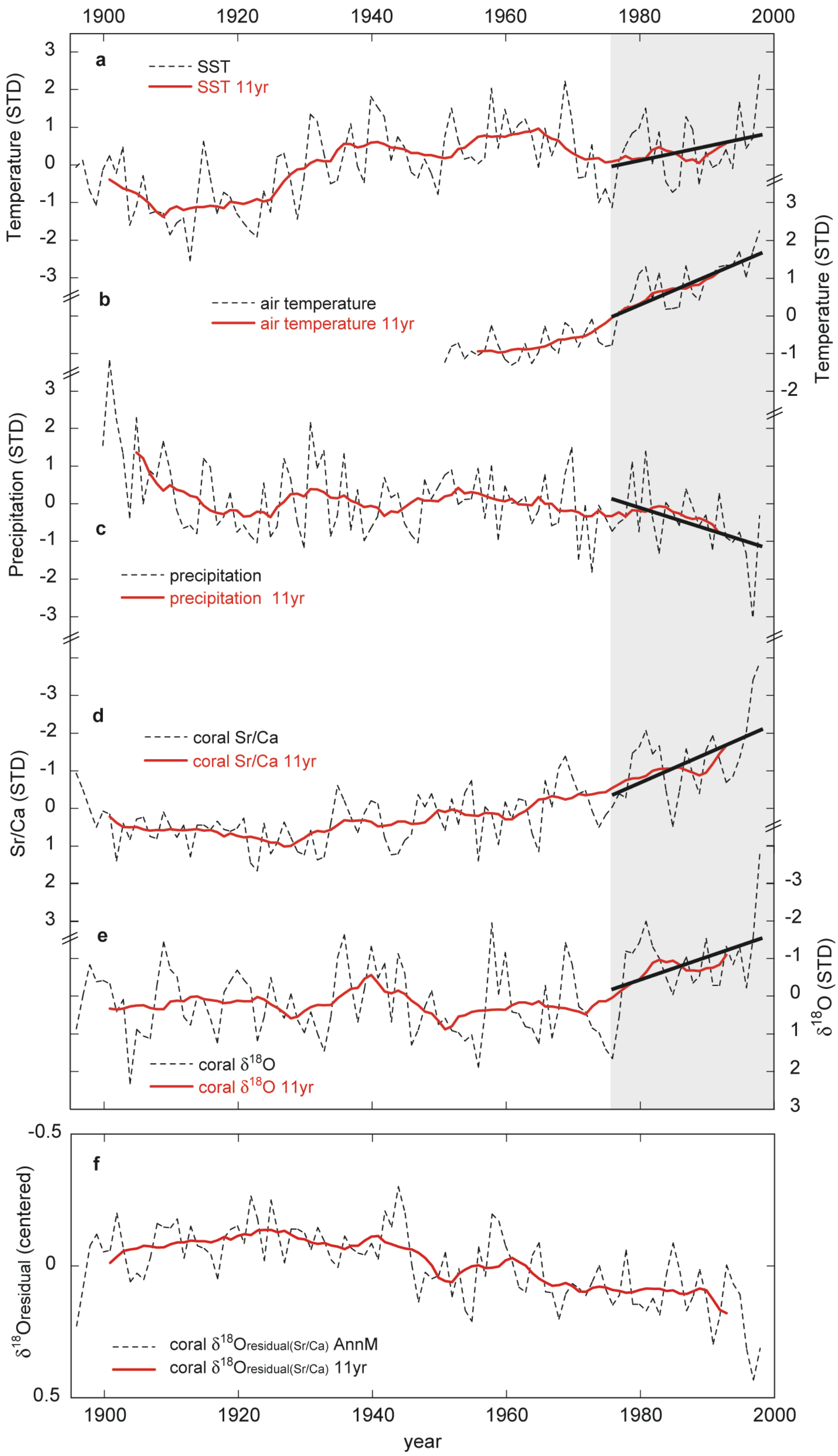


Figure 4-7. Comparison between mean annual instrumental data (thin stippled lines): (a) ERSST, (b) locally measured air temperature, (c) precipitation averaged over a box including the study site (15° to 20°N and 55° to 65°W), and coral records: (d) $\delta^{18}O$, (e) Sr/Ca. Thick solid lines represent 11-point moving averages. The recent period between 1976 and 1999 is indicated by gray shading in order to highlight the change since the mid-1970s and the inverse relationship between temperature and precipitation. Linear trends shown were calculated based on mean annual data for the 1976-1998 time period. Time series were standardized by subtracting the mean and dividing by the standard deviation prior to comparison. (f) Guadeloupe coral $\delta^{18}O_{residual(Sr/Ca)}$ time series generated by removing the Sr/Ca-derived temperature component of the coral $\delta^{18}O$ signal. The resultant $\delta^{18}O_{residual(Sr/Ca)}$ is

an estimate of seawater $\delta^{18}O$. Shown time series was centered by removing the mean. Stippled line represents annually averaged data, solid line is 11-point moving average.

The trend in Guadeloupe coral $\delta^{18}O$ amounts to a decrease of about 0.19‰ between 1950 and 1998, although the largest part of the decrease occurred since 1976 (0.17‰) (Fig. 4-7d). When interpreted strictly as temperature signal, this trend would correspond to a warming of around 1°C, assuming coral $\delta^{18}O$-SST relationships of -0.18 to -0.22 ‰/°C that have been reported for *Porites* corals from the Indo-Pacific (Gagan et al., 1994; Juillet-Leclerc and Schmidt, 2001; Weber and Woodhead, 1972; Wellington et al., 1996), and are consistent with relationships for fast-growing *Diploria strigosa* corals (this study and Hetzinger et al. (2006), range: -0.18 and -0.20 ‰/°C). This warming is lower than the increase observed in air temperature at the study site, and the warming calculated from coral Sr/Ca alone. However, in contrast to Sr/Ca, which reflects temperature variability at the study site, coral skeletal $\delta^{18}O$ is not only influenced by water temperature, but also by seawater $\delta^{18}O$ ($\delta^{18}O_{sw}$) which is known to be linearly related to SSS that is influenced by the precipitation-evaporation balance.

The combination of coral $\delta^{18}O$ and Sr/Ca at Guadeloupe provides the opportunity to examine changes in the hydrologic balance at the study site by estimating seawater $\delta^{18}O$. Past $\delta^{18}O_{sw}$ variations can potentially be reconstructed by removing the temperature component of the coral $\delta^{18}O$ signal using Sr/Ca-derived temperature. We calculate relative changes of $\delta^{18}O_{sw}$ following the methods described in Linsley et al. (2006) and Ren et al. (2002), assuming a coral $\delta^{18}O$-SST relationship of -0.2 per mil/1°C (e.g., Gagan et al. (1994), corresponding to the values presented in Table 4-2) and a coral Sr/Ca-SST relationship of -0.043 mmol/mol per 1°C (Table 4-2). The resulting signal ($\delta^{18}O_{residual(Sr/Ca)}$, Fig. 4-7f) is an estimate of seawater $\delta^{18}O$ (Iijima et al., 2005; Linsley et al., 2006). The $\delta^{18}O_{residual(Sr/Ca)}$ time series is centered and then smoothed using an 11-point running filter to highlight the decadal to interdecadal variability of the record (Figure 4-7f).

A comparison between the coral $\delta^{18}O_{residual(Sr/Ca)}$ and a regional precipitation average (displayed in Fig. 4-7c) shows that both records are highly correlated at low frequencies until the middle of the last century (r = -0.83, 1950-1993, $p<0.0001$; based on 11-year running averages), and documents that coral $\delta^{18}O$ is also influenced by the hydrological cycle. However, the reasons underlying the observed lack of correlation between calculated $\delta^{18}O_{residual(Sr/Ca)}$ and the precipitation record before 1950 cannot be completely determined, and may be due to several different factors, for example, related to the coral proxies itself or to the circumstances at the study site. Similar difficulties in Sr/Ca-derived $\delta^{18}O_{sw}$-records have been encountered in previous studies, e.g., Quinn et al. (2006) and S.Y. Cahyarini (pers. comm.). For example, a study by Kilbourne and co-workers (2004) found that $\delta^{18}O_{sw}$ variations reconstructed via the same method (i.e., using coral Sr/Ca-derived

temperature) can be noisy and do not necessarily yield a better proxy for variations in the hydrological balance as, for example, coral $\delta^{18}O$-anomaly time series.
However, it is possible that local $\delta^{18}O_{sw}$ variations at the Guadeloupe study site are captured by the coral proxy record, but there is no option to verify these local data, which most probably deviate from observational datasets that have been averaged over wide regions and are based on sporadic spot measurements only (e.g., ship-track data). Hence, the major problem in the interpretation of coral derived $\delta^{18}O_{sw}$ reconstructions is the general lack of *in-situ* $\delta^{18}O_{sw}$ records, which hampers a proper calibration and verification of coral-derived data.

Our results indicate that the Guadeloupe coral records mainly local temperature variability. In particular, the strong relationship of coral Sr/Ca to local air temperature (Fig. 4-6b) points to a distinct influence of local climatic effects onto the coral proxies. This is not surprising with regard to the close proximity of the sampling site to the main island of Guadeloupe (Fig. 4-1), which has a pronounced mountainous relief. Thus, local circulation patterns related to island geography, which generally are more vigorous in the tropics than in higher latitudes (Hastenrath, 1991), potentially influence surface waters at the location of coral growth.

In general, it is expected that total precipitation will increase together with an increase in tropical SSTs, as in theory warmer SSTs will lead to an increase in evaporation, and thereby an increase in precipitation. However, an opposite pattern is observed at the study site. Local air temperature trends upward since the mid-1970s, whereas simultaneously regional (land) precipitation exhibits a clear downward trend (Figs. 4-7b,c), suggesting a decreasing influence of precipitation on coral proxies at the study site since that time. A study by Kumar et al. (2004) has revealed that, indeed, land surface temperatures have increased together with SSTs in the tropical latitudes during the past 50 years, whereas over land the precipitation trend differs from the trend seen in surface temperatures. According to their analysis, the trends in precipitation over land and oceans differ significantly after the distinct shift around 1976. Based on the analysis of observed data and data from atmospheric general circulation model simulations, Kumar et al. (2004) report that the tropical oceanic rainfall has increased on the whole, consistent with the increase in SSTs, whereas the precipitation over the tropical land regions exhibits a general reduction. These findings are consistent with the inverse relationship found between surface temperature and precipitation at Guadeloupe since around the mid-1970s (Fig. 4-7), and diverge from the scenarios observed in the Indian and Pacific Oceans, where both temperature and precipitation increase in response to increasing SSTs. Our coral captures the strong upward trend in local temperature at Guadeloupe since the mid-1970s (Figs. 4-6,7) that is not as well represented in averaged grid-SST data. A combination of increasing surface temperature and decreasing precipitation over land regions in the Caribbean could have negative consequences on human activities, especially in the context of a persistent upward trend in tropical temperature that has been related to human influences.

Spectral analysis of coral proxies

In order to evaluate our proxy data in the frequency domain and to analyze the linkage between the coral proxy records and climate variability, we have applied several methods of statistical and spectral analysis to the linearly detrended coral $\delta^{18}O$ (Sr/Ca) time series. Prior to analysis, we have computed seasonal mean $\delta^{18}O$ (Sr/Ca) time series from the monthly resolved coral proxies for boreal spring (March-May, MAM), the season where the influence of remote forcings on climate variability in the north tropical Atlantic and Caribbean region is strongest (e.g., Czaja et al. (2002), Enfield and Mayer (1997)). These records are shown in Figure 4-8a,e.

A spectral analysis of the seasonally averaged coral $\delta^{18}O$ time series using the Multitaper method (MTM (Thomson, 1982)) displays statistically significant (90%) spectral peaks in the record that are centered at periods of 2.6, 3.1, 4.9-5.3 years, and around 9.1 to 13.5 years (Fig. 4-8d). In addition, wavelet power spectra (Fig. 4-8b,f) were computed following the methods of Torrence and Compo (1998). Wavelet analysis of the coral $\delta^{18}O$ shows a time varying response of the variability in the record (Fig. 4-8b). Coral $\delta^{18}O$ shows significant decadal variability with a period of approximately 9-14 years with exception of the 1920 to 1950 time period, where significant interannual variability with a period around 3-5 years is evident (Fig. 4-8b). A weak interdecadal signal with a period around 20 years is evident between 1930 and 1960. Because of the occurrence in both spectral analysis methods and regarding the signal strength, we interpret the variability in the decadal band as the dominant signal in the coral $\delta^{18}O$ time series (see also global wavelet in Fig. 4-8c).

MTM spectral analysis reveals significant spectral peaks centered at periods of 2.4 to 2.9 years (Fig. 4-8h) in the Sr/Ca record. The wavelet spectrum suggests that interannual variability in coral Sr/Ca was strongest after around 1920 up to present with a periodicity of around 2-3 years (Fig. 4-8f). A decadal signal in coral Sr/Ca is evident in the post-1960s interval up to the 1990s. However, this signal has to be interpreted with caution after the mid-1980s since then variance is reduced in this band because zero-padding has reduced the variance (Fig. 4-8f). The decadal signal observed in the wavelet analysis is not statistically significant in the MTM spectral analysis. In summary, the results from both methods indicate that strongest variability in the coral Sr/Ca record is found in the interannual band (compare Fig. 4-8f-h). Coral Sr/Ca variations at Guadeloupe are coherent with coral $\delta^{18}O$ variations (Fig. 4-9), suggesting that both proxies are responding to similar forcing, especially at the interannual (2-3 years) to decadal (9-14 years) time scales. Wavelet analysis of the coral Sr/Ca record also documents the diminution of spectral power in the decadal band in the middle of the 20th century, as is also observed in the coral $\delta^{18}O$ record (compare Fig. 4-8b,f).

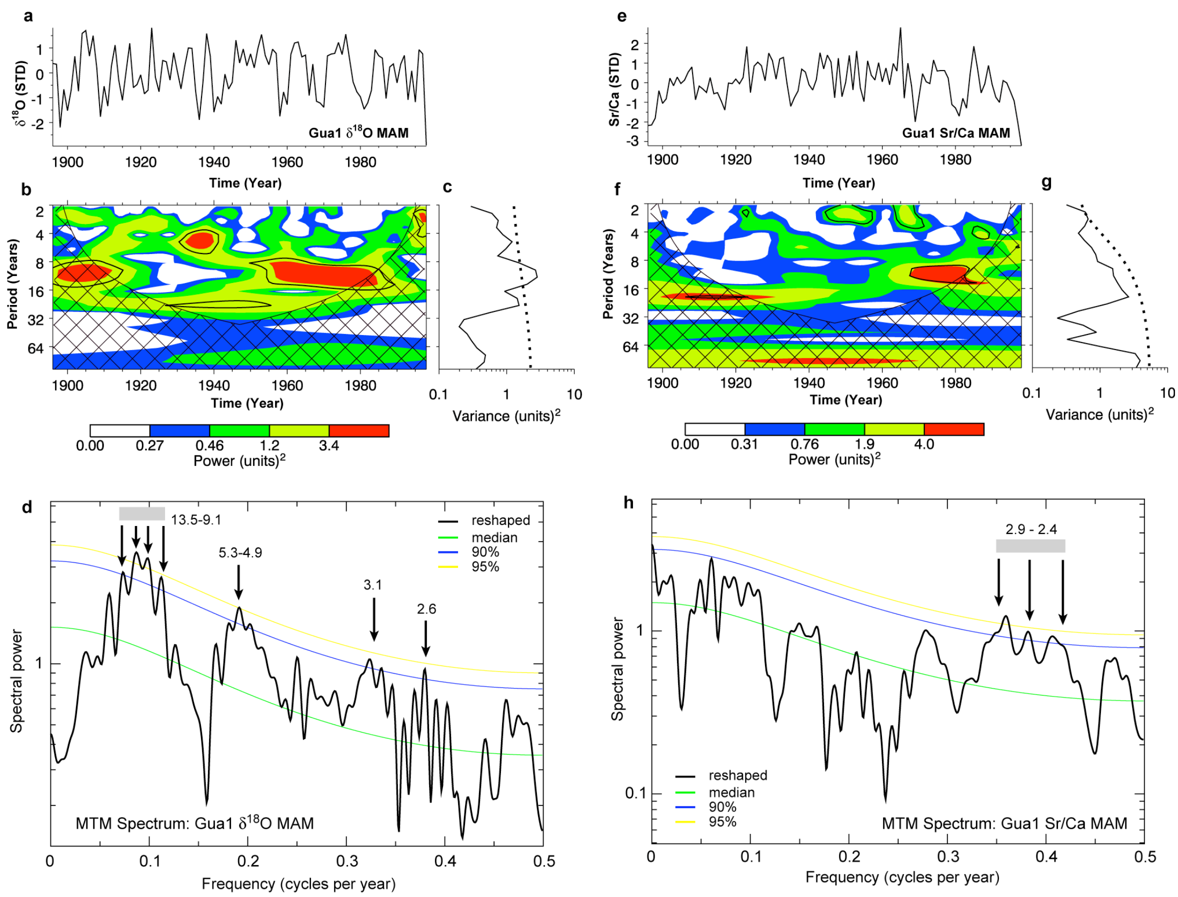


Figure 4-8. Spectral analysis of seasonally averaged Guadeloupe coral proxy time series. Wavelet power spectra: (a) Gua1 coral $\delta^{18}O$ (MAM) time series. (b) Wavelet power spectrum of coral $\delta^{18}O$. (c,g) Global wavelet power spectra (black line). The dashed line is the significance for the global wavelet spectra, assuming the same significance level and background spectrum as in (b,f). (e) Gua1 coral Sr/Ca (MAM) time series, and (f) wavelet power spectrum of coral Sr/Ca. Wavelet power spectra were generated using the method of Torrence and Compo (1998). Black contours indicate that the amplitude within is significant at the 90% level against a red noise background. The cross-hatched region is the cone of influence, where zero padding has reduced the variance. All time series were normalized and detrended prior to analysis. The results of Multitaper Method (MTM): (d) coral $\delta^{18}O$, and (h) Sr/Ca time series (1895-1999). Periods (years) of peaks significant at the 90% level are indicated. The significance estimates in the MTM are independent of the spectral power.

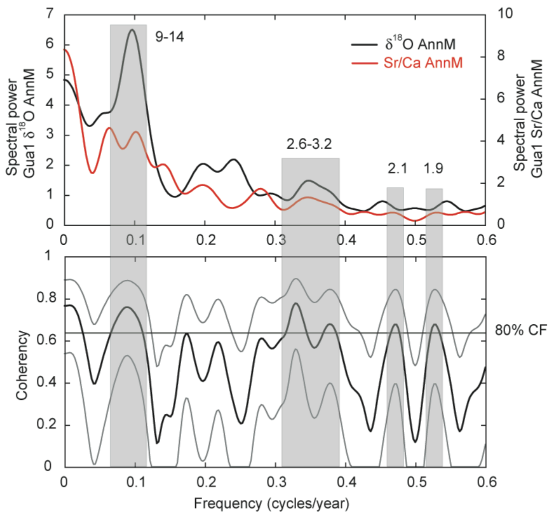


Figure 4-9. Results of a Blackman –Tukey cross-spectral analysis between annually averaged coral $\delta^{18}O$ and coral Sr/Ca time series for the interval 1896-1998 using a Bartlett window. The records were normalized and detrended prior to analysis. Nonzero coherence (lower panel) is higher than 0.64 (80% level). The periods (in years) at which the two time series are coherent at the 80% confidence level (CL) are shown in the variance spectra (upper panel) as numbers.

Quantitative comparison between geochemical proxies and climate indices

In order to investigate the causes for the concentration of variance in certain frequency bands of our geochemical coral proxy time series (Fig. 4-8), we have compared the proxy records to climate indices describing prominent modes of the global climate system. Recent observational and model-based studies have shown that both the NAO and the ENSO system exert a strong influence on climate variability in the northern tropical Atlantic and the Caribbean region (Curtis and Hastenrath, 1995; Czaja et al., 2002; Enfield and Mayer, 1997; George and Saunders, 2001; Giannini et al., 2001a; 2001b; Giannini et al., 2000; Saravanan and Chang, 2000). The El Niño-Southern Oscillation phenomenon originates in the tropical Pacific Ocean but is known to influence seasonal climate variability (e.g., rainfall and temperature) on a global scale via atmospheric teleconnection patterns (Philander, 1990). For example, the ENSO system has documented teleconnections with Atlantic climate and is known to influence wind stress, rainfall, and the occurrence of hurricanes in the Caribbean (Chang et al., 2000; Enfield and Mayer, 1997; Giannini et al., 2000; Gray, 1984; Tang and Neelin, 2004). The North Atlantic Oscillation has a strong influence on large-scale variations in the atmospheric circulation over the North Atlantic and surrounding continents (including the Caribbean region), controlling regional distribution of temperature and rainfall (Hurrell, 1995). It is well established from both observational (Deser and Timlin, 1997) and modeling studies (Halliwell, 1998) that NAO variability intrinsic to the atmosphere is able to drive large-scale changes in SST over the North Atlantic. A study by George and Saunders (2001) has demonstrated that the wintertime NAO affects the precipitation over the Caribbean in the following year, and suggests that this forcing is a result of SST anomalies set up by the winter trade winds.

Previous studies, which use mostly post-1950 observational SST data in combination with model results as a data basis, have shown that the Nino3 index (an index of SST averaged over the central Pacific commonly used as a measure of the ENSO amplitude) in boreal winter is positively correlated with SST anomalies in the tropical North Atlantic in the following boreal spring (e.g., Alexander and Scott, 2002; Chang et al., 1998; Enfield and Mayer, 1997; Handoh et al., 2006). In addition, these studies also suggest the presence of non-ENSO influences on the seasonal-to-interannual variability of the NTA, which can be related to the variability of the NAO. In a study by Czaja et al. (2002), an SST index which has been defined over the center of action of the dominant mode of NTA SST variability (5-25°N, 60-20°W; (e.g., Dommenget and Latif, 2000; Nobre and Shukla, 1996)) and averaged over time in spring (MAM), when this mode is most pronounced, has been used to identify the role of remote forcing by ENSO and NAO modes on the dominant pattern of NTA SST variability. They found that almost all NTA-SST extreme events from 1950-1999 can be related to either NAO or ENSO.

The results from this analysis suggest that the strong impact of ENSO and NAO forcings onto the NTA region results from a modulation of the strength of the trade winds in winter (Czaja et al., 2002). ENSO and NAO related anomalies in sea level pressure (SLP) are expected to modulate the strength of the trade winds over the NTA region, but with positive ENSO and NAO events opposing each other, i.e., positive ENSO events are associated with anomalous westerlies inducing heating over the NTA region, and the same pattern observable for negative NAO phases (Czaja et al., 2002). Hence, warm El Niño years (positive Nino3 index) are typically associated with warm SSTs in the NTA, cold La Niña years (negative Nino3 index) are associated with cold NTA conditions, whereas positive NAO events corresponding to cold NTA conditions, and reversely, negative NAO events tend to be associated with warm NTA SST conditions (Czaja et al., 2002). Another observed phenomenon is that, occasionally, the external forcings are interconnected in the way that ENSO and NAO related anomalies may add constructively to create SST anomalies in the northern tropical Atlantic, but they may also cancel each other out (Czaja et al., 2002; Giannini et al., 2001a).

However, the remote impact on interannual and decadal climate variability in the north tropical Atlantic sector still needs to be better quantified and understood, especially on longer time scales (Liu et al., 2004). Central to understanding the causes of climate variability in the tropical Atlantic, and the variability in the atmosphere-ocean system in general, is understanding variability in SST (Sutton et al., 2000). Before 1950, regional instrumental observations of climate parameters (e.g., SST) become sparser and are spatiotemporally incomplete, and especially prior to the past century observational data coverage decreases rapidly (Smith and Reynolds, 2003). Therefore proxy data can help to extend such records back in time. Given the strong seasonal dependence of both ENSO and NAO variability (Czaja, 2004; Sutton et al., 2000), it is crucial that the used proxies do not only capture the annual, but also the seasonal mean variability in the region. Both of our coral-derived proxy records display monthly resolution and hence meet the criterion for studying seasonally phase-locked climate variations in this region.

We investigate the influence of external climate forcings on the NTA climate variability by quantitatively comparing data from our monthly resolved coral proxy time series to the two most prominent modes of external forcing, namely ENSO and NAO. We have chosen coral $\delta^{18}O$ for in-depth comparison with large-scale climate indices, because coral oxygen isotopes are known to reflect large-scale climate variability in the NTA region better than Sr/Ca (Hetzinger et al., 2006). In contrast to coral Sr/Ca, that is believed to be controlled by temperature only, coral $\delta^{18}O$ is also influenced by seawater $\delta^{18}O$ which is known to covary with SSS and is largely influenced by the hydrological cycle (Delaygue et al., 2000).

Year-to-year variations of northern tropical Atlantic SSTs are largest in boreal spring, lagging ENSO and NAO events, which are most pronounced in winter, by 3-4 months (Sutton et al., 2000). We use the ENSO phases from the so-called Nino3 equatorial Pacific (5°S-5°N, 90°-150°W) SST index in winter (DJF) (based on SST anomalies from the ERSST.v2 dataset (Smith and Reynolds, 2004)), the NAO phases were determined from the wintertime (DJFM) sea level pressure index of Jones et al. (1997), respectively. The NAO is defined as the normalized sea-level pressure difference between the Azores and Iceland. Both climate indices are compared to seasonally averaged coral $\delta^{18}O$ from Guadeloupe for the months March-April-May (MAM) of the following boreal spring (Fig. 4-10). Note that for the comparison of coral proxy time series with climate indices, we have filled the 3-year gap (October 1978 to October 1981) in the coral proxy time series with calculated coral $\delta^{18}O$ values, that have been estimated based on the coral $\delta^{18}O$-SST calibration equations obtained through linear regression with SST data (Table 4-2).

In Figure 4-10, high and low years/events of the Nino3 and the NAO index (i.e., exceeding ±1 standard deviation), which correspond to years with high and low coral $\delta^{18}O$ values, were marked with filled and unfilled circles (squares), respectively. For example, strong El Niño (La Niña) events that correspond to negative (positive) coral $\delta^{18}O$ peaks in the record (Fig. 4-10) are clearly identifiable in the coral time series (e.g., the El Niño (warm) events of 1941, 1965/66, 1982/83, 1987, 1997/98; the La Niña (cool) events of 1973/75, 1984). An opposite phase relationship exists between the NAO and coral aragonite $\delta^{18}O$, for instance, positive (negative) NAO phases correspond to positive (negative) coral $\delta^{18}O$ values (e.g., the positive NAO event of 1973; and the negative NAO event of 1969; Fig. 4-10).

However, during certain years, the impact of the ENSO on SST in the NTA region can be reduced (or sometimes even cancelled out) by the opposing influence of the NAO (Giannini et al., 2001a). This relationship is manifested in our record, for example, in the years 1903 and 1925, where a positive ENSO phase (El Niño) coincides with a positive NAO phase, and hence coral $\delta^{18}O$ values are shifted to more positive values (Fig. 4-10). This effect is most pronounced in the years 1972/73 and 1982/83, where strong El Niño events are not or only weakly recorded by the coral $\delta^{18}O$ (Fig. 4-10), because during these years the impact of ENSO on NTA SST is reduced due to the positive NAO phases in the preceding boreal winter (Czaja et al. (2002), their Fig. 1). The same effect (i.e., the attenuation of the ENSO signal on SST in this region) can be observed when negative ENSO phases (La Niña events) coincide with negative NAO phases (e.g., in the years 1918, 1954-56, 1995).

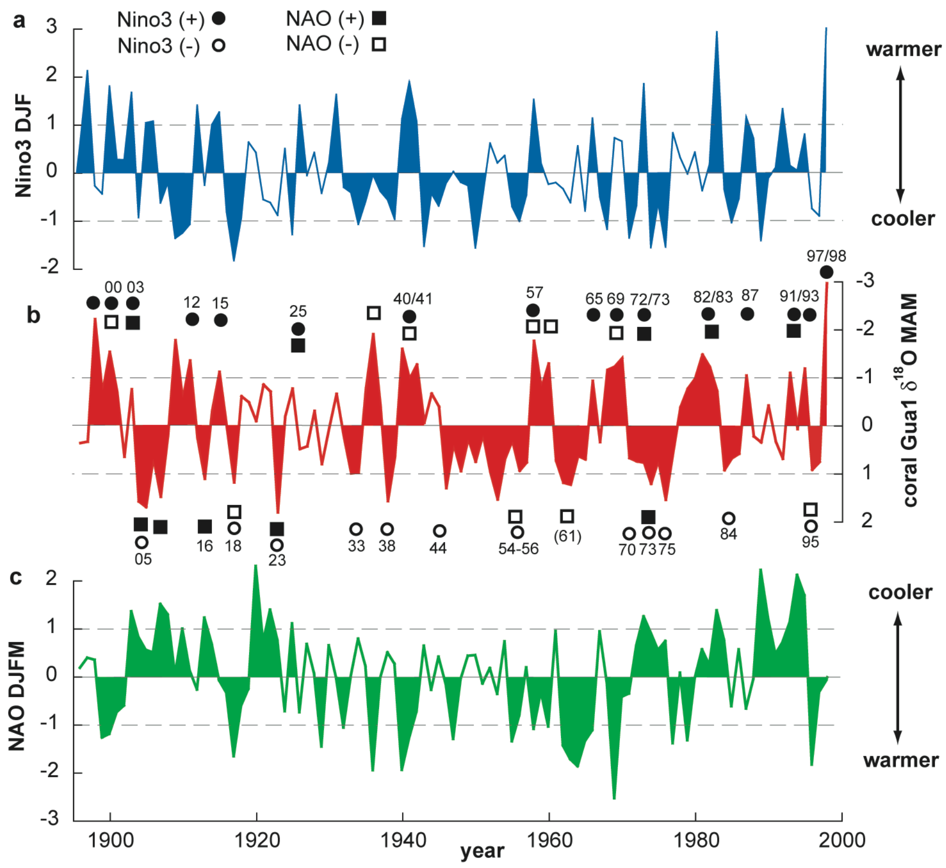


Figure 4-10. **Comparison between seasonal mean values of (a) the winter Nino3 index (DJF, blue curve, defined as monthly resolved mean SST anomalies averaged over the region 5°S to 5°N and 90°W to 150°W), (b) Gua1 coral oxygen isotopes from the following spring (MAM, red curve), and (c) the winter NAO index (Jones et al., 1997) (DJFM, green curve). Years of high (larger than +1 STD) and low (lower than –1 STD) phases of Gua1 $\delta^{18}O$, Nino3 and NAO are indicated as filled curves. In (b), high and low phases of the Nino3 (NAO index), which correspond to years with high/low peaks in the $\delta^{18}O$ time series, were marked with filled and unfilled circles (squares), respectively. Numbers above circles indicate the years of strong El Niño (positive)/La Niña (negative) events for the 20th century (as defined by exceeding ± 1 STD in the Nino3 index). All time series were normalized and linearly detrended prior to analysis (STD = standard deviation). Note the reversal of the y-axis in (b) coral $\delta^{18}O$.**

On the other hand, the SST-signal in the coral $\delta^{18}O$ time series gets enhanced when a positive ENSO phase and a negative NAO phase add up constructively to build up a warm anomaly in the NTA region (e.g., in the years 1941, 1957, and most pronounced in 1969, where a strong negative NAO phase prevailed; Fig. 4-10). Again, the same mechanism applies when a negative ENSO phase coincides with a positive NAO event to build up a cool anomaly (e.g., in the year 1923). However, the relationship is not always valid, e.g., the year 1961 is an exception, with a negative NAO event observable in the record (Fig. 4-10) and with no ENSO event in the same year. Based on the above theory, this constellation of external forcings should lead to anomalously warm SST in the NTA region, but we observe positive coral $\delta^{18}O$ values, which usually indicate colder conditions.

Table 4-3 gives a summary of the quantitative comparison between the seasonally averaged coral $\delta^{18}O$ record and the Nino3 (NAO) index (Fig. 4-10). Our analysis indicates that over 17 warm events (negative $\delta^{18}O$) counted in the coral time series (1896-1998), only 2 are not either related to ENSO or the NAO. A similar pattern is observable for the cool events (positive $\delta^{18}O$). 14 out of 15 cool events observed in the coral $\delta^{18}O$ are either related to ENSO, the NAO, or a combination of both (Table 4-3). A quantitative comparison between coral Sr/Ca (averaged over the same season as coral $\delta^{18}O$) and the NAO and Nino3 indices in winter (not shown) indicates that the Sr/Ca time series is able to capture the warm/cool SST events in the NTA region only to a lesser degree than coral $\delta^{18}O$.

Gua1 $\delta^{18}O$ March-May	no. of events in d18O	related to ENSO or NAO or combination	related to ENSO (only)	related to NAO (only)	ENSO / NAO combination	neither NAO nor ENSO related
<= -1 STD (warm)	17	**15**	7	2	6	**2**
>= +1 STD (cool)	15	**14**	5	2	7	**1**

<u>Table 4-3.</u> Statistics based on Figure 10: Years with strong ENSO/NAO activity and events in coral $\delta^{18}O$ for the 1896-1999 time period are defined as being larger than 1 STD and lower than -1 STD. The number of positive and negative events in the Gua1 coral $\delta^{18}O$ (March-May) record are given, as well as the number of positive (negative) ENSO and NAO events. The indices are defined over the months December-February (ENSO, Nino3 index) and December-March (NAO, Jones et al. (1997)) for the 1896-1999 time interval.

In summary, after examining the dependence of NTA SST variability on remote forcings by climate variability outside the tropical Atlantic via studying a seasonally resolved coral-based proxy record, our results confirm the observations made by Czaja et al. (2002), who interpreted the NTA SST variability as being largely a response to remote NAO and/or ENSO forcing. Furthermore, our proxy-based study supports the hypothesis for an opposite phase relationship between the NAO and ENSO. The results from a quantitative comparison between single positive/negative ENSO/NAO events and the respective events recorded in a coral $\delta^{18}O$ time series have clearly shown that external forcings (NAO and ENSO) can interfere constructively to build SST anomalies in the NTA region throughout the 20th century.

Results outlined in the previous paragraph indicate that the Guadeloupe coral $\delta^{18}O$ record successfully captures the ENSO teleconnection to the Caribbean. This is confirmed in Figure 4-11, where we examine the correlation between seasonal coral proxies and climate indices through time. A running correlation analysis between coral $\delta^{18}O$ (MAM) and the Nino3 index (DJF) indicates high and robust correlations between the 1920s and present (Fig. 4-11a). The correlation coefficients between both time series decrease before around 1920. Similar, but marginally weaker correlations are observed between coral Sr/Ca and Nino3 (Fig. 4-11c).

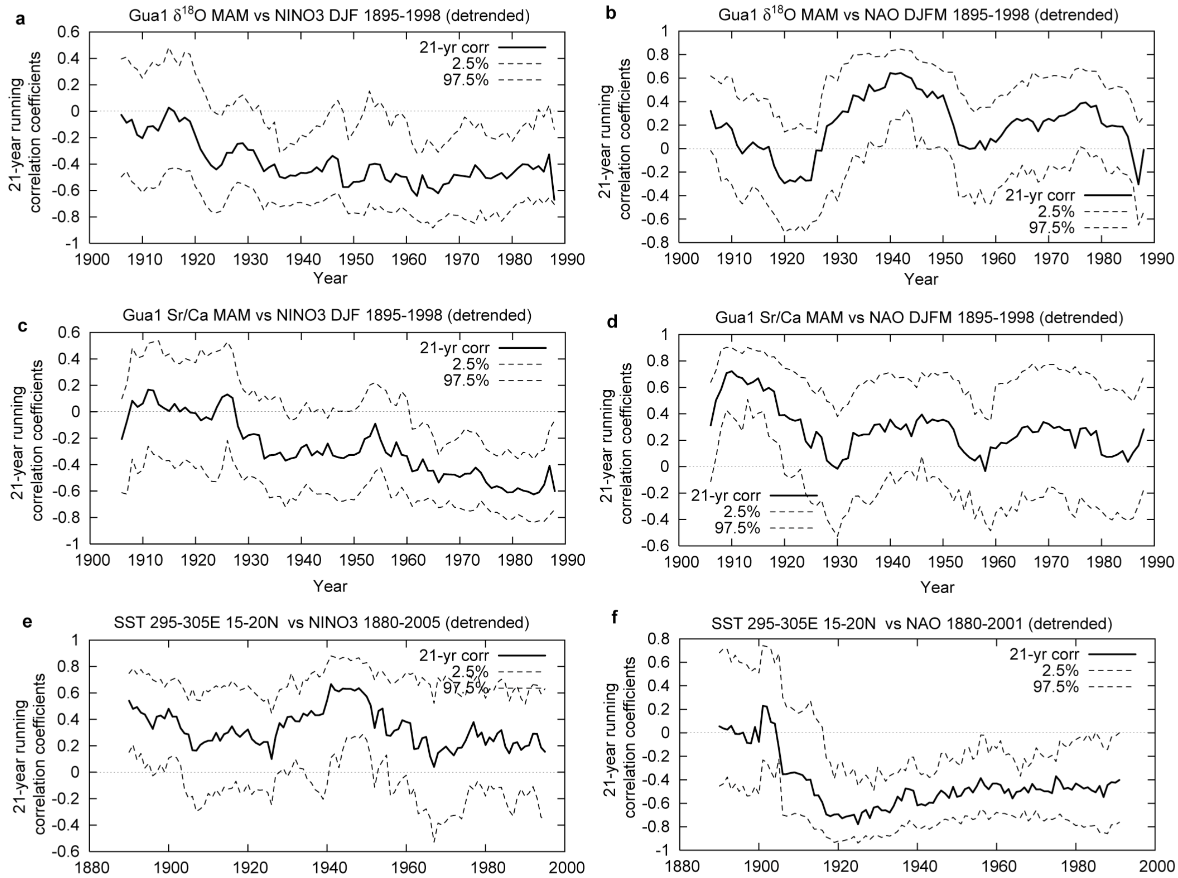


Figure 4-11. Running correlation coefficients between seasonally averaged coral $\delta^{18}O$ (MAM) and (a) Nino3 index (DJF) (Kaplan et al., 1998), and (b) NAO index (Jones et al., 1997) (DJFM); and between coral Sr/Ca (MAM) and (c) Nino3 index (DJF), and (d) NAO index (DJFM). An SST average was computed for the grid box 15°-20°N and 55°-65°W including the study site using annual mean ERSST.v2 data. In (e), this SST average is correlated to the Nino3 index (annual averages), and in (f) to the NAO index, respectively. Correlations are computed using 21-year sliding windows. Confidence limits on correlation coefficients (dashed lines) were calculated with bootstrap methods (1000 sample Monte Carlo). Correlation coefficients are plotted at the midpoint of each 21-year window and were computed at http://climexp.knmi.nl/ (van Oldenborgh and Burgers, 2005).

Both coral proxies display more consistent and stronger correlations to the Pacific ENSO than locally averaged grid-SST data (Fig. 4-11e). In contrast, the correlation coefficients between coral $\delta^{18}O$ (Sr/Ca) and the NAO index are highly variable on decadal-to-multidecadal time scales (Fig. 4-11b,d). The change in the relationship between coral $\delta^{18}O$ and ENSO (Nino3 index) around the 1920s is similar to the decrease in correlation observed between coral $\delta^{18}O$ and local SST at around the same time (Fig. 4-5a). A similar decoupling was reported for SST and the NAO in the 1920s (Paeth et al., 2003; Rodwell et al., 1999) (Fig. 4-11e) and has been linked to a phase reversal from positive to negative correlations between the NAO index and SST between the turn of the 19/20th century to around 1930.
Consistent with the findings shown in Figure 4-10 and Table 4-3, which demonstrate that more positive/negative events in the coral $\delta^{18}O$ time series can be related directly to the influence of ENSO rather than to the NAO, the high correlations between coral proxies and the Nino3 index (Fig. 4-11) also suggest a stronger influence of the ENSO on climate at the study site.

Variability in time-frequency space: Interannual variability

In order to analyze the relationship between coral $\delta^{18}O$ and the two prominent modes of external forcing on NTA climate variability, ENSO and the NAO, in time-frequency space, we have performed statistical analysis of time series for the period 1896-1998. A BT cross-spectral analysis between seasonally averaged coral $\delta^{18}O$ and the winter Nino3 index (Fig. 4-12a) indicates that the time series are coherent at periods of around 2 to 4 years. Cross-spectral analysis between the coral $\delta^{18}O$ (MAM) and the winter NAO index (Jones et al., 1997) indicates that the two time series are coherent at the decadal-to-interdecadal band, but not on interannual scales (Fig. 4-12b).

In addition, we have computed wavelet coherence spectra (Fig. 4-12c,d), which can be used to find regions in time frequency space where two time series co-vary (but do not necessarily have high common power (Grinsted et al., 2004)). Results from wavelet coherency spectra calculated between seasonally averaged coral $\delta^{18}O$ (MAM) and the NAO (DJFM) and Nino3 (DJF) indices show that coherency exists between coral $\delta^{18}O$ and both climate indices on interannual scale (around 2-5 years; Fig. 4-12c,d). The same coherency pattern was found in the interannual band in the previous Blackman-Tukey cross spectral analysis of coral $\delta^{18}O$ and Nino3 (Fig. 4-12a), whereas no coherency exists between coral $\delta^{18}O$ and the NAO in the interannual band (Fig. 4-12b). This relationship strongly suggests that the interannual variability seen in the coral $\delta^{18}O$ record is related to ENSO (see also Fig. 4-8a-d). However, regarding the variation of coherency with time, we note that the coherency between coral $\delta^{18}O$ record and Nino3 index at the 2-3 year band seems to be reduced between 1910 and 1930, whereas at the same time the coherency between $\delta^{18}O$ and

NAO is increased (Fig. 4-12 c,d). This pattern is even stronger pronounced in the Sr/Ca record (compare Fig. 4-12c,d to Fig. 4-13c,d).

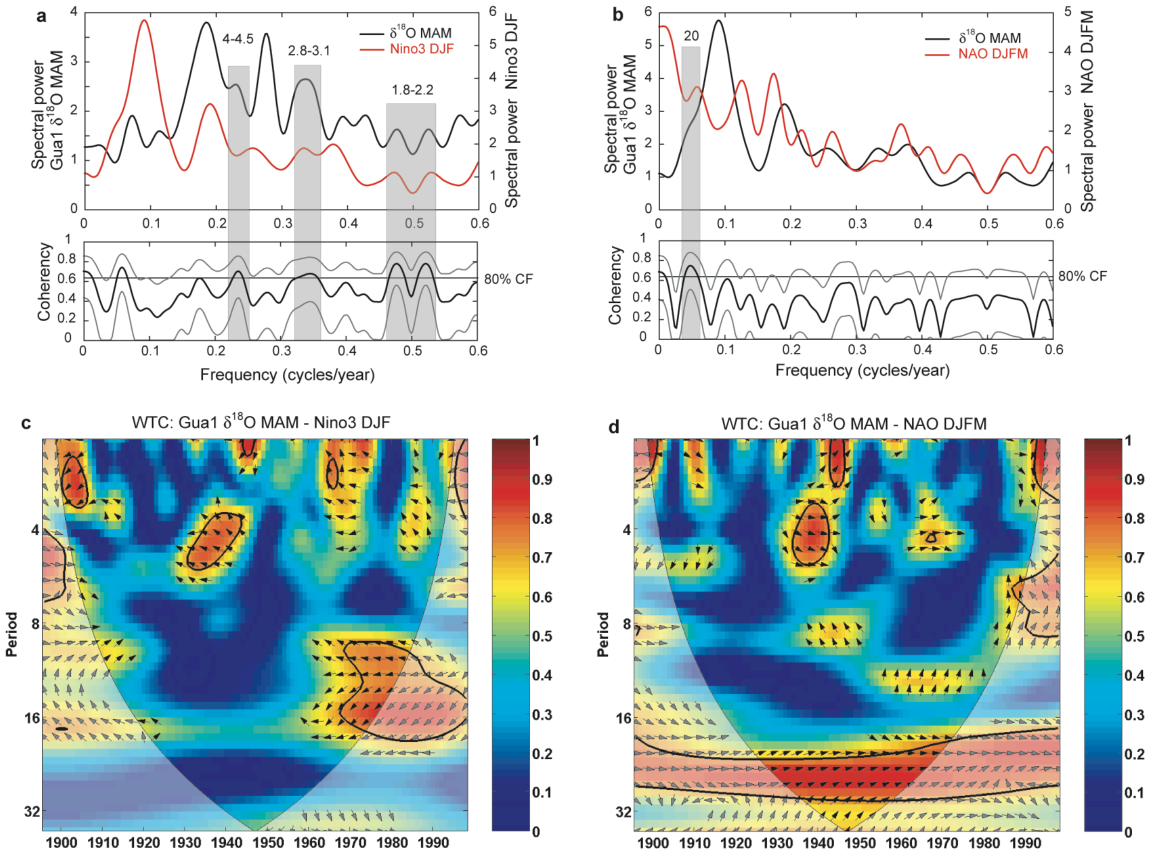
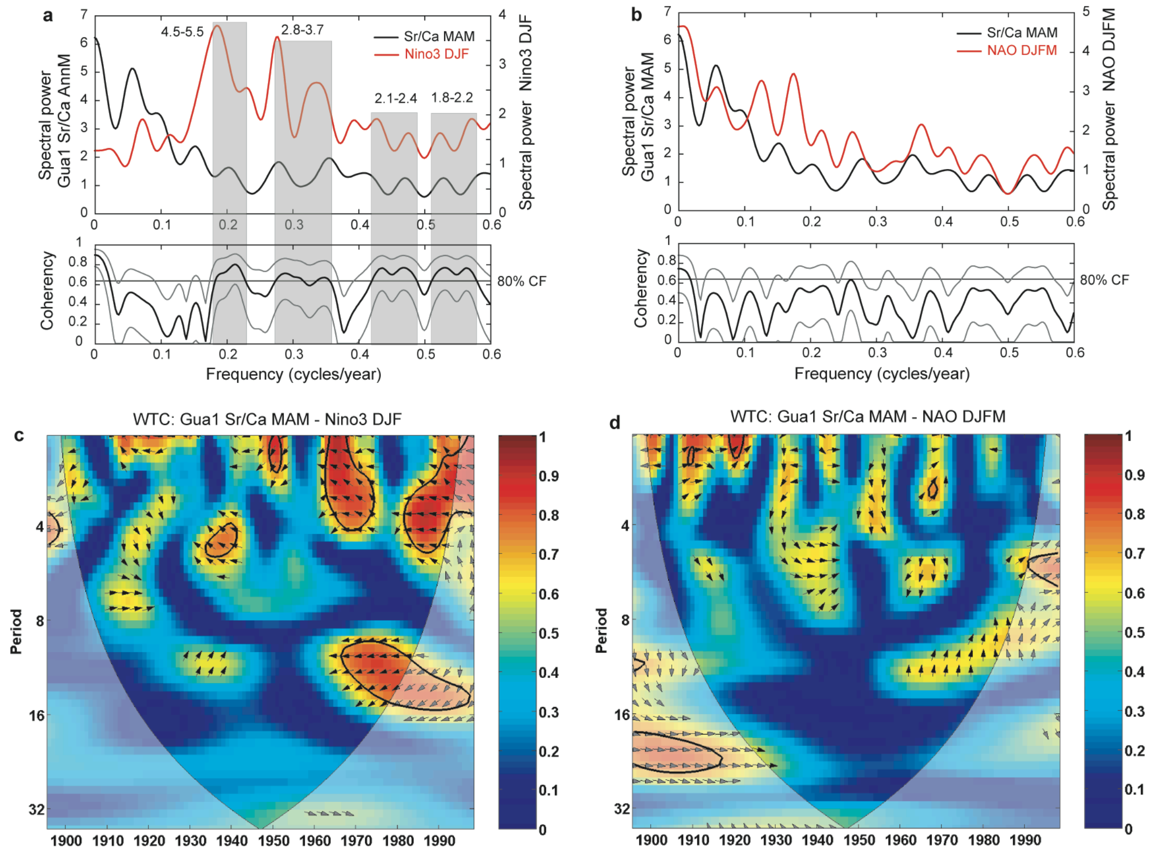


Figure 4-12. Results of a Blackman-Tukey cross-spectral analysis between seasonally averaged coral $\delta^{18}O$ (MAM) and (a) the Nino3 index in winter (DJF), and (b) the winter NAO index (DJFM) for the time period 1895-1999 calculated with the Analyseries software package (Paillard et al., 1996). Nonzero coherence is higher than 0.64 (80% level). Results from wavelet coherence spectra between seasonal coral $\delta^{18}O$ (MAM) and (c) the Nino3 index for winter (DJF), and (d) the NAO index (DJFM). The plots were computed using wavelet coherency software by Grinsted et al. (2004). Thick black contour indicates the 5% significance level against red noise.

Cross BT analysis between coral Sr/Ca and Nino3 index (Fig. 4-13a) displays significant coherency between both time series on interannual time scales (around 2-5 years) similar to the pattern observed previously for the coral $\delta^{18}O$ record. In contrast, no coherency was found between coral Sr/Ca (MAM) and the NAO (Fig. 4-13b).

Wavelet coherency spectra computed between seasonal coral Sr/Ca (MAM) and the Nino3 (DJF) and NAO (DJFM) indices have revealed the following patterns: No coherence exists between the seasonally averaged coral Sr/Ca and the Nino3 index before 1930 (Figure 4-13c). From the 1930s towards the present high coherency is evident on interannual time scales with periods around 2-5 years. An opposing pattern is observed in the spectrum between coral Sr/Ca and NAO. Before approximately 1930 coherency on interannual scale is observed between both time series (Fig. 4-13d), whereas no coherency is evident from the 1940s towards the present.



<u>Figure 4-13.</u> Results from cross BT analysis between coral Sr/Ca (MAM) and (a) the Nino3 index in winter (DJF), and (b) the winter NAO index (DJFM). Nonzero coherence is higher than 0.64 (80% level). (c) shows wavelet coherence spectra between seasonal coral Sr/Ca (MAM) and the Nino3 index for winter (DJF), and in (d) between coral Sr/Ca (MAM) and the NAO index (DJFM).

A study by Hurrell et al. (2003) has indicated that regarding the spectral behaviour of the NAO index, no preferred time scale of NAO variability is evident. In general, enhanced power is observed at quasi-biennial periods and in the decadal band, but no significant peaks are evident. A study by Hurrell and van Loon (1997) has examined the time evolution of these spectral signals using a station based NAO index, and has shown that the quasi-biennial variance was enhanced in the late 19th and early 20th centuries, whereas the variance in the decadal band was enhanced over the latter half of the 20th century. This pattern corresponds very well to the results from wavelet coherence spectral analyses of both Guadeloupe coral proxies which suggest a shift in coherency between coral proxy data and the NAO/ENSO systems around 1930. The coral data imply an influence of the NAO on interannual climate variability in the tropical Atlantic from the beginning of the 20^{th} century to around 1930. From around the 1930s, variability on interannual time scales seems to be related to Pacific ENSO forcing.

Hence, our observations, which indicate the existence of a strong relationship between interannual variability in coral proxies and the Pacific ENSO system, are consistent with recent analyses suggesting that interannual variability of the NTA SST mode is largely dictated by the ENSO (e.g., Czaja et al., 2002; Wu et al., 2004). According to these studies, the remote influence of ENSO dominates over NAO at interannual timescales (2-7 years) through the 20^{th} century, but has less impact on the decadal variability in the tropical Atlantic region.

Variability in time-frequency space: Decadal to interdecadal variability

Both the MTM and the wavelet power spectrum provide evidence for a significant decadal variability in the coral $\delta^{18}O$ time series with a period of approximately 8-14 years (Fig. 4-8b-d). A wavelet coherence analysis between coral $\delta^{18}O$ and the Nino3 index shows no coherency on the decadal band from 1895 to around 1960. Beginning with the mid 1960s, coherency between the records on decadal scale (around 9 to 16 years) is observed up to present. However, this signal has to be interpreted with caution because after the mid 1980s variance is reduced in this band due to zero-padding (Fig. 4-12c). A much stronger coherency is found between coral $\delta^{18}O$ and the NAO. Figure 4-12d displays strong decadal-to-interdecadal coherency between coral $\delta^{18}O$ and the NAO index throughout the entire period of record. This result is consistent with the coherency found between coral $\delta^{18}O$ and the NAO in the same band using BT cross-spectral analysis (Fig. 4-12b). Hence, we interpret this signal to be robust and infer from the results of the different spectral analyses that the influence of the NAO on the coral $\delta^{18}O$ record dominates over the influence of the ENSO system at decadal and longer timescales.

A decadal signal in seasonal coral Sr/Ca is evident only from the late 1960s until the mid-1980s (Fig. 4-8f), whereas no significant decadal signal is present in the MTM analysis of coral Sr/Ca (Fig. 4-8h), and cross spectral analysis indicates no obvious relationship between coral Sr/Ca and Nino3 and NAO on decadal time scales (Fig. 4-13a,b). The wavelet coherency analysis shows evidence for coherency between coral Sr/Ca and Nino3 on the decadal band only from the late 1960s (Fig. 4-13c). This pattern is similar to the coherency found between coral $\delta^{18}O$ and Nino3 (compare Figs. 4-12c and 4-13c). However, both wavelet coherency analysis and cross BT analysis show no coherency between coral Sr/Ca and the NAO on decadal time scales as previously observed for coral $\delta^{18}O$ (Fig. 4-13b,d). Thus, we suppose that coral Sr/Ca is able to reflect decadal variability only to a weaker degree than coral $\delta^{18}O$.

Based on the consistent results obtained through different spectral analysis tools, we interpret the decadal to interdecadal signal found in the coral $\delta^{18}O$ time series as robust (Figs. 4-8, 4-12, 4-13). Decadal to interdecadal variability captured by this proxy record is similar to the variability of tropical Atlantic climate on the same timescale found by other studies using observational- and model-based approaches. However, the mechanisms underlying the observed low-frequency climate phenomena in the Atlantic are complex and subject of intensive discussion (e.g., Dommenget and Latif, 2000; Enfield and Mayer, 1997; Huang et al., 2004; Hurrell, 1995; Hurrell and van Loon, 1997; Kushnir et al., 2002; Marshall et al., 2001; Nobre and Shukla, 1996; Xie and Carton, 2004; Xie and Tanimoto, 1998). Low-frequency climate variability in the tropical Atlantic region appears to be closely linked to decadal to interdecadal fluctuations in tropical Atlantic SST (Marshall et al., 2001). Several studies have observed significant decadal-interdecadal scale variability (with a period of around 8-20 years) in tropical Atlantic SST, precipitation, and the frequency of tropical cyclones (Carton et al., 1996; Chang et al., 1997; Elsner et al., 2000; Gray et al., 1997; Handoh et al., 2006; Joyce et al., 2000).

Our analyses suggest that the strong decadal-to-interdecadal scale variability evident throughout the coral $\delta^{18}O$ record is related to the NAO, which is in good correspondence to the results of Czaja et al. (2002), who found that the influence of the NAO dominates over ENSO on timescales longer than decadal and accounts for approximately half of the low-frequency variability of SST in the NTA region.

Summary and Conclusions

We have produced a 104-year high-resolution record of climate variability in the eastern Caribbean Sea based on variations in oxygen isotopes and Sr/Ca measured in a coral core from Guadeloupe Island, Lesser Antilles. Our analysis of the geochemical proxy time series leads to the following conclusions:

1. Both coral proxies are linearly correlated over the entire period of record on monthly and on mean annual scales and display robust relationships to SST until around 1950. Calibration equations are consistent with published values from other coral species and regions.
2. Both coral $\delta^{18}O$ and Sr/Ca exhibit a decreasing trend, which is most pronounced since the mid-1970s and is similar to the increase in SST and air temperature at the study site, around the same time when instrumental observations registered widespread changes in tropical climate. The trend to lower values is stronger pronounced in coral Sr/Ca than in the $\delta^{18}O$ record, and represents a warming of approximately 1.1-2°C, coherent with the increase in air temperature observed near the study site, which is much stronger than the warming of SSTs. Coral Sr/Ca reliably records the strong surface temperature increase at the study site and is even higher correlated to *in-situ* air temperature than to gridded SST data. Hence, coral Sr/Ca can be utilized as a reliable proxy for local annual to interannual temperature variations.
3. The $\delta^{18}O_{sw}$ contribution to coral $\delta^{18}O$ was estimated by calculating the $\delta^{18}O_{residual}$ via subtracting the temperature component from measured coral $\delta^{18}O$ using Sr/Ca-derived

temperature. Coral $\delta^{18}O_{residual(Sr/Ca)}$ and regional precipitation are highly correlated at low frequencies until the middle of the 20th century, documenting that coral $\delta^{18}O$ is also influenced by the hydrological cycle.

4. The coral $\delta^{18}O$ and Sr/Ca time series contain abundant interannual- to interdecadal-scale variability. Results from different spectral analysis tools indicate that variability in the decadal band is the dominant signal in the coral $\delta^{18}O$ time series. In contrast, strongest variability in the coral Sr/Ca record is found in the interannual band. Cross coherency analysis indicates that coral $\delta^{18}O$ and Sr/Ca variations at Guadeloupe are coherent and suggests that both proxies respond to similar forcing.
5. Coral $\delta^{18}O$ shows a close relationship to major climate signals affecting the seasonal cycle of SST in the NTA region. A running correlation analysis reveals that the coral $\delta^{18}O$ record from Guadeloupe successfully captures the ENSO teleconnection to the Caribbean, whereas the relationship between coral $\delta^{18}O$ and the NAO is highly variable on decadal-to-multidecadal time scales.
6. Between 1896 and 1998 only 1 (2) out of 15 (17) extreme positive (negative) events captured by the seasonally averaged coral $\delta^{18}O$ record cannot be explained by external forcing through either ENSO or NAO related influence. It is indicated that the ENSO exerts the strongest interannual scale influence on the study site, confirming the observations made by Czaja et al. (2002), who interpreted the NTA SST variability as being largely a response to remote NAO and/or ENSO forcing. Hence, our proxy-based study provides evidence that external forcings play an important role in NTA climate variability, as well as their influence can interfere constructively to build SST anomalies in the NTA region throughout the 20th century.
7. Results from cross-spectral and wavelet coherency analyses between coral proxies and climate variables suggest that interannual climate variability at the study site is largely dictated by Pacific ENSO forcing, whereas at decadal and longer timescales the influence of the NAO dominates over the ENSO influence.

In summary, the Guadeloupe record (1895-1999) provides a first-rate measure of climate variability in the Caribbean and NTA region over the last century on seasonal to interdecadal time scales and represents the, so far, longest high-resolution multi-proxy coral record from the Atlantic region. In the future, the obtained proxy-SST calibrations from modern fast-growing *Diploria strigosa* corals can also be used for the calibration of fossil coral specimens from the same area. Records from different coral colonies that exhibit overlapping life-spans can be spliced together in order to generate multi-specimen records or master chronologies (Cobb et al., 2003), similar to techniques commonly used in dendrochronology. Hence, understanding the modern relationships between climate variability and coral geochemistry of the Guadeloupe record provides the basis for interpreting fossil coral records of the same species and helps to interpret climate variability in the geologic past.

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CHAPTER 5

Caribbean coral tracks Atlantic Multidecadal Oscillation and past hurricane activity

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ABSTRACT

It is highly debated whether or not global warming contributed to the strong hurricane activity observed during the last decade. The crux of the recent debate is the limited length of the reliable instrumental record that exacerbates the detection of possible long-term changes in hurricane activity, which naturally exhibits strong multidecadal variations that are associated with the Atlantic Multidecadal Oscillation (AMO). The AMO, itself a major mode of climate variability, remains also poorly understood because of limited data.

Here, we present the first marine coral-based proxy record ($\delta^{18}O$) that clearly captures multidecadal variations in hurricane activity and the AMO. Our record, obtained from a brain coral situated in the Atlantic hurricane domain, is equally sensitive to variations in SST and seawater $\delta^{18}O$ ($\delta^{18}O_{sw}$), with the latter being strongly linked to precipitation, by this means amplifying large-scale climate signals in coral $\delta^{18}O$. The coral provides the longest, so far, continuous proxy-based record of hurricane activity, and interestingly exhibits a long-term increase over the last century. As multidecadal SST variations in this region are closely related to the AMO, this study raises new possibilities to extend the limited observations and to gain new insights into the mechanisms underlying the AMO and long-term hurricane variations.

INTRODUCTION

The 2005 hurricane season gave a dramatic outlook on the extreme socio-economic consequences of above normal hurricane years. Improved knowledge of long-term changes in hurricanes is of great importance, since the population of coastal areas affected directly by landfalls of major hurricanes is increasing. Some studies have argued that the recent changes in hurricane activity are only part of natural multidecadal cycles (e.g., Goldenberg et al., 2001), while others suggest that anthropogenic climate change may play a substantial role in this increase (Emanuel, 2005; Mann and Emanuel, 2006; Webster et al., 2005). It is well established that hurricanes form over the tropical oceans in regions where SSTs exceed 26°C (Gray, 1968). Theory and observations indicate that hurricane activity is most sensitive to small increases in SST between 26-29°C (DeMaria and Kaplan, 1994). In the Atlantic region, SSTs and hurricane activity display strong variations on interannual to multidecadal time scales. Recent studies suggest that decadal-to-multidecadal SST variability in the North Atlantic, which has been referred to as Atlantic Multidecadal Oscillation (Kerr, 2000), affects the number of hurricanes forming in the northern tropical Atlantic (Goldenberg et al., 2001).

Observations show a nonlinear upward trend in tropical Atlantic SST over the 20th century. The trend, which is superimposed on natural multidecadal variability, has been linked to human-induced global warming (Houghton et al., 2001). However, it is still under debate how much of the observed warming in the tropical Atlantic can be attributed to the influences of anthropogenic climate change (Mann and Emanuel, 2006). This is largely because temporal and spatial resolution of observed SST decreases rapidly in the early historical record.

Despite the SST trend, no evidence for a secular increase in hurricane activity has been found when examining the frequency of hurricane occurrence solely (Pielke Jr., 2005b). A different picture unfolds for storm intensity. Model simulations indicate a tendency for more intense hurricanes in greenhouse gas-induced climate change scenarios (Knutson and Tuleya, 2004), although the magnitude and timing of the expected change in hurricane intensity remains unclear. It has been suggested that tropical cyclone intensity is correlated with multidecadal fluctuations of North Atlantic SST (Gray, 1990; Latif et al., 2007), and several recent studies (Hoyos et al., 2006; Webster et al., 2005) provide evidence for a direct link between hurricane intensity and SST changes in the hurricane formation regions. Unfortunately, the record of Atlantic hurricane activity is not considered very reliable before 1944, when routine aircraft reconnaissance in the Atlantic started (Goldenberg et al., 2001). Therefore, the length of this record is too short to detect long-term changes in hurricane behaviour.

In this context, the most important and highly controversial issue is whether or not the recent upward trend in hurricane activity lies outside the range of natural variability (Landsea et al., 2006; Pielke Jr., 2005a). Longer records are needed, that help to extend the history of Atlantic hurricane activity back in time and shed light onto the causes of the recent upward trend. Long-lived corals from the tropical oceans can provide accurate records of key climatic parameters with a fidelity and temporal resolution comparable to instrumental climate data. The oxygen isotopic composition ($\delta^{18}O$) of coral skeletal aragonite is a function of both SST and seawater $\delta^{18}O$ (Quinn et al., 1998), the latter being dependent mainly on the evaporation-precipitation balance (Delaygue et al., 2000). However, compared to the extensive research employing coral paleoclimate reconstructions from the Indo-Pacific Ocean (Cobb et al., 2003), only few studies have analysed coral proxy records from the tropical Atlantic (e.g., Goodkin et al., 2005; Moses et al., 2006). None of these proxy records provided a clear link to the most important climatic indices in the North Atlantic: the AMO and hurricane activity. A recent study (Hetzinger et al., 2006) has demonstrated for the first time that fast-growing, massive Caribbean brain corals of the species *Diploria strigosa* can provide accurate, monthly resolved records of climate variability in the tropical North Atlantic, the region where Atlantic tropical cyclones develop (the so-called „main development region" or MDR; 10° to 20°N (Goldenberg et al., 2001)).

Here we present a new monthly-resolved coral proxy record ($\delta^{18}O$) from the southeastern Caribbean. We compare a strong multidecadal signal found in the coral record with the dominant mode of low-frequency climate variability in the Atlantic Ocean, the AMO. The utilization of coral $\delta^{18}O$ as a proxy for past hurricane activity, that allows to gain a better understanding of long-term hurricane variations, is assessed by comparing the proxy-based record to an index of Atlantic hurricane activity.

DATA AND METHODS

The Archipelago Los Roques is located approximately 140 km off the northern coast of Venezuela at the southern boundary of the Caribbean Current and reflects open-ocean conditions (Supplementary Figure S1). In December 2004, we drilled a 1.15 m coral core from a hemispherical *Diploria strigosa* colony growing in a water depth of 2 m in the fringing reef near Cayo Sal (11.77°N, 66.75°W), at the southernmost rim of the archipelago. Micro-samples for oxygen isotope analysis were retrieved in 1 mm increments yielding approximately monthly resolution. Coral $\delta^{18}O$ was analyzed using a Thermo Finnigan Gasbench II Deltaplus at IFM-GEOMAR (for detailed descriptions see Supplementary Methods). The monthly $\delta^{18}O$-record extends from 1918 to 2004 (Fig. 5-1a and Fig. S2).

RESULTS AND DISCUSSION

Figure 5-1a confirms that year-to-year variations in coral $\delta^{18}O$ are significantly correlated with SST at the study site. Both coral $\delta^{18}O$ and SST show pronounced multidecadal variations with a period of approximately 60 years (Fig. 5-1b). However, the magnitude of the multidecadal variations in coral $\delta^{18}O$ is larger than expected based on SST alone. The standard deviation of the smoothed SST index shown in Figure 5-1b is 0.12°C (based on SST from the HadISSTv.1.1 database (Rayner et al., 2003)), while the standard deviation of coral $\delta^{18}O$ is 0.06 per mil, which would correspond to 0.3°C, assuming well established relationships. Hence, about 50% of the variance is due to variations in $\delta^{18}O_{sw}$. The $\delta^{18}O_{sw}$ contribution is estimated by calculating the $\delta^{18}O_{residual}$ (i.e., by subtracting the SST component from measured coral $\delta^{18}O$; for details see Supplementary Methods). Figure 5-1c compares the $\delta^{18}O_{residual}$ with a regional precipitation index computed from weather stations in the south-eastern Caribbean including the study site. The $\delta^{18}O_{residual}$ and precipitation are highly correlated at low frequencies. This implies that the $\delta^{18}O_{sw}$ variations are primarily atmospheric-driven. Both indices show pronounced multidecadal fluctuations with a period of approximately 60 years. We note that warmer SSTs at Los Roques broadly coincide with higher precipitation in the south-eastern Caribbean at multidecadal time scales, effectively amplifying the climate signal in the coral $\delta^{18}O$ record (compare Figs. 5-1b and 5-1c).

Previous studies have shown that low-frequency SST variability in the tropical North Atlantic influences the intensity of hurricanes (e.g., Webster et al., 2005). Los Roques coral $\delta^{18}O$ correlates very well with large-scale SST variations in the tropical North Atlantic (Fig. 5-2), especially to

SST in the south-central part of the MDR of Atlantic hurricanes, making this site a very sensitive location for the detection of past changes in hurricane activity. As precipitation co-varies with SST and is largely controlled by static stability of the atmosphere, which is also a controlling factor for hurricane formation, we hypothesize that the coral $\delta^{18}O$ record may be used to infer past changes in hurricane behaviour.

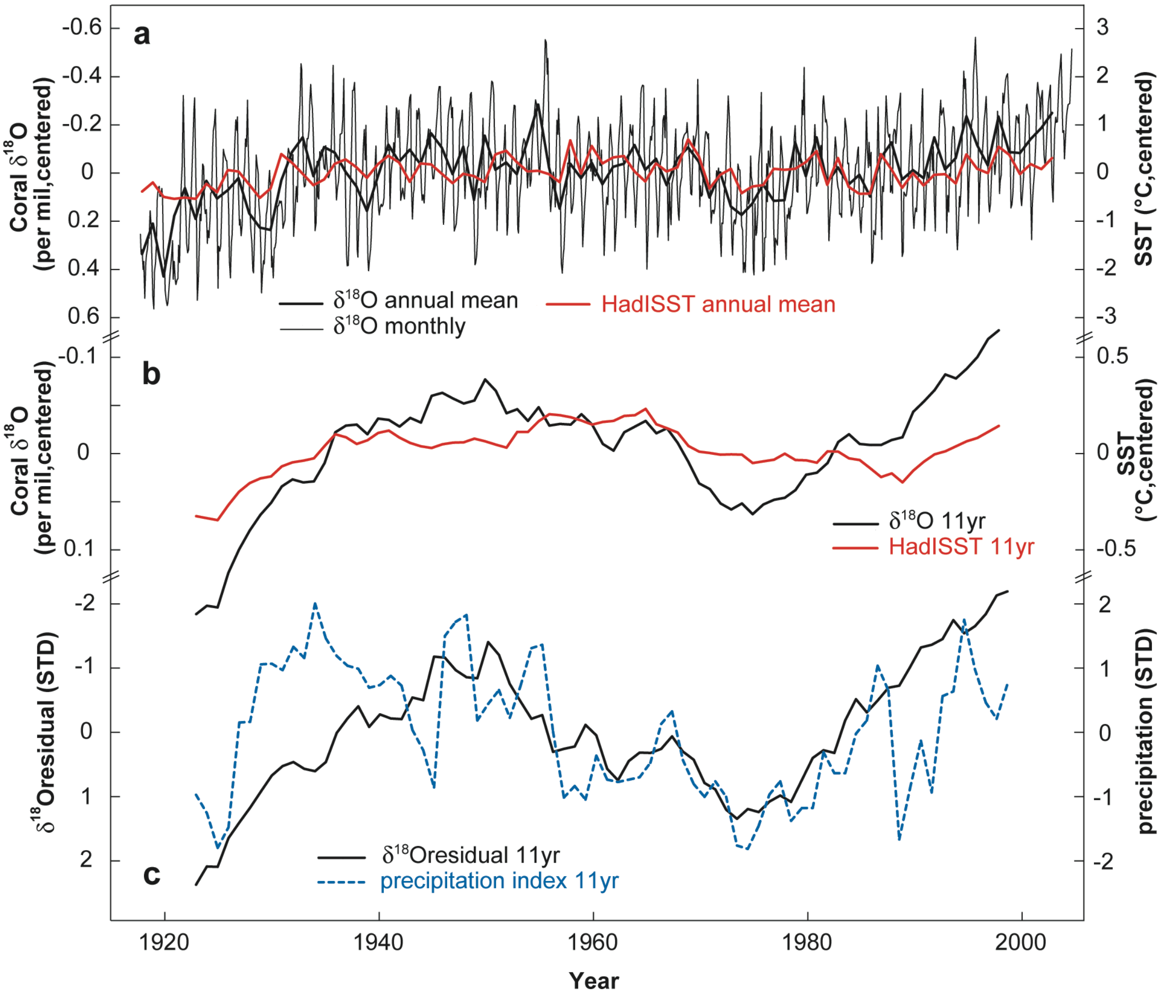

Figure 5-1. Coral $\delta^{18}O$ chronology and climate parameters. (a) Monthly and annual mean oxygen isotopes ($\delta^{18}O$) from the Los Roques coral core compared to annual grid SST (HadISST 1.1) centered on the study site (12°N, 66°W). Coral $\delta^{18}O$ and local SST data are negatively correlated (r = -0.58 for annual means). The correlation is significant at the 1% level, assuming 83 degrees of freedom (DOF). (b) Comparison between coral $\delta^{18}O$ and SST data averaged using an 11-year running filter. The correlation is high (r = -0.69; 1923-1998). Data in (a, b) were centered by subtracting the mean and scaled so that –0.2‰ $\delta^{18}O$ corresponds to 1°C. (c) Coral $\delta^{18}O_{residual}$ compared to a south-eastern Caribbean precipitation index computed from 60 stations for the region 70° to 60°W, 10° to 13°N. Monthly weather station precipitation data was extracted from the Global Historical Climate Network (NOAA NCDC GHCNv.2 obtained at http://iridl.ldeo.columbia.edu/). Both time series were averaged using an 11-year running filter. The correlation is high (r = -0.46; 1923-1998; and r = -0.67 for detrended values). Note: correlations in (b, c) are not significant at the 5% level due to the reduced DOF; even so, it is clear that the multidecadal fluctuations in the $\delta^{18}O_{residual}$ (c) follow the precipitation index. Data shown in (c) were normalized to unit variance (STD = standard deviation) for comparison.

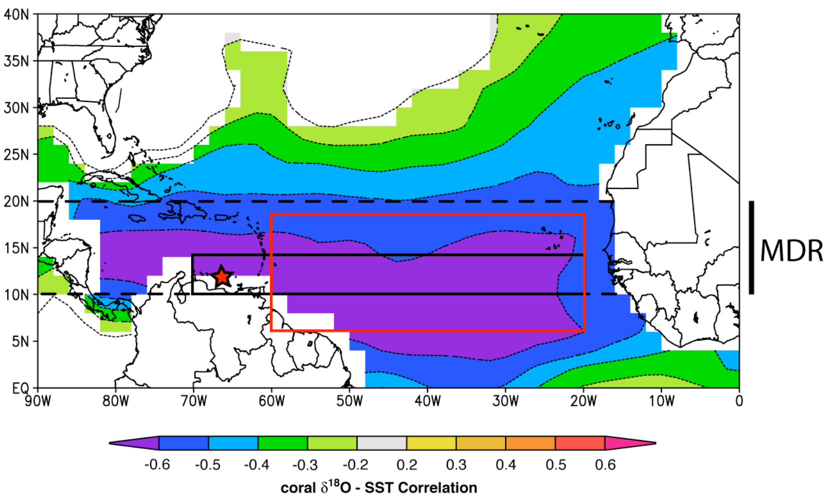

Figure 5-2. Spatial distribution of correlations between annual mean coral δ^{18}O and SST extracted from the NCDCv2 SST dataset (Smith and Reynolds, 2004). Dashed lines indicate northern and southern boundaries (10° to 20°N) of the Main Development Region (MDR) of Atlantic hurricanes. Correlation of coral δ^{18}O and SST is high and significant at the 1% level in the south-central portion of the MDR (black box; 10° to 14°N, 20° to 70°W) used by Goldenberg et al. (2001) (r = -0.67), as well as in the box used by Emanuel (2005) (r = -0.65; red box; 6°-18°N, 20°-60°W). Asterisk marks location of Los Roques study site. Map is created with http://climexp.knmi.nl (van Oldenborgh and Burgers, 2005).

To evaluate this hypothesis, we compare the coral δ^{18}O record to the index of Accumulated Cyclone Energy (ACE), a measure of hurricane activity which takes into account the number, strength and duration of all tropical storms in a season (Bell et al., 2000), and shows pronounced multidecadal variability. An ordinary least squares regression analysis indicates the existence of a strong and statistically significant relationship between seasonal mean August-September-October (ASO) averaged coral δ^{18}O, which represents the climatological peak of the Atlantic hurricane season, and the ACE index (Fig. 5-3a, r = -0.66, 1920-2002). A comparison with the so-called Power Dissipation Index or PDI (Emanuel, 2005), another commonly used hurricane index, revealed similar results (ACE and PDI indices correlate at 0.97 (Klotzbach, 2006)). Note that proxy records with at least seasonal resolution are a prerequisite for the reconstruction of hurricane activity in the tropical North Atlantic, as the hurricane season is restricted to the summer months. The coral proxy record is a particularly good indicator of decadal-multidecadal swings in the ACE index (Fig. 5-3a), and its relationship to the ACE index is equal to or better than the relationship between SST and ACE. The correlations for unsmoothed (5-year mean) summer values (ASO) are r = -0.44 (-0.54) for HadISST averaged over the region most favourable for hurricane development (Emanuel, 2005) (6°-18°N, 20°-60°W) and the ACE, and r = -0.52 (-0.66) between coral δ^{18}O and the ACE index for 1918-2004, and 1920-2002 for the 5-yr running mean, respectively.

These findings corroborate the ability of the coral to record SST variations in the Atlantic hurricane MDR, which are associated with variability of hurricane activity on low frequencies, thereby supporting the results of previous studies (e.g., Emanuel, 2005; Mann and Emanuel, 2006) that have proposed a strong linkage between tropical Atlantic SST and tropical cyclone activity. Hence, our findings suggest that coral-derived proxy data can be used to infer changes in hurricane activity on timescales that extend well beyond the reliable record. This appears to be due to the fact that the coral is sensitive to both SST and SST-covariant changes in precipitation within the MDR that amplify the large-scale climate signals in coral $\delta^{18}O$.

In addition, Figure 5-3a shows a clear and statistically significant negative trend in the coral $\delta^{18}O$ record that is superimposed on the decadal to multidecadal cycles. The observed trend in the coral $\delta^{18}O$ indicates a significant warming and freshening of surface waters in the genesis region of tropical cyclones.

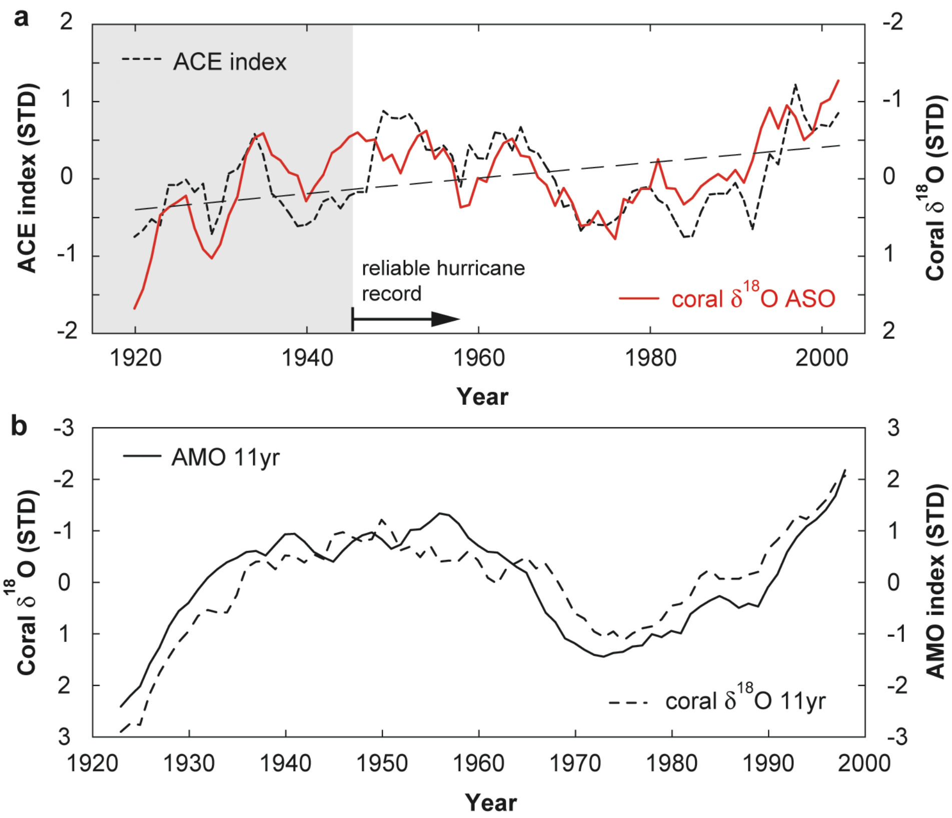

Figure 5-3. (a) Comparison between coral $\delta^{18}O$ and the index of Accumulated Cyclone Energy (ACE) for the North Atlantic. Data shown are for the peak months of the Atlantic hurricane season (August-October; ASO), and were averaged using a 5-year running filter. The correlation is high (r = -0.66) and significant at the 1% level, assuming 14 DOF (1920-2002); r = -0.52 for unsmoothed ASO data (not shown), 1918-2004. Dashed line represents the upward trend seen in coral $\delta^{18}O$ over the 1920-2002 time period. The trend is statistically significant at the 0.1% level, assuming 9 DOF. (b) Comparison between coral $\delta^{18}O$ and the AMO index (North Atlantic SST averaged between 0 and 70°N (Enfield et al., 2001)). Seasonal mean values were removed from the monthly data before averaging to annual resolution. Then an 11-year running filter was applied. The correlation is high (r = -0.86) and statistically significant at the 5% level (r = -0.81), even with only 4 effective DOF.

Making the coral proxy of equal importance, is the close relationship between the decadal to multidecadal cycles in the coral $\delta^{18}O$ and the AMO (Fig. 5-3b). The AMO is the major mode of low-frequency climate variability in the North Atlantic Ocean (Enfield et al., 2001). Its global impacts on climate and ecology are only recently becoming appreciated (Enfield and Cid-Serrano, 2006; Goldenberg et al., 2001; Knight et al., 2006). The mechanisms underlying this multidecadal variability remain controversial, primarily because of the limited instrumental record (Latif et al., 2006). Despite the fundamental importance of the AMO for Northern Hemisphere climate variability, most available reconstructions of the AMO are solely based on continental proxies with annual or lower resolution (Delworth and Mann, 2000; Gray et al., 2004). So far, coral proxies failed to show a clear AMO signature and could not be used for the reconstruction of this important climate mode. In Figure 5-3b, we compare our Los Roques coral $\delta^{18}O$ record with the AMO index of Enfield and co-workers (2001), which provides an index of multidecadal SST anomalies in the Atlantic basin north of the equator. The correlation between the smoothed Los Roques coral $\delta^{18}O$ and the similarly smoothed AMO index is high ($r = -0.86$; Fig. 5-3b) and statistically significant. Owing to the predominance of the AMO signal in the south-eastern Caribbean, both in SST and rainfall (see also Sutton and Hodson (2005), their figure 2E and G), our coral $\delta^{18}O$ index provides an excellent record of multidecadal variability in the North Atlantic Ocean. We suggest the Archipelago Los Roques as an ideal site for coral-based AMO reconstructions in the future.

As *Diploria strigosa* coral colonies are abundant throughout the entire Caribbean and western Atlantic region and can live up to several hundred years, we are confident that corals of this genus will become an important new marine archive that can be used in future studies to reconstruct AMO variability beyond the instrumental record. Long-term, high-resolution reconstructions of AMO variability are of fundamental importance, since observation- and model-based studies (Delworth and Mann, 2000; Folland et al., 1986; Knight et al., 2005; Latif et al., 2004) imply that changes in the strength of the North Atlantic thermohaline circulation (THC) drive the associated multidecadal variability in SST. Thus, long proxy records of AMO variability may be used to infer past THC changes and forecast future THC behavior (Knight et al., 2005). Fossil *Diploria strigosa* corals could provide important insights on changes of the THC in times of different climatic boundary conditions such as glacial/interglacial times.

SUPPLEMENTARY INFORMATION

METHODS

Sampling:

The coral core was sectioned longitudinally into 7 mm thick slabs. The coral slabs were x-rayed in order to expose annual density band couplets. Powdered samples for stable isotope analysis were collected using a low-speed micro drill. The slabs were sampled continuously along the corallite walls (theca), in order to avoid mixing of sample powder from different skeletal elements. Samples for oxygen isotope analysis were retrieved at approximately 1 mm increments, yielding a mean resolution of 12 samples per year.

Oxygen isotope analysis and chronology:

Coral $\delta^{18}O$ was analyzed using a Thermo Finnigan Gasbench II Deltaplus at IFM-GEOMAR. The isotopic ratios are reported in ‰ VPDB relative to NBS 19, and the analytical uncertainty is less than 0.06‰ (1σ).

The chronology was developed on the basis of the seasonal cycle in coral $\delta^{18}O$, and by counting the well-developed annual density bands. The coral $\delta^{18}O$-record extends from 1918 to 2004. Linear interpolation was used in order to obtain monthly resolution for statistical analysis. The uncertainty of the age model is approximately 1-2 months in any given year. The overlapping parts of sampling transects along different thecal walls were used to assess the reproducibility of the oxygen isotopic signal. Reproducibility is excellent (RSD: 1.45%, n = 39).

Calculation of $\delta^{18}O_{residual}$:

The $\delta^{18}O_{residual}$ is calculated by subtracting the temperature component from measured coral $\delta^{18}O$ using instrumental SST (HadISST 1.1). The resulting signal is an estimate of seawater $\delta^{18}O$ ($\delta^{18}O_{sw}$) (Iijima et al., 2005; Linsley et al., 2006). We calculated relative changes of $\delta^{18}O_{sw}$ following the methods described in Linsley et al. (2006) and Ren et al. (2002), assuming a $\delta^{18}O_{coral}$-SST relationship of -0.2 per mil/1°C, which corresponds to the average coral $\delta^{18}O$-SST slope obtained by SST-calibrations of *Porites* corals from the Indo-Pacific (range: -0.18 and -0.22 per mil per 1°C (Gagan et al., 1994; Juillet-Leclerc and Schmidt, 2001; Weber and Woodhead, 1972; Wellington et al., 1996)), and a *Diploria strigosa* coral from the Atlantic (range: -0.18 and -0.20 per mil per 1° (Hetzinger et al., 2006)). We centered the $\delta^{18}O_{residual}$ and smoothed the time series with an 11 point running mean.

Significance of correlations:

All shown correlations were computed using ordinary least squares regression with zero-lag. The significance levels reported were determined using a very conservative estimate of the degrees of freedom (n-2) after taking into account the autocorrelation of the time series. The significance levels were estimated at: http://www.met.rdg.ac.uk/cag/stats/corr.html.

Calculation of mean errors:

The measurement errors of any two isotopic determinations are independent, and the mean error reduces according to the formula: $\sigma_{Total} = (\sigma^2/N)^{1/2}$; where N is the number of independent measurements and σ the analytical error. For annual mean $\delta^{18}O$ values calculated from twelve monthly values, the total analytical uncertainty reduces to ±0.017‰. For 11-year averages the uncertainty reduces to ±0.005‰, respectively.

SUPPLEMENTARY FIGURES S1 AND S2

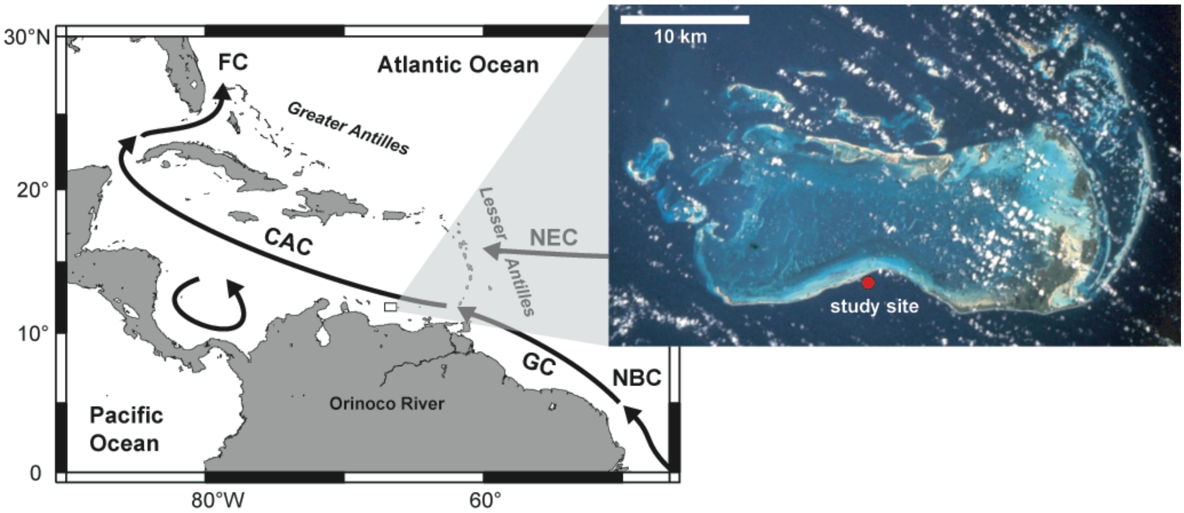

Figure S1. Oceanographic setting of the western tropical Atlantic and Caribbean region showing major surface currents. The small box indicates the location of the study site. The inlet shows the location map of the Los Roques Archipelago. The sampling locality „Cayo Sal" is marked by a red circle. Major surface currents are indicated based on data from Gordon (1967): CAC: Caribbean Current; FC: Florida Current; NBC: North Brazil Current; GC: Guyana Current; NEC: North Equatorial Current. The inlet-image was obtained at http://eol.jsc.nasa.gov and is courtesy of the Earth Sciences and Image Analysis Laboratory, NASA Johnson Space Center.

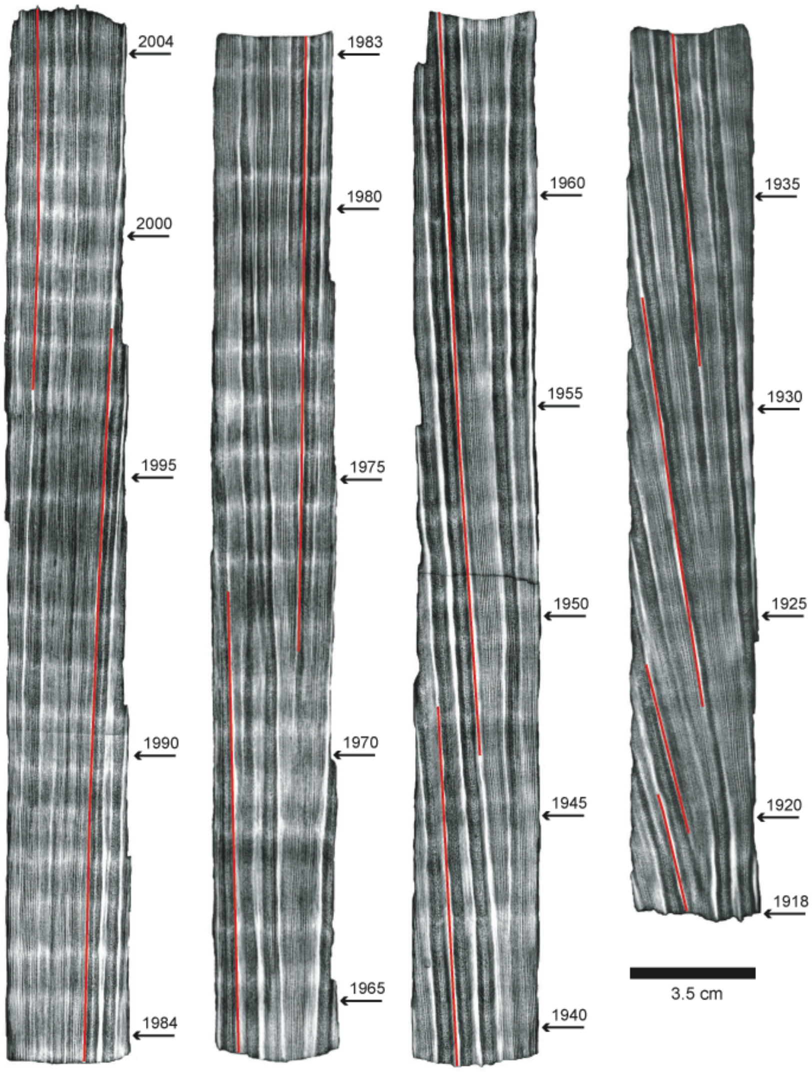

Figure S2. X-radiograph prints of slabs from coral core Roq6 (*Diploria strigosa*). Alternating high (light) and low density (dark) bands can be observed clearly and banding is in a near perpendicular orientation with respect to the axis of the coral core. In the skeletal density banding pattern, one year of coral growth is representated by one high- and low-density band couplet. Years indicate coral chronology. Sampling transects are indicated by red solid vertical lines on each slab. Note the goodness of fit between individual slabs.

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CHAPTER 6 – SUMMARY AND CONCLUSIONS

Within the framework of this thesis cores sampled from living colonies of fast-growing *Diploria strigosa* corals, a previously under-utilized massive-growing and in the tropical Atlantic widely abundant species, were evaluated as potential archives of past climatic variability and environmental changes. This approach allowed for the first time the production of multidecadal to century-long coral-based proxy time series from the Atlantic region, that concurrently display high temporal resolution. Through this combination, the investigation of north tropical Atlantic climate variability is enabled on time scales potentially extending beyond the length of observational records. For this purpose, highly-resolved geochemical multi-proxy records were generated from coral cores that stem from two study sites located in the southeastern Caribbean Sea.

In the following paragraphs, the major conclusions from the previous chapters are summarized, as well as possible future perspectives are outlined.

Summary of chapters 3-5 and major conclusions

A calibration exercise using the upper part of a century-long coral record collected from a massive growing *Diploria strigosa* colony off the southern coast of Guadeloupe island, located at the eastern boundary of the Caribbean Sea, yields robust relationships between measured coral proxies ($\delta^{18}O$ and Sr/Ca) and SST on monthly and on mean annual scales as long as microsampling for geochemical proxies is confined to a single skeletal element (the thecal wall) instead of bulk sampling. The generated coral proxy-SST calibrations are consistent with published values using other coral species from different regions, and represent the first proxy-SST calibration equations for the Atlantic braincoral *Diploria strigosa*. High correlations observed between coral proxies and local air temperature on a mean annual scale demonstrate the applicability of geochemical proxies measured from *Diploria strigosa* corals as reliable recorders for interannual temperature variability at the study site. Moreover, the coral proxies are highly correlated to seasonal and annual mean time series of SST indices from the Caribbean and tropical North Atlantic region, testifying the ability of the *Diploria strigosa* record to track year-to-year variability of SST over a wide region. Because the coral proxy time series are able to resolve the seasonal-scale variability, they meet the criterion for studying seasonally phase-locked climate variations and can potentially be used to detect the seasonal dependence of remote forcing on NTA SST, e.g., by Pacific ENSO events.

In a following study, the entire century-long (1895-1999) multi-proxy record from Guadeloupe was examined with regard to underlying trends and climate signals. Both coral proxies ($\delta^{18}O$ and Sr/Ca) exhibit a decreasing trend during the past decades, which is most pronounced since the mid-1970s. The trend to lower values is stronger pronounced in coral Sr/Ca than in the $\delta^{18}O$ record, and represents a warming of approximately 1.1-2°C, coherent with the increase in air temperature observed near the study site, which is much stronger than the warming of SST. Coral Sr/Ca reliably records the strong surface temperature increase at the study site and is even higher correlated to *in-situ* air temperature than to gridded SST data. Hence, coral Sr/Ca can be utilized as a reliable proxy for local annual to interannual temperature variations. Since coral skeletal $\delta^{18}O$ is not only influenced by water temperature, but also by seawater $\delta^{18}O$ ($\delta^{18}O_{sw}$), the warming calculated from coral $\delta^{18}O$ is lower than the increase observed in air temperature and the warming calculated from coral Sr/Ca alone. The $\delta^{18}O_{sw}$ contribution to coral $\delta^{18}O$ was estimated by calculating the $\delta^{18}O_{residual}$ via subtracting the Sr/Ca-derived temperature component from measured coral $\delta^{18}O$. Coral $\delta^{18}O_{residual(Sr/Ca)}$ and regional precipitation are highly correlated at low frequencies until the middle of the 20th century, documenting that coral $\delta^{18}O$ is influenced by the hydrological cycle as well.

Coral oxygen isotopes capture large-scale climate variability in the NTA region better than Sr/Ca, which reflects rather local temperature variations, and show a close relationship to major climate signals from the tropical Pacific and North Atlantic (ENSO and NAO). Results from a quantitative comparison between extreme events in the respective indices (Nino3 and NAO index) and events recorded in seasonal coral $\delta^{18}O$ imply that SST variability at the study site is highly linked to Pacific and North Atlantic variability, by this means supporting the assumptions of previous observational- and model-based studies which suggest a strong impact of ENSO and NAO forcings onto seasonal NTA climate variability through a modulation of trade wind strength in winter. The proxy-based results provide evidence that the influence of external forcings can interfere constructively to build SST anomalies in the NTA region. As a consequence, nearly all extreme events (positive/negative) in seasonally averaged coral $\delta^{18}O$ record can be connected with external forcing through the ENSO or NAO, with ENSO exerting the strongest influence. Results from cross-spectral and wavelet coherency analyses between coral proxies and climate variables imply that interannual climate variability at Guadeloupe is largely dictated by Pacific ENSO forcing, whereas at decadal and longer timescales the influence of the NAO is dominant.

The Archipelago Los Roques is situated in the southeastern Caribbean Sea, north of the Venezuelan coast, and lies in the pathway of the Caribbean Current, the dominant surface current within the Caribbean basin. This makes Los Roques a very sensitive location for the detection of long-term tropical North Atlantic climate variability. Coral $\delta^{18}O$ obtained from a Los Roques *Diploria strigosa* coral provides a near-century-long (1918-2004) monthly resolved time series that can be utilized to study past climate variability. Year-to-year variations in coral $\delta^{18}O$ are significantly correlated with SST at the study site and large-scale SST variations in the tropical North Atlantic, the main development region (MDR) of Atlantic hurricanes. Both coral $\delta^{18}O$ and local SST show pronounced multidecadal variations. However, the magnitude of the variations in coral $\delta^{18}O$ is larger than expected based on SST alone. About 50% of the variance in coral $\delta^{18}O$ can be explained by variations in $\delta^{18}O_{sw}$, which can be estimated by calculating the $\delta^{18}O_{residual}$ (i.e., by subtracting the temperature component from measured coral $\delta^{18}O$). The $\delta^{18}O_{residual}$ and a regional precipitation index are highly correlated at low frequencies, suggesting that seawater $\delta^{18}O$ variations are primarily atmospheric-driven. In addition, the coral record exhibits a clear negative trend superimposed on the decadal to multidecadal cycles, indicating a significant warming and freshening of surface waters in the genesis region of Atlantic tropical cyclones during the past decades.

Warmer SSTs at Los Roques broadly coincide with higher precipitation in the south-eastern Caribbean at multidecadal time scales, effectively strengthening the climate signal in the coral $\delta^{18}O$ record, which is equally sensitive to both SST and $\delta^{18}O_{sw}$ changes. The latter are largely due to precipitation, which in turn is controlled by the static stability of the atmosphere, which is also a controlling factor for hurricane formation. One important climatic parameter in the tropical Atlantic is the activity of hurricanes. In general, the detection of long-term changes and trends in hurricane activity is hampered due to the limited length of the reliable instrumental record and the known inhomogeneity in the observational databases which result from changes in observing practice and technology over the years. The coral $\delta^{18}O$ record from Los Roques displays a strong and statistically significant relationship to different indices of hurricane activity (the index of Accumulated Cyclone Energy (ACE) (Bell et al., 2000), and the hurricane Power Dissipation Index or PDI (Emanuel, 2005)) during the climatological peak of the Atlantic hurricane season in boreal summer and is a particularly good indicator of decadal-multidecadal swings in these indices. This suggests that coral-derived proxy data from Los Roques can be used to infer changes in past hurricane activity on timescales that extend well beyond the reliable record. Moreover, the coral $\delta^{18}O$ time series from Los Roques provides the longest, so far, continuous proxy-based record of hurricane activity and is the first coral-based record that clearly captures multidecadal variations in hurricane activity. It appears that the combination of both signals (SST and $\delta^{18}O_{sw}$) in coral $\delta^{18}O$ leads to an amplification of large-scale climate signals in the record, and makes coral $\delta^{18}O$ even a better proxy for hurricane activity than SST alone.

Atlantic hurricane activity naturally exhibits strong multidecadal variations that are associated with the AMO, the major mode of low-frequency variability in the North Atlantic Ocean (Kerr, 2000) that has global impacts on climate and ecology (e.g., Enfield and Cid-Serrano, 2006). However, the mechanisms underlying this multidecadal variability remain controversial, primarily because of the limited instrumental record (Latif et al., 2006). The Los Roques coral $\delta^{18}O$ displays strong multidecadal variability with a period of approximately 60 years, that appears to be closely related to the Atlantic Multidecadal Oscillation (AMO). A strong and statistically significant correlation found between the coral and the AMO index corroborates the applicability of coral $\delta^{18}O$ as an excellent tool to study multidecadal climate variability in the Atlantic Ocean.

Outlook – future perspectives

Results from this study have shown that fast-growing *Diploria strigosa* corals from the tropical Atlantic hold great potential as archives for the reconstruction of past environmental parameters and climate variability on a wide range of time scales. As *Diploria strigosa* coral colonies are abundant throughout the entire Caribbean and western tropical Atlantic region and can live up to several hundred years, we are confident that corals of this species will become an important and easily accessible marine archive.

The results obtained from both study sites can be seen as case studies for the development of longer records extending well past industrial times that could help to better quantify the impact of external forcings on interannual and decadal climate variability in the north tropical Atlantic sector, and represent an important step towards understanding low-frequency climate variability and the underlying mechanisms. The development of such records is crucial for the production of long-term high-resolution reconstructions of multidecadal climate variability (e.g., the AMO), that are of fundamental importance, since observation- and model-based studies alike (Delworth and Mann, 2000; Folland et al., 1986; Latif et al., 2004) imply that changes in the strength of the North Atlantic thermohaline circulation (THC) drive the associated multidecadal variability in SST. Thus, long proxy records of AMO variability may be used to infer past THC changes and forecast future THC behavior (Knight et al., 2005). A better knowledge of natural multidecadal variations is also of great significance in order to be able to decipher the substructures, and more importantly, the causes of observed long-term trends in Atlantic climate variables (e.g., in SSTs and hurricane activity), and hence could possibly help to distinguish anthropogenic influences from natural variations in these records.

Due to the isolated setting of the Archipelago Los Roques, which is distant from continental influence (e.g., river runoff) and reflects open ocean conditions, this site is particularly suited for long-term climate reconstructions. The topography of the Los Roques archipelago, which exhibits no significant relief, minimizes the likelihood that environmental parameters of surface waters at the site of coral growth are affected by land effects and localized circulation patterns. The combination of these factors make the Archipelago Los Roques a prime location for further studies of long-term climate variations using corals, and in particular for the reconstruction of low-frequency climate variability beyond pre-industrial times. Therefore, longer coral records from this site shall be developed to reconstruct climate variability even further back in time to answer the question as to whether the statistics of climate variables have changed in response to global warming.

Understanding the modern relationships between climate variability and coral geochemistry provides the basis for interpreting fossil coral records from the same region and help to interpret climate variability in the geologic past. Thereby, the obtained proxy-SST calibrations from modern coral specimens play an important role in the development of long-term reconstructions of environmental variables that extend over multiple centuries, and even millennia, and could provide important insights, e.g., on environmental changes in times of different climatic boundary conditions such as glacial/interglacial times.

CITED REFERENCES

Aharon, P., 1991, Recorders of reef environmental histories: stable isotopes in corals, giant clams, and calcareous algae: Coral Reefs, v. 10, p. 71-90.

Alexander, M., and Scott, J., 2002, The influence of ENSO on air-sea interaction in the Atlantic: Geophysical Research Letters, v. 29, p. doi:10.1029/2001GL014347.

Alibert, C., and McCulloch, M.T., 1997, Strontium/calcium ratios in modern Porites corals from the Great Barrier Reef as a proxy for sea surface temperature: Calibration of the thermometer and monitoring of ENSO: Paleoceanography, v. 12, p. 345-363.

Allison, N., and Finch, A.A., 2004, High-resolution Sr/Ca records in modern *Porites lobata* corals: effects of skeletal extension rate and architecture: Geochemistry Geophysics Geosystems, v. 5, p. doi:10.1029/2004GC000696.

Allison, N., Finch, A.A., Newville, M., and Sutton, S., 2005, Strontium in coral aragonite: 3. Sr coordination and geochemistry in relation to skeletal architecture: Geochimica et Cosmochimica Acta.

Andrade, C.A., and Barton, E.D., 2000, Eddy development and motion in the Caribbean Sea: Journal of Geophysical Research-Oceans, v. 105, p. 26191-26201.

Arkin, P.A., 1982, The relationship between interannual variability in the 200mb tropical wind field and the Southern Oscillation: Monthly Weather Review, v. 110, p. 1393-1404.

Beck, C., Grieser, J., and Rudolf, B., 2005, A new monthly precipitation climatology for the global land areas for the period 1951 to 2000, Climate Status Report 2004: Offenbach, Germany, German Weather Service.

Beck, J.W., Edwards, R.L., Ito, E., Taylor, F.W., Recy, J., Rougerie, F., Joannot, P., and Henin, C., 1992, Sea-Surface Temperature from Coral Skeletal Strontium/Calcium Ratios: Science, v. 257, p. 644-647.

Bell, G.D., Halpert, M.S., Schnell, R.C., Higgins, R.W., Lawrimore, J., Kousky, V.E., Tinker, R., Thiaw, W., Chelliah, M., and Artusa, A., 2000, Climate assessment for 1999: Bulletin American Meteorological Society, v. 81, p. 1328.

Berger, A.L., Melice, J.L., and Hinnov, L., 1991, A strategy for frequency spectra of Quaternary climate records: Climate Dynamics, v. 5, p. 227-240.

Bigg, G.R., and Rohling, E.J., 2000, An oxygen isotope data set for marine waters: Journal of Geophysical Research, v. 105, p. 8527-8535.

Blackman, R.B., and Tukey, J.W., 1958, The Measurement of Power Spectra from the Point of View of Communication Engineering: Mineola, New York, Dover, 190 p.

Bonilla, J., Senior, W., Bugden, J., Zafiriou, O., and Jones, R., 1993, Seasonal distribution of nutrients and primary productivity on the eastern continental shelf of Venezuela as influenced by the Orinoco River: Journal of Geophysical Research, v. 98, p. 2245-2257.

Boyer, T.P., and Levitus, S., 2002, Harmonic analysis of climatological sea surface salinity: Journal of Geophysical Research-Oceans, v. 107, p. doi:10.1029/2001JC000829.

Broecker, W.S., and Peng, T.H., 1982, Tracers in the Sea: New York, Lamont-Doherty Geological Observatory, 690 p.

Cane, M.A., 2005, The evolution of El nino, past and future: Earth and Planetary Science Letters, v. 230, p. 227-240.

Cardinal, D., Hamelin, B., Bard, E., and Pätzold, J., 2001, Sr/Ca, U/Ca and $d^{18}O$ records in recent massive corals from Bermuda: relationships with sea surface temperature: Chemical Geology, v. 176.

Carton, J.A., Cao, X., Giese, B.S., and da Silva, A.M., 1996, Decadal and interannual SST variability in the tropical Atlantic: Journal of Physical Oceanography, v. 26, p. 1165-1175.

Carton, J.A., and Giese, B.S., 2005, SODA: A reanalysis of ocean climate: Journal of Geophysical Research, v. submitted.

Centurioni, L.R., and Niiler, P.P., 2003, On the surface currents of the Caribbean Sea: Geophysical Research Letters.

Chang, P., Ji, L., and Li, H., 1997, A decadal climate variation in the tropical Atlantic Ocean from thermodynamic air-sea interactions: Nature, v. 385.

Chang, P., Ji, L., Li, H., Penland, C., and Matrosova, L., 1998, Prediction of tropical Atlantic sea surface temperature: Geophysical Research Letters, v. 25, p. 1193-1196.

Chang, P., Saravanan, R., Ji, L., and Hegerl, G.C., 2000, The effect of local sea surface temperatures on atmospheric circulation over the tropical Atlantic sector: Journal of Climate, v. 13, p. 2195-2216.

Charles, C.D., Cobb, K., Moore, M.D., and Fairbanks, R.G., 2003, Monsoon-tropical ocean interaction in a network of coral records spanning the 20th century: Marine Geology, v. 201, p. 207-222.

Charles, C.D., Hunter, D.E., and Fairbanks, R.G., 1997, Interaction between the ENSO and the Asian monsoon in a coral record of tropical climate: Science, v. 277, p. 925-928.

Cobb, K.M., Charles, C.D., Cheng, H., and Edwards, R.L., 2003, El Nino/Southern Oscillation and tropical Pacific climate during the last millennium: Nature, v. 424, p. 271-276.

Cobb, K.M., Charles, C.D., and Hunter, D.E., 2001, A central tropical Pacific coral demonstrates Pacific, Indian, and Atlantic decadal climate connections: Geophysical Research Letters, v. 28, p. 2209-2212.

Cohen, A.L., Layne, G.D., and Hart, S.R., 2001, Kinetic controls of skeletal Sr/Ca in a symbiotic coral: Implications for the paleotemperature proxy: Paleoceanography, v. 16, p. 20-26.

Cohen, A.L., and McConnaughey, T.A., 2003, Geochemical Perspectives on Coral Mineralization: Reviews in Mineralogy and Geochemistry, v. 54, p. 151-187.

Cohen, A.L., Owens, K.E., Lane, G.D., and Shimizu, N., 2002, The effect of algal symbionts on the accuracy of Sr/Ca paleotemperatures from coral: Nature, v. 296, p. 331-333.

Cohen, A.L., Smith, S.R., McCartney, M.S., and van Etten, J., 2004, How brain corals record climate: an integration of skeletal structure, growth and chemistry of Diploria labyrinthiformis from Bermuda: Marine Ecology Progress Series, v. 271, p. 147-158.

Cole, J.E., Dunbar, R.B., McClanahan, T.R., and Muthiga, N.A., 2000, Tropical Pacific Forcing of Decadal SST variability in the Western Indian Ocean over the Past Two Centuries: Science, v. 287, p. 617-619.

Cole, J.E., and Fairbanks, R.G., 1990, The Southern Oscillation recorded in the $d^{18}O$ of corals from Tarawa Atoll: Paleoceanography, v. 5, p. 669-683.

Cole, J.E., Fairbanks, R.G., and Shen, G.T., 1993, Recent Variability in the Southern Oscillation: isotopic results from a Tarawa Atoll coral: Science, v. 260, p. 1790-1793.

Corredor, J.E., and Morell, J.E., 2001, Seasonal variation of physical and biogeochemical features in eastern Caribbean Surface Water: Journal of Geophysical Research, v. 106, p. 4517-4525.

Corrège, T., 2006, Sea surface temperature and salinity reconstruction from coral geochemical tracers: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 232, p. 408-428.

Corrège, T., Gagan, M.K., Beck, J.W., Burr, G.S., Cabioch, G., and Le Cornec, F., 2004, Interdecadal variation in the extent of South Pacific tropical waters during the Younger Dryas event: Nature, v. 428, p. 927-929.

Covey, D., and Hastenrath, S., 1978, The Pacific El Nino phenomenon and the Atlantic circulation: Monthly Weather Review, v. 106, p. 1280-1287.

Craig, H., 1957, Isotopic standards for carbon and oxygen correction factors for mass spectrometric analysis of carbon dioxide: Geochimica et Cosmochimica Acta, v. 12, p. 133-149.

Craig, H., and Gordon, L.I., 1965, Deuterium and oxygen 18 variations in the ocean and the marine atmosphere, *in* Tongiorgi, E., ed., Stable Isotopes in Oceanographic studies and Paleotemperatures: Pisa, CNR, p. 9-130.

Crowley, T.J., 2000, Causes of climate change over the past 1000 years: Science, v. 289, p. 270-277.

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

Curtis, S., Adler, R., Huffman, G., Nelkin, E., and Dolvin, D., 2001, Evolution of tropical and extra-tropical precipitation anomalies during the 1997-1999 ENSO cycle: International Journal of Climatology, v. 21, p. 961-973.

Curtis, S., and Hastenrath, S., 1995, Forcing of anomalous sea surface temperature evolution in the tropical Atlantic during Pacific warm events: Journal of Geophysical Research, v. 100, p. 15835-15847.

Czaja, A., 2004, Why is the Tropical Atlantic SST Variability Stronger in Boreal Spring?: Journal of Climate, v. 17, p. 3017-3025.

Czaja, A., van der Vaart, P., and Marshall, J., 2002, A Diagnostic Study of the Role of Remote Forcing in Tropical Atlantic Variability: Journal of Climate, v. 15, p. 3280-3290.

Dana, J.D., 1848, United States Exploring Expedition during the Years 1838-1842 under the Command of Charles Wilkes: Zoophytes, v. 7, p. 121-708.

de Villiers, S., Greaves, M., and Elderfield, H., 2002, An intensity ratio calibration method for the accurate determination of Mg/Ca and Sr/Ca of marine carbonates by ICP-AES: Geochemistry Geophysics Geosystems, v. 3, p. 2001GC000169.

de Villiers, S., Nelson, B.K., and Chivas, A.R., 1995, Biological Controls on Coral Sr/Ca and d18O Reconstructions of Sea Surface Temperature: Science, v. 269, p. 1247-1249.

de Villiers, S., Shen, G.T., and Nelson, B.K., 1994, The Sr/Ca-temperature relationship in coralline aragonite: Influence of variability in $(Sr/Ca)_{seawater}$ and skeletal growth parameters: Geochimica et Cosmochimica Acta, v. 58, p. 197-208.

Delaygue, G., Jouzel, J., and Dutay, J.-C., 2000, Oxygen 18-salinity relationship simulated by an oceanic general circulation model: Earth and Planetary Science Letters, v. 178, p. 113-123.

Delcroix, T., Gourdeau, L., and Henin, C., 1998, Sea surface salinity changes along the Fiji-Japan shipping track during the 1996 La Nina and 1997 El Nino period: Geophysical Research Letters, v. 25, p. 3169-3172.

Delworth, T.L., and Mann, M.E., 2000, Observed and simulated multidecadal variability in the Northern Hemisphere: Climate Dynamics, v. 16, p. 661-676.

DeMaria, M., and Kaplan, J., 1994, Sea Surface Temperature and the Maximum Intensity of Atlantic Tropical Cyclones: Journal of Climate, v. 7, p. 1324-1334.

Deser, C., and Timlin, M.S., 1997, Atmosphere-ocean interaction on weekly timescales in the North Atlantic and Pacific: Journal of Climate, v. 10, p. 393-408.

Dommenget, D., and Latif, M., 2000, Interannual to decadal variability in the tropical Atlantic: Journal of Climate, v. 13, p. 777-792.

Draschba, S., Pätzold, J., and Wefer, G., 2000, North Atlantic climate variability since AD 1350 recorded in $d^{18}O$ and skeletal density of Bermuda corals: International Journal of Earth Sciences, v. 88, p. 733-741.

Druffel, E.R.M., and Suess, H.E., 1983, On the radiocarbon record in banded corals: Exchange parameters and net transport of $^{14}CO_2$ between atmosphere and surface ocean: Journal of Geophysical Research, v. 88, p. 1271-1280.

Dunbar, R.B., and Wellington, G.M., 1981, Stable isotopes in a branching coral monitor seasonal temperature variation: Nature, v. 293, p. 453-455.

Dunbar, R.B., Wellington, G.M., Colgan, M.W., and Glynn, P., 1994, Eastern Pacific sea surface temperature since 1600 A.D.: The $d^{18}O$ record of climate variability in Galapagos corals: Paleoceanography, v. 9, p. 291-315.

Elliott, J., Jewson, S.P., and Sutton, R.T., 2001, The impact of the 1997/98 El Nino events on the Atlantic Ocean: Journal of Climate, v. 14, p. 1069-1077.

Elsner, J.B., Jagger, T.H., and Niu, X.F., 2000a, Changes in the rates of North Atlantic major hurricane activity during the 20th century: Geophysical Research Letters, v. 27, p. 1743-1746.

Elsner, J.B., Liu, K.-B., and Kocher, B., 2000b, Spatial variations in major U.S. hurricane activity: Statistics and physical mechanisms: Journal of Climate, v. 13, p. 2293-2305.

Emanuel, K., 2005, Increasing destructiveness of tropical cyclones over the past 30 years: Nature, v. 436, p. 686-688.

Emiliani, C., 1955, Pleistocene Temperatures: Journal of Geology, v. 63, p. 538-578.

Emiliani, C., Hudson, J.H., Shinn, E.A., and George, R.Y., 1978, Oxygen and Carbon Isotopic Growth Record in a Reef Coral from the Florida Keys and a Deep-Sea Coral from Blake Plateau: Science, v. 202, p. 627-629.

Enfield, D.B., and Alfaro, E.J., 1999, The Dependence of Caribbean Rainfall on the Interaction of the Tropical Atlantic and Pacific Oceans: Journal of Climate, v. 12, p. 2093-2103.

Enfield, D.B., and Cid-Serrano, L., 2006, Projecting the risk of future climate shifts: International Journal of Climatology, v. 26, p. 885-895.

Enfield, D.B., and Mayer, D.A., 1997, Tropical Atlantic sea surface temperature variability and its relation to El Nino-Southern Oscillation: Journal of Geophysical Research, v. 102, p. 929-945.

Enfield, D.B., Mestas-Nunez, A.M., and Trimble, P.J., 2001, The Atlantic multidecadal oscillation and its relation to rainfall and river flows in the continental U.S.: Geophysical Research Letters, v. 28, p. 2077-2080.

Epstein, S., Buchsbaum, R., Lowenstamm, H.A., and Orey, H.C., 1953, Revised carbonate-water isotopic temperature scale: Geological Society of America bulletin, v. 64, p. 1315-1326.

Evans, M.N., Fairbanks, R.G., and Rubenstone, J.L., 1999, The thermal oceanographic signal of El Nino reconstructed from a Kiritimati Island coral: Journal of Geophysical Research, v. 104, p. 13409-13421.

Evans, M.N., Kaplan, A., and Cane, M.A., 2000, Intercomparison of coral oxygen isotope data and historical sea surface temperature (SST): Potential for coral-based SST field reconstructions: Paleoceanography, v. 15, p. 551-563.

Fairbanks, R.G., and Dodge, R.E., 1979, Annual periodicity of the 18O/16O and 13C/12C ratios in the coral Montastraea annularis: Geochimica et Cosmochimica Acta, v. 43, p. 1009-1020.

Fallon, S.J., McCulloch, M.T., Woesik, R., and van Sinclair, D.J., 1999, Corals at their latitudal limits: laser ablation trace element systematics in *Porites* from Shirigai Bay, Japan: Earth and Planetary Science Letters, v. 172, p. 221-238.

Felis, T., Pätzold, J., Loya, Y., Fine, M., Nawar, A.H., and Wefer, G., 2000, A coral oxygen isotope record from the northern Red Sea documenting NAO, ENSO, and North Pacific teleconnections on Middle East climate variability since the year 1750: Paleoceanography, v. 15, p. 679-694.

Ferrier-Pages, C., Boisson, F., Allemand, D., and Tambutte, E., 2002, Kinematics of strontium uptake in the scleractinian coral Stylophora pistillata: Marine Ecology Progress Series, v. 245, p. 93-100.

Folland, C.K., Palmer, T.N., and Parker, D.E., 1986, Sahel rainfall and worldwide sea temperatures, 1901-85: Nature, v. 320, p. 602-607.

Fratantoni, D.M., 2001, North Atlantic surface circulation during the 1990`s observed with satellite-tracked drifters: Journal of Geophysical Research.

Froelich, P.N., Atwood, D.K., and Giese, G.S., 1978, Influence of Amazon River discharge on surface salinity and dissolved silicate concentration in the Caribbean Sea: Deep Sea Research, v. 25, p. 735-744.

Gagan, M.K., Ayliffe, L.K., Beck, J.W., Cole, J.E., Druffel, E.R.M., Dunbar, R.B., and Schrag, D.P., 2000, New views of tropical paleoclimates from corals: Quaternary Science Reviews, v. 19, p. 45-64.

Gagan, M.K., Ayliffe, L.K., Hopley, D., Cali, J.A., Mortimer, G.E., Chappell, J., McCulloch, M.T., and Head, M.J., 1998, Temperature and surface-ocean water balance of the mid-Holocene tropical western Pacific: Science, v. 279, p. 1014-1018.

Gagan, M.K., Chivas, A.R., and Isdale, P.J., 1994, High-resolution isotopic records from corals using ocean temperature and mass-spawning chronometers: Earth and Planetary Science Letters, v. 121, p. 549-558.

George, S.E., and Saunders, M.A., 2001, North Atlantic Oscillation impact on tropical north Atlantic winter atmospheric variability: Geophysical Research Letters, v. 28, p. 1015-1018.

Ghil, M., Allen, R.M., Dettinger, M.D., Ide, K., Kondrashov, D., Mann, M.E., Robertson, A., Saunders, A., Tian, Y., Varadi, F., and Yiou, P., 2002, Advanced spectral methods for climatic time series: Reviews of Geophysics, v. 40, p. doi:10.1029/2000RG000092.

Giannini, A., Cane, M.A., and Kushnir, Y., 2001a, Interdecadal changes in the ENSO teleconnection to the Caribbean region and the North Atlantic Oscillation: Journal of Climate, v. 14, p. 2867-2879.

Giannini, A., Chiang, J.C.H., Cane, M.A., Kushnir, Y., and Seager, R., 2001b, The ENSO teleconnection to the tropical Atlantic Ocean: Contributions of the remote and local SSTs to rainfall variability in the tropical Americas: Journal of Climate, v. 14, p. 4530-4544.

Giannini, A., Kushnir, Y., and Cane, M.A., 2000, Interannual Variability of Caribbean Rainfall, ENSO, and the Atlantic Ocean: Journal of Climate, v. 13, p. 297-311.

Gischler, E., and Oschmann, W., 2005, Historical climate variation in Belize (Central America) as recorded in scleractinian coral skeletons: Palaios, v. 20, p. 159-174.

Goldenberg, S.B., Landsea, C.W., Mestas-Nunez, A.M., and Gray, W.M., 2001, The recent increase in Atlantic hurricane activity: Causes and implications: Science, v. 293, p. 474-479.

Goldenberg, S.B., and Shapiro, L.J., 1996, Physical mechanisms for the association of El Nino and West African rainfall with Atlantic major hurricane activity: Journal of Climate, v. 9, p. 1169-1187.

Goodkin, N.F., Hughen, K.A., and Cohen, A.L., 2007, A multicoral calibration method to approximate a universal equation relating Sr/Ca and growth rate to sea surface temperature: Paleoceanography, v. 22, p. doi:10.1029/2006PA001312.

Goodkin, N.F., Hughen, K.A., Cohen, A.L., and Smith, S.R., 2005, Record of Little Ice Age sea surface temperatures at Bermuda using a growth-dependent calibration of coral Sr/Ca: Paleoceanography, v. 20, p. doi:10.1029/2005PA001140.

Gordon, A.L., 1967, Circulation of the Caribbean Sea: Journal of Geophysical Research, v. 72, p. 6207-6223.

Gray, S.T., Graumlich, L.J., Betancourt, J.L., and Pederson, G.T., 2004, A tree-ring based reconstruction of the Atlantic Multidecadal Oscillation since 1567 A.D.: Geophysical Research Letters, v. 31, p. doi:10.1029/2004GL019932.

Gray, W.M., 1968, Global view of the origins of tropical disturbances and storms: Monthly Weather Review, v. 96, p. 669-700.

—, 1984, Atlantic seasonal hurricane frequency. Part 1: El Nino and 30 mb quasi-biennial oscillation influences: Monthly Weather Review.

—, 1990, Strong association between west African rainfall and US landfall of intense hurricanes: Science, v. 249, p. 1251-1256.

Gray, W.M., Sheaff, J.D., and Landsea, C.W., 1997, Climate trends associated with multidecadal variability of Atlantic hurricane activity, *in* Diaz, H., and Pulwarty, R.S., eds., Hurricanes: Climate and Socioeconomic Impacts: New York, Springer, p. 15-53.

Grinsted, A., Moore, J.C., and Jevrejeva, S., 2004, Application of the cross wavelet transform and wavelet coherence to geophysical time series: Nonlinear Processes in Geophysics, v. 11, p. 561-566.

Grodsky, S.A., Carton, J.A., and Bingham, F.M., 2006, Low frequency variation of sea surface salinity in the tropical Atlantic: Geophysical Research Letters, v. 33, p. doi:10.1029/2006GL026426.

Guilderson, T.P., Cole, J.E., and Southon, J.R., 2005, Pre-bomb d14C variability and the Suess Effect in Cariaco basin surface waters as recorded in hermatypic corals: Radiocarbon, v. 47, p. 57-65.

Guilderson, T.P., Fairbanks, R.G., and Rubenstone, J.L., 2001, Tropical Atlantic coral oxygen isotopes: glacial-interglacial sea surface temperatures and climate change: Marine Geology, v. 172, p. 75-89.

Guilderson, T.P., and Schrag, D., 1999, Reliability of coral records from the western Pacific warm pool: A comparison using age-otimized records: Paleoceanography, v. 4, p. 457-464.

Halliwell, G.R., 1998, Simulation of North Atlantic decadal/multidecadal winter SST anomalies driven by basin-scale atmospheric circulation anomalies: Journal of Geophysical Research, v. 28, p. 5-21.

Handoh, I.C., Matthews, A.J., Bigg, G.R., and Stevens, D.P., 2006, Interannual variability of the tropical Atlantic independent of and associated with ENSO: Part I. The North Tropical Atlantic: International Journal of Climatology, v. 26, p. 1937-1956.

Hastenrath, S., 1976, Variations in low-latitude circulation and extreme climatic events in the tropical Americas: Journal of the Atmospheric Sciences, v. 33, p. 202-215.

—, 1978, On modes of tropical circulation and climate anomalies: Journal of Atmospheric Science, v. 35, p. 2222-2231.

—, 1984, Interannual variability and annual cycle: Mechanisms of circulation and climate in the tropical Atlantic sector: Monthly Weather Review, v. 112, p. 1097-1107.

—, 1991, Climate Dynamics of the Tropics: Dordrecht, The Netherlands, Kluwer Academic Publishers, 488 p.

Hastenrath, S., Castro, L.C., and Acietuno, P., 1987, The Southern Oscillation in the tropical Atlantic sector: Contributions to Atmospheric Physics, v. 60, p. 447-463.

Hastenrath, S., and Greischar, L., 1993, Circulation mechanisms related to Northeast Brazil rainfall anomalies: Journal of Geophysical Research, v. 98, p. 5093-5102.

Heiss, G.A., 1994, Coral reefs in the Red Sea: growth, production and stable isotopes, GEOMAR Report 32, p. 1-141.

Helmle, K.P., Dodge, R.E., and Ketcham, R.A., 2002, Skeletal architecture and density banding in Diploria strigosa by X-ray computed tomography: Proceedings 9th International Coral Reef Symposium.

Hendy, E., Gagan, M.K., Alibert, C.A., McCulloch, M.T., Lough, J.M., and Isdale, P.J., 2002, Abrupt Decrease in Tropical Pacific Sea Surface Salinity at End of Little Ice Age: Science, v. 295, p. 1511-1514.

Hernandez-Guerra, A., and Joyce, T.M., 2000, Water Masses and Circulation in the Surface Layers of the Caribbean at 66°W: Geophysical Research Letters.

Hetzinger, S., Pfeiffer, M., Dullo, W.-C., Ruprecht, E., and Garbe-Schönberg, D., 2006, Sr/Ca and $d^{18}O$ in a fast-growing *Diploria strigosa* coral: Evaluation of a new climate archive for the tropical Atlantic: Geochemistry Geophysics Geosystems, v. 7, p. doi:10.1029/2006GC001347.

Hoerling, M.P., Hurrell, J.W., and Xu, T., 2001, Tropical origins for recent North Atlantic climate change: Science, v. 292, p. doi:10.1126/science.1058582.

Hogg, N.G., and Johns, W.E., 1995, Western boundary currents: Reviews of Geophysics Supplement, v. U.S. National Report to IUGG 1991-1994, p. 1311-1344.

Houghton, J.T., Ding, Y., Griggs, D.J., Noguer, M., van der Linden, P.J., Dai, X., Maskell, K., and Johnson, C.A., 2001, Climate Change 2001: The Scientific Basis: Intergovernmental Panel on Climate Change.

Hoyos, C.D., Agudelo, P.A., Webster, P.J., and Curry, J.A., 2006, Deconvolution of the Factors Contributing to the Increase in Global Hurricane Intensity: Science, v. 312, p. 94-97.

Huang, B.H., Schopf, P.F., and Shukla, J., 2004, Intrinsic ocean-atmosphere variability of the tropical Atlantic Ocean: Journal of Climate, v. 17, p. 2058-2077.

Hughen, K.A., Schrag, D., and Jacobsen, S.B., 1999, El Nino during the last interglacial period recorded by a fossil coral from Indonesia: Geophysical Research Letters, v. 26, p. 3129-3132.

Hurrell, J.W., 1995, Decadal Trends in the North Atlantic Oscillation: Regional temperatures and Precipitation: Science, v. 269, p. 676-679.

Hurrell, J.W., Kushnir, Y., Ottersen, G., and Visbeck, M., 2003a, The North Atlantic Oscillation - Climatic Significance and Environmental Impact: Washington, DC, American Geophysical Union, 279 p.

—, 2003b, An Overview of the North Atlantic Oscillation, *in* Hurrell, J.W., Kushnir, Y., Ottersen, G., and Visbeck, M., eds., The North Atlantic Oscillation - Climatic Significance and Environmental Impact: Washington, DC, American Geophysical Union, p. 1-35.

Hurrell, J.W., and van Loon, H., 1997, Decadal variations in climate associated with the North Atlantic Oscillation: Climatic Change, v. 36, p. 310-326.

Iijima, H., Kayanne, H., Morimoto, M., and Abe, O., 2005, Interannual sea surface salinity changes in the western Pacific from 1954 to 2000 based on coral isotope analysis: Geophysical Research Letters, v. 32, p. doi:10.1029/2004GL022026.

Johns, W.E., Townsend, T.L., Fratantoni, D.M., and Wilson, W.D., 2002, On the Atlantic inflow to the Caribbean Sea: Deep-Sea Research Part I-Oceanographic Research Papers, v. 49, p. 211-243.

Jones, P.D., Jonsson, T., and Wheeler, D., 1997a, Extension of the North Atlantic Oscillation using early instrumental pressure observations from Gibraltar and southwest Iceland: International Journal of Climatology, v. 17, p. 1433-1450.

—, 1997b, Extension to the North Atlantic Oscillation using early instrumental pressure observations from Gibraltar and South-West Iceland: International Journal of Climatology, v. 17, p. 1433-1450.

Jones, P.D., Osborn, T.J., and Briffa, K.R., 2001, The evolution of climate over the last millennium: Science, v. 292, p. 662-667.

Joyce, T.M., Deser, C., and Spall, M.A., 2000, The relation between decadal variability of subtropical mode water and the North Atlantic Oscillation: Journal of Climate, v. 13, p. 2550-2569.

Joyce, T.M., Hernandez-Guerra, A., and Smethie Jr., W. M., 2001, Zonal circulation in the NW Atlantic and Caribbean from a meridional World Ocean Circulation Experiment hydrographic section at 66°W: Journal of Geophysical Research.

Juillet-Leclerc, A., and Schmidt, G.A., 2001, A calibration of the oxygen isotope paleothermometer of coral aragonite from Porites: Geophysical Research Letters, v. 28, p. 4135-4138.

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

Kerr, R.A., 2000, A North Atlantic Climate Pacemaker for the Centuries: Science, v. 288, p. 1984-1985.

Kilbourne, K.H., Quinn, T.M., Taylor, F.W., Delcroix, T., and Gouriou, Y., 2004, El Nino-Southern Oscillation-related salinity variations recorded in the skeletal geochemistry of a Porites coral from Espiritu Santo, Vanuatu: Paleoceanography, v. 19, p. doi:10.1029/2004PA001033.

Kinard, W.F., Atwood, D.K., and Giese, G.C., 1974, Dissolved oxygen as evidence for 18°C Sargasso Sea water in the eastern Caribbean Sea: Deep Sea Research Part I, v. 21, p. 79-82.

Kinsman, D.J.J., and Holland, H.D., 1969, The co-precipitation of cations with CaCO3 - IV. The co-precipitation of Sr2+ with aragonite between 16°C and 96°C: Geochimica et Cosmochimica Acta, v. 33, p. 1-17.

Klein, S.A., Soden, B.J., and Lau, N.-C., 1999, Remote sea surface temperature variations during ENSO: evidence for a tropical atmospheric bridge: Journal of Climate, v. 12, p. 917-932.

Klotzbach, P.J., 2006, Trends in global tropical cyclone activity over the past twenty years (1986-2005): Geophysical Research Letters, v. 33, p. doi:10.1029/2006GL025881.

Knight, J.R., Allan, R.J., Folland, C.K., Vellinga, M., and Mann, M.E., 2005, A signature of persistent natural thermohaline circulation cycles in observed climate: Geophysical Research Letters, v. 32, p. doi:10.1029/2005GL024233.

Knight, J.R., Folland, C.K., and Scaife, A.A., 2006, Climate impacts of the Atlantic Multidecadal Oscillation: Geophysical Research Letters, v. 33, p. doi:10.1029/2006GL026242.

Knutson, D.W., Buddemeier, R.W., and Smith, S.V., 1972, Coral chronometers: seasonal growth bands in reef corals: Science, v. 177, p. 270-272.

Knutson, T.R., and Tuleya, R.E., 2004, Impact of CO_2-induced warming on simulated hurricane intensity and precipitation: Sensitivity to the choice of climate model and convective parameterization: Journal of Climate, v. 17, p. 3477-3495.

Kuhnert, H., Crüger, T., and Pätzold, J., 2005, NAO signature in a Bermuda coral Sr/Ca record: Geochemistry Geophysics Geosystems, v. 6, p. doi:10.1029/2004GC000786.

Kuhnert, H., Pätzold, J., Hatcher, B., Wyrwoll, K.-H., Eisenhauer, A., Collins, L.B., Zhu, Z.R., and Wefer, G., 1999, A 200-year coral stable isotope record from a high-latitude reef off Western Australia: Coral Reefs, v. 18, p. 1-12.

Kuhnert, H., Pätzold, J., Schnetger, B., and Wefer, G., 2002, Sea-surface temperature variability in the 16th century at Bermuda inferred from coral records: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 179, p. 159-171.

Kumar, A., Yang, F., Goddard, L., and Schubert, S., 2004, Differing Trend in the Tropical Surface Temperatures and Precipitation over Land and Oceans: Journal of Climate, v. 17, p. 653-664.

Kushnir, Y., Seager, R., Miller, J., and Chiang, J.C.H., 2002, A simple coupled model of tropical Atlantic decadal climate variability: Geophysical Research Letters, v. 29, p. doi:10.1029/2002GL015874.

Landsea, C.W., Harper, B.A., Hoarau, K., and Knaff, J.A., 2006, Can We Detect Trends in Extreme Tropical Cyclones: Science, v. 313, p. 452-454.

Landsea, C.W., Pielke Jr., R.A., Mestas-Nunez, A.M., and Knaff, J.A., 1999, Atlantic basin hurricanes: Indices of climatic changes: Climatic Change, v. 42, p. 89-129.

Latif, M., 2001, Tropical Pacific / Atlantic Ocean Interactions at Multi-Decadal Time Scales: Geophysical Research Letters, v. 28, p. 539-542.

Latif, M., Collins, M., Pohlmann, H., and Keenlyside, N.S., 2006, A Review of Predictability Studies of Atlantic Sector Climate on Decadal Time Scales: Journal of Climate, v. 19, p. 5971-5987.

Latif, M., Keenlyside, N.S., and Bader, J., 2007, Tropical sea surface temperature, vertical wind shear, and hurricane development: Geophysical Research Letters, v. 34, p. doi:10.1029/2006GL027969.

Latif, M., Roeckner, E., Botzet, M., Esch, M., Haak, H., Hagemann, S., Jungclaus, J., Legutke, S., Marsland, S., and Mikolajewicz, U., 2004, Reconstructing, Monitoring, and Predicting Multidecadal-Scale Changes in the North Atlantic Thermohaline Circulation with Sea Surface Temperature: Journal of Climate, v. 17, p. 1605-1614.

Latif, M., Roeckner, E., Mikolajewicz, U., and Voss, R., 2000, Tropical Stabilization of the Thermohaline Circulation in a Greenhouse Warming Simulation: Journal of Climate, v. 13, p. 1809-1813.

Leder, J.J., Swart, P.K., Szmant, A.M., and Dodge, R.E., 1996, The origin of variations in the isotopic record of scleractinian corals .1. Oxygen: Geochimica Et Cosmochimica Acta, v. 60, p. 2857-2870.

Levitus, S., and Boyer, T.P., 1994, World Ocean Atlas 1994 Volume 4: Temperature, NOAA Atlas NESDIS 4: Washington D. C., U.S. Department of Commerce, p. 129.

Levitus, S., Burgett, R., and Boyer, T.P., 1994, World Ocean Atlas 1994 Volume 3: Salinity, NOAA Atlas NESDIS 4: Washington D. C., U.S. Department of Commerce, p. 111.

Linsley, B.K., Dunbar, R.B., Wellington, G.M., and Mucciarone, D.A., 1994, A coral based reconstruction of Intertropical Convergence Zone variability over Central America since 1707: Journal of Geophysical Research, v. 99, p. 9977-9994.

Linsley, B.K., Kaplan, A., Gouriou, Y., Salinger, J., deMenocal, P.B., Wellington, G.M., and Howe, S.S., 2006, Tracking the extent of the South Pacific Convergence Zone since the early 1600s: Geochemistry Geophysics Geosystems, v. 7, p. doi:10.1029/2005GC001115.

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

Linsley, B.K., Wellington, G.M., Schrag, D.P., Ren, L., Salinger, M.J., and Tudhope, A.W., 2004, 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, v. 22, p. 1-11.

Liu, Z., Zhang, Q., and Wu, L., 2004, Remote impact on tropical Atlantic climate variability: Statistical assessment and dynamic assessment: Journal of Climate, v. 17, p. 1529-1549.

Mann, M.E., Bradley, R.S., and Hughes, M.K., 1998, Global-scale temperature patterns and climate forcing over the past six centuries: Nature, v. 392, p. 779-787.

Mann, M.E., and Emanuel, K., 2006, Atlantic Hurricane Trends Linked to Climate Change: Eos Transactions, v. 87, p. 233-244.

Mann, M.E., and Lees, J., 1996, Robust Estimation of Background Noise and Signal Detection in Climatic Time Series: Climatic Change, v. 33, p. 409-445.

Mann, M.E., Park, J., and Bradley, R.S., 1995, Global interdecadal and century-scale climate oscillations during the past five centuries: Nature, v. 378, p. 266-270.

Mantua, N.J., Hare, S.R., Zhang, Y., Wallace, J.M., and Francis, R.C., 1997, A Pacific interdecadal climate oscillation with impacts on salmon production: Bulletin American Meteorological Society, v. 78, p. 1069-1079.

Marshall, J.F., Kushnir, Y., Battisti, D., Chang, P., Czaja, A., Dickson, R., Hurrell, J.W., McCartney, M.S., Saravanan, R., and Visbeck, M., 2001, North Atlantic climate variability: phenomena, impacts and mechanisms: International Journal of Climatology, v. 21, p. 1863-1898.

Marshall, J.F., and McCulloch, M.T., 2002, An assessment of the Sr/Ca ratio in shallow water hermatypic corals as a proxy for sea surface temperature: Geochimica et Cosmochimica Acta, v. 66, p. 3263-3280.

Martinson, D.G., Pisias, N.G., Hays, J.D., Imbrie, J., Morre, T.C., and Shackleton, N.J., 1987, Age dating and the orbital theory of the ice ages: Development of a high-resolution 0-300.000 year chronostratigraphy: Quaternary Research, v. 27, p. 1-29.

McConnaughey, T., 1989a, ^{13}C and ^{18}O isotopic disequilibrium in biological carbonates: I. Patterns: Geochimica Et Cosmochimica Acta, v. 53, p. 151-162.

—, 1989b, ^{13}C and ^{18}O isotopic disequilibrium in biological carbonates: II. In Vitro simulation of kinetic isotope effects: Geochimica et Cosmochimica Acta, v. 53, p. 163-171.

McConnaughey, T.A., 1989c, C-13 and O-18 isotopic disequilibria in biological carbonates: I. Patterns: Geochimica et Cosmochimica Acta, v. 53, p. 151-162.

McCrea, J.M., 1950, On the isotopic chemistry of carbonates and a paleotemperature scale: Journal of Chemical Physics, v. 18, p. 849-857.

McCulloch, M.T., Gagan, M.K., Mortimer, G.E., Chivas, A.R., and Isdale, P.J., 1994, A high-resolution Sr/Ca and $d^{18}O$ coral record from the Great Barrier Reef, Australia, and the 1982-1983 El Nino: Geochimica et Cosmochimica Acta, v. 58, p. 2747-2754.

Mendez, J., 1978, Archipielago Los Roques / Islas Aves. Cuadernos Lagoven, Cromotip, 48 p.

Mestas-Nunez, A.M., and Enfield, D.B., 1999, Rotated Global Modes of Non-ENSO Sea Surface Temperature Variability: Journal of Climate, v. 12, p. 2734-2746.

Metcalf, W.G., 1976, Caribbean-Atlantic exchange through the Anegada-Jungfern Passage: Journal of Geophysical Research, v. 81, p. 6401-6409.

Milliman, J.D., and Meade, R.H., 1983, World-wide delivery of river sediments to the oceans: Journal of Geology, v. 91, p. 1-21.

Mitsuguchi, T., Matsumato, E., Abe, O., Uchida, T., and Isdale, P.J., 1996, Mg/Ca thermometry in coral skeletons: Science, v. 274, p. 961-963.

Morrison, J.M., and Nowlin, W.D., 1982, General distribution of water masses within the eastern Caribbean Sea during the winter 1972 and fall of 1973: Journal of Geophysical Research, v. 87, p. 4207-4229.

Morrison, J.M., and Smith, O.P., 1990, Geostrophic transport variability along the Aves Ridge in the eastern Caribbean Sea during 1985-1986: Journal of Geophysical Research, v. 95, p. 699-710.

Moses, C.S., Swart, P.K., and Dodge, R.E., 2006a, Calibration of stable oxygen isotopes in Siderastrea radians (Cnidaria:Scleractinia): Implications for slow-growing corals: Geochemistry Geophysics Geosystems, v. 7, p. doi:10.1029/2005GC001196.

Moses, C.S., Swart, P.K., and Rosenheim, B.E., 2006b, Evidence of multidecadal salinity variability in the eastern tropical North Atlantic: Paleoceanography, v. 21, p. doi:10.1029/2005PA001257.

Moura, A.D., and Shukla, J., 1981, On the dynamics of droughts in Northeast Brazil - observations, theory and numerical experiments with a general circulation model: Journal of Atmospheric Science, v. 38, p. 2653-2675.

Müller-Karger, C., McClain, C., Fisher, T., Esaias, W., and Varela, R., 1989, Pigment distribution in the Caribbean Sea: Observations from space: Progress in Oceanography, v. 23.

Murphy, S.J., Hurlburt, H.E., and O`Brien, J.J., 1999, The connectivity of eddy variability in the Caribbean Sea, the Gulf of Mexico, and the Atlantic Ocean: Journal of Geophysical Research, v. 104, p. 1431-1453.

Nobre, P., and Shukla, J., 1996, Variations of sea surface temperature, wind stress, and rainfall over the tropical Atlantic and South America: Journal of Climate, v. 9, p. 2464-2479.

Nyberg, J., 2002, Luminescence intensity in coral skeletons from Mona Island in the Caribbean Sea and its link to precipitation and wind speed: Philosophical Transactions: The Royal Society of London, v. 360, p. 749-766.

Östlund, H.G., Craig, H., Broecker, W.S., and Spencer, D., 1987, GEOSECS Atlantic, Pacific and Indian Ocean Expeditions, Shore-Based Data and Graphics, Technical Report, Volume 7, U.S. National Science Foundation.

Paeth, H., Latif, M., and Hense, A., 2003, Global SST influence on twentieth century NAO variability: Climate Dynamics, v. 21, p. 63-75.

Paillard, D., Labeyrie, L., and Yiou, P., 1996, Macintosh program performs time-series analysis: Eos Transactions AGU, v. 77, p. 379.

Penland, C., and Matrosova, L., 1998, Prediction of tropical Atlantic sea surface temperatures using Linear Inverse Modeling: Journal of Climate, v. 11, p. 486-496.

Peterson, L.C., Overpeck, J.T., Kipp, N.G., and Imbrie, J., 1991, A high-resolution late Quaternary upwelling record from the anoxic Cariaco Basin, Venezuela: Paleoceanography, v. 6, p. 99-119.

Pfeiffer, M., and Dullo, W.-C., 2006, Monsson-induced cooling of the western equatorial Indian Ocean as recorded in coral oxygen isotope records from the Seychelles covering the period of 1840-1994 AD: Quaternary Science Reviews, v. 25, p. 993-1009.

Pfeiffer, M., Dullo, W.-C., and Eisenhauer, A., 2004a, Variability of the Intertropical Convergence Zone recorded in coral isotopic records from the central Indian Ocean (Chagos Archipelago): Quaternary Research, v. 61, p. 245-255.

Pfeiffer, M., Timm, O., Dullo, W.-C., and Garbe-Schönberg, D., 2006, Paired coral Sr/Ca and $d^{18}O$ records form the Chagos Archipelago: Late twentieth century warming affects rainfall variability in the tropical Indian Ocean: Geology, v. 34, p. doi:10.1130/G23162A.1.

Pfeiffer, M., Timm, O., Dullo, W.-C., and Podlech, S., 2004b, Oceanic forcing of interannual and multidecadal climate variability in the southwestern Indian Ocean: Evidence from a 160 year coral isotopic record (La Reunion, 55°E, 21°S): Paleoceanography, v. 19, p. PA4006, doi:10.1029/2003PA000964.

Philander, S.G.H., 1990, El Niño, La Niña, and the Southern Oscillation: San Diego, California, Academic Press, 289 p.

Pielke Jr., R.A., 2005a, Are there trends in hurricane destruction?: Nature, v. 438, p. doi:10.1038/nature4426.

—, 2005b, Hurricanes and global warming: Bulletin American Meteorological Society, v. 86, p. 1571-1575.

Quinn, T.M., Crowley, T.J., and Taylor, F.W., 1996, New stable isotope results from a 173-year coral from Espiritu Santo, Vanuatu: Geophysical Research Letters, v. 23, p. 3413-3416.

Quinn, T.M., Crowley, T.J., Taylor, F.W., Henin, C., Joannot, P., and Join, Y., 1998, A multicentury stable isotope record from a New Caledonia coral: Interannual and decadal sea surface temperature variability in the southwest Pacific since 1657 AD: Paleoceanography, v. 13, p. 412-426.

Quinn, T.M., and Sampson, D.E., 2002, A multiproxy approach to reconstructing sea surface conditions using coral skelton geochemistry: Paleoceanography, v. 17, p. doi:10.1029/2000PA000528.

Quinn, T.M., and Taylor, F.W., 2006, SST artifacts in coral proxy records produced by early marine diagenesis in a modern coral from Rabaul, Papua New Guinea: Geophysical Research Letters, v. 33, p. doi:10.1029/2005GL024972.

Quinn, T.M., Taylor, F.W., and Crowley, T.J., 2006, Coral-based climate variability in the Western Pacific Warm Pool since 1867: Journal of Geophysical Research, v. 111, p. doi:10.1029/2005JC003243.

Rasmusson, E.M., and Carpenter, T.H., 1982, Variations in tropical sea surface temperature and surface wing fields associated with the southern Oscillation/El Nino: Monthly Weather Review, v. 110, p. 354-384.

Rayner, N.A., Parker, D.E., Horton, E.B., Folland, C.K., Alexander, L.V., Rowell, D.P., Kent, E.C., and Kaplan, A., 2003, Global analyses of SST, sea ice, and night marine air temperature since the late nineteenth century: Journal of Geophysical Research, v. 108, p. doi:10.1029/2002JD002670.

Ren, L., Linsley, B.K., Wellington, G.M., Schrag, D., and Hoegh-Guldberg, O., 2002, Deconvolving the $d^{18}O$ seawater component from subseasonal coral $d^{18}O$ and Sr/Ca at Rarotonga in the southwestern subtropical Pacific for the period 1726 to 1997: Geochimica et Cosmochimica Acta, v. 67, p. 1609-1621.

Reuer, M.K., Boyle, E.A., and Cole, J.E., 2003, A mid-twentieth century reduction in tropical upwelling inferred from coralline trace element proxies: Earth and Planetary Science Letters, v. 210, p. 437-452.

Reynaud, S., Ferrier-Pages, C., Boisson, F., Allemand, D., and Fairbanks, R.G., 2004, Effect of light and temperature on calcification and strontium uptake in the scleractinian coral *Acropora verweyi*: Marine Ecology Progress Series, v. 279, p. 105-112.

Reynolds, R.W., Rayner, N.A., Smith, T.M., Stokes, D.C., and Wang, W., 2002, An improved in situ and satellite SST analysis for climate: Journal of Climate, v. 15.

Richardson, P.L., 2005, Caribbean current and eddies as observed by surface drifters: Deep Sea Research II.

Richardson, P.L., and McKee, T.K., 1984, Average Seasonal Variation of the Atlantic Equatorial Currents from Historical Ship Drifts: Journal of Physical Oceanography, v. 14, p. 1226-1238.

Rodwell, M.J., Rowell, D.P., and Folland, C.K., 1999, Oceanic forcing of the wintertime North Atlantic Oscillation and European climate: Nature, v. 398, p. 320-323.

Roemmich, D., 1981, Circulation in the Caribbean Sea: A well-resolved inverse problem: Journal of Geophysical Research, v. 81, p. 7993-8005.

Rohling, E.J., and Bigg, G.R., 1998, Paleosalinity and $d^{18}O$: A critical assessment: Journal of Geophysical Research, v. 103, p. 1307-1318.

Saravanan, R., and Chang, P., 2000, Interaction between tropical Atlantic variability and El Nino-Southern Oscillation: Journal of Climate, v. 13, p. 2177-2194.

Sato, O.T., and Rossby, T., 1995, Seasonal and low frequency variations in dynamic height anomaly and transport of the Gulf Stream: Deep Sea Research Part I, v. 42, p. 149-164.

Saunders, M.A., Chandler, R.E., Merchant, C.J., and Roberts, F.P., 2000, Atlantic hurricanes and NW Pacific typhoons: ENSO spatial impacts on occurrence and landfall: Geophysical Research Letters, v. 27, p. 1147-1150.

Schlesinger, M.E., and Ramankutty, N., 1994, An oscillation in the global climate system of period 65-70 years: Nature, v. 367, p. 723-726.

Schmidt, G.A., 1998, Oxygen-18 variations in a global ocean model: Geophysical Research Letters, v. 25, p. 1201-1204.

—, 1999, Error analysis of paleosalinity calculations: Paleoceanography, v. 14, p. 422-429.

Schmidt, G.A., Bigg, G.R., and Rohling, E.J., 2000, Global Seawater Oxygen-18 Database: http://data.giss.nasa.gov/o18data/.

Schmitz, W.J., Luyten, J.R., and Schmitt, R.W., 1993, On the Florida Current T/S envelope: Bulletin of Marine Science, v. 53, p. 1048-1065.

Schmitz, W.J., and McCartney, M.S., 1993, On the North Atlantic circulation: Rev. Geophys., v. 31, p. 29-49.

Schmitz, W.J., and Richardson, P.L., 1991, On the Sources of the Florida Current: Deep-Sea Research Part a-Oceanographic Research Papers, v. 38, p. S379-S409.

Schrag, D.P., 1999, Rapid determination of high-precision Sr/Ca ratios in corals and other marine carbonates: Paleoceanography, v. 14, p. 97-102.

Shackleton, N.J., and Opdyke, N.D., 1973, Oxygen isotope and paleomagnetic stratigraphy of equatorial Pacific Core V28-238; oxygen isotope temperatures and ice volumes on a 105 year and 106 year scale: Quaternary Research, v. 3, p. 39-55.

Shen, C.-C., Lee, T., Liu, K.-K., Hsu, H.-H., Edwards, R.L., Wang, C.-H., Lee, M.-Y., Chen, Y.-G., Lee, H.-J., and Sun, H.-T., 2005, An evaluation of quantitative reconstruction of past precipitation records using coral skeletal Sr/Ca and d18O data: Earth and Planetary Science Letters, v. 237, p. 370-386.

Shen, C.C., Lee, T., Chen, C.Y., Wang, C.H., Dai, C.F., and Li, L.A., 1996, The calibration of D[Sr/Ca] versus sea surface temperature relationship for Porites corals: Geochimica Et Cosmochimica Acta, v. 60, p. 3849-3858.

Sinclair, D.J., Williams, B., and Risk, M., 2006, A biological origin for climate signals in corals-Trace element "vital effects" are ubiquitious in Scleractinian coral skeletons: Geophysical Research Letters, v. 33, p. doi:10.1029/2006GL027183.

Smith, J.M., Quinn, T.M., Helmle, K.P., and Halley, R.B., 2006, Reproducibility of geochemical and climatic signals in the Atlantic coral *Montastrea faveolata*: Paleoceanography, v. 21, p. doi:10.1029/2005PA001187.

Smith, S.V., Buddemeier, R.W., Redalje, R.C., and Houck, J.E., 1979, Strontium-calcium thermometry in coral skeletons: Science, v. 204, p. 404-407.

Smith, T.M., and Reynolds, R.W., 2003, Extended reconstruction of global sea surface temperatures based on COADS data (1854-1997): Journal of Climate, v. 16, p. 1495-1510.

—, 2004, Improved extended reconstruction of SST (1854-1997): Journal of Climate, v. 17, p. 2466-2477.

Spalding, M.D., Ravilious, C., and Green, E.P., 2001, World Atlas of Coral Reefs: Berkeley, University of California Press, 424 p.

Stalcup, M.C., and Metcalf, W.G., 1972, Current measurements in the passages of the Lesser Antilles: Journal of Geophysical Research, v. 77, p. 1032-1049.

Sutton, R.T., and Hodson, D.L.R., 2005, Atlantic Ocean Forcing of North American and European Summer Climate: Science, v. 309, p. 115-118.

Sutton, R.T., Jewson, S.P., and Rowell, D.P., 2000, The Elements of Climate Variability in the Tropical Atlantic Region: Journal of Climate, v. 13, p. 3261-3284.

Suzuki, A., Hibino, K., Iwase, A., and Kawahata, H., 2005, Intercolony variability of skeletal oxygen and carbon isotope signatures of cultured *Porites* corals: Temperature-controlled experiments: Geochimica et Cosmochimica Acta, v. 69, p. 4453-4462.

Swart, P.K., 1983, Carbon and Oxygen isotope fractionation in scleractinian corals: a review: Earth-Science Reviews, v. 19, p. 51-80.

Swart, P.K., Elderfield, H., and Greaves, M.J., 2002, A high-resolution calibration of Sr/Ca thermometry using the Caribbean coral Montastrea annularis: Geochemistry Geophysics Geosystems, v. 3, p. doi:10.1029/2002GC000306.

Swart, P.K., Leder, J.J., Szmant, A.M., and Dodge, R.E., 1996, The origin of variations in the isotopic record of scleractinian corals: II. Carbon: Geochimica et Cosmochimica Acta, v. 60, p. 2871-2885.

Tang, B.H., and Neelin, J.D., 2004, ENSO influence on Atlantic hurricanes via tropospheric warming: Geophysical Research Letters, v. 31, p. doi:10.1029/2005GL021072.

Taylor, A.M., Enfield, D.B., and Chen, A.A., 2002, Influence of the tropical Atlantic versus the tropical Pacific on Caribbean rainfall: Journal of Geophysical Research, v. 107, p. doi:10.1029/2001JC001097.

Thomson, D.J., 1982, Spectrum estimation and harmonic analysis: Proceedings IEEE, v. 70, p. 1055-1096.

—, 1990, Time series analysis of Holocene climate data: Philosophical Transactions: The Royal Society of London, v. A 330, p. 601-616.

Torrence, C., and Compo, G.P., 1998, A practical guide to wavelet analysis: Bulletin of the American Meteorological Society, v. 79, p. 61-78.

Trenberth, K.E., 1997, The Definition of El Nino: Bulletin of the American Meteorological Society, v. 78, p. 2771-2777.

Trenberth, K.E., and Hurrell, J.W., 1994, Decadal atmosphere-ocean variations in the Pacific: Climate Dynamics, v. 9, p. 303-319.

Tudhope, A.W., Chilcott, C.P., McCulloch, M., Cook, E.R., Chappell, J., Ellam, R.M., Lea, D.W., Lough, J.M., and Shimmield, G.B., 2001, Variability in the El Nino-Southern oscillation through a glacial-interglacial cycle: Science, v. 291, p. 1511-1517.

Tudhope, A.W., Shimmield, G.B., Chilcott, C.P., Jebb, M., Fallick, A.E., and Dalgleish, A.N., 1995, 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 Guinea: Earth and Planetary Science Letters, v. 136.

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

van Oldenborgh, G.J., and Burgers, G., 2005, Searching for decadal variations in ENSO precipitation teleconnections: Geophysical Research Letters, v. 32, p. doi:10.1029/2005GL023110.

Vellinga, M., and Wu, P., 2004, Low-Latitude Freshwater Influence on Centennial Variability of the Atlantic Thermohaline Circulation: Journal of Climate, v. 17, p. 4498-4511.

Visbeck, M., Cullen, H., Krahmann, G., and Nail, N., 1998, An ocean model`s response to North Atlantic Oscillation-like wind forcing: Geophysical Research Letters, v. 25, p. 4521-4524.

Visbeck, M., Hurrell, J.W., Polvani, L., and Cullen, H.M., 2001, The North Atlantic Oscillation: Past, present, and future: Proceedings of the National Academy of Sciences, v. 98, p. 12876-12877.

Wang, C., and Enfield, D.B., 2001, The tropical western hemisphere warm pool: Geophysical Research Letters, v. 28, p. 1635-1638.

Watanabe, T., and Oba, T., 1999, Daily reconstruction of water temperature from oxygen isotopic ratios of a modern Tridacna shell using a freezing microtome sampling technique: Journal of Geophysical Research, v. 104, p. 20667-20674.

Watanabe, T., Winter, A., and Oba, T., 2001, Seasonal changes in sea surface temperature and salinity during the Little Ice Age in the Caribbean Sea deduced from Mg/Ca and 18O/16O ratios in corals: Marine Geology, v. 173, p. 21-35.

Watanabe, T., Winter, A., Oba, T., Anzai, R., and Ishioroshi, T., 2002, Evaluation of the fidelity of isotope records as an environmental proxy in the coral Montastrea: Coral Reefs, v. 21, p. 169-178.

Weber, J.N., 1973, Incorporation of strontium into reef coral skeletal carbonate: Geochimica et Cosmochimica Acta, v. 37, p. 2173-2190.

Weber, J.N., and Woodhead, P.M.J., 1972, Temperature dependance of oxygen-18 concentration in reef coral carbonates: Journal of Geophysical Research, v. 77, p. 463-473.

Webster, P.J., Holland, G.J., Curry, J.A., and Chang, H.-R., 2005, Changes in the Tropical Cyclone Number, Duration, and Intensity in a Warming Environment: Science, v. 309, p. 1844-1846.

Weil, E., 2003, The corals and coral reefs of Venezuela, *in* Cortes, J., ed., Latin American Coral Reefs: Amsterdam, Elsevier Science B.V., p. 303-330.

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

Wells, S.M., 1988, Coral Reefs of the World. Volume 1: Atlantic and Eastern Pacific: Switzerland and Cambridge, U.K./UNEP, Nairobi, Kenya, UNEP Regional Seas Directories and Bibliographies, 373 p.

Williams-Trujillo, W., 1980, Las Maravillosas Islas de Venezuela: Caracas, Edit. Croma, 202 p.

Winter, A., Ishioroshi, H., Watanabe, T., Oba, T., and Christy, J., 2000, Caribbean sea surface temperatures: two-to-three degrees cooler than present during the Little Ice Age: Geophysical Research Letters, v. 27, p. 3365-3368.

Winter, A., Paul, A., Nyberg, J., Oba, T., Lundberg, J., Schrag, D., and Taggart, B., 2003, Orbital control of low-latitude seasonality during the Eemian: Geophysical Research Letters, v. 30, p. doi:10.1029/2002GL016275.

Woodruff, S.D., Diaz, H., Elms, J.D., and Worley, S.J., 1998, COADS release 2 data and metadata enhancements for improvements of marine surface flux fields: Physics and Chemistry of the Earth, v. 23, p. 517-527.

Wu, L., and Liu, Z., 2002, Is tropical Atlantic variability driven by the North Atlantic Ocillation?: Geophysical Research Letters, v. 29, p. doi:10.1029/2002GL014939.

Wu, L., Zhang, Q., and Liu, Z., 2004, Toward understanding tropical Atlantic variability using coupled model surgery, *in* Wang, C., Xie, S.-P., and Carton, J.A., eds., Earth´s Climate - The Ocean-Atmosphere Interaction, Volume Geophysical Monograph Series 147: Washington, DC, American Geophysical Union, p. 157-170.

Wüst, G., 1964, Stratification and circulation in the Antillean-Caribbean Basins: Palisades, NY, Columbia University Press, 201 p.

Xie, P., and Arkin, P.A., 1996, Analyses of Global Monthly Precipitation Using Gauge Observations, Satellite Estimates, and Numerical Model Predictions: Journal of Climate, v. 9, p. 840-858.

Xie, S.-P., and Carton, J.A., 2004, Tropical Atlantic variability: Patterns, mechanisms, and impacts, *in* Wang, C., Xie, S.-P., and Carton, J.A., eds., Earth Climate: The Ocean-Atmosphere Interaction, Geophys. Monogr. Ser., Volume 147: Washington , D. C., AGU, p. 121-142.

Xie, S.-P., and Tanimoto, Y., 1998, A pan-Atlantic decadal climate oscillation: Geophysical Research Letters, v. 25, p. 2185-2188.

Yiou, P., Loutre, M.F., and Bart, E., 1996, Spectral analysis of climate data: Surveys in Geophysics, v. 17, p. 619-663.

Zaucker, F., and Broecker, W.S., 1992, The influence of atmospheric moisture transport on the fresh water balance of the Atlantic drainage basin: general circulation model simulations and observations: Journal of Geophysical Research, v. 97, p. 2765-2773.

Zhang, Y., Wallace, J.M., and Battisti, D., 1997, ENSO-like interdecadal variability: 1900-93: Journal of Climate, v. 10, p. 1004-1020.

Zinke, J., Dullo, W.-C., Heiss, G.A., and Eisenhauer, A., 2004, ENSO and Indian Ocean subtropical dipole variability is recorded in a coral record off southwest Madagascar for the period 1659 to 1995: Earth and Planetary Science Letters, v. 228, p. 177-194.

Appendix A.1
oxygen isotope and trace element data for coral core from Guadeloupe (Gua 1, slab A) and age model

core Gua1, slab A (1999-1981)

sample ID	new no.	Sr/Ca (mmol/mol)	d13-C (per mil)	d18-O (per mil)	timemarker year.month	anchor High/Low	1st interpolation new no.	Sr/Ca (mmol/mol)	d13-C (per mil)	d18-O (per mil)	timemarker year.month	2nd interpolation (monthly resolution) new no.	timemarker year.month	Sr/Ca (mmol/mol)	d13-C (per mil)	d18-O (per mil)
187	1	8.868	-0.660	-4.083	1999.21	L	167	8.965	0.657	-4.030	1981.21	167.00	1981.21	8.965	0.657	-4.030
188	2	8.740	-0.527	-4.079			166	8.826	1.123	-4.307	1981.29	165.96	1981.29	8.825	1.077	-4.309
189	3	8.711	-0.609	-4.591	1998.71	H	165	8.801	0.012	-4.361	1981.37	164.93	1981.38	8.802	0.110	-4.331
190	4	8.756	-0.281	-4.849			164	8.818	1.336	-3.959	1981.46	164.00	1981.46	8.818	1.336	-3.959
191	5	8.744	0.202	-4.480			163	8.749	0.979	-4.111	1981.54	162.96	1981.54	8.750	0.949	-4.125
192	6	8.777	0.035	-4.287			162	8.769	0.256	-4.437	1981.62	161.93	1981.63	8.767	0.204	-4.455
193	7	8.780	-0.135	-4.472			161	8.748	-0.444	-4.683	1981.71	161.00	1981.71	8.748	-0.444	-4.683
194	8	8.785	-0.210	-4.324	1998.21	L	160	8.758	-0.356	-4.489	1981.83	160.31	1981.79	8.755	-0.383	-4.548
195	9	8.753	0.201	-4.451			159	8.794	-1.007	-4.223	1981.96	159.64	1981.88	8.771	-0.590	-4.394
196	10	8.729	-0.313	-4.527			158	8.820	-0.376	-3.896	1982.08	159.00	1981.96	8.794	-1.007	-4.223
197	11	8.745	0.078	-4.423			157	8.895	0.423	-4.123	1982.21	158.31	1982.04	8.812	-0.569	-3.996
198	12	8.696	0.418	-4.569	1997.71	H	156	8.879	-0.158	-4.060	1982.31	157.64	1982.13	8.847	-0.089	-3.977
199	13	8.715	0.171	-4.452			155	8.847	-0.273	-4.237	1982.41	157.00	1982.21	8.895	0.423	-4.123
200	14	8.772	-0.189	-4.316			154	8.851	-0.263	-4.352	1982.51	156.17	1982.29	8.882	-0.061	-4.071
996	15	8.844	0.200	-3.823			153	8.807	-0.355	-4.341	1982.61	155.33	1982.38	8.858	-0.235	-4.178
997	16	8.816	-0.072	-3.791	1997.21	L	152	8.800	-0.967	-4.449	1982.71	154.50	1982.46	8.849	-0.268	-4.295
998	17	8.827	-0.315	-3.967			151	8.819	-1.347	-4.386	1982.81	153.67	1982.54	8.836	-0.294	-4.348
999	18	8.785	-0.510	-4.177			150	8.842	-1.509	-4.151	1982.91	152.83	1982.63	8.806	-0.457	-4.359
1000	19	8.800	-0.115	-4.377			149	8.882	-1.411	-4.010	1983.01	152.00	1982.71	8.800	-0.967	-4.449
1001	20	8.770	0.026	-4.464	1996.71	H	148	8.878	-1.009	-3.938	1983.11	151.17	1982.79	8.816	-1.284	-4.397
1002	21	8.780	0.431	-4.283			147	8.884	-0.473	-3.950	1983.21	150.33	1982.88	8.834	-1.455	-4.229
1003	22	8.775	0.473	-4.279			146	8.849	-0.246	-4.040	1983.31	149.50	1982.96	8.862	-1.460	-4.081
1004	23	8.825	0.634	-4.102			145	8.836	0.012	-4.272	1983.41	148.67	1983.04	8.881	-1.277	-3.986
1005	24	8.839	0.405	-3.956			144	8.817	-0.409	-4.377	1983.51	147.83	1983.13	8.879	-0.920	-3.940
1006	25	8.866	0.300	-3.731			143	8.783	-0.297	-4.402	1983.61	147.00	1983.21	8.884	-0.473	-3.950
1007	26	8.879	0.151	-3.827	1996.21	L	142	8.774	-0.417	-4.374	1983.71	146.17	1983.29	8.855	-0.284	-4.025
1008	27	8.861	-0.086	-3.889			141	8.791	-0.645	-4.312	1983.78	145.33	1983.38	8.840	-0.074	-4.195
1009	28	8.868	0.007	-4.077			140	8.816	-0.564	-4.231	1983.85	144.50	1983.46	8.827	-0.199	-4.325
1010	29	8.823	-0.310	-4.355			139	8.843	-0.758	-4.247	1983.92	143.67	1983.54	8.806	-0.372	-4.385
1011	30	8.803	-0.104	-4.358	1995.71	H	138	8.858	-0.917	-3.946	1983.99	142.83	1983.63	8.782	-0.317	-4.397
1012	31	8.814	0.361	-4.401			137	8.918	-0.769	-3.968	1984.07	142.00	1983.71	8.774	-0.417	-4.374
1013	32	8.812	0.957	-4.281			136	8.891	-0.561	-3.850	1984.14	140.81	1983.79	8.796	-0.630	-4.297
1014	33	8.894	0.358	-4.246			135	8.931	-0.124	-3.744	1984.21	139.62	1983.88	8.826	-0.638	-4.237
1015	34	8.880	0.449	-3.970	1995.21	L	134	8.920	0.023	-3.811	1984.31	138.43	1983.96	8.852	-0.849	-4.075
1016	35	8.869	0.297	-3.955			133	8.894	0.212	-4.037	1984.41	137.33	1984.04	8.898	-0.818	-3.961
1017	36	8.857	-0.175	-4.325			132	8.862	0.244	-4.185	1984.51	136.19	1984.13	8.896	-0.601	-3.872
1018	37	8.885	0.467	-4.359			131	8.815	0.117	-4.333	1984.61	135.00	1984.21	8.931	-0.124	-3.744
1019	38	8.790	0.711	-4.419	1994.71	H	130	8.818	0.152	-4.291	1984.71	134.17	1984.29	8.922	-0.002	-3.800
1020	39	8.821	0.533	-4.312			129	8.836	-0.091	-4.505	1984.79	133.33	1984.38	8.903	0.149	-3.962
1021	40	8.837	0.343	-4.176			128	8.884	0.004	-4.498	1984.87	132.50	1984.46	8.878	0.228	-4.111
1022	41	8.883	0.443	-3.896			127	8.892	-0.615	-4.363	1984.96	131.67	1984.54	8.846	0.202	-4.234
1023	42	8.921	0.163	-3.964	1994.21	L	126	8.917	-0.591	-4.147	1985.04	130.83	1984.63	8.816	0.123	-4.326
1024	43	8.905	-0.371	-3.930			125	8.947	-0.577	-3.963	1985.12	130.00	1984.71	8.818	0.152	-4.291
1025	44	8.858	-0.265	-4.235			124	8.976	0.083	-3.796	1985.21	128.96	1984.79	8.838	-0.087	-4.505
1026	45	8.808	-0.003	-4.342	1993.71	H	123	8.963	-0.127	-3.915	1985.33	127.93	1984.88	8.885	-0.042	-4.488
1027	46	8.891	0.806	-4.406			122	8.939	0.210	-3.963	1985.46	127.00	1984.96	8.892	-0.615	-4.363
1028	47	8.849	0.177	-4.450			121	8.872	-0.046	-4.182	1985.58	125.96	1985.04	8.918	-0.590	-4.139
1029	48	8.845	0.015	-4.430			120	8.845	0.068	-4.387	1985.71	124.93	1985.13	8.949	-0.528	-3.951
1030	49	8.907	0.053	-4.099			119	8.862	-0.602	-4.349	1985.81	124.00	1985.21	8.976	0.083	-3.796
1031	50	8.922	0.065	-3.953	1993.21	L	118	8.891	-0.676	-4.249	1985.91	123.31	1985.29	8.967	-0.063	-3.879
1032	51	8.898	0.257	-3.877			117	8.915	-0.603	-4.009	1986.01	122.64	1985.38	8.954	-0.006	-3.932
1033	52	8.836	-0.471	-4.210			116	8.936	-0.287	-3.763	1986.11	122.00	1985.46	8.939	0.210	-3.963
1034	53	8.857	-0.099	-4.433			115	8.953	-0.103	-3.769	1986.21	121.31	1985.54	8.892	0.032	-4.115
1035	54	8.837	0.570	-4.403			114	8.917	0.379	-3.890	1986.31	120.64	1985.63	8.862	-0.005	-4.256
1036	55	8.830	0.540	-4.300	1992.71	H	113	8.898	0.088	-4.071	1986.41	120.00	1985.71	8.845	0.068	-4.387
1037	56	8.840	0.469	-4.313			112	8.857	0.350	-4.139	1986.51	119.17	1985.79	8.859	-0.490	-4.355
1038	57	8.845	0.339	-4.064			111	8.845	0.342	-4.365	1986.61	118.33	1985.88	8.881	-0.651	-4.282
1039	58	8.853	0.053	-3.896			110	8.837	0.199	-4.549	1986.71	117.50	1985.96	8.903	-0.640	-4.129
1040	59	8.852	-0.132	-3.813			109	8.809	-0.146	-4.437	1986.87	116.67	1986.04	8.922	-0.498	-3.927
1041	60	8.877	-0.437	-3.919	1992.21	L	108	8.857	-0.429	-4.186	1987.04	115.83	1986.13	8.939	-0.256	-3.764
1042	61	8.824	-0.452	-4.000			107	8.916	-0.168	-3.868	1987.21	115.00	1986.21	8.953	-0.103	-3.769
1043	62	8.786	-0.143	-4.369			106	8.892	-0.053	-3.994	1987.27	114.17	1986.29	8.923	0.299	-3.870
1044	63	8.778	0.297	-4.341	1991.71	H	105	8.868	0.024	-4.289	1987.33	113.33	1986.38	8.904	0.185	-4.011
1045	64	8.790	0.474	-4.167			104	8.841	-0.257	-4.360	1987.40	112.50	1986.46	8.878	0.219	-4.105
1046	65	8.831	0.609	-4.075			103	8.789	-0.266	-4.467	1987.46	111.67	1986.54	8.853	0.347	-4.214
1047	66	8.864	0.381	-3.922			102	8.817	-0.059	-4.396	1987.52	110.83	1986.63	8.844	0.318	-4.396
1048	67	8.891	0.090	-3.875	1991.21	L	101	8.781	-0.390	-4.438	1987.58	110.00	1986.71	8.837	0.199	-4.549
1049	68	8.862	-0.307	-3.938			100	8.773	-0.885	-4.371	1987.65	109.48	1986.79	8.822	0.019	-4.491
1050	69	8.794	-0.341	-4.166			99	8.752	-1.008	-4.222	1987.71	108.96	1986.88	8.811	-0.157	-4.427
1051	70	8.779	0.085	-4.343			98	8.832	-1.063	-4.163	1987.83	108.47	1986.96	8.834	-0.296	-4.304
1052	71	8.803	0.839	-4.425			97	8.867	-0.326	-3.953	1987.96	107.98	1987.04	8.858	-0.424	-4.180
1053	72	8.770	0.571	-4.305	1990.71	H	96	8.911	-0.206	-3.839	1988.08	107.49	1987.13	8.887	-0.296	-4.024
1054	73	8.816	0.414	-4.263			95	8.904	-0.146	-3.800	1988.21	107.00	1987.21	8.916	-0.168	-3.868
1055	74	8.871	0.376	-4.239			94	8.897	0.113	-3.989	1988.31	105.61	1987.29	8.883	-0.023	-4.109
1056	75	8.891	0.062	-4.045			93	8.890	0.537	-4.066	1988.41	104.33	1987.38	8.850	-0.163	-4.336
1057	76	8.906	0.236	-3.936	1990.21	L	92	8.866	0.227	-4.249	1988.51	103.00	1987.46	8.789	-0.266	-4.467
1058	77	8.849	-0.366	-4.339			91	8.802	0.062	-4.413	1988.61	101.61	1987.54	8.803	-0.188	-4.412
1059	78	8.850	-0.156	-4.493			90	8.786	-0.582	-4.420	1988.71	100.33	1987.63	8.776	-0.720	-4.393
1060	79	8.845	0.835	-4.512			89	8.818	-0.819	-4.391	1988.79	99.00	1987.71	8.752	-1.008	-4.222
1061	80	8.810	0.623	-4.346	1989.71	H	88	8.824	-0.776	-4.232	1988.87	98.31	1987.79	8.808	-1.046	-4.181
1062	81	8.871	0.537	-4.308			87	8.884	-0.888	-4.114	1988.96	97.64	1987.88	8.845	-0.798	-4.088
1063	82	8.885	0.389	-4.004			86	8.899	-0.371	-3.860	1989.04	97.00	1987.96	8.867	-0.326	-3.953
1064	83	8.924	0.195	-3.994			85	8.926	-0.367	-3.747	1989.12	96.31	1988.04	8.898	-0.243	-3.874
1065	84	8.946	-0.232	-3.814	1989.21	L	84	8.946	-0.232	-3.814	1989.21	95.64	1988.13	8.908	-0.184	-3.825
1066	85	8.926	-0.367	-3.747			83	8.924	0.195	-3.994	1989.33	95.00	1988.21	8.904	-0.146	-3.800
1067	86	8.899	-0.371	-3.860			82	8.885	0.389	-4.004	1989.46	94.17	1988.29	8.898	0.070	-3.958
1068	87	8.884	-0.888	-4.114			81	8.871	0.537	-4.308	1989.58	93.33	1988.38	8.892	0.396	-4.040
1069	88	8.824	-0.776	-4.232			80	8.810	0.623	-4.346	1989.71	92.50	1988.46	8.878	0.382	-4.158
1070	89	8.818	-0.819	-4.391			79	8.845	0.835	-4.512	1989.83	91.67	1988.54	8.845	0.172	-4.304
1071	90	8.786	-0.582	-4.420	1988.71	H	78	8.850	-0.156	-4.493	1989.96	90.83	1988.63	8.799	-0.045	-4.414
1072	91	8.802	0.062	-4.413			77	8.849	-0.366	-4.339	1990.08	90.00	1988.71	8.786	-0.582	-4.420
1073	92	8.866	0.227	-4.249			76	8.906	0.236	-3.936	1990.21	88.96	1988.79	8.818	-0.817	-4.384
1074	93	8.890	0.537	-4.066			75	8.891	0.062	-4.045	1990.33	87.93	1988.88	8.828	-0.784	-4.223
1075	94	8.897	0.113	-3.989			74	8.871	0.376	-4.239	1990.46	87.00	1988.96	8.884	-0.888	-4.114
1076	95	8.904	-0.146	-3.800	1988.21	L	73	8.816	0.414	-4.263	1990.58	85.96	1989.04	8.900	-0.371	-3.855
1077	96	8.911	-0.206	-3.839			72	8.770	0.571	-4.305	1990.71	84.93	1989.13	8.927	-0.357	-3.752
1078	97	8.867	-0.326	-3.953			71	8.803	0.839	-4.425	1990.81	84.00	1989.21	8.946	-0.232	-3.814
1079	98	8.832	-1.063	-4.163			70	8.779	0.085	-4.343	1990.91	83.31	1989.29	8.931	0.065	-3.939
1080	99	8.752	-1.008	-4.222	1987.71	H	69	8.794	-0.341	-4.166	1991.01	82.64	1989.38	8.910	0.265	-3.998
1081	100	8.773	-0.885	-4.371			68	8.862	-0.307	-3.938	1991.11	82.00	1989.46	8.885	0.389	-4.004
1082	101	8.781	-0.390	-4.438			67	8.891	0.090	-3.875	1991.21	81.31	1989.54	8.875	0.492	-4.215
1083	102	8.817	-0.059	-4.396			66	8.864	0.381	-3.922	1991.33	80.64	1989.63	8.849	0.568	-4.322
1084	103	8.789	-0.266	-4.467			65	8.831	0.609	-4.075	1991.46	80.00	1989.71	8.810	0.623	-4.346
1085	104	8.841	-0.257	-4.360			64	8.790	0.474	-4.167	1991.58	79.31	1989.79	8.834	0.770	-4.461
1086	105	8.868	0.024	-4.289			63	8.778	0.297	-4.341	1991.71	78.64	1989.88	8.847	0.479	-4.505
1087	106	8.892	-0.053	-3.994			62	8.786	-0.143	-4.369	1991.87	78.00	1989.96	8.850	-0.156	-4.493
1088	107	8.916	-0.168	-3.868	1987.21	L	61	8.824	-0.452	-4.000	1992.04	77.31	1990.04	8.849	-0.302	-4.386

Appendix A.1
oxygen isotope and trace element data for coral core from Guadeloupe (Gua 1, slab A) and age model

sample ID	new no.	Sr/Ca (mmol/mol)	d13-C (per mil)	d18-O (per mil)	timemarker year.month	anchor High/Low
1089	108	8.857	-0.429	-4.186		
1090	109	8.809	-0.146	-4.437		
1091	110	8.837	0.199	-4.549	1986.71	H
1092	111	8.845	0.342	-4.365		
1093	112	8.857	0.350	-4.139		
1094	113	8.898	0.088	-4.071		
1095	114	8.917	0.379	-3.890		
1096	115	8.953	-0.103	-3.769	1986.21	L
1097	116	8.936	-0.287	-3.763		
1098	117	8.915	-0.603	-4.009		
1099	118	8.891	-0.676	-4.249		
1100	119	8.862	-0.602	-4.349		
1101	120	8.845	0.068	-4.387	1985.71	H
1102	121	8.872	-0.046	-4.182		
1103	122	8.939	0.210	-3.963		
1104	123	8.963	-0.127	-3.915		
1105	124	8.976	0.083	-3.796	1985.21	L
1106	125	8.947	-0.577	-3.963		
1107	126	8.917	-0.591	-4.147		
1108	127	8.892	-0.615	-4.363		
1109	128	8.884	0.004	-4.498		
1116	129	8.836	-0.091	-4.505		
1117	130	8.818	0.152	-4.291	1984.71	H
1118	131	8.815	0.117	-4.333		
1119	132	8.862	0.244	-4.185		
1120	133	8.894	0.212	-4.037		
1121	134	8.920	0.023	-3.811		
1122	135	8.931	-0.124	-3.744	1984.21	L
1123	136	8.891	-0.561	-3.850		
1124	137	8.918	-0.769	-3.968		
1125	138	8.858	-0.917	-3.946		
1126	139	8.843	-0.758	-4.247		
1127	140	8.816	-0.564	-4.231		
1128	141	8.791	-0.645	-4.312		
1129	142	8.774	-0.417	-4.374	1983.71	H
1130	143	8.783	-0.297	-4.402		
1131	144	8.817	-0.409	-4.377		
1132	145	8.836	0.012	-4.272		
1133	146	8.849	-0.246	-4.040		
1134	147	8.884	-0.473	-3.950	1983.21	L
1135	148	8.878	-1.009	-3.938		
1136	149	8.882	-1.411	-4.010		
1137	150	8.842	-1.509	-4.151		
1138	151	8.819	-1.347	-4.386		
1139	152	8.800	-0.967	-4.449	1982.71	H
1140	153	8.807	-0.355	-4.341		
1141	154	8.851	-0.263	-4.352		
1142	155	8.847	-0.273	-4.237		
1143	156	8.879	-0.158	-4.060		
201	157	8.895	0.423	-4.123	1982.21	L
202	158	8.820	-0.376	-3.896		
203	159	8.794	-1.007	-4.223		
204	160	8.758	-0.356	-4.489		
205	161	8.748	-0.444	-4.683	1981.71	H
206	162	8.769	0.256	-4.437		
207	163	8.749	0.979	-4.111		
208	164	8.818	1.336	-3.959		
209	165	8.801	0.012	-4.361		
210	166	8.826	1.123	-4.307		
211	167	8.965	0.657	-4.030	1981.21	L

1st interpolation new no.	Sr/Ca (mmol/mol)	d13-C (per mil)	d18-O (per mil)	timemarker year.month
60	8.877	-0.437	-3.919	1992.21
59	8.852	-0.132	-3.813	1992.31
58	8.853	0.053	-3.896	1992.41
57	8.845	0.339	-4.064	1992.51
56	8.840	0.469	-4.313	1992.61
55	8.830	0.540	-4.300	1992.71
54	8.837	0.570	-4.403	1992.81
53	8.857	-0.099	-4.433	1992.91
52	8.836	-0.471	-4.210	1993.01
51	8.898	0.257	-3.877	1993.11
50	8.922	0.065	-3.953	1993.21
49	8.907	0.053	-4.099	1993.31
48	8.845	0.015	-4.430	1993.41
47	8.849	0.177	-4.450	1993.51
46	8.891	0.806	-4.406	1993.61
45	8.808	-0.003	-4.342	1993.71
44	8.858	-0.265	-4.235	1993.87
43	8.905	-0.371	-3.930	1994.04
42	8.921	0.163	-3.964	1994.21
41	8.883	0.443	-3.896	1994.33
40	8.837	0.343	-4.176	1994.46
39	8.821	0.533	-4.312	1994.58
38	8.790	0.711	-4.419	1994.71
37	8.885	0.467	-4.359	1994.83
36	8.857	-0.175	-4.325	1994.96
35	8.869	0.297	-3.955	1995.08
34	8.880	0.449	-3.970	1995.21
33	8.894	0.358	-4.246	1995.33
32	8.812	0.957	-4.281	1995.46
31	8.814	0.361	-4.401	1995.58
30	8.803	-0.104	-4.358	1995.71
29	8.823	-0.310	-4.355	1995.83
28	8.868	0.007	-4.077	1995.96
27	8.861	-0.086	-3.889	1996.08
26	8.879	0.151	-3.827	1996.21
25	8.866	0.300	-3.731	1996.29
24	8.839	0.405	-3.956	1996.37
23	8.825	0.634	-4.102	1996.46
22	8.775	0.473	-4.279	1996.54
21	8.780	0.431	-4.283	1996.62
20	8.770	0.026	-4.464	1996.71
19	8.800	-0.115	-4.377	1996.83
18	8.785	-0.510	-4.177	1996.96
17	8.827	-0.315	-3.967	1997.08
16	8.816	-0.072	-3.791	1997.21
15	8.844	0.200	-3.823	1997.33
14	8.772	-0.189	-4.316	1997.46
13	8.715	0.171	-4.452	1997.58
12	8.696	0.418	-4.569	1997.71
11	8.745	0.078	-4.423	1997.83
10	8.729	-0.313	-4.527	1997.96
9	8.753	0.201	-4.451	1998.08
8	8.785	-0.210	-4.324	1998.21
7	8.780	-0.135	-4.472	1998.31
6	8.777	0.035	-4.287	1998.41
5	8.744	0.202	-4.480	1998.51
4	8.756	-0.281	-4.849	1998.61
3	8.711	-0.609	-4.591	1998.71
2	8.740	-0.527	-4.079	1998.96
1	8.868	-0.660	-4.083	1999.21

2nd interpolation (monthly resolution) new no.	timemarker year.month	Sr/Ca (mmol/mol)	d13-C (per mil)	d18-O (per mil)
76.64	1990.13	8.869	-0.150	-4.194
76.00	1990.21	8.906	0.236	-3.936
75.31	1990.29	8.896	0.115	-4.012
74.64	1990.38	8.884	0.175	-4.115
74.00	1990.46	8.871	0.376	-4.239
73.31	1990.54	8.833	0.402	-4.256
72.64	1990.63	8.799	0.470	-4.278
72.00	1990.71	8.770	0.571	-4.305
71.17	1990.79	8.798	0.794	-4.405
70.33	1990.88	8.787	0.336	-4.370
69.50	1990.96	8.787	-0.128	-4.255
68.67	1991.04	8.817	-0.330	-4.090
67.83	1991.13	8.867	-0.241	-3.928
67.00	1991.21	8.891	0.090	-3.875
66.31	1991.29	8.872	0.292	-3.908
65.64	1991.38	8.852	0.463	-3.977
65.00	1991.46	8.831	0.609	-4.075
64.31	1991.54	8.803	0.515	-4.139
63.64	1991.63	8.786	0.410	-4.229
63.00	1991.71	8.778	0.297	-4.341
62.48	1991.79	8.782	0.068	-4.356
61.96	1991.88	8.787	-0.155	-4.355
61.47	1991.96	8.806	-0.307	-4.174
60.98	1992.04	8.825	-0.452	-3.998
60.49	1992.13	8.851	-0.444	-3.959
60.00	1992.21	8.877	-0.437	-3.919
59.17	1992.29	8.856	-0.183	-3.831
58.33	1992.38	8.853	-0.009	-3.868
57.50	1992.46	8.849	0.196	-3.980
56.67	1992.54	8.843	0.382	-4.147
55.83	1992.63	8.838	0.481	-4.311
55.00	1992.71	8.830	0.540	-4.300
54.17	1992.79	8.836	0.565	-4.386
53.33	1992.88	8.850	0.124	-4.423
52.50	1992.96	8.847	-0.285	-4.322
51.67	1993.04	8.857	-0.228	-4.099
50.83	1993.13	8.902	0.225	-3.890
50.00	1993.21	8.922	0.065	-3.953
49.17	1993.29	8.910	0.055	-4.075
48.33	1993.38	8.866	0.028	-4.320
47.50	1993.46	8.847	0.096	-4.440
46.67	1993.54	8.863	0.387	-4.435
45.83	1993.63	8.877	0.671	-4.395
45.00	1993.71	8.808	-0.003	-4.342
44.48	1993.79	8.834	-0.139	-4.286
43.96	1993.88	8.860	-0.269	-4.223
43.47	1993.96	8.883	-0.321	-4.074
42.98	1994.04	8.905	-0.361	-3.931
42.49	1994.13	8.913	-0.099	-3.947
42.00	1994.21	8.921	0.163	-3.964
41.31	1994.29	8.895	0.357	-3.917
40.64	1994.38	8.866	0.407	-3.997
40.00	1994.46	8.837	0.343	-4.176
39.31	1994.54	8.826	0.475	-4.270
38.64	1994.63	8.810	0.597	-4.350
38.00	1994.71	8.790	0.711	-4.419
37.31	1994.79	8.856	0.542	-4.377
36.64	1994.88	8.875	0.237	-4.347
36.00	1994.96	8.857	-0.175	-4.325
35.31	1995.04	8.865	0.153	-4.068
34.64	1995.13	8.873	0.352	-3.960
34.00	1995.21	8.880	0.449	-3.970
33.31	1995.29	8.890	0.386	-4.162
32.64	1995.38	8.865	0.573	-4.259
32.00	1995.46	8.812	0.957	-4.281
31.31	1995.54	8.813	0.543	-4.364
30.64	1995.63	8.810	0.194	-4.386
30.00	1995.71	8.803	-0.104	-4.358
29.31	1995.79	8.817	-0.247	-4.356
28.64	1995.88	8.839	-0.196	-4.255
28.00	1995.96	8.868	0.007	-4.077
27.31	1996.04	8.863	-0.058	-3.946
26.64	1996.13	8.867	-0.001	-3.867
26.00	1996.21	8.879	0.151	-3.827
24.96	1996.29	8.865	0.304	-3.740
23.93	1996.38	8.838	0.422	-3.967
23.00	1996.46	8.825	0.634	-4.102
21.96	1996.54	8.775	0.471	-4.279
20.93	1996.63	8.779	0.401	-4.296
20.00	1996.71	8.770	0.026	-4.464
19.31	1996.79	8.791	-0.072	-4.404
18.64	1996.88	8.795	-0.257	-4.305
18.00	1996.96	8.785	-0.510	-4.177
17.31	1997.04	8.814	-0.375	-4.031
16.64	1997.13	8.823	-0.228	-3.904
16.00	1997.21	8.816	-0.072	-3.791
15.31	1997.29	8.835	0.117	-3.813
14.64	1997.38	8.818	0.060	-4.000
14.00	1997.46	8.772	-0.189	-4.316
13.31	1997.54	8.732	0.061	-4.410
12.64	1997.63	8.708	0.260	-4.494
12.00	1997.71	8.696	0.418	-4.569
11.31	1997.79	8.730	0.182	-4.468
10.64	1997.88	8.739	-0.062	-4.460
10.00	1997.96	8.729	-0.313	-4.527
9.31	1998.04	8.746	0.044	-4.474
8.64	1998.13	8.764	0.053	-4.405
8.00	1998.21	8.785	-0.210	-4.324
7.17	1998.29	8.781	-0.148	-4.447
6.33	1998.38	8.778	-0.022	-4.349
5.50	1998.46	8.761	0.119	-4.384
4.67	1998.54	8.748	0.041	-4.603
3.83	1998.63	8.749	-0.336	-4.806
3.00	1998.71	8.711	-0.609	-4.591
2.67	1998.79	8.721	-0.582	-4.420
2.33	1998.88	8.730	-0.554	-4.250
2.00	1998.96	8.740	-0.527	-4.079
1.67	1999.04	8.783	-0.571	-4.080
1.33	1999.13	8.825	-0.616	-4.082
1.00	1999.21	8.868	-0.660	-4.083

Appendix A.2

oxygen isotope and trace element data for coral core from Guadeloupe (Gua 1, slabs B-F) and age model

core Gua1, slab B-F (1978-1895)

							1st interpolation						2nd interpolation (monthly resolution)				
sample ID	new no.	Sr/ Ca (mmol/mol)	d13-C (per mil)	d18-O (per mil)	timemarker year.month	anchor High/Low	new no.	Sr/ Ca (mmol/mol)	d13-C (per mil)	d18-O (per mil)	timemarker year.month	new no.	timemarker year.month	Sr/ Ca (mmol/mol)	d13-C (per mil)	d18-O (per mil)
976	1	8.859	-0.053	-4.516	1978.71	H	822	8.838	-0.446	-4.022	1895.70	822.00	1895.70	8.838	-0.446	-4.022
977	2	8.869	-0.113	-4.426			821	8.956	-0.262	-3.812	1895.83	821.36	1895.78	8.914	-0.328	-3.887
978	3	8.870	0.164	-4.377			820	8.935	-0.007	-3.794	1895.95	820.69	1895.87	8.950	-0.184	-3.807
979	4	8.892	0.206	-4.386			819	8.967	0.186	-3.803	1896.08	820.00	1895.95	8.935	-0.007	-3.794
980	5	8.895	0.250	-4.094			818	8.926	0.367	-3.827	1896.20	819.36	1896.03	8.956	0.117	-3.800
981	6	8.915	0.193	-4.014			817	8.924	0.461	-3.790	1896.30	818.69	1896.12	8.954	0.241	-3.810
982	7	8.941	0.190	-3.914	1978.21	L	816	8.852	0.425	-3.958	1896.40	818.00	1896.20	8.926	0.367	-3.827
983	8	8.964	-0.698	-3.954			815	8.820	0.197	-4.259	1896.50	817.17	1896.28	8.924	0.445	-3.796
984	9	8.881	-0.752	-3.951			814	8.799	0.210	-4.196	1896.60	816.33	1896.37	8.876	0.437	-3.902
985	10	8.829	-0.690	-4.258			813	8.765	0.446	-4.137	1896.70	815.50	1896.45	8.836	0.311	-4.109
986	11	8.778	-0.133	-4.334	1977.71	H	812	8.826	0.261	-4.175	1896.78	814.67	1896.53	8.813	0.201	-4.238
987	12	8.848	0.480	-4.441			811	8.776	-0.009	-4.164	1896.87	813.83	1896.62	8.793	0.249	-4.186
988	13	8.880	0.754	-4.195			810	8.873	-0.262	-4.098	1896.95	813.00	1896.70	8.765	0.446	-4.137
943	14	8.820	1.172	-4.045			809	8.900	0.421	-3.865	1897.03	811.96	1896.78	8.824	0.251	-4.175
944	15	8.935	0.545	-3.985			808	8.881	0.460	-4.050	1897.12	811.04	1896.87	8.778	0.001	-4.164
945	16	8.929	0.741	-3.902			807	8.911	0.567	-3.799	1897.20	810.00	1896.95	8.873	-0.262	-4.098
946	17	8.928	0.212	-3.747	1977.21	L	806	8.919	0.698	-3.844	1897.28	808.96	1897.03	8.899	0.422	-3.872
947	18	8.967	0.429	-3.740			805	8.897	0.707	-3.898	1897.37	808.04	1897.12	8.882	0.459	-4.043
948	19	8.909	-0.092	-3.873			804	8.866	0.566	-4.120	1897.45	807.00	1897.20	8.911	0.567	-3.799
949	20	8.880	0.084	-4.065			803	8.836	0.103	-4.450	1897.53	805.96	1897.28	8.918	0.698	-3.846
950	21	8.814	-0.243	-4.281	1976.71	H	802	8.832	0.458	-4.477	1897.62	805.04	1897.37	8.898	0.707	-3.896
951	22	8.842	0.457	-4.244			801	8.823	-0.147	-4.337	1897.70	804.00	1897.45	8.866	0.566	-4.120
952	23	8.890	0.412	-4.143			800	8.840	-0.336	-4.387	1897.77	802.96	1897.53	8.836	0.116	-4.451
953	24	8.883	0.337	-4.042			799	8.875	-0.007	-4.099	1897.84	802.04	1897.62	8.832	0.445	-4.476
954	25	8.927	0.443	-3.784			798	8.883	-0.104	-3.968	1897.91	801.00	1897.70	8.823	-0.147	-4.337
955	26	8.965	0.256	-3.535	1976.21	L	797	8.952	0.444	-3.946	1897.99	799.81	1897.78	8.847	-0.273	-4.332
956	27	8.914	-0.381	-3.726			796	8.976	0.565	-3.891	1898.06	798.62	1897.87	8.878	-0.044	-4.049
957	28	8.869	-0.532	-3.857			795	8.964	0.738	-3.879	1898.13	797.50	1897.95	8.918	0.170	-3.957
958	29	8.853	-0.171	-4.129	1975.71	H	794	8.995	0.981	-3.989	1898.20	796.38	1898.03	8.967	0.519	-3.912
959	30	8.856	0.519	-4.266			793	8.900	0.887	-4.188	1898.28	795.19	1898.12	8.966	0.705	-3.881
960	31	8.893	0.175	-4.135			792	8.866	0.624	-4.403	1898.37	794.00	1898.20	8.995	0.981	-3.989
961	32	8.933	0.444	-4.022			791	8.880	0.886	-4.344	1898.45	792.96	1898.28	8.899	0.877	-4.196
962	33	8.920	0.261	-3.864			790	8.844	0.589	-4.286	1898.53	792.04	1898.37	8.867	0.634	-4.395
963	34	8.907	0.169	-3.804			789	8.829	0.335	-4.473	1898.62	791.00	1898.45	8.880	0.886	-4.344
964	35	8.969	-0.191	-3.896	1975.21	L	788	8.846	0.167	-4.386	1898.70	789.96	1898.53	8.843	0.580	-4.293
216	36	8.914	0.223	-3.978			787	8.811	0.067	-4.221	1898.80	789.04	1898.62	8.830	0.344	-4.466
217	37	8.909	-0.270	-4.159			786	8.924	0.130	-3.915	1898.90	788.00	1898.70	8.846	0.167	-4.386
218	38	8.846	0.503	-4.356	1974.71	H	785	8.958	0.308	-3.856	1899.00	787.17	1898.78	8.817	0.084	-4.249
219	39	8.890	0.998	-4.159			784	9.010	0.628	-3.814	1899.10	786.33	1898.87	8.886	0.109	-4.017
220	40	8.908	0.608	-4.047			783	9.027	0.611	-3.858	1899.20	785.50	1898.95	8.941	0.219	-3.886
221	41	8.959	0.151	-3.792			782	8.961	0.787	-3.919	1899.28	784.67	1899.03	8.975	0.415	-3.842
222	42	8.954	-0.043	-3.726	1974.21	L	781	8.914	0.815	-4.180	1899.37	783.83	1899.12	9.013	0.625	-3.821
223	43	8.930	-0.249	-3.783			780	8.847	0.623	-4.265	1899.45	783.00	1899.20	9.027	0.611	-3.858
224	44	8.910	0.121	-4.213			779	8.821	0.430	-4.373	1899.53	781.96	1899.28	8.959	0.788	-3.929
225	45	8.859	0.206	-4.123	1973.71	H	778	8.864	0.170	-4.377	1899.62	781.04	1899.37	8.916	0.814	-4.170
226	46	8.867	0.563	-4.232			777	8.797	0.083	-4.434	1899.70	780.00	1899.45	8.847	0.623	-4.265
227	47	8.898	0.941	-3.940			776	8.913	-0.117	-4.290	1899.80	778.96	1899.53	8.823	0.420	-4.373
228	48	8.904	0.857	-3.900			775	8.917	0.069	-4.045	1899.90	778.04	1899.62	8.862	0.180	-4.377
229	49	8.923	0.589	-3.775	1973.21	L	774	8.936	0.338	-4.019	1900.00	777.00	1899.70	8.797	0.083	-4.434
230	50	8.925	0.550	-3.982			773	8.953	0.460	-3.901	1900.10	776.17	1899.78	8.894	-0.084	-4.314
231	51	8.843	0.151	-4.134			772	8.970	0.580	-3.981	1900.20	775.33	1899.87	8.916	0.007	-4.127
232	52	8.850	0.421	-4.433			771	8.927	0.280	-4.212	1900.30	774.50	1899.95	8.927	0.204	-4.032
233	53	8.829	0.328	-4.329	1972.71	H	770	8.929	0.230	-4.126	1900.40	773.67	1900.03	8.942	0.379	-3.980
234	54	8.869	0.442	-4.078			769	8.886	0.380	-4.148	1900.50	772.83	1900.12	8.956	0.480	-3.914
235	55	8.879	0.478	-3.867			768	8.824	0.365	-4.204	1900.60	772.00	1900.20	8.970	0.580	-3.981
236	56	8.951	0.330	-3.834	1972.21	L	767	8.825	0.222	-4.417	1900.70	771.17	1900.28	8.934	0.330	-4.174
237	57	8.912	0.044	-3.845			766	8.889	0.289	-4.299	1900.78	770.33	1900.37	8.928	0.247	-4.155
238	58	8.902	0.377	-3.856			765	8.851	0.170	-4.117	1900.87	769.50	1900.45	8.908	0.305	-4.137
239	59	8.833	0.254	-4.298			764	8.876	0.132	-4.009	1900.95	768.67	1900.53	8.865	0.375	-4.167
240	60	8.840	0.396	-4.274			763	8.931	0.277	-3.932	1901.03	767.83	1900.62	8.824	0.341	-4.240
241	61	8.814	0.867	-4.301	1971.71	H	762	8.955	0.323	-3.776	1901.12	767.00	1900.70	8.825	0.222	-4.417
242	62	8.864	0.699	-4.249			761	8.974	0.486	-3.892	1901.20	765.96	1900.78	8.888	0.285	-4.292
243	63	8.927	0.604	-3.957			760	8.942	0.370	-3.950	1901.28	765.04	1900.87	8.852	0.174	-4.124
244	64	8.935	0.482	-3.764	1971.21	L	759	8.936	0.498	-4.135	1901.37	764.00	1900.95	8.876	0.132	-4.009
245	65	8.924	0.046	-3.829			758	8.930	0.764	-4.071	1901.45	762.96	1901.03	8.932	0.279	-3.926
246	66	8.880	-0.396	-3.910			757	8.852	0.484	-4.234	1901.53	762.04	1901.12	8.954	0.321	-3.782
247	67	8.849	-0.872	-4.094			756	8.875	0.803	-4.398	1901.62	761.00	1901.20	8.974	0.486	-3.892
248	68	8.814	-0.258	-4.100			755	8.838	0.159	-4.270	1901.70	759.96	1901.28	8.942	0.375	-3.957
249	69	8.826	-0.295	-4.229	1970.71	H	754	8.826	0.336	-4.375	1901.80	759.04	1901.37	8.936	0.493	-4.128
250	70	8.863	0.151	-4.107			753	8.868	0.500	-4.306	1901.90	758.00	1901.45	8.930	0.764	-4.071
251	71	8.840	-0.154	-4.617			752	8.912	0.291	-3.988	1902.00	756.96	1901.53	8.853	0.496	-4.240
252	72	8.868	0.015	-4.287			751	9.002	0.366	-3.853	1902.10	756.04	1901.62	8.874	0.791	-4.392
253	73	8.881	0.645	-4.154			750	8.991	0.370	-3.680	1902.20	755.00	1901.70	8.838	0.159	-4.270
254	74	8.915	0.192	-4.039	1970.21	L	749	8.989	0.430	-3.813	1902.30	754.17	1901.78	8.828	0.307	-4.358
255	75	8.916	0.009	-3.980			748	8.972	0.219	-4.025	1902.40	753.33	1901.87	8.854	0.445	-4.329
256	76	8.859	-0.313	-4.152			747	8.964	0.255	-4.050	1902.50	752.50	1901.95	8.890	0.396	-4.147
257	77	8.853	-0.351	-4.120			746	8.924	-0.101	-4.309	1902.60	751.67	1902.03	8.942	0.316	-3.943
258	78	8.838	0.259	-4.290			745	8.877	0.077	-4.241	1902.70	750.83	1902.12	9.000	0.367	-3.824
259	79	8.851	0.814	-4.254			744	8.886	0.317	-4.348	1902.77	750.00	1902.20	8.991	0.370	-3.680
260	80	8.786	0.440	-4.439	1969.71	H	743	8.915	0.599	-4.275	1902.84	749.17	1902.28	8.989	0.420	-3.791
261	81	8.841	0.964	-4.356			742	8.949	0.054	-4.297	1902.91	748.33	1902.37	8.978	0.289	-3.954
262	82	8.815	0.787	-4.222			741	8.888	-0.105	-4.104	1902.99	747.50	1902.45	8.968	0.237	-4.038
263	83	8.882	0.775	-4.013	1969.21	L	740	8.968	-0.356	-4.028	1903.06	746.67	1902.53	8.951	0.136	-4.136
264	84	8.876	0.414	-4.085			739	8.964	-0.211	-3.774	1903.13	745.83	1902.62	8.916	-0.071	-4.298
265	85	8.852	0.048	-3.886			738	9.011	0.291	-4.119	1903.20	745.00	1902.70	8.877	0.077	-4.241
266	86	8.788	0.436	-4.256	1968.71	H	737	8.980	0.321	-3.918	1903.28	743.81	1902.78	8.892	0.371	-4.334
267	87	8.811	0.897	-4.222			736	8.925	0.387	-3.959	1903.37	742.62	1902.87	8.928	0.391	-4.283
268	88	8.868	0.660	-4.253			735	8.890	0.633	-4.243	1903.45	741.50	1902.95	8.919	-0.026	-4.201
269	89	8.954	0.489	-3.962	1968.21	L	734	8.831	0.400	-4.258	1903.53	740.38	1903.03	8.938	-0.260	-4.057
270	90	8.875	-0.213	-3.748			733	8.858	0.636	-4.194	1903.62	739.19	1903.12	8.965	-0.239	-3.822
271	91	8.831	0.102	-3.780			732	8.838	0.314	-4.325	1903.70	738.00	1903.20	9.011	0.291	-4.119
272	92	8.877	0.364	-4.009			731	8.831	0.043	-4.261	1903.78	736.96	1903.28	8.978	0.323	-3.920
273	93	8.802	0.787	-4.326	1967.71	H	730	8.885	0.288	-4.093	1903.87	736.04	1903.37	8.927	0.385	-3.957
274	94	8.840	0.856	-4.280			729	8.961	0.031	-3.801	1903.95	735.00	1903.45	8.890	0.633	-4.243
275	95	8.895	0.762	-4.051			728	8.974	-0.054	-3.686	1904.03	733.96	1903.53	8.832	0.409	-4.256
276	96	8.918	0.200	-4.039			727	9.005	0.263	-3.528	1904.12	733.04	1903.62	8.857	0.627	-4.196
277	97	9.001	0.070	-3.732	1967.21	L	726	9.023	0.435	-3.611	1904.20	732.00	1903.70	8.838	0.314	-4.325
278	98	8.967	-0.089	-3.760			725	9.017	0.652	-3.676	1904.28	730.96	1903.78	8.833	0.052	-4.255
279	99	8.903	-0.435	-3.935			724	8.917	0.732	-3.765	1904.37	730.04	1903.87	8.883	0.279	-4.099
280	100	8.863	-0.723	-4.167			723	8.940	0.909	-3.851	1904.45	729.00	1903.95	8.961	0.031	-3.801
281	101	8.805	0.167	-4.391	1966.71	H	722	8.917	0.927	-4.117	1904.53	727.96	1904.03	8.975	-0.042	-3.680
282	102	8.820	0.399	-4.209			721	8.886	0.917	-4.156	1904.62	727.04	1904.12	9.004	0.251	-3.534

Appendix A.2
oxygen isotope and trace element data for coral core from Guadeloupe (Gua 1, slabs B-F) and age model

							1st interpolation					2nd interpolation (monthly resolution)				
sample ID	new no.	Sr/ Ca (mmol/mol)	d13-C (per mil)	d18-O (per mil)	timemarker year.month	anchor High/Low	new no.	Sr/ Ca (mmol/mol)	d13-C (per mil)	d18-O (per mil)	timemarker year.month	new no.	timemarker year.month	Sr/ Ca (mmol/mol)	d13-C (per mil)	d18-O (per mil)
283	103	8.869	0.926	-4.153			720	8.847	0.554	-4.129	1904.70	726.00	1904.20	9.023	0.435	-3.611
284	104	8.917	0.745	-3.994	1966.21	L	719	8.854	0.075	-4.188	1904.83	724.96	1904.28	9.013	0.655	-3.679
285	105	8.914	0.322	-3.906			718	8.867	0.230	-3.922	1904.95	724.04	1904.37	8.921	0.729	-3.762
286	106	8.879	0.475	-3.954			717	8.952	0.157	-3.687	1905.08	723.00	1904.45	8.940	0.909	-3.851
287	107	8.865	-0.301	-4.185			716	8.996	0.500	-3.549	1905.20	721.96	1904.53	8.916	0.927	-4.118
288	108	8.837	0.313	-4.246	1965.71	H	715	8.969	0.677	-3.620	1905.30	721.04	1904.62	8.887	0.917	-4.155
289	109	8.855	0.708	-4.180			714	8.942	0.357	-3.965	1905.40	720.00	1904.70	8.847	0.554	-4.129
290	110	8.974	1.083	-3.926			713	8.895	0.236	-4.138	1905.50	719.36	1904.78	8.851	0.247	-4.167
291	111	9.008	0.730	-3.974			712	8.841	-0.040	-4.212	1905.60	718.69	1904.87	8.858	0.122	-4.107
292	112	9.009	0.527	-3.878			711	8.814	0.024	-4.520	1905.70	718.00	1904.95	8.867	0.230	-3.922
293	113	9.030	0.457	-3.750	1965.21	L	710	8.855	0.210	-4.477	1905.78	717.36	1905.03	8.921	0.183	-3.771
294	114	8.991	-0.045	-3.779			709	8.874	0.952	-4.291	1905.87	716.69	1905.12	8.965	0.262	-3.645
295	115	8.949	0.161	-3.951			708	8.872	1.262	-4.043	1905.95	716.00	1905.20	8.996	0.500	-3.549
296	116	8.883	-0.115	-4.115			707	8.905	0.511	-4.086	1906.03	715.17	1905.28	8.974	0.648	-3.608
297	117	8.850	-0.228	-4.374	1964.71	H	706	8.949	0.568	-3.734	1906.12	714.33	1905.37	8.951	0.464	-3.850
298	118	8.919	0.575	-4.232			705	8.986	0.854	-3.708	1906.20	713.50	1905.45	8.919	0.297	-4.052
299	119	8.892	0.701	-4.138			704	8.982	0.557	-3.753	1906.26	712.67	1905.53	8.877	0.144	-4.163
300	120	8.923	0.419	-4.006			703	8.986	0.413	-3.886	1906.33	711.83	1905.62	8.837	-0.029	-4.263
301	121	8.923	0.407	-3.941			702	8.954	0.420	-3.945	1906.39	711.00	1905.70	8.814	0.024	-4.520
302	122	8.972	0.395	-3.694	1964.21	L	701	8.869	0.183	-4.201	1906.45	709.96	1905.78	8.856	0.237	-4.470
303	123	8.972	0.429	-3.788			700	8.848	0.135	-4.246	1906.51	709.04	1905.87	8.873	0.925	-4.298
304	124	8.890	0.175	-3.873			699	8.837	0.126	-4.266	1906.58	708.00	1905.95	8.872	1.262	-4.043
305	125	8.829	0.236	-4.047			698	8.872	0.024	-4.285	1906.64	706.96	1906.03	8.907	0.513	-4.073
306	126	8.800	0.403	-4.429	1963.71	H	697	8.849	-0.354	-4.209	1906.70	706.04	1906.12	8.947	0.566	-3.747
307	127	8.844	0.543	-4.366			696	8.823	-0.476	-4.084	1906.77	705.00	1906.20	8.986	0.854	-3.708
308	128	8.902	0.711	-4.262			695	8.861	-0.294	-4.123	1906.84	703.67	1906.28	8.983	0.509	-3.797
309	129	8.901	0.782	-4.015			694	8.887	-0.424	-3.892	1906.91	702.39	1906.37	8.966	0.417	-3.922
310	130	8.928	0.591	-3.895			693	8.951	-0.293	-3.553	1906.99	701.00	1906.45	8.869	0.183	-4.201
311	131	8.958	0.586	-3.778			692	8.984	-0.262	-3.458	1907.06	699.67	1906.53	8.844	0.132	-4.253
312	132	8.981	0.258	-3.658	1963.21	L	691	8.980	-0.085	-3.455	1907.13	698.39	1906.62	8.858	0.064	-4.278
313	133	8.888	0.117	-3.791			690	9.002	-0.464	-3.634	1907.20	697.00	1906.70	8.849	-0.354	-4.209
314	134	8.867	-0.036	-4.214			689	9.007	0.306	-3.686	1907.33	695.81	1906.78	8.830	-0.441	-4.091
315	135	8.876	-0.002	-4.291			688	8.885	0.352	-4.047	1907.45	694.62	1906.87	8.871	-0.344	-4.035
316	136	8.861	0.199	-4.398			687	8.864	0.176	-4.392	1907.58	693.50	1906.95	8.919	-0.359	-3.723
317	137	8.856	0.264	-4.303	1962.71	H	686	8.857	0.013	-4.463	1907.70	692.38	1907.03	8.971	-0.274	-3.494
318	138	8.849	0.461	-4.215			685	8.871	0.192	-4.470	1907.76	691.19	1907.12	8.981	-0.119	-3.456
319	139	8.879	0.430	-4.155			684	8.902	-0.195	-4.366	1907.83	690.00	1907.20	9.002	-0.464	-3.634
320	140	8.921	0.319	-3.838			683	8.858	-0.191	-4.298	1907.89	689.36	1907.28	9.005	0.030	-3.667
321	141	8.928	0.264	-3.643	1962.21	L	682	8.905	0.036	-3.981	1907.95	688.69	1907.37	8.970	0.320	-3.796
322	142	8.893	0.362	-3.687			681	8.926	0.027	-3.853	1908.01	688.00	1907.45	8.885	0.352	-4.047
323	143	8.919	0.000	-3.986			680	8.973	0.201	-3.907	1908.08	687.36	1907.53	8.872	0.239	-4.268
324	144	8.900	-0.102	-4.128			679	9.016	0.260	-3.897	1908.14	686.69	1907.62	8.862	0.126	-4.414
325	145	8.808	0.544	-4.444	1961.71	H	678	9.037	0.342	-3.780	1908.20	686.00	1907.70	8.857	0.013	-4.463
326	146	8.863	0.789	-4.321			677	8.982	0.603	-3.907	1908.30	684.67	1907.78	8.881	0.063	-4.435
327	147	8.889	0.911	-4.187			676	8.965	0.662	-3.985	1908.40	683.39	1907.87	8.875	-0.193	-4.324
328	148	8.915	1.098	-3.902			675	8.860	0.463	-4.064	1908.50	682.00	1907.95	8.905	0.036	-3.981
329	149	8.958	0.663	-3.906			674	8.853	0.512	-4.488	1908.60	680.67	1908.03	8.942	0.085	-3.871
330	150	8.963	0.380	-3.747	1961.21	L	673	8.884	0.636	-4.607	1908.70	679.39	1908.12	8.999	0.237	-3.901
331	151	8.944	0.086	-3.884			672	8.852	0.397	-4.272	1908.78	678.00	1908.20	9.037	0.342	-3.780
332	152	8.924	-0.210	-3.969			671	8.878	-0.180	-4.348	1908.87	677.17	1908.28	8.991	0.560	-3.886
333	153	8.910	-0.069	-4.148			670	8.904	0.106	-4.083	1908.95	676.33	1908.37	8.971	0.642	-3.959
334	154	8.843	0.230	-4.303			669	8.916	-0.021	-4.123	1909.03	675.50	1908.45	8.913	0.563	-4.025
335	155	8.796	0.061	-4.414	1960.71	H	668	8.959	0.377	-4.058	1909.12	674.67	1908.53	8.858	0.479	-4.205
336	156	8.838	0.338	-4.464			667	8.964	0.675	-4.034	1909.20	673.83	1908.62	8.858	0.533	-4.508
337	157	8.847	0.490	-4.366			666	8.936	0.806	-4.166	1909.30	673.00	1908.70	8.884	0.636	-4.607
338	158	8.880	0.624	-4.232			665	8.913	0.687	-4.294	1909.40	671.96	1908.78	8.853	0.376	-4.275
339	159	8.884	0.421	-4.190			664	8.872	0.551	-4.516	1909.50	671.04	1908.87	8.877	-0.159	-4.345
340	160	8.996	0.814	-3.979	1960.21	L	663	8.865	1.041	-4.564	1909.60	670.00	1908.95	8.904	0.106	-4.083
341	161	8.946	0.579	-3.981			662	8.854	0.374	-4.407	1909.70	668.96	1909.03	8.918	-0.006	-4.121
342	162	8.954	0.437	-3.903			661	8.856	0.162	-4.112	1909.83	668.04	1909.12	8.957	0.362	-4.060
343	163	8.958	0.563	-3.900			660	8.881	0.030	-3.900	1909.95	667.00	1909.20	8.964	0.675	-4.034
344	164	8.929	0.135	-3.897			659	8.931	0.192	-3.869	1910.08	666.17	1909.28	8.941	0.784	-4.144
345	165	8.944	0.120	-4.051			658	8.976	0.238	-4.001	1910.20	665.33	1909.37	8.921	0.727	-4.251
346	166	8.892	0.188	-4.210			657	8.964	0.308	-3.886	1910.30	664.50	1909.45	8.893	0.619	-4.405
347	167	8.906	0.960	-4.329	1959.71	H	656	8.949	0.421	-4.093	1910.40	663.67	1909.53	8.870	0.714	-4.532
348	168	8.888	0.790	-4.292			655	8.920	0.631	-4.250	1910.50	662.83	1909.62	8.863	0.930	-4.538
349	169	8.893	0.830	-4.372			654	8.873	1.331	-4.374	1910.60	662.00	1909.70	8.854	0.374	-4.407
350	170	8.918	0.789	-4.192			653	8.872	0.967	-4.472	1910.70	661.36	1909.78	8.855	0.238	-4.218
351	171	8.947	0.731	-4.057			652	8.864	0.559	-4.362	1910.80	660.69	1909.87	8.864	0.122	-4.047
352	172	8.999	0.765	-3.954	1959.21	L	651	8.864	0.325	-4.276	1910.90	660.00	1909.95	8.881	0.030	-3.900
353	173	8.948	0.649	-3.811			650	8.896	0.269	-4.021	1911.00	659.36	1910.03	8.913	0.134	-3.880
354	174	8.949	0.413	-3.863			649	8.963	0.724	-3.881	1911.10	658.69	1910.12	8.945	0.206	-3.909
355	175	8.958	0.222	-3.917			648	8.987	0.745	-3.941	1911.20	658.00	1910.20	8.976	0.238	-4.001
356	176	8.984	0.208	-4.076			647	8.958	0.492	-4.066	1911.30	657.17	1910.28	8.966	0.296	-3.905
357	177	8.923	0.035	-4.077			646	8.911	0.900	-4.379	1911.40	656.33	1910.37	8.954	0.383	-4.024
358	178	8.931	0.025	-4.377			645	8.887	1.094	-4.363	1911.50	655.50	1910.45	8.935	0.526	-4.172
359	179	8.880	0.087	-4.411			644	8.893	1.145	-4.354	1911.60	654.67	1910.53	8.904	0.864	-4.291
360	180	8.880	0.522	-4.497	1958.71	H	643	8.880	0.582	-4.380	1911.70	653.83	1910.62	8.873	1.270	-4.390
361	181	8.822	0.405	-4.484			642	8.915	0.406	-4.114	1911.83	653.00	1910.70	8.872	0.967	-4.472
362	182	8.826	0.458	-4.529			641	8.935	0.281	-3.847	1911.95	652.17	1910.78	8.865	0.627	-4.380
363	183	8.869	0.981	-4.281			640	8.964	0.547	-3.755	1912.08	651.33	1910.87	8.864	0.403	-4.305
364	184	8.949	1.017	-4.173			639	8.970	0.620	-3.792	1912.20	650.50	1910.95	8.880	0.297	-4.149
365	185	8.950	0.462	-4.127	1958.21	L	638	8.945	0.720	-3.881	1912.33	649.67	1911.03	8.918	0.421	-3.974
366	186	8.906	-0.141	-4.002			637	8.898	0.864	-4.160	1912.45	648.83	1911.12	8.967	0.728	-3.891
367	187	8.870	-0.284	-4.083			636	8.873	1.621	-4.392	1912.58	648.00	1911.20	8.987	0.745	-3.941
368	188	8.839	0.095	-4.372			635	8.852	0.724	-4.281	1912.70	647.17	1911.28	8.963	0.534	-4.045
369	189	8.831	0.211	-4.379	1957.71	H	634	8.890	0.377	-4.103	1912.87	646.33	1911.37	8.927	0.764	-4.275
370	190	8.837	0.435	-4.507			633	8.904	0.532	-3.901	1913.03	645.50	1911.45	8.899	0.997	-4.371
371	191	8.866	0.548	-4.193			632	9.023	0.693	-3.711	1913.20	644.67	1911.53	8.889	1.111	-4.360
372	192	8.859	0.633	-4.277			631	8.936	0.596	-3.794	1913.30	643.83	1911.62	8.891	1.051	-4.358
373	193	8.884	0.544	-3.954			630	8.968	0.618	-3.764	1913.40	643.00	1911.70	8.880	0.582	-4.380
374	194	8.947	0.550	-3.891			629	8.932	0.688	-4.065	1913.50	642.36	1911.78	8.902	0.469	-4.209
375	195	8.993	0.422	-3.659	1957.21	L	628	8.928	0.965	-4.188	1913.60	641.69	1911.87	8.921	0.368	-4.032
376	196	8.994	0.425	-3.534			627	8.921	1.217	-4.351	1913.70	641.00	1911.95	8.935	0.281	-3.847
377	197	8.952	-0.012	-3.576			626	8.920	0.414	-4.349	1913.83	640.36	1912.03	8.954	0.452	-3.788
378	198	8.976	0.117	-3.537			625	8.927	0.304	-4.152	1913.95	639.69	1912.12	8.966	0.569	-3.766
379	199	8.970	0.467	-4.066			624	8.963	0.563	-3.853	1914.08	639.00	1912.20	8.970	0.620	-3.792
380	200	8.941	1.131	-4.171			623	8.976	0.746	-3.887	1914.20	638.36	1912.28	8.954	0.684	-3.849
381	201	8.912	1.075	-4.099	1956.71	H	622	8.931	0.670	-3.934	1914.33	637.69	1912.37	8.931	0.764	-3.966
382	202	8.924	0.833	-4.215			621	8.896	0.676	-4.271	1914.45	637.00	1912.45	8.898	0.864	-4.160
383	203	8.923	0.781	-4.090			620	8.890	0.862	-4.403	1914.58	636.36	1912.53	8.882	1.349	-4.309
384	204	8.959	0.652	-3.877			619	8.860	1.164	-4.217	1914.70	635.69	1912.62	8.867	1.347	-4.358
385	205	8.985	0.485	-3.684	1956.21	L	618	8.870	1.152	-4.254	1914.80	635.00	1912.70	8.852	0.724	-4.281
386	206	8.934	0.358	-3.724			617	8.875	0.966	-4.024	1914.90	634.51	1912.78	8.871	0.554	-4.194

Appendix A.2
oxygen isotope and trace element data for coral core from Guadeloupe (Gua 1, slabs B-F) and age model

sample ID	new no.	Sr/ Ca (mmol/mol)	d13-C (per mil)	d18-O (per mil)	timemarker year.month	anchor High/Low	1st interpolation new no.	Sr/ Ca (mmol/mol)	d13-C (per mil)	d18-O (per mil)	timemarker year.month	2nd interpolation (monthly resolution) new no.	timemarker year.month	Sr/ Ca (mmol/mol)	d13-C (per mil)	d18-O (per mil)
387	207	8.938	0.083	-3.709			616	8.915	0.539	-3.856	1915.00	634.02	1912.87	8.889	0.384	-4.106
388	208	8.833	0.116	-4.125			615	8.968	0.434	-3.866	1915.10	633.50	1912.95	8.897	0.455	-4.002
389	209	8.817	0.958	-4.320	1955.71	H	614	8.971	0.616	-3.933	1915.20	632.98	1913.03	8.906	0.535	-3.897
390	210	8.800	1.135	-4.212			613	8.954	0.570	-4.006	1915.28	632.49	1913.12	8.965	0.614	-3.804
391	211	8.793	0.715	-4.279			612	8.923	0.429	-4.236	1915.37	632.00	1913.20	9.023	0.693	-3.711
392	212	8.866	0.633	-4.022			611	8.954	0.925	-4.219	1915.45	631.17	1913.28	8.951	0.612	-3.780
393	213	8.950	0.718	-3.684	1955.21	L	610	8.895	1.143	-4.353	1915.53	630.33	1913.37	8.957	0.611	-3.774
394	214	8.944	0.355	-3.738			609	8.866	0.337	-4.397	1915.62	629.50	1913.45	8.950	0.653	-3.915
395	215	8.919	0.142	-3.639			608	8.836	0.090	-4.184	1915.70	628.67	1913.53	8.931	0.780	-4.106
396	216	8.932	0.350	-3.888			607	8.876	0.479	-3.981	1915.87	627.83	1913.62	8.927	1.007	-4.215
397	217	8.863	0.096	-4.293			606	8.916	0.933	-3.792	1916.03	627.00	1913.70	8.921	1.217	-4.351
398	218	8.801	0.704	-4.265	1954.71	H	605	8.939	0.388	-3.812	1916.20	626.36	1913.78	8.920	0.702	-4.350
399	219	8.813	1.067	-4.232			604	8.930	0.598	-3.941	1916.33	625.69	1913.87	8.922	0.380	-4.289
400	220	8.873	1.044	-3.933			603	8.932	0.802	-4.143	1916.45	625.00	1913.95	8.927	0.304	-4.152
401	221	8.906	1.021	-3.960			602	8.941	1.106	-4.325	1916.58	624.36	1914.03	8.950	0.470	-3.960
402	222	8.949	0.671	-3.708	1954.21	L	601	8.859	1.015	-4.241	1916.70	623.69	1914.12	8.967	0.619	-3.863
403	223	8.883	0.355	-3.850			600	8.881	0.603	-4.301	1916.80	623.00	1914.20	8.976	0.746	-3.887
404	224	8.866	0.408	-4.054			599	8.910	0.118	-3.980	1916.90	622.36	1914.28	8.947	0.697	-3.917
405	225	8.850	0.383	-4.149			598	8.914	0.272	-3.779	1917.00	621.69	1914.37	8.920	0.672	-4.037
406	226	8.863	1.248	-4.430	1953.71	H	597	8.938	0.355	-3.709	1917.10	621.00	1914.45	8.896	0.676	-4.271
407	227	8.877	1.338	-4.198			596	8.908	0.727	-3.674	1917.20	620.36	1914.53	8.892	0.795	-4.356
408	228	8.878	0.423	-4.375			595	8.910	0.600	-3.733	1917.30	619.69	1914.62	8.881	0.954	-4.346
409	229	8.967	0.750	-3.946			594	8.945	0.756	-3.902	1917.40	619.00	1914.70	8.860	1.164	-4.217
410	230	8.988	0.581	-3.774			593	8.913	0.574	-4.035	1917.50	618.17	1914.78	8.868	1.154	-4.248
411	231	8.998	0.429	-3.557	1953.21	L	592	8.872	0.692	-4.237	1917.60	617.33	1914.87	8.873	1.028	-4.101
412	232	8.921	0.280	-3.603			591	8.844	1.134	-4.298	1917.70	616.50	1914.95	8.895	0.753	-3.940
413	233	8.908	-0.339	-3.881			590	8.889	0.434	-4.314	1917.80	615.67	1915.03	8.933	0.504	-3.859
414	234	8.811	-0.201	-4.152			589	8.918	0.298	-4.142	1917.90	614.83	1915.12	8.969	0.464	-3.877
415	235	8.854	0.641	-4.141			588	8.972	0.371	-3.925	1918.00	614.00	1915.20	8.971	0.616	-3.933
416	236	8.841	0.879	-4.387	1952.71	H	587	8.997	0.460	-3.737	1918.10	612.96	1915.28	8.953	0.565	-4.015
417	237	8.854	0.939	-4.301			586	9.006	0.366	-3.830	1918.20	612.04	1915.37	8.924	0.434	-4.227
418	238	8.863	1.012	-4.152			585	8.957	0.422	-4.005	1918.30	611.00	1915.45	8.954	0.925	-4.219
419	239	8.864	1.168	-3.985			584	8.896	0.447	-4.250	1918.40	609.96	1915.53	8.894	1.113	-4.355
420	240	8.908	0.853	-4.215			583	8.911	0.724	-4.261	1918.50	609.04	1915.62	8.867	0.367	-4.395
421	241	8.909	1.047	-3.743			582	8.875	1.025	-4.301	1918.60	608.00	1915.70	8.836	0.090	-4.184
422	242	8.919	0.625	-3.829			581	8.848	0.973	-4.306	1918.70	607.51	1915.78	8.856	0.281	-4.084
423	243	8.934	0.415	-3.677	1952.21	L	580	8.860	0.143	-4.223	1918.83	607.02	1915.87	8.875	0.471	-3.985
424	244	8.936	-0.304	-3.816			579	8.876	0.270	-4.099	1918.95	606.50	1915.95	8.896	0.706	-3.887
425	245	8.944	-0.199	-3.774			578	8.935	0.451	-3.884	1919.08	605.98	1916.03	8.916	0.922	-3.792
426	246	8.891	-0.315	-4.134			577	8.994	0.573	-3.978	1919.20	605.49	1916.12	8.928	0.655	-3.802
427	247	8.899	0.200	-4.061			576	8.948	0.518	-3.920	1919.30	605.00	1916.20	8.939	0.388	-3.812
428	248	8.859	0.300	-4.377			575	8.928	0.474	-4.064	1919.40	604.36	1916.28	8.933	0.523	-3.895
429	249	8.852	0.465	-4.281	1951.71	H	574	8.875	0.733	-4.427	1919.50	603.69	1916.37	8.931	0.660	-4.003
430	250	8.883	0.412	-4.289			573	8.874	0.760	-4.190	1919.60	603.00	1916.45	8.932	0.802	-4.143
431	251	8.886	0.508	-4.000			572	8.881	0.931	-4.192	1919.70	602.36	1916.53	8.938	0.997	-4.260
432	252	8.964	0.667	-3.949			571	8.879	0.398	-4.371	1919.78	601.69	1916.62	8.916	1.078	-4.299
433	253	9.019	0.164	-3.850	1951.21	L	570	8.933	0.275	-4.301	1919.87	601.00	1916.70	8.859	1.015	-4.241
434	254	8.973	0.186	-3.761			569	8.905	0.229	-4.125	1919.95	600.17	1916.78	8.877	0.672	-4.291
435	255	8.935	-0.161	-3.712			568	8.919	0.267	-3.964	1920.03	599.33	1916.87	8.900	0.280	-4.087
436	256	8.895	0.221	-3.958			567	8.993	0.558	-3.859	1920.12	598.50	1916.95	8.912	0.195	-3.880
437	257	8.881	-0.287	-4.163			566	8.970	0.973	-3.813	1920.20	597.67	1917.03	8.922	0.300	-3.756
438	258	8.904	0.801	-4.345			565	8.999	0.680	-3.954	1920.30	596.83	1917.12	8.933	0.417	-3.703
439	259	8.833	0.681	-4.454	1950.71	H	564	8.912	0.782	-4.061	1920.40	596.00	1917.20	8.908	0.727	-3.674
440	260	8.841	0.653	-4.212			563	8.921	0.836	-4.156	1920.50	595.17	1917.28	8.910	0.621	-3.723
441	261	8.889	0.737	-3.998			562	8.864	0.668	-4.359	1920.60	594.33	1917.37	8.933	0.704	-3.846
442	262	8.926	0.581	-3.899			561	8.830	0.755	-4.522	1920.70	593.50	1917.45	8.929	0.665	-3.969
443	263	8.945	0.336	-3.883			560	8.881	0.822	-4.560	1920.80	592.67	1917.53	8.899	0.613	-4.102
444	264	8.930	0.244	-3.743	1950.21	L	559	8.873	0.392	-4.300	1920.90	591.83	1917.62	8.867	0.766	-4.247
445	265	8.949	0.253	-3.750			558	8.917	0.412	-3.901	1921.00	591.00	1917.70	8.844	1.134	-4.298
446	266	8.900	-0.219	-4.016			557	8.984	0.299	-3.917	1921.10	590.17	1917.78	8.882	0.551	-4.311
447	267	8.891	-0.275	-4.111			556	9.018	0.644	-3.934	1921.20	589.33	1917.87	8.908	0.343	-4.199
448	268	8.867	0.217	-4.263			555	8.939	0.703	-4.016	1921.30	588.50	1917.95	8.945	0.335	-4.034
449	269	8.819	0.656	-4.524	1949.71	H	554	8.890	0.511	-4.209	1921.40	587.67	1918.03	8.980	0.401	-3.862
450	270	8.830	0.445	-4.409			553	8.884	0.594	-4.339	1921.50	586.83	1918.12	8.999	0.444	-3.753
451	271	8.862	0.499	-4.221			552	8.848	0.880	-4.415	1921.60	586.00	1918.20	9.006	0.366	-3.830
452	272	8.873	0.812	-4.078			551	8.853	0.732	-4.312	1921.70	585.17	1918.28	8.965	0.413	-3.976
453	273	8.915	0.840	-3.903			550	8.844	-0.068	-4.246	1921.80	584.33	1918.37	8.916	0.439	-4.168
454	274	8.928	0.663	-3.784	1949.21	L	549	8.863	0.451	-3.999	1921.90	583.50	1918.45	8.904	0.586	-4.256
455	275	8.918	0.479	-3.807			548	8.902	0.143	-4.011	1922.00	582.67	1918.53	8.899	0.824	-4.274
456	276	8.882	0.164	-4.039			547	8.954	0.399	-3.864	1922.10	581.83	1918.62	8.871	1.016	-4.302
457	277	8.849	-0.042	-4.205			546	8.966	0.458	-3.861	1922.20	581.00	1918.70	8.848	0.973	-4.306
458	278	8.759	0.223	-4.387	1948.71	H	545	8.978	0.363	-4.137	1922.33	580.36	1918.78	8.856	0.441	-4.253
459	279	8.811	0.524	-4.339			544	8.940	0.525	-4.102	1922.45	579.69	1918.87	8.865	0.182	-4.185
460	280	8.873	0.317	-4.407			543	8.931	0.723	-4.291	1922.58	579.00	1918.95	8.876	0.270	-4.099
461	281	8.908	0.422	-4.233			542	8.906	0.725	-4.340	1922.70	578.36	1919.03	8.914	0.386	-3.961
462	282	8.958	0.621	-3.959			541	8.996	0.577	-4.269	1922.78	577.69	1919.12	8.953	0.488	-3.913
463	283	8.983	0.704	-3.784			540	8.958	0.424	-4.094	1922.87	577.00	1919.20	8.994	0.573	-3.978
464	284	8.995	0.763	-3.668	1948.21	L	539	8.936	0.079	-4.196	1922.95	576.17	1919.28	8.956	0.527	-3.930
465	285	8.940	0.263	-3.788			538	9.002	0.325	-3.965	1923.03	575.33	1919.37	8.935	0.489	-4.016
466	286	8.882	0.268	-4.032			537	9.039	0.430	-3.684	1923.12	574.50	1919.45	8.902	0.604	-4.246
467	287	8.860	0.925	-4.270			536	9.040	0.497	-3.619	1923.20	573.67	1919.53	8.875	0.742	-4.348
468	288	8.825	0.957	-4.224	1947.71	H	535	9.020	0.676	-3.568	1923.27	572.83	1919.62	8.875	0.789	-4.190
469	289	8.858	0.927	-4.123			534	9.005	0.948	-3.710	1923.34	572.00	1919.70	8.881	0.931	-4.192
470	290	8.890	0.919	-4.037			533	9.017	0.774	-3.916	1923.41	570.96	1919.78	8.881	0.393	-4.368
471	291	8.907	1.163	-3.894			532	8.932	0.785	-4.042	1923.49	570.04	1919.87	8.931	0.280	-4.304
472	292	8.919	0.702	-3.828	1947.21	L	531	8.881	0.488	-4.275	1923.56	569.00	1919.95	8.905	0.229	-4.125
473	293	8.909	0.860	-3.792			530	8.913	1.136	-4.305	1923.63	567.96	1920.03	8.922	0.278	-3.960
474	294	8.897	0.771	-3.800			529	8.912	1.216	-4.422	1923.70	567.04	1920.12	8.990	0.547	-3.863
475	295	8.863	0.370	-3.954			528	8.888	0.358	-4.302	1923.80	566.00	1920.20	8.970	0.973	-3.813
476	296	8.872	0.397	-4.129			527	8.880	0.646	-4.033	1923.90	565.17	1920.28	8.994	0.729	-3.931
477	297	8.896	0.835	-4.143			526	8.900	0.626	-3.834	1924.00	564.33	1920.37	8.941	0.748	-4.025
478	298	8.871	1.442	-4.308	1946.71	H	525	8.931	0.788	-3.747	1924.10	563.50	1920.45	8.917	0.809	-4.109
479	299	8.889	0.922	-4.346			524	8.976	0.677	-3.929	1924.20	562.67	1920.53	8.902	0.780	-4.224
480	300	8.920	1.050	-4.050			523	8.930	0.873	-3.925	1924.28	561.83	1920.62	8.858	0.683	-4.386
481	301	8.922	0.820	-4.022			522	8.917	0.743	-3.964	1924.37	561.00	1920.70	8.830	0.755	-4.522
482	302	8.971	0.786	-3.877			521	8.915	0.735	-4.238	1924.45	560.17	1920.78	8.873	0.811	-4.554
483	303	8.970	0.834	-3.714			520	8.886	0.971	-4.256	1924.53	559.33	1920.87	8.876	0.535	-4.387
488	304	8.980	0.698	-3.671	1946.21	L	519	8.889	0.598	-4.408	1924.62	558.50	1920.95	8.895	0.402	-4.101
489	305	8.947	0.056	-3.798			518	8.871	0.149	-4.318	1924.70	557.67	1921.03	8.939	0.374	-3.906
490	306	8.933	0.455	-3.785			517	8.889	0.321	-4.110	1924.83	556.83	1921.12	8.990	0.357	-3.920
491	307	8.924	-0.008	-3.983			516	8.898	0.369	-3.758	1924.95	556.00	1921.20	9.018	0.644	-3.934
492	308	8.924	-0.192	-4.173			515	8.966	0.701	-3.863	1925.08	555.17	1921.28	8.952	0.693	-4.002
493	309	8.863	-0.137	-4.411			514	8.992	0.486	-3.967	1925.20	554.33	1921.37	8.906	0.575	-4.145
494	310	8.815	0.518	-4.416	1945.71	H	513	8.993	0.670	-4.070	1925.30	553.50	1921.45	8.887	0.553	-4.274

Appendix A.2

oxygen isotope and trace element data for coral core from Guadeloupe (Gua 1, slabs B-F) and age model

							1st interpolation					2nd interpolation (monthly resolution)				
sample ID	new no.	Sr/ Ca	d13-C	d18-O	timemarker	anchor	new no.	Sr/ Ca	d13-C	d18-O	timemarker	new no.	timemarker	Sr/ Ca	d13-C	d18-O
		(mmol/mol)	(per mil)	(per mil)	year.month	High/Low		(mmol/mol)	(per mil)	(per mil)	year.month		year.month	(mmol/mol)	(per mil)	(per mil)
495	311	8.844	0.510	-4.420			512	8.964	1.096	-4.020	1925.40	552.67	1921.53	8.872	0.689	-4.364
496	312	8.885	0.501	-4.209			511	8.894	1.261	-4.245	1925.50	551.83	1921.62	8.849	0.855	-4.398
497	313	8.920	0.481	-4.266			510	8.877	1.371	-4.340	1925.60	551.00	1921.70	8.853	0.732	-4.312
498	314	8.958	0.349	-4.075			509	8.882	1.096	-4.413	1925.70	550.17	1921.78	8.846	0.065	-4.257
499	315	8.987	0.452	-3.927			508	8.918	0.875	-4.295	1925.83	549.33	1921.87	8.857	0.278	-4.081
500	316	9.017	0.297	-3.948	1945.21	L	507	8.980	0.377	-4.133	1925.95	548.50	1921.95	8.883	0.297	-4.005
501	317	8.990	-0.058	-3.945			506	9.017	0.286	-3.868	1926.08	547.67	1922.03	8.919	0.228	-3.962
502	318	8.981	-0.026	-4.026			505	9.021	0.600	-3.801	1926.20	546.83	1922.12	8.956	0.409	-3.864
503	319	8.955	0.290	-4.249			504	8.979	0.594	-3.841	1926.30	546.00	1922.20	8.966	0.458	-3.861
504	320	8.885	0.735	-4.522			503	8.963	0.556	-3.948	1926.40	545.36	1922.28	8.974	0.397	-4.038
505	321	8.867	0.839	-4.652	1944.71	H	502	8.915	0.810	-4.166	1926.50	544.69	1922.37	8.966	0.413	-4.126
506	322	8.889	0.929	-4.306			501	8.854	0.814	-4.285	1926.60	544.00	1922.45	8.940	0.525	-4.102
507	323	8.968	0.362	-4.329			500	8.846	1.021	-4.309	1926.70	543.36	1922.53	8.934	0.652	-4.223
508	324	8.960	0.653	-4.216			499	8.849	0.882	-4.342	1926.78	542.69	1922.62	8.923	0.724	-4.306
509	325	8.966	0.430	-3.755	1944.21	L	498	8.878	0.553	-4.226	1926.87	542.00	1922.70	8.906	0.725	-4.340
510	326	8.983	0.199	-3.813			497	8.883	0.532	-4.047	1926.95	540.96	1922.78	8.995	0.571	-4.263
511	327	8.972	-0.001	-3.704			496	8.925	0.253	-3.941	1927.03	540.04	1922.87	8.959	0.430	-4.100
512	328	8.910	-0.051	-3.823			495	8.982	0.788	-3.752	1927.12	539.00	1922.95	8.936	0.079	-4.196
513	329	8.912	0.382	-4.060			494	8.994	0.852	-3.765	1927.20	537.96	1923.03	9.003	0.329	-3.955
514	330	8.893	1.328	-4.285	1943.71	H	493	8.999	0.947	-3.886	1927.30	537.04	1923.12	9.038	0.426	-3.694
515	331	8.894	0.936	-4.306			492	8.945	0.836	-3.968	1927.40	536.00	1923.20	9.040	0.497	-3.619
536	332	8.909	1.350	-4.390			491	8.878	0.709	-4.249	1927.50	534.81	1923.28	9.017	0.728	-3.595
537	333	8.906	0.821	-4.334			490	8.849	0.858	-4.433	1927.60	533.62	1923.37	9.010	0.882	-3.788
538	334	8.960	0.973	-4.089			489	8.862	0.197	-4.296	1927.70	532.50	1923.45	8.975	0.780	-3.979
539	335	9.018	0.511	-3.914			488	8.855	-0.088	-4.199	1927.80	531.38	1923.53	8.900	0.601	-4.186
540	336	9.001	0.554	-3.807	1943.21	L	487	8.821	0.004	-3.903	1927.90	530.19	1923.62	8.907	1.013	-4.299
541	337	8.991	0.433	-3.755			486	8.872	0.306	-3.963	1928.00	529.00	1923.70	8.912	1.216	-4.422
542	338	8.962	0.038	-3.755			485	8.938	0.761	-3.786	1928.10	528.17	1923.78	8.892	0.501	-4.322
543	339	8.926	-0.147	-3.848			484	8.966	0.729	-3.930	1928.20	527.33	1923.87	8.883	0.550	-4.123
544	340	8.927	-0.152	-4.040			483	8.963	1.071	-3.907	1928.30	526.50	1923.95	8.890	0.636	-3.934
545	341	8.904	0.725	-4.355			482	8.937	1.192	-4.095	1928.40	525.67	1924.03	8.910	0.680	-3.805
546	342	8.916	0.787	-4.340			481	8.876	1.124	-4.221	1928.50	524.83	1924.12	8.939	0.770	-3.777
547	343	8.854	0.693	-4.635	1942.71	H	480	8.887	1.456	-4.334	1928.60	524.00	1924.20	8.976	0.677	-3.929
548	344	8.951	1.253	-4.129			479	8.908	1.384	-4.401	1928.70	522.96	1924.28	8.930	0.868	-3.926
549	345	8.927	0.447	-4.183			478	8.932	0.595	-4.344	1928.77	522.04	1924.37	8.917	0.748	-3.963
550	346	8.955	0.439	-4.103			477	8.917	0.011	-4.287	1928.84	521.00	1924.45	8.915	0.735	-4.238
551	347	8.943	-0.019	-4.078	1942.21	L	476	8.920	0.144	-4.017	1928.91	519.96	1924.53	8.886	0.957	-4.262
552	348	8.930	-0.029	-3.977			475	8.956	0.142	-3.862	1928.99	519.04	1924.62	8.889	0.612	-4.402
553	349	8.860	-0.142	-3.962			474	8.990	0.262	-3.827	1929.06	518.00	1924.70	8.871	0.149	-4.318
554	350	8.829	0.126	-4.122			473	8.975	0.404	-3.711	1929.13	517.36	1924.78	8.883	0.259	-4.185
555	351	8.812	0.120	-4.324	1941.71	H	472	9.027	0.667	-3.613	1929.20	516.69	1924.87	8.892	0.336	-4.002
556	352	8.882	0.983	-4.347			471	8.996	0.678	-3.963	1929.33	516.00	1924.95	8.898	0.369	-3.758
557	353	8.848	0.955	-4.465			470	8.946	0.903	-4.006	1929.45	515.36	1925.03	8.942	0.582	-3.825
558	354	8.863	0.737	-4.401			469	8.888	1.026	-4.319	1929.58	514.69	1925.12	8.974	0.635	-3.895
559	355	8.878	0.225	-4.376			468	8.842	0.681	-4.492	1929.70	514.00	1925.20	8.992	0.486	-3.967
560	356	8.893	0.540	-4.177			467	8.899	0.130	-4.191	1929.83	513.17	1925.28	8.993	0.639	-4.053
561	357	8.963	0.158	-4.097			466	8.917	0.149	-3.983	1929.95	512.33	1925.37	8.974	0.954	-4.037
562	358	8.953	0.006	-3.809	1941.21	L	465	8.959	0.610	-3.712	1930.08	511.50	1925.45	8.929	1.179	-4.133
563	359	9.001	-0.536	-3.802			464	9.009	0.772	-3.831	1930.20	510.67	1925.53	8.888	1.298	-4.277
564	360	8.952	-0.391	-3.965			463	8.997	0.673	-3.833	1930.28	509.83	1925.62	8.878	1.325	-4.352
565	361	8.865	-0.158	-4.311			462	8.967	0.808	-4.070	1930.37	509.00	1925.70	8.882	1.096	-4.413
566	362	8.840	0.253	-4.391			461	8.944	0.915	-3.996	1930.45	508.36	1925.78	8.905	0.954	-4.337
567	363	8.820	0.413	-4.384	1940.71	H	460	8.895	1.042	-4.237	1930.53	507.69	1925.87	8.937	0.723	-4.246
568	364	8.874	0.395	-4.366			459	8.934	1.281	-4.224	1930.62	507.00	1925.95	8.980	0.377	-4.133
569	365	8.895	0.443	-4.207			458	8.898	0.388	-4.261	1930.70	506.36	1926.03	9.004	0.319	-3.963
570	366	8.937	0.463	-4.146			457	8.862	0.354	-4.222	1930.80	505.69	1926.12	9.018	0.382	-3.848
571	367	8.952	0.112	-4.124	1940.21	L	456	8.924	0.585	-3.937	1930.90	505.00	1926.20	9.021	0.600	-3.801
572	368	8.899	0.267	-3.917			455	8.962	0.623	-3.795	1931.00	504.17	1926.28	8.986	0.595	-3.834
573	369	8.849	-0.369	-4.059			454	8.962	0.608	-3.815	1931.10	503.33	1926.37	8.968	0.569	-3.912
574	370	8.842	-0.225	-4.128			453	8.980	0.863	-3.882	1931.20	502.50	1926.45	8.939	0.683	-4.057
575	371	8.834	-0.261	-4.397			452	8.952	0.998	-4.076	1931.33	501.67	1926.53	8.895	0.811	-4.206
576	372	8.850	0.944	-4.497	1939.71	H	451	8.891	0.955	-4.268	1931.45	500.83	1926.62	8.853	0.849	-4.289
577	373	8.817	0.414	-4.556			450	8.847	0.796	-4.262	1931.58	500.00	1926.70	8.846	1.021	-4.309
578	374	8.885	0.532	-4.242			449	8.862	0.284	-4.289	1931.70	498.96	1926.78	8.850	0.870	-4.338
579	375	8.925	0.641	-4.009			448	8.893	0.123	-4.074	1931.80	498.04	1926.87	8.877	0.565	-4.230
580	376	8.959	0.437	-3.827			447	8.881	0.029	-3.950	1931.90	497.00	1926.95	8.883	0.532	-4.047
581	377	8.989	0.243	-3.745	1939.21	L	446	9.011	0.141	-3.770	1932.00	495.96	1927.03	8.927	0.273	-3.934
582	378	8.983	0.143	-3.794			445	8.989	-0.035	-3.851	1932.10	495.04	1927.12	8.980	0.768	-3.759
583	379	8.955	-0.091	-3.815			444	9.002	0.270	-3.788	1932.20	494.00	1927.20	8.994	0.852	-3.765
584	380	8.896	-0.185	-3.981			443	9.007	0.293	-3.857	1932.28	493.17	1927.28	8.998	0.931	-3.866
585	381	8.917	-0.550	-4.041			442	8.968	0.855	-4.018	1932.37	492.33	1927.37	8.963	0.873	-3.941
586	382	8.867	-0.163	-4.313			441	8.943	0.553	-4.195	1932.45	491.50	1927.45	8.912	0.773	-4.109
587	383	8.893	0.450	-4.328	1938.71	H	440	8.924	0.593	-4.253	1932.53	490.67	1927.53	8.868	0.759	-4.310
588	384	8.867	0.500	-4.399			439	8.899	0.915	-4.258	1932.62	489.83	1927.62	8.851	0.748	-4.410
589	385	8.896	0.369	-4.292			438	8.848	-0.130	-4.375	1932.70	489.00	1927.70	8.862	0.197	-4.296
590	386	8.936	0.409	-3.918			437	8.876	-0.026	-4.049	1932.80	488.17	1927.78	8.856	-0.041	-4.215
591	387	8.970	0.331	-3.698			436	8.927	-0.025	-3.759	1932.90	487.33	1927.87	8.832	-0.027	-4.002
592	388	8.986	0.235	-3.605	1938.21	L	435	9.024	-0.082	-3.776	1933.00	486.50	1927.95	8.847	0.155	-3.933
593	389	8.909	-0.344	-4.020			434	9.006	0.442	-3.637	1933.10	485.67	1928.03	8.894	0.458	-3.904
594	390	8.886	-0.803	-4.129			433	9.024	0.731	-3.680	1933.20	484.83	1928.12	8.943	0.756	-3.810
595	391	8.835	-0.683	-4.406	1937.71	H	432	8.989	0.676	-3.769	1933.30	484.00	1928.20	8.966	0.729	-3.930
596	392	8.907	0.867	-4.443			431	8.950	0.406	-3.999	1933.40	483.17	1928.28	8.964	1.014	-3.911
597	393	8.874	1.010	-4.179			430	8.893	0.472	-4.172	1933.50	482.33	1928.37	8.946	1.152	-4.032
598	394	8.888	0.808	-4.175			429	8.910	0.840	-4.238	1933.60	481.50	1928.45	8.907	1.158	-4.158
599	395	8.928	0.701	-4.005			428	8.850	0.715	-4.284	1933.70	480.67	1928.53	8.880	1.235	-4.259
600	396	8.962	0.404	-3.833	1937.21	L	427	8.888	0.347	-4.236	1933.78	479.83	1928.62	8.891	1.444	-4.345
601	397	8.966	0.304	-3.850			426	8.920	-0.065	-4.022	1933.87	479.00	1928.70	8.908	1.384	-4.401
602	398	8.881	-0.173	-4.046			425	8.918	0.294	-3.835	1933.95	477.81	1928.78	8.929	0.484	-4.333
603	399	8.849	0.583	-4.379			424	8.937	0.398	-3.707	1934.03	476.62	1928.87	8.918	0.062	-4.184
604	400	8.900	0.684	-4.491	1936.71	H	423	8.951	0.296	-3.760	1934.12	475.50	1928.95	8.938	0.143	-3.940
605	401	8.839	0.598	-4.350			422	8.973	0.889	-3.665	1934.20	474.38	1929.03	8.977	0.216	-3.840
606	402	8.921	0.540	-4.298			421	8.947	1.154	-3.724	1934.28	473.19	1929.12	8.978	0.377	-3.733
607	403	8.921	0.482	-4.069	1936.21	L	420	8.921	0.460	-3.977	1934.37	472.00	1929.20	9.027	0.667	-3.613
608	404	8.900	0.548	-3.943			419	8.966	0.575	-3.937	1934.45	471.36	1929.28	9.007	0.674	-3.837
609	405	8.846	-0.032	-4.064			418	8.856	0.364	-4.280	1934.53	470.69	1929.37	8.981	0.747	-3.976
610	406	8.841	-0.224	-4.265			417	8.859	0.174	-4.381	1934.62	470.00	1929.45	8.946	0.903	-4.006
611	407	8.842	-0.011	-4.436	1935.71	H	416	8.847	0.112	-4.637	1934.70	469.36	1929.53	8.909	0.982	-4.207
612	408	8.845	0.392	-4.532			415	8.888	0.903	-4.173	1934.80	468.69	1929.62	8.874	0.921	-4.372
613	409	8.855	0.642	-4.332			414	8.868	-0.228	-4.192	1934.90	468.00	1929.70	8.842	0.681	-4.492
614	410	8.874	0.735	-4.146			413	8.922	0.117	-3.985	1935.00	467.36	1929.78	8.879	0.328	-4.299
615	411	8.952	0.693	-3.836	1935.21	L	412	8.902	0.259	-3.893	1935.10	466.69	1929.87	8.905	0.136	-4.127
616	412	8.902	0.259	-3.893			411	8.952	0.693	-3.836	1935.20	466.00	1929.95	8.917	0.149	-3.983
617	413	8.922	0.117	-3.985			410	8.874	0.735	-4.146	1935.33	465.36	1930.03	8.944	0.445	-3.809
618	414	8.868	-0.228	-4.192			409	8.855	0.642	-4.332	1935.45	464.69	1930.12	8.974	0.660	-3.748

Appendix A.2
oxygen isotope and trace element data for coral core from Guadeloupe (Gua 1, slabs B-F) and age model

							1st interpolation					2nd interpolation (monthly resolution)				
sample ID	new no.	Sr/ Ca (mmol/mol)	d13-C (per mil)	d18-O (per mil)	timemarker year.month	anchor High/Low	new no.	Sr/ Ca (mmol/mol)	d13-C (per mil)	d18-O (per mil)	timemarker year.month	new no.	timemarker year.month	Sr/ Ca (mmol/mol)	d13-C (per mil)	d18-O (per mil)
619	415	8.888	0.903	-4.173			408	8.845	0.392	-4.532	1935.58	464.00	1930.20	9.009	0.772	-3.831
620	416	8.847	0.112	-4.637	1934.71	H	407	8.842	-0.011	-4.436	1935.70	462.96	1930.28	8.996	0.678	-3.842
621	417	8.859	0.174	-4.381			406	8.841	-0.224	-4.265	1935.83	462.04	1930.37	8.968	0.803	-4.061
622	418	8.856	0.364	-4.280			405	8.846	-0.032	-4.064	1935.95	461.00	1930.45	8.944	0.915	-3.996
623	419	8.966	0.575	-3.937			404	8.900	0.548	-3.943	1936.08	459.96	1930.53	8.896	1.051	-4.237
624	420	8.921	0.460	-3.977			403	8.921	0.482	-4.069	1936.20	459.04	1930.62	8.933	1.272	-4.224
625	421	8.947	1.154	-3.724			402	8.921	0.540	-4.298	1936.37	458.00	1930.70	8.898	0.388	-4.261
626	422	8.973	0.889	-3.665	1934.21	L	401	8.839	0.598	-4.350	1936.53	457.17	1930.78	8.868	0.360	-4.229
627	423	8.951	0.296	-3.760			400	8.900	0.684	-4.491	1936.70	456.33	1930.87	8.903	0.508	-4.032
628	424	8.937	0.398	-3.707			399	8.849	0.583	-4.379	1936.83	455.50	1930.95	8.943	0.604	-3.866
629	425	8.918	0.294	-3.835			398	8.881	-0.173	-4.046	1936.95	454.67	1931.03	8.962	0.618	-3.802
630	426	8.920	-0.065	-4.022			397	8.966	0.304	-3.850	1937.08	453.83	1931.12	8.965	0.651	-3.826
631	427	8.888	0.347	-4.236			396	8.962	0.404	-3.833	1937.20	453.00	1931.20	8.980	0.863	-3.882
632	428	8.850	0.715	-4.284	1933.71	H	395	8.928	0.701	-4.005	1937.30	452.36	1931.28	8.962	0.950	-4.006
633	429	8.910	0.840	-4.238			394	8.888	0.808	-4.175	1937.40	451.69	1931.37	8.933	0.985	-4.135
634	430	8.893	0.472	-4.172			393	8.874	1.010	-4.179	1937.50	451.00	1931.45	8.891	0.955	-4.268
635	431	8.950	0.406	-3.999			392	8.907	0.867	-4.443	1937.60	450.36	1931.53	8.863	0.853	-4.264
636	432	8.989	0.676	-3.769			391	8.835	-0.683	-4.406	1937.70	449.69	1931.62	8.852	0.640	-4.270
637	433	9.024	0.731	-3.680	1933.21	L	390	8.886	-0.803	-4.129	1937.87	449.00	1931.70	8.862	0.284	-4.289
638	434	9.006	0.442	-3.637			389	8.909	-0.344	-4.020	1938.03	448.17	1931.78	8.888	0.150	-4.110
639	435	9.024	-0.082	-3.776			388	8.986	0.235	-3.605	1938.20	447.33	1931.87	8.885	0.060	-3.991
640	436	8.927	-0.025	-3.759			387	8.970	0.331	-3.698	1938.30	446.50	1931.95	8.946	0.085	-3.860
641	437	8.876	-0.026	-4.049			386	8.936	0.409	-3.918	1938.40	445.67	1932.03	9.004	0.082	-3.797
642	438	8.848	-0.130	-4.375	1932.71	H	385	8.896	0.369	-4.292	1938.50	444.83	1932.12	8.991	0.016	-3.841
643	439	8.899	0.915	-4.258			384	8.867	0.500	-4.399	1938.60	444.00	1932.20	9.002	0.270	-3.788
644	440	8.924	0.593	-4.253			383	8.893	0.450	-4.328	1938.70	442.96	1932.28	9.006	0.314	-3.863
645	441	8.943	0.553	-4.195			382	8.867	-0.163	-4.313	1938.78	442.04	1932.37	8.969	0.834	-4.012
646	442	8.968	0.855	-4.018			381	8.917	-0.550	-4.041	1938.87	441.00	1932.45	8.943	0.553	-4.195
647	443	9.007	0.293	-3.857			380	8.896	-0.185	-3.981	1938.95	439.96	1932.53	8.923	0.605	-4.253
648	444	9.002	0.270	-3.788	1932.21	L	379	8.955	-0.091	-3.815	1939.03	439.04	1932.62	8.900	0.903	-4.258
649	445	8.989	-0.035	-3.851			378	8.983	0.143	-3.794	1939.12	438.00	1932.70	8.848	-0.130	-4.375
650	446	9.011	0.141	-3.770			377	8.989	0.243	-3.745	1939.20	437.17	1932.78	8.871	-0.043	-4.103
651	447	8.881	0.029	-3.950			376	8.959	0.437	-3.827	1939.30	436.33	1932.87	8.910	-0.025	-3.856
652	448	8.893	0.123	-4.074			375	8.925	0.641	-4.009	1939.40	435.50	1932.95	8.976	-0.054	-3.768
653	449	8.862	0.284	-4.289	1931.71	H	374	8.885	0.532	-4.242	1939.50	434.67	1933.03	9.018	0.093	-3.730
654	450	8.847	0.796	-4.262			373	8.817	0.414	-4.556	1939.60	433.83	1933.12	9.009	0.490	-3.644
655	451	8.891	0.955	-4.268			372	8.850	0.944	-4.497	1939.70	433.00	1933.20	9.024	0.731	-3.680
656	452	8.952	0.998	-4.076			371	8.834	-0.261	-4.397	1939.80	432.17	1933.28	8.995	0.685	-3.754
657	453	8.980	0.863	-3.882	1931.21	L	370	8.842	-0.225	-4.128	1939.90	431.33	1933.37	8.963	0.496	-3.922
658	454	8.962	0.608	-3.815			369	8.849	-0.369	-4.059	1940.00	430.50	1933.45	8.922	0.439	-4.086
659	455	8.962	0.623	-3.795			368	8.899	0.267	-3.917	1940.10	429.67	1933.53	8.899	0.595	-4.194
660	456	8.924	0.585	-3.937			367	8.952	0.112	-4.124	1940.20	428.83	1933.62	8.900	0.819	-4.246
661	457	8.862	0.354	-4.222			366	8.937	0.463	-4.146	1940.33	428.00	1933.70	8.850	0.715	-4.284
662	458	8.898	0.388	-4.261	1930.71	H	365	8.895	0.443	-4.207	1940.45	426.96	1933.78	8.889	0.332	-4.228
663	459	8.934	1.281	-4.224			364	8.874	0.395	-4.366	1940.58	426.04	1933.87	8.919	-0.050	-4.030
664	460	8.895	1.042	-4.237			363	8.820	0.413	-4.384	1940.70	425.00	1933.95	8.918	0.294	-3.835
665	461	8.944	0.915	-3.996			362	8.840	0.253	-4.391	1940.80	423.96	1934.03	8.938	0.394	-3.709
666	462	8.967	0.808	-4.070			361	8.865	-0.158	-4.311	1940.90	423.04	1934.12	8.950	0.300	-3.758
667	463	8.997	0.673	-3.833			360	8.952	-0.391	-3.965	1941.00	422.00	1934.20	8.973	0.889	-3.665
668	464	9.009	0.772	-3.831	1930.21	L	359	9.001	-0.536	-3.802	1941.10	420.96	1934.28	8.946	1.128	-3.733
669	465	8.959	0.610	-3.712			358	8.953	0.006	-3.809	1941.20	420.04	1934.37	8.922	0.486	-3.968
670	466	8.917	0.149	-3.983			357	8.963	0.158	-4.097	1941.27	419.00	1934.45	8.966	0.575	-3.937
671	467	8.899	0.130	-4.191			356	8.893	0.540	-4.177	1941.34	417.96	1934.53	8.856	0.357	-4.284
672	468	8.842	0.681	-4.492	1929.71	H	355	8.878	0.225	-4.376	1941.41	417.04	1934.62	8.859	0.181	-4.377
673	469	8.888	1.026	-4.319			354	8.863	0.737	-4.401	1941.49	416.00	1934.70	8.847	0.112	-4.637
674	470	8.946	0.903	-4.006			353	8.848	0.955	-4.465	1941.56	415.17	1934.78	8.881	0.771	-4.250
675	471	8.996	0.678	-3.963			352	8.882	0.983	-4.347	1941.63	414.33	1934.87	8.875	0.149	-4.186
676	472	9.027	0.667	-3.613	1929.21	L	351	8.812	0.120	-4.324	1941.70	413.50	1934.95	8.895	-0.056	-4.089
677	473	8.975	0.404	-3.711			350	8.829	0.126	-4.122	1941.83	412.67	1935.03	8.915	0.164	-3.954
678	474	8.990	0.262	-3.827			349	8.860	-0.142	-3.962	1941.95	411.83	1935.12	8.910	0.331	-3.884
679	475	8.956	0.142	-3.862			348	8.930	-0.029	-3.977	1942.08	411.00	1935.20	8.952	0.693	-3.836
680	476	8.920	0.144	-4.017			347	8.943	-0.019	-4.078	1942.20	410.36	1935.28	8.902	0.720	-4.035
681	477	8.917	0.011	-4.287			346	8.955	0.439	-4.103	1942.33	409.69	1935.37	8.868	0.707	-4.203
682	478	8.932	0.595	-4.344			345	8.927	0.447	-4.183	1942.45	409.00	1935.45	8.855	0.642	-4.332
683	479	8.908	1.384	-4.401	1928.71	H	344	8.951	1.253	-4.129	1942.58	408.36	1935.53	8.849	0.482	-4.460
684	480	8.887	1.456	-4.334			343	8.854	0.693	-4.635	1942.70	407.69	1935.62	8.844	0.269	-4.503
685	481	8.876	1.124	-4.221			342	8.916	0.787	-4.340	1942.77	407.00	1935.70	8.842	-0.011	-4.436
686	482	8.937	1.192	-4.095			341	8.904	0.725	-4.355	1942.84	406.36	1935.78	8.841	-0.148	-4.326
687	483	8.963	1.071	-3.907			340	8.927	-0.152	-4.040	1942.91	405.69	1935.87	8.843	-0.165	-4.204
688	484	8.966	0.729	-3.930	1928.21	L	339	8.926	-0.147	-3.848	1942.99	405.00	1935.95	8.846	-0.032	-4.064
689	485	8.938	0.761	-3.786			338	8.962	0.038	-3.755	1943.06	404.36	1936.03	8.881	0.340	-3.986
690	486	8.872	0.306	-3.963			337	8.991	0.433	-3.755	1943.13	403.69	1936.12	8.906	0.528	-3.982
691	487	8.821	0.004	-3.903			336	9.001	0.554	-3.807	1943.20	403.00	1936.20	8.921	0.482	-4.069
692	488	8.855	-0.088	-4.199			335	9.018	0.511	-3.914	1943.28	402.51	1936.28	8.921	0.510	-4.181
693	489	8.862	0.197	-4.296	1927.71	H	334	8.960	0.973	-4.089	1943.37	402.02	1936.37	8.921	0.539	-4.294
706	490	8.849	0.858	-4.433			333	8.906	0.821	-4.334	1943.45	401.50	1936.45	8.880	0.569	-4.324
707	491	8.878	0.709	-4.249			332	8.909	1.350	-4.390	1943.53	400.98	1936.53	8.840	0.600	-4.353
708	492	8.945	0.836	-3.968			331	8.894	0.936	-4.306	1943.62	400.49	1936.62	8.870	0.642	-4.422
709	493	8.999	0.947	-3.886			330	8.893	1.328	-4.285	1943.70	400.00	1936.70	8.900	0.684	-4.491
710	494	8.994	0.852	-3.765	1927.21	L	329	8.912	0.382	-4.060	1943.80	399.36	1936.78	8.867	0.619	-4.419
711	495	8.982	0.788	-3.752			328	8.910	-0.051	-3.823	1943.90	398.69	1936.87	8.859	0.352	-4.277
712	496	8.925	0.253	-3.941			327	8.972	-0.001	-3.704	1944.00	398.00	1936.95	8.881	-0.173	-4.046
713	497	8.883	0.532	-4.047			326	8.983	0.199	-3.813	1944.10	397.36	1937.03	8.935	0.133	-3.920
714	498	8.878	0.553	-4.226			325	8.966	0.430	-3.755	1944.20	396.69	1937.12	8.965	0.335	-3.845
715	499	8.849	0.882	-4.342			324	8.960	0.653	-4.216	1944.33	396.00	1937.20	8.962	0.404	-3.833
716	500	8.846	1.021	-4.309	1926.71	H	323	8.968	0.362	-4.329	1944.45	395.17	1937.28	8.934	0.652	-3.976
717	501	8.854	0.814	-4.285			322	8.889	0.929	-4.306	1944.58	394.33	1937.37	8.901	0.772	-4.118
718	502	8.915	0.810	-4.166			321	8.867	0.839	-4.652	1944.70	393.50	1937.45	8.881	0.909	-4.177
719	503	8.963	0.556	-3.948			320	8.885	0.735	-4.522	1944.80	392.67	1937.53	8.885	0.962	-4.267
720	504	8.979	0.594	-3.841			319	8.955	0.290	-4.249	1944.90	391.83	1937.62	8.895	0.609	-4.437
721	505	9.021	0.600	-3.801	1926.21	L	318	8.981	-0.026	-4.026	1945.00	391.00	1937.70	8.835	-0.683	-4.406
722	506	9.017	0.286	-3.868			317	8.990	-0.058	-3.945	1945.10	390.51	1937.78	8.860	-0.742	-4.270
723	507	8.980	0.377	-4.133			316	9.017	0.297	-3.948	1945.20	390.02	1937.87	8.885	-0.801	-4.134
724	508	8.918	0.875	-4.295			315	8.987	0.452	-3.927	1945.28	389.50	1937.95	8.898	-0.574	-4.075
725	509	8.882	1.096	-4.413	1925.71	H	314	8.958	0.349	-4.075	1945.37	388.98	1938.03	8.911	-0.333	-4.012
726	510	8.877	1.371	-4.340			313	8.920	0.481	-4.266	1945.45	388.49	1938.12	8.948	-0.049	-3.808
727	511	8.894	1.261	-4.245			312	8.885	0.501	-4.209	1945.53	388.00	1938.20	8.986	0.235	-3.605
728	512	8.964	1.096	-4.020			311	8.844	0.510	-4.420	1945.62	387.17	1938.28	8.973	0.315	-3.683
729	513	8.993	0.670	-4.070			310	8.815	0.518	-4.416	1945.70	386.33	1938.37	8.947	0.383	-3.845
730	514	8.992	0.486	-3.967	1925.21	L	309	8.863	-0.137	-4.411	1945.78	385.50	1938.45	8.916	0.389	-4.105
731	515	8.966	0.701	-3.863			308	8.924	-0.192	-4.173	1945.87	384.67	1938.53	8.886	0.413	-4.328
732	516	8.898	0.369	-3.758			307	8.924	-0.008	-3.983	1945.95	383.83	1938.62	8.871	0.492	-4.387
733	517	8.889	0.321	-4.110			306	8.933	0.455	-3.785	1946.03	383.00	1938.70	8.893	0.450	-4.328
734	518	8.871	0.149	-4.318	1924.71	H	305	8.947	0.056	-3.798	1946.12	381.96	1938.78	8.869	-0.177	-4.303

Appendix A.2
oxygen isotope and trace element data for coral core from Guadeloupe (Gua 1, slabs B-F) and age model

sample ID	new no.	Sr/ Ca (mmol/mol)	d13-C (per mil)	d18-O (per mil)	timemarker year.month	anchor High/Low	1st interpolation new no.	Sr/ Ca (mmol/mol)	d13-C (per mil)	d18-O (per mil)	timemarker year.month	2nd interpolation (monthly resolution) new no.	timemarker year.month	Sr/ Ca (mmol/mol)	d13-C (per mil)	d18-O (per mil)
735	519	8.889	0.598	-4.408			304	8.980	0.698	-3.671	1946.20	381.04	1938.87	8.915	-0.536	-4.051
736	520	8.886	0.971	-4.256			303	8.970	0.834	-3.714	1946.28	380.00	1938.95	8.896	-0.185	-3.981
737	521	8.915	0.735	-4.238			302	8.971	0.786	-3.877	1946.37	378.96	1939.03	8.956	-0.082	-3.814
738	522	8.917	0.743	-3.964			301	8.922	0.820	-4.022	1946.45	378.04	1939.12	8.982	0.134	-3.795
739	523	8.930	0.873	-3.925			300	8.920	1.050	-4.050	1946.53	377.00	1939.20	8.989	0.243	-3.745
740	524	8.976	0.677	-3.929	1924.21	L	299	8.889	0.922	-4.346	1946.62	376.17	1939.28	8.964	0.405	-3.813
741	525	8.931	0.788	-3.747			298	8.871	1.442	-4.308	1946.70	375.33	1939.37	8.936	0.573	-3.948
742	526	8.900	0.626	-3.834			297	8.896	0.835	-4.143	1946.78	374.50	1939.45	8.905	0.587	-4.126
743	527	8.880	0.646	-4.033			296	8.872	0.397	-4.129	1946.87	373.67	1939.53	8.862	0.493	-4.347
744	528	8.888	0.358	-4.302			295	8.863	0.370	-3.954	1946.95	372.83	1939.62	8.823	0.502	-4.546
745	529	8.912	1.216	-4.422	1923.71	H	294	8.897	0.771	-3.800	1947.03	372.00	1939.70	8.850	0.944	-4.497
746	530	8.913	1.136	-4.305			293	8.909	0.860	-3.792	1947.12	371.17	1939.78	8.837	-0.060	-4.414
747	531	8.881	0.488	-4.275			292	8.919	0.702	-3.828	1947.20	370.33	1939.87	8.839	-0.237	-4.218
748	532	8.932	0.785	-4.042			291	8.907	1.163	-3.894	1947.33	369.50	1939.95	8.846	-0.297	-4.094
749	533	9.017	0.774	-3.916			290	8.890	0.919	-4.037	1947.45	368.67	1940.03	8.866	-0.157	-4.012
750	534	9.005	0.948	-3.710			289	8.858	0.927	-4.123	1947.58	367.83	1940.12	8.908	0.241	-3.952
751	535	9.020	0.676	-3.568			288	8.825	0.957	-4.224	1947.70	367.00	1940.20	8.952	0.112	-4.124
752	536	9.040	0.497	-3.619	1923.21	L	287	8.860	0.925	-4.270	1947.83	366.36	1940.28	8.942	0.337	-4.138
753	537	9.039	0.430	-3.684			286	8.882	0.268	-4.032	1947.95	365.69	1940.37	8.924	0.457	-4.165
754	538	9.002	0.325	-3.965			285	8.940	0.263	-3.788	1948.08	365.00	1940.45	8.895	0.443	-4.207
755	539	8.936	0.079	-4.196			284	8.995	0.763	-3.668	1948.20	364.36	1940.53	8.882	0.412	-4.309
756	540	8.958	0.424	-4.094			283	8.983	0.704	-3.784	1948.28	363.69	1940.62	8.858	0.401	-4.372
757	541	8.996	0.577	-4.269			282	8.958	0.621	-3.959	1948.37	363.00	1940.70	8.820	0.413	-4.384
758	542	8.906	0.725	-4.340	1922.71	H	281	8.908	0.422	-4.233	1948.45	362.17	1940.78	8.837	0.280	-4.390
759	543	8.931	0.723	-4.291			280	8.873	0.317	-4.407	1948.53	361.33	1940.87	8.857	-0.021	-4.338
760	544	8.940	0.525	-4.102			279	8.811	0.524	-4.339	1948.62	360.50	1940.95	8.909	-0.275	-4.138
761	545	8.978	0.363	-4.137			278	8.759	0.223	-4.387	1948.70	359.67	1941.03	8.968	-0.439	-3.911
762	546	8.966	0.458	-3.861	1922.21	L	277	8.849	-0.042	-4.205	1948.83	358.83	1941.12	8.993	-0.446	-3.803
763	547	8.954	0.399	-3.864			276	8.882	0.164	-4.039	1948.95	358.00	1941.20	8.953	0.006	-3.809
764	548	8.902	0.143	-4.011			275	8.918	0.479	-3.807	1949.08	356.81	1941.28	8.950	0.231	-4.112
765	549	8.863	0.451	-3.999			274	8.928	0.663	-3.784	1949.20	355.62	1941.37	8.887	0.420	-4.253
766	550	8.844	-0.068	-4.246			273	8.915	0.840	-3.903	1949.30	354.50	1941.45	8.871	0.481	-4.389
767	551	8.853	0.732	-4.312	1921.71	H	272	8.873	0.812	-4.078	1949.40	353.38	1941.53	8.854	0.872	-4.441
768	552	8.848	0.880	-4.415			271	8.862	0.499	-4.221	1949.50	352.19	1941.62	8.876	0.978	-4.369
769	553	8.884	0.594	-4.339			270	8.830	0.445	-4.409	1949.60	351.00	1941.70	8.812	0.120	-4.324
770	554	8.890	0.511	-4.209			269	8.819	0.656	-4.524	1949.70	350.36	1941.78	8.823	0.124	-4.195
771	555	8.939	0.703	-4.016			268	8.867	0.217	-4.263	1949.80	349.69	1941.87	8.838	0.044	-4.073
772	556	9.018	0.644	-3.934	1921.21	L	267	8.891	-0.275	-4.111	1949.90	349.00	1941.95	8.860	-0.142	-3.962
773	557	8.984	0.299	-3.917			266	8.900	-0.219	-4.016	1950.00	348.36	1942.03	8.905	-0.070	-3.972
774	558	8.917	0.412	-3.901			265	8.949	0.253	-3.750	1950.10	347.69	1942.12	8.934	-0.026	-4.008
775	559	8.873	0.392	-4.300			264	8.930	0.244	-3.743	1950.20	347.00	1942.20	8.943	-0.019	-4.078
776	560	8.881	0.822	-4.560			263	8.945	0.336	-3.883	1950.30	346.36	1942.28	8.951	0.275	-4.094
777	561	8.830	0.755	-4.522	1920.71	H	262	8.926	0.581	-3.899	1950.40	345.69	1942.37	8.946	0.441	-4.127
778	562	8.864	0.668	-4.359			261	8.889	0.737	-3.998	1950.50	345.00	1942.45	8.927	0.447	-4.183
779	563	8.921	0.836	-4.156			260	8.841	0.653	-4.212	1950.60	344.36	1942.53	8.942	0.964	-4.148
780	564	8.912	0.782	-4.061			259	8.833	0.681	-4.454	1950.70	343.69	1942.62	8.921	1.082	-4.284
781	565	8.999	0.680	-3.954			258	8.904	0.801	-4.345	1950.78	343.00	1942.70	8.854	0.693	-4.635
782	566	8.970	0.973	-3.813	1920.21	L	257	8.881	-0.287	-4.163	1950.87	341.81	1942.78	8.914	0.775	-4.343
783	567	8.993	0.558	-3.859			256	8.895	0.221	-3.958	1950.95	340.62	1942.87	8.913	0.391	-4.235
784	568	8.919	0.267	-3.964			255	8.935	-0.161	-3.712	1951.03	339.50	1942.95	8.927	-0.150	-3.944
785	569	8.905	0.229	-4.125			254	8.973	0.186	-3.761	1951.12	338.38	1943.03	8.948	-0.032	-3.790
786	570	8.933	0.275	-4.301			253	9.019	0.164	-3.850	1951.20	337.19	1943.12	8.985	0.358	-3.755
787	571	8.879	0.398	-4.371			252	8.964	0.667	-3.949	1951.33	336.00	1943.20	9.001	0.554	-3.807
788	572	8.881	0.931	-4.192	1919.71	H	251	8.886	0.508	-4.000	1951.45	334.96	1943.28	9.016	0.528	-3.920
789	573	8.874	0.760	-4.190			250	8.883	0.412	-4.289	1951.58	334.04	1943.37	8.962	0.956	-4.083
790	574	8.875	0.733	-4.427			249	8.852	0.465	-4.281	1951.70	333.00	1943.45	8.906	0.821	-4.334
791	575	8.928	0.474	-4.064			248	8.859	0.300	-4.377	1951.78	331.96	1943.53	8.908	1.335	-4.387
792	576	8.948	0.518	-3.920			247	8.899	0.200	-4.061	1951.87	331.04	1943.62	8.895	0.951	-4.309
793	577	8.994	0.573	-3.978	1919.21	L	246	8.891	-0.315	-4.134	1951.95	330.00	1943.70	8.893	1.328	-4.285
794	578	8.935	0.451	-3.884			245	8.944	-0.199	-3.774	1952.03	329.17	1943.78	8.909	0.540	-4.098
795	579	8.876	0.270	-4.099			244	8.936	-0.304	-3.816	1952.12	328.33	1943.87	8.911	0.093	-3.902
796	580	8.860	0.143	-4.223			243	8.934	0.415	-3.677	1952.20	327.50	1943.95	8.941	-0.026	-3.764
797	581	8.848	0.973	-4.306	1918.71	H	242	8.919	0.625	-3.829	1952.27	326.67	1944.03	8.976	0.066	-3.740
798	582	8.875	1.025	-4.301			241	8.909	1.047	-3.743	1952.34	325.83	1944.12	8.980	0.238	-3.803
799	583	8.911	0.724	-4.261			240	8.908	0.853	-4.215	1952.41	325.00	1944.20	8.966	0.430	-3.755
800	584	8.896	0.447	-4.250			239	8.864	1.168	-3.985	1952.49	324.36	1944.28	8.962	0.573	-4.051
801	585	8.957	0.422	-4.005			238	8.863	1.012	-4.152	1952.56	323.69	1944.37	8.962	0.564	-4.251
802	586	9.006	0.366	-3.830	1918.21	L	237	8.854	0.939	-4.301	1952.63	323.00	1944.45	8.968	0.362	-4.329
803	587	8.997	0.460	-3.737			236	8.841	0.879	-4.387	1952.70	322.36	1944.53	8.917	0.725	-4.314
804	588	8.972	0.371	-3.925			235	8.854	0.641	-4.141	1952.80	321.69	1944.62	8.882	0.902	-4.412
805	589	8.918	0.298	-4.142			234	8.811	-0.201	-4.152	1952.90	321.00	1944.70	8.867	0.839	-4.652
806	590	8.889	0.434	-4.314			233	8.908	-0.339	-3.881	1953.00	320.17	1944.78	8.882	0.752	-4.544
807	591	8.844	1.134	-4.298	1917.71	H	232	8.921	0.280	-3.603	1953.10	319.33	1944.87	8.932	0.438	-4.340
808	592	8.872	0.692	-4.237			231	8.998	0.429	-3.557	1953.20	318.50	1944.95	8.968	0.132	-4.138
809	593	8.913	0.574	-4.035			230	8.988	0.581	-3.774	1953.30	317.67	1945.03	8.984	-0.037	-3.999
810	594	8.945	0.756	-3.902			229	8.967	0.750	-3.946	1953.40	316.83	1945.12	8.995	0.001	-3.946
811	595	8.910	0.600	-3.733			228	8.878	0.423	-4.375	1953.50	316.00	1945.20	9.017	0.297	-3.948
812	596	8.908	0.727	-3.674	1917.21	L	227	8.877	1.338	-4.198	1953.60	314.96	1945.28	8.986	0.448	-3.932
813	597	8.938	0.355	-3.709			226	8.863	1.248	-4.430	1953.70	314.04	1945.37	8.959	0.353	-4.070
814	598	8.914	0.272	-3.779			225	8.850	0.383	-4.149	1953.83	313.00	1945.45	8.920	0.481	-4.266
815	599	8.910	0.118	-3.980			224	8.866	0.408	-4.054	1953.95	311.96	1945.53	8.883	0.501	-4.217
816	600	8.881	0.603	-4.301			223	8.883	0.355	-3.850	1954.08	311.04	1945.62	8.846	0.510	-4.412
817	601	8.859	1.015	-4.241	1916.71	H	222	8.949	0.671	-3.708	1954.20	310.00	1945.70	8.815	0.518	-4.416
818	602	8.941	1.106	-4.325			221	8.906	1.021	-3.960	1954.33	308.96	1945.78	8.865	-0.139	-4.402
819	603	8.932	0.802	-4.143			220	8.873	1.044	-3.933	1954.45	308.04	1945.87	8.922	-0.190	-4.182
820	604	8.930	0.598	-3.941			219	8.813	1.067	-4.232	1954.58	307.00	1945.95	8.924	-0.008	-3.983
821	605	8.939	0.388	-3.812	1916.21	L	218	8.801	0.704	-4.265	1954.70	305.96	1946.03	8.934	0.440	-3.785
822	606	8.916	0.933	-3.792			217	8.863	0.096	-4.293	1954.80	305.04	1946.12	8.946	0.071	-3.798
823	607	8.876	0.479	-3.981			216	8.932	0.350	-3.888	1954.90	304.00	1946.20	8.980	0.698	-3.671
824	608	8.836	0.090	-4.184	1915.71	H	215	8.919	0.142	-3.639	1955.00	302.96	1946.28	8.970	0.832	-3.720
825	609	8.866	0.337	-4.397			214	8.944	0.355	-3.738	1955.10	302.04	1946.37	8.971	0.788	-3.871
826	610	8.895	1.143	-4.353			213	8.950	0.718	-3.684	1955.20	301.00	1946.45	8.922	0.820	-4.022
827	611	8.954	0.925	-4.219			212	8.866	0.633	-4.022	1955.33	299.96	1946.53	8.919	1.045	-4.061
828	612	8.923	0.429	-4.236			211	8.793	0.715	-4.279	1955.45	299.04	1946.62	8.890	0.927	-4.335
829	613	8.954	0.570	-4.006			210	8.800	1.135	-4.212	1955.58	298.00	1946.70	8.871	1.442	-4.308
830	614	8.971	0.616	-3.933	1915.21	L	209	8.817	0.958	-4.320	1955.70	296.96	1946.78	8.895	0.819	-4.142
831	615	8.968	0.434	-3.866			208	8.833	0.116	-4.125	1955.83	296.04	1946.87	8.873	0.413	-4.130
832	616	8.915	0.539	-3.856			207	8.938	0.083	-3.709	1955.95	295.00	1946.95	8.863	0.370	-3.954
833	617	8.875	0.966	-4.024			206	8.934	0.358	-3.724	1956.08	293.96	1947.03	8.897	0.774	-3.800
834	618	8.870	1.152	-4.254			205	8.985	0.485	-3.684	1956.20	293.04	1947.12	8.909	0.857	-3.792
835	619	8.860	1.164	-4.217	1914.71	H	204	8.959	0.652	-3.877	1956.33	292.00	1947.20	8.919	0.702	-3.828
836	620	8.890	0.862	-4.403			203	8.923	0.781	-4.090	1956.45	291.36	1947.28	8.911	0.998	-3.870
837	621	8.896	0.676	-4.271			202	8.924	0.833	-4.215	1956.58	290.69	1947.37	8.902	1.088	-3.938
838	622	8.931	0.670	-3.934			201	8.912	1.075	-4.099	1956.70	290.00	1947.45	8.890	0.919	-4.037

Appendix A.2
oxygen isotope and trace element data for coral core from Guadeloupe (Gua 1, slabs B-F) and age model

							1st interpolation					2nd interpolation (monthly resolution)				
sample ID	new no.	Sr/ Ca (mmol/mol)	d13-C (per mil)	d18-O (per mil)	timemarker year.month	anchor High/Low	new no.	Sr/ Ca (mmol/mol)	d13-C (per mil)	d18-O (per mil)	timemarker year.month	new no.	timemarker year.month	Sr/ Ca (mmol/mol)	d13-C (per mil)	d18-O (per mil)
839	623	8.976	0.746	-3.887	1914.21	L	200	8.941	1.131	-4.171	1956.78	289.36	1947.53	8.869	0.924	-4.092
840	624	8.963	0.563	-3.853			199	8.970	0.467	-4.066	1956.87	288.69	1947.62	8.848	0.936	-4.154
841	625	8.927	0.304	-4.152			198	8.976	0.117	-3.537	1956.95	288.00	1947.70	8.825	0.957	-4.224
842	626	8.920	0.414	-4.349			197	8.952	-0.012	-3.576	1957.03	287.36	1947.78	8.847	0.936	-4.253
843	627	8.921	1.217	-4.351	1913.71	H	196	8.994	0.425	-3.534	1957.12	286.69	1947.87	8.867	0.724	-4.197
844	628	8.928	0.965	-4.188			195	8.993	0.422	-3.659	1957.20	286.00	1947.95	8.882	0.268	-4.032
845	629	8.932	0.688	-4.065			194	8.947	0.550	-3.891	1957.28	285.36	1948.03	8.919	0.265	-3.876
846	630	8.968	0.618	-3.764			193	8.884	0.544	-3.954	1957.37	284.69	1948.12	8.957	0.416	-3.751
847	631	8.936	0.596	-3.794			192	8.859	0.633	-4.277	1957.45	284.00	1948.20	8.995	0.763	-3.668
848	632	9.023	0.693	-3.711	1913.21	L	191	8.866	0.548	-4.193	1957.53	282.96	1948.28	8.982	0.701	-3.790
849	633	8.904	0.532	-3.901			190	8.837	0.435	-4.507	1957.62	282.04	1948.37	8.959	0.624	-3.953
850	634	8.890	0.377	-4.103			189	8.831	0.211	-4.379	1957.70	281.00	1948.45	8.908	0.422	-4.233
851	635	8.852	0.724	-4.281	1912.71	H	188	8.839	0.095	-4.372	1957.83	279.96	1948.53	8.871	0.325	-4.404
852	636	8.873	1.621	-4.392			187	8.870	-0.284	-4.083	1957.95	279.04	1948.62	8.813	0.516	-4.342
853	637	8.898	0.864	-4.160			186	8.906	-0.141	-4.002	1958.08	278.00	1948.70	8.759	0.223	-4.387
854	638	8.945	0.720	-3.881			185	8.950	0.462	-4.127	1958.20	277.36	1948.78	8.817	0.053	-4.270
855	639	8.970	0.620	-3.792	1912.21	L	184	8.949	1.017	-4.173	1958.30	276.69	1948.87	8.859	0.021	-4.154
856	640	8.964	0.547	-3.755			183	8.869	0.981	-4.281	1958.40	276.00	1948.95	8.882	0.164	-4.039
857	641	8.935	0.281	-3.847			182	8.826	0.458	-4.529	1958.50	275.36	1949.03	8.905	0.366	-3.890
858	642	8.915	0.406	-4.114			181	8.822	0.405	-4.484	1958.60	274.69	1949.12	8.921	0.535	-3.800
859	643	8.880	0.582	-4.380	1911.71	H	180	8.880	0.522	-4.497	1958.70	274.00	1949.20	8.928	0.663	-3.784
860	644	8.893	1.145	-4.354			179	8.880	0.087	-4.411	1958.76	273.17	1949.28	8.917	0.811	-3.883
861	645	8.887	1.094	-4.363			178	8.931	0.025	-4.377	1958.83	272.33	1949.37	8.887	0.821	-4.020
862	646	8.911	0.900	-4.379			177	8.923	0.035	-4.077	1958.89	271.50	1949.45	8.868	0.656	-4.150
863	647	8.958	0.492	-4.066			176	8.984	0.208	-4.076	1958.95	270.67	1949.53	8.851	0.481	-4.284
864	648	8.987	0.745	-3.941	1911.21	L	175	8.958	0.222	-3.917	1959.01	269.83	1949.62	8.828	0.480	-4.428
865	649	8.963	0.724	-3.881			174	8.949	0.413	-3.863	1959.08	269.00	1949.70	8.819	0.656	-4.524
866	650	8.896	0.269	-4.021			173	8.948	0.649	-3.811	1959.14	268.17	1949.78	8.859	0.290	-4.307
867	651	8.864	0.325	-4.276			172	8.999	0.765	-3.954	1959.20	267.33	1949.87	8.883	-0.111	-4.162
868	652	8.864	0.559	-4.362			171	8.947	0.731	-4.057	1959.30	266.50	1949.95	8.896	-0.247	-4.064
869	653	8.872	0.967	-4.472	1910.71	H	170	8.918	0.789	-4.192	1959.40	265.67	1950.03	8.916	-0.062	-3.927
870	654	8.873	1.331	-4.374			169	8.893	0.830	-4.372	1959.50	264.83	1950.12	8.946	0.252	-3.749
871	655	8.920	0.631	-4.250			168	8.888	0.790	-4.292	1959.60	264.00	1950.20	8.930	0.244	-3.743
872	656	8.949	0.421	-4.093			167	8.906	0.960	-4.329	1959.70	263.17	1950.28	8.943	0.321	-3.860
873	657	8.964	0.308	-3.886			166	8.892	0.188	-4.210	1959.77	262.33	1950.37	8.932	0.499	-3.894
874	658	8.976	0.238	-4.001	1910.21	L	165	8.944	0.120	-4.051	1959.84	261.50	1950.45	8.908	0.659	-3.949
875	659	8.931	0.192	-3.869			164	8.929	0.135	-3.897	1959.91	260.67	1950.53	8.873	0.709	-4.069
876	660	8.881	0.030	-3.900			163	8.958	0.563	-3.900	1959.99	259.83	1950.62	8.840	0.658	-4.252
877	661	8.856	0.162	-4.112			162	8.954	0.437	-3.903	1960.06	259.00	1950.70	8.833	0.681	-4.454
878	662	8.854	0.374	-4.407	1909.71	H	161	8.946	0.579	-3.981	1960.13	257.96	1950.78	8.903	0.761	-4.338
879	663	8.865	1.041	-4.564			160	8.996	0.814	-3.979	1960.20	257.04	1950.87	8.882	-0.247	-4.170
880	664	8.872	0.551	-4.516			159	8.884	0.421	-4.190	1960.30	256.00	1950.95	8.895	0.221	-3.958
881	665	8.913	0.687	-4.294			158	8.880	0.624	-4.232	1960.40	254.96	1951.03	8.936	-0.148	-3.714
882	666	8.936	0.806	-4.166			157	8.847	0.490	-4.366	1960.50	254.04	1951.12	8.972	0.173	-3.759
883	667	8.964	0.675	-4.034	1909.21	L	156	8.838	0.338	-4.464	1960.60	253.00	1951.20	9.019	0.164	-3.850
884	668	8.959	0.377	-4.058			155	8.796	0.061	-4.414	1960.70	252.36	1951.28	8.984	0.486	-3.913
885	669	8.916	-0.021	-4.123			154	8.843	0.230	-4.303	1960.80	251.69	1951.37	8.940	0.618	-3.965
886	670	8.904	0.106	-4.083			153	8.910	-0.069	-4.148	1960.90	251.00	1951.45	8.886	0.508	-4.000
887	671	8.878	-0.180	-4.348			152	8.924	-0.210	-3.969	1961.00	250.36	1951.53	8.884	0.446	-4.185
888	672	8.852	0.397	-4.272			151	8.944	0.086	-3.884	1961.10	249.69	1951.62	8.874	0.428	-4.287
889	673	8.884	0.636	-4.607	1908.71	H	150	8.963	0.380	-3.747	1961.20	249.00	1951.70	8.852	0.465	-4.281
890	674	8.853	0.512	-4.488			149	8.958	0.663	-3.906	1961.30	247.96	1951.78	8.860	0.296	-4.365
891	675	8.860	0.463	-4.064			148	8.915	1.098	-3.902	1961.40	247.04	1951.87	8.898	0.204	-4.073
892	676	8.965	0.662	-3.985			147	8.889	0.911	-4.187	1961.50	246.00	1951.95	8.891	-0.315	-4.134
893	677	8.982	0.603	-3.907			146	8.863	0.789	-4.321	1961.60	244.96	1952.03	8.944	-0.203	-3.776
894	678	9.037	0.342	-3.780	1908.21	L	145	8.808	0.544	-4.444	1961.70	244.04	1952.12	8.936	-0.300	-3.814
895	679	9.016	0.260	-3.897			144	8.900	-0.102	-4.128	1961.83	243.00	1952.20	8.934	0.415	-3.677
896	680	8.973	0.201	-3.907			143	8.919	0.000	-3.986	1961.95	241.81	1952.28	8.917	0.705	-3.813
897	681	8.926	0.027	-3.853			142	8.893	0.362	-3.687	1962.08	240.62	1952.37	8.909	0.973	-3.923
898	682	8.905	0.036	-3.981			141	8.928	0.264	-3.643	1962.20	239.50	1952.45	8.886	1.011	-4.100
899	683	8.858	-0.191	-4.298			140	8.921	0.319	-3.838	1962.33	238.38	1952.53	8.863	1.071	-4.088
900	684	8.902	-0.195	-4.366			139	8.879	0.430	-4.155	1962.45	237.19	1952.62	8.856	0.953	-4.273
901	685	8.871	0.192	-4.470			138	8.849	0.461	-4.215	1962.58	236.00	1952.70	8.841	0.879	-4.387
902	686	8.857	0.013	-4.463	1907.71	H	137	8.856	0.264	-4.303	1962.70	235.17	1952.78	8.852	0.681	-4.182
903	687	8.864	0.176	-4.392			136	8.861	0.199	-4.398	1962.80	234.33	1952.87	8.825	0.080	-4.148
904	688	8.885	0.352	-4.047			135	8.876	-0.002	-4.291	1962.90	233.50	1952.95	8.860	-0.270	-4.017
905	689	9.007	0.306	-3.686			134	8.867	-0.036	-4.214	1963.00	232.67	1953.03	8.912	-0.133	-3.788
906	690	9.002	-0.464	-3.634	1907.21	L	133	8.888	0.117	-3.791	1963.10	231.83	1953.12	8.934	0.305	-3.595
907	691	8.980	-0.085	-3.455			132	8.981	0.258	-3.658	1963.20	231.00	1953.20	8.998	0.429	-3.557
908	692	8.984	-0.262	-3.458			131	8.958	0.586	-3.778	1963.28	230.17	1953.28	8.990	0.556	-3.738
909	693	8.951	-0.293	-3.553			130	8.928	0.591	-3.895	1963.37	229.33	1953.37	8.974	0.694	-3.889
910	694	8.887	-0.424	-3.892			129	8.901	0.782	-4.015	1963.45	228.50	1953.45	8.923	0.587	-4.161
911	695	8.861	-0.294	-4.123			128	8.902	0.711	-4.262	1963.53	227.67	1953.53	8.878	0.728	-4.316
912	696	8.823	-0.476	-4.084			127	8.844	0.543	-4.366	1963.62	226.83	1953.62	8.875	1.323	-4.237
913	697	8.849	-0.354	-4.209	1906.71	H	126	8.800	0.403	-4.429	1963.70	226.00	1953.70	8.863	1.248	-4.430
914	698	8.872	0.024	-4.285			125	8.829	0.236	-4.047	1963.83	225.36	1953.78	8.855	0.694	-4.250
915	699	8.837	0.126	-4.266			124	8.890	0.175	-3.873	1963.95	224.69	1953.87	8.855	0.391	-4.120
916	700	8.848	0.135	-4.246			123	8.972	0.429	-3.788	1964.08	224.00	1953.95	8.866	0.408	-4.054
917	701	8.869	0.183	-4.201			122	8.972	0.395	-3.694	1964.20	223.36	1954.03	8.877	0.374	-3.923
918	702	8.954	0.420	-3.945			121	8.923	0.407	-3.941	1964.30	222.69	1954.12	8.903	0.452	-3.807
919	703	8.986	0.413	-3.886			120	8.923	0.419	-4.006	1964.40	222.00	1954.20	8.949	0.671	-3.708
920	704	8.982	0.557	-3.753			119	8.892	0.701	-4.138	1964.50	221.36	1954.28	8.921	0.895	-3.870
921	705	8.986	0.854	-3.708	1906.21	L	118	8.919	0.575	-4.232	1964.60	220.69	1954.37	8.896	1.028	-3.952
922	706	8.949	0.568	-3.734			117	8.850	-0.228	-4.374	1964.70	220.00	1954.45	8.873	1.044	-3.933
923	707	8.905	0.511	-4.086			116	8.883	-0.115	-4.115	1964.83	219.36	1954.53	8.835	1.059	-4.125
924	708	8.872	1.262	-4.043			115	8.949	0.161	-3.951	1964.95	218.69	1954.62	8.809	0.956	-4.242
925	709	8.874	0.952	-4.291			114	8.991	-0.045	-3.779	1965.08	218.00	1954.70	8.801	0.704	-4.265
1151	710	8.855	0.210	-4.477			113	9.030	0.457	-3.750	1965.20	217.17	1954.78	8.853	0.197	-4.288
1152	711	8.814	0.024	-4.520	1905.71	H	112	9.009	0.527	-3.878	1965.30	216.33	1954.87	8.909	0.265	-4.023
1153	712	8.841	-0.040	-4.212			111	9.008	0.730	-3.974	1965.40	215.50	1954.95	8.926	0.246	-3.764
1154	713	8.895	0.236	-4.138			110	8.974	1.083	-3.926	1965.50	214.67	1955.03	8.927	0.213	-3.672
1155	714	8.942	0.357	-3.965			109	8.855	0.708	-4.180	1965.60	213.83	1955.12	8.945	0.416	-3.729
1156	715	8.969	0.677	-3.620			108	8.837	0.313	-4.246	1965.70	213.00	1955.20	8.950	0.718	-3.684
1157	716	8.996	0.500	-3.549	1905.21	L	107	8.865	-0.301	-4.185	1965.83	212.36	1955.28	8.896	0.664	-3.901
1158	717	8.952	0.157	-3.687			106	8.879	0.475	-3.954	1965.95	211.69	1955.37	8.844	0.658	-4.101
1159	718	8.867	0.230	-3.922			105	8.914	0.322	-3.906	1966.08	211.00	1955.45	8.793	0.715	-4.279
1160	719	8.854	0.075	-4.188			104	8.917	0.745	-3.994	1966.20	210.36	1955.53	8.797	0.984	-4.236
1161	720	8.847	0.554	-4.129	1904.71	H	103	8.869	0.926	-4.153	1966.37	209.69	1955.62	8.805	1.081	-4.245
1162	721	8.886	0.917	-4.156			102	8.820	0.399	-4.209	1966.53	209.00	1955.70	8.817	0.958	-4.320
1163	722	8.917	0.927	-4.117			101	8.805	0.167	-4.391	1966.70	208.36	1955.78	8.827	0.418	-4.195
1164	723	8.940	0.909	-3.851			100	8.863	-0.723	-4.167	1966.83	207.69	1955.87	8.865	0.106	-3.998
1165	724	8.917	0.732	-3.765			99	8.903	-0.435	-3.935	1966.95	207.00	1955.95	8.938	0.083	-3.709
1166	725	9.017	0.652	-3.676			98	8.967	-0.089	-3.760	1967.08	206.36	1956.03	8.935	0.259	-3.719
1167	726	9.023	0.435	-3.611	1904.21	L	97	9.001	0.070	-3.732	1967.20	205.69	1956.12	8.950	0.397	-3.712

Appendix A.2

oxygen isotope and trace element data for coral core from Guadeloupe (Gua 1, slabs B-F) and age model

							1st interpolation					2nd interpolation (monthly resolution)				
sample ID	new no.	Sr/ Ca (mmol/mol)	d13-C (per mil)	d18-O (per mil)	timemarker year.month	anchor High/Low	new no.	Sr/ Ca (mmol/mol)	d13-C (per mil)	d18-O (per mil)	timemarker year.month	new no.	timemarker year.month	Sr/ Ca (mmol/mol)	d13-C (per mil)	d18-O (per mil)
1168	727	9.005	0.263	-3.528			96	8.918	0.200	-4.039	1967.33	205.00	1956.20	8.985	0.485	-3.684
1169	728	8.974	-0.054	-3.686			95	8.895	0.762	-4.051	1967.45	204.36	1956.28	8.968	0.592	-3.808
1170	729	8.961	0.031	-3.801			94	8.840	0.856	-4.280	1967.58	203.69	1956.37	8.948	0.691	-3.942
1171	730	8.885	0.288	-4.093			93	8.802	0.787	-4.326	1967.70	203.00	1956.45	8.923	0.781	-4.090
1172	731	8.831	0.043	-4.261			92	8.877	0.364	-4.009	1967.83	202.36	1956.53	8.924	0.814	-4.170
1173	732	8.838	0.314	-4.325	1903.71	H	91	8.831	0.102	-3.780	1967.95	201.69	1956.62	8.920	0.907	-4.180
1174	733	8.858	0.636	-4.194			90	8.875	-0.213	-3.748	1968.08	201.00	1956.70	8.912	1.075	-4.099
1175	734	8.831	0.400	-4.258			89	8.954	0.489	-3.962	1968.20	199.96	1956.78	8.942	1.106	-4.167
1176	735	8.890	0.633	-4.243			88	8.868	0.660	-4.253	1968.37	199.04	1956.87	8.969	0.492	-4.070
1177	736	8.925	0.387	-3.959			87	8.811	0.897	-4.222	1968.53	198.00	1956.95	8.976	0.117	-3.537
1178	737	8.980	0.321	-3.918			86	8.788	0.436	-4.256	1968.70	196.96	1957.03	8.954	0.004	-3.574
1179	738	9.011	0.291	-4.119	1903.21	L	85	8.852	0.048	-3.886	1968.87	196.04	1957.12	8.992	0.409	-3.536
1180	739	8.964	-0.211	-3.774			84	8.876	0.414	-4.085	1969.03	195.00	1957.20	8.993	0.422	-3.659
1181	740	8.968	-0.356	-4.028			83	8.882	0.775	-4.013	1969.20	193.96	1957.28	8.945	0.550	-3.893
1182	741	8.888	-0.105	-4.104			82	8.815	0.787	-4.222	1969.37	193.04	1957.37	8.886	0.544	-3.952
1183	742	8.949	0.054	-4.297			81	8.841	0.964	-4.356	1969.53	192.00	1957.45	8.859	0.633	-4.277
1184	743	8.915	0.599	-4.275			80	8.786	0.440	-4.439	1969.70	190.96	1957.53	8.865	0.544	-4.205
1185	744	8.886	0.317	-4.348			79	8.851	0.814	-4.254	1969.78	190.04	1957.62	8.838	0.439	-4.495
1186	745	8.877	0.077	-4.241	1902.71	H	78	8.838	0.259	-4.290	1969.87	189.00	1957.70	8.831	0.211	-4.379
1187	746	8.924	-0.101	-4.309			77	8.853	-0.351	-4.120	1969.95	188.36	1957.78	8.836	0.137	-4.375
1188	747	8.964	0.255	-4.050			76	8.859	-0.313	-4.152	1970.03	187.69	1957.87	8.848	-0.021	-4.284
1189	748	8.972	0.219	-4.025			75	8.916	0.009	-3.980	1970.12	187.00	1957.95	8.870	-0.284	-4.083
1190	749	8.989	0.430	-3.813			74	8.915	0.192	-4.039	1970.20	186.36	1958.03	8.893	-0.192	-4.031
1191	750	8.991	0.370	-3.680	1902.21	L	73	8.881	0.645	-4.154	1970.30	185.69	1958.12	8.919	0.043	-4.040
1192	751	9.002	0.366	-3.853			72	8.868	0.015	-4.287	1970.40	185.00	1958.20	8.950	0.462	-4.127
1193	752	8.912	0.291	-3.988			71	8.840	-0.154	-4.617	1970.50	184.17	1958.28	8.949	0.925	-4.165
1194	753	8.868	0.500	-4.306			70	8.863	0.151	-4.107	1970.60	183.33	1958.37	8.896	0.993	-4.245
1195	754	8.826	0.336	-4.375			69	8.826	-0.295	-4.229	1970.70	182.50	1958.45	8.848	0.720	-4.405
1196	755	8.838	0.159	-4.270	1901.71	H	68	8.814	-0.258	-4.100	1970.80	181.67	1958.53	8.825	0.440	-4.514
1197	756	8.875	0.803	-4.398			67	8.849	-0.872	-4.094	1970.90	180.83	1958.62	8.832	0.425	-4.486
1198	757	8.852	0.484	-4.234			66	8.880	-0.396	-3.910	1971.00	180.00	1958.70	8.880	0.522	-4.497
1199	758	8.930	0.764	-4.071			65	8.924	0.046	-3.829	1971.10	178.67	1958.78	8.897	0.066	-4.400
1200	759	8.936	0.498	-4.135			64	8.935	0.482	-3.764	1971.20	177.39	1958.87	8.926	0.031	-4.194
1201	760	8.942	0.370	-3.950			63	8.927	0.604	-3.957	1971.37	176.00	1958.95	8.984	0.208	-4.076
1202	761	8.974	0.486	-3.892	1901.21	L	62	8.864	0.699	-4.249	1971.53	174.67	1959.03	8.955	0.286	-3.899
1203	762	8.955	0.323	-3.776			61	8.814	0.867	-4.301	1971.70	173.39	1959.12	8.948	0.557	-3.831
1204	763	8.931	0.277	-3.932			60	8.840	0.396	-4.274	1971.80	172.00	1959.20	8.999	0.765	-3.954
1205	764	8.876	0.132	-4.009			59	8.833	0.254	-4.298	1971.90	171.17	1959.28	8.956	0.737	-4.040
1206	765	8.851	0.170	-4.117			58	8.902	0.377	-3.856	1972.00	170.33	1959.37	8.928	0.770	-4.147
1207	766	8.889	0.289	-4.299			57	8.912	0.044	-3.845	1972.10	169.50	1959.45	8.906	0.810	-4.282
1208	767	8.825	0.222	-4.417	1900.71	H	56	8.951	0.330	-3.834	1972.20	168.67	1959.53	8.891	0.817	-4.345
1209	768	8.824	0.365	-4.204			55	8.879	0.478	-3.867	1972.37	167.83	1959.62	8.891	0.818	-4.298
1210	769	8.886	0.380	-4.148			54	8.869	0.442	-4.078	1972.53	167.00	1959.70	8.906	0.960	-4.329
1218	770	8.929	0.230	-4.126			53	8.829	0.328	-4.329	1972.70	165.81	1959.78	8.902	0.175	-4.180
1219	771	8.927	0.280	-4.212			52	8.850	0.421	-4.433	1972.83	164.62	1959.87	8.938	0.126	-3.992
1220	772	8.970	0.580	-3.981	1900.21	L	51	8.843	0.151	-4.134	1972.95	163.50	1959.95	8.944	0.349	-3.899
1221	773	8.953	0.460	-3.901			50	8.925	0.550	-3.982	1973.08	162.38	1960.03	8.956	0.485	-3.902
1222	774	8.936	0.338	-4.019			49	8.923	0.589	-3.775	1973.20	161.19	1960.12	8.948	0.552	-3.966
1223	775	8.917	0.069	-4.045			48	8.904	0.857	-3.900	1973.33	160.00	1960.20	8.996	0.814	-3.979
1224	776	8.913	-0.117	-4.290			47	8.898	0.941	-3.940	1973.45	159.17	1960.28	8.903	0.487	-4.155
1225	777	8.797	0.083	-4.434	1899.71	H	46	8.867	0.563	-4.232	1973.58	158.33	1960.37	8.881	0.556	-4.218
1226	778	8.864	0.170	-4.377			45	8.859	0.206	-4.123	1973.70	157.50	1960.45	8.864	0.557	-4.299
1227	779	8.821	0.430	-4.373			44	8.910	0.121	-4.213	1973.87	156.67	1960.53	8.844	0.439	-4.399
1228	780	8.847	0.623	-4.265			43	8.930	-0.249	-3.783	1974.03	155.83	1960.62	8.831	0.292	-4.456
1229	781	8.914	0.815	-4.180			42	8.954	-0.043	-3.726	1974.20	155.00	1960.70	8.796	0.061	-4.414
1230	782	8.961	0.787	-3.919			41	8.959	0.151	-3.792	1974.33	154.17	1960.78	8.835	0.202	-4.322
1231	783	9.027	0.611	-3.858	1899.21	L	40	8.908	0.608	-4.047	1974.45	153.33	1960.87	8.888	0.031	-4.200
1232	784	9.010	0.628	-3.814			39	8.890	0.998	-4.159	1974.58	152.50	1960.95	8.917	-0.140	-4.059
1233	785	8.958	0.308	-3.856			38	8.846	0.503	-4.356	1974.70	151.67	1961.03	8.931	-0.111	-3.941
1234	786	8.924	0.130	-3.915			37	8.909	-0.270	-4.159	1974.87	150.83	1961.12	8.947	0.135	-3.861
1235	787	8.811	0.067	-4.221			36	8.914	0.223	-3.978	1975.03	150.00	1961.20	8.963	0.380	-3.747
1236	788	8.846	0.167	-4.386	1898.71	H	35	8.969	-0.191	-3.896	1975.20	149.17	1961.28	8.959	0.616	-3.880
1237	789	8.829	0.335	-4.473			34	8.907	0.169	-3.804	1975.28	148.33	1961.37	8.929	0.953	-3.903
1238	790	8.844	0.589	-4.286			33	8.920	0.261	-3.864	1975.37	147.50	1961.45	8.902	1.005	-4.045
1239	791	8.880	0.886	-4.344			32	8.933	0.444	-4.022	1975.45	146.67	1961.53	8.880	0.870	-4.232
1240	792	8.866	0.624	-4.403			31	8.893	0.175	-4.135	1975.53	145.83	1961.62	8.854	0.748	-4.342
1241	793	8.900	0.887	-4.188			30	8.856	0.519	-4.266	1975.62	145.00	1961.70	8.808	0.544	-4.444
1242	794	8.995	0.981	-3.989	1898.21	L	29	8.853	-0.171	-4.129	1975.70	144.36	1961.78	8.867	0.130	-4.241
1243	795	8.964	0.738	-3.879			28	8.869	-0.532	-3.857	1975.87	143.69	1961.87	8.906	-0.071	-4.085
1244	796	8.976	0.565	-3.891			27	8.914	-0.381	-3.726	1976.03	143.00	1961.95	8.919	0.000	-3.986
1245	797	8.952	0.444	-3.946			26	8.965	0.256	-3.535	1976.20	142.36	1962.03	8.902	0.232	-3.794
1246	798	8.883	-0.104	-3.968			25	8.927	0.443	-3.784	1976.30	141.69	1962.12	8.904	0.332	-3.674
1247	799	8.875	-0.007	-4.099			24	8.883	0.337	-4.042	1976.40	141.00	1962.20	8.928	0.264	-3.643
1248	800	8.840	-0.336	-4.387			23	8.890	0.412	-4.143	1976.50	140.36	1962.28	8.924	0.299	-3.768
1249	801	8.823	-0.147	-4.337	1897.71	H	22	8.842	0.457	-4.244	1976.60	139.69	1962.37	8.908	0.353	-3.935
1250	802	8.832	0.458	-4.477			21	8.814	-0.243	-4.281	1976.70	139.00	1962.45	8.879	0.430	-4.155
1251	803	8.836	0.103	-4.450			20	8.880	0.084	-4.065	1976.83	138.36	1962.53	8.860	0.450	-4.193
1252	804	8.866	0.566	-4.120			19	8.909	-0.092	-3.873	1976.95	137.69	1962.62	8.851	0.401	-4.242
1253	805	8.897	0.707	-3.898			18	8.967	0.429	-3.740	1977.08	137.00	1962.70	8.856	0.264	-4.303
1254	806	8.919	0.698	-3.844			17	8.928	0.212	-3.747	1977.20	136.17	1962.78	8.860	0.210	-4.382
1255	807	8.911	0.567	-3.799	1897.21	L	16	8.929	0.741	-3.902	1977.28	135.33	1962.87	8.871	0.065	-4.327
1256	808	8.881	0.460	-4.050			15	8.935	0.545	-3.985	1977.37	134.50	1962.95	8.872	-0.019	-4.253
1257	809	8.900	0.421	-3.865			14	8.820	1.172	-4.045	1977.45	133.67	1963.03	8.874	0.015	-4.073
1258	810	8.873	-0.262	-4.098			13	8.880	0.754	-4.195	1977.53	132.83	1963.12	8.904	0.141	-3.769
1259	811	8.776	-0.009	-4.164			12	8.848	0.480	-4.441	1977.62	132.00	1963.20	8.981	0.258	-3.658
1260	812	8.826	0.261	-4.175			11	8.778	-0.133	-4.334	1977.70	130.96	1963.28	8.957	0.586	-3.782
1261	813	8.765	0.446	-4.137	1896.71	H	10	8.829	-0.690	-4.258	1977.83	130.04	1963.37	8.929	0.591	-3.891
1262	814	8.799	0.210	-4.196			9	8.881	-0.752	-3.951	1977.95	129.00	1963.45	8.901	0.782	-4.015
1263	815	8.820	0.197	-4.259			8	8.964	-0.698	-3.954	1978.08	127.96	1963.53	8.900	0.705	-4.266
1264	816	8.852	0.425	-3.958			7	8.941	0.190	-3.914	1978.20	127.04	1963.62	8.846	0.549	-4.362
1265	817	8.924	0.461	-3.790			6	8.915	0.193	-4.014	1978.28	126.00	1963.70	8.800	0.403	-4.429
1266	818	8.926	0.367	-3.827	1896.21	L	5	8.895	0.250	-4.094	1978.37	125.36	1963.78	8.819	0.296	-4.184
1267	819	8.967	0.186	-3.803			4	8.892	0.206	-4.386	1978.45	124.69	1963.87	8.848	0.217	-3.994
1268	820	8.935	-0.007	-3.794			3	8.870	0.164	-4.377	1978.53	124.00	1963.95	8.890	0.175	-3.873
1269	821	8.956	-0.262	-3.812			2	8.869	-0.113	-4.426	1978.62	123.36	1964.03	8.943	0.338	-3.819
1270	822	8.838	-0.446	-4.022	1895.71	H	1	8.859	-0.053	-4.516	1978.70	122.69	1964.12	8.972	0.419	-3.759
												122.00	1964.20	8.972	0.395	-3.694
												121.17	1964.28	8.931	0.405	-3.900
												120.33	1964.37	8.923	0.415	-3.984
												119.50	1964.45	8.908	0.560	-4.072
												118.67	1964.53	8.901	0.659	-4.169
												117.83	1964.62	8.908	0.441	-4.256
												117.00	1964.70	8.850	-0.228	-4.374
												116.36	1964.78	8.871	-0.156	-4.208

Appendix A.2
oxygen isotope and trace element data for coral core from Guadeloupe (Gua 1, slabs B-F) and age model

							1st interpolation					2nd interpolation (monthly resolution)				
sample ID	new no.	Sr/ Ca (mmol/mol)	d13-C (per mil)	d18-O (per mil)	timemarker year.month	anchor High/Low	new no.	Sr/ Ca (mmol/mol)	d13-C (per mil)	d18-O (per mil)	timemarker year.month	new no.	timemarker year.month	Sr/ Ca (mmol/mol)	d13-C (per mil)	d18-O (per mil)
												115.69	1964.87	8.903	-0.031	-4.065
												115.00	1964.95	8.949	0.161	-3.951
												114.36	1965.03	8.976	0.029	-3.841
												113.69	1965.12	9.003	0.108	-3.770
												113.00	1965.20	9.030	0.457	-3.750
												112.17	1965.28	9.013	0.515	-3.857
												111.33	1965.37	9.008	0.662	-3.942
												110.50	1965.45	8.991	0.907	-3.950
												109.67	1965.53	8.934	0.958	-4.011
												108.83	1965.62	8.852	0.642	-4.191
												108.00	1965.70	8.837	0.313	-4.246
												107.36	1965.78	8.855	-0.081	-4.207
												106.69	1965.87	8.869	-0.064	-4.114
												106.00	1965.95	8.879	0.475	-3.954
												105.36	1966.03	8.901	0.377	-3.923
												104.69	1966.12	8.915	0.451	-3.933
												104.00	1966.20	8.917	0.745	-3.994
												103.51	1966.28	8.893	0.834	-4.072
												103.02	1966.37	8.870	0.922	-4.150
												102.50	1966.45	8.845	0.663	-4.181
												101.98	1966.53	8.820	0.394	-4.213
												101.49	1966.62	8.812	0.281	-4.302
												101.00	1966.70	8.805	0.167	-4.391
												100.36	1966.78	8.842	-0.404	-4.247
												99.69	1966.87	8.875	-0.635	-4.096
												99.00	1966.95	8.903	-0.435	-3.935
												98.36	1967.03	8.944	-0.213	-3.823
												97.69	1967.12	8.977	-0.040	-3.751
												97.00	1967.20	9.001	0.070	-3.732
												96.36	1967.28	8.948	0.153	-3.929
												95.69	1967.37	8.911	0.372	-4.043
												95.00	1967.45	8.895	0.762	-4.051
												94.36	1967.53	8.860	0.822	-4.198
												93.69	1967.62	8.828	0.835	-4.294
												93.00	1967.70	8.802	0.787	-4.326
												92.36	1967.78	8.850	0.516	-4.123
												91.69	1967.87	8.863	0.284	-3.939
												91.00	1967.95	8.831	0.102	-3.780
												90.36	1968.03	8.859	-0.100	-3.759
												89.69	1968.12	8.899	0.002	-3.813
												89.00	1968.20	8.954	0.489	-3.962
												88.51	1968.28	8.912	0.573	-4.105
												88.02	1968.37	8.870	0.657	-4.247
												87.50	1968.45	8.840	0.779	-4.238
												86.98	1968.53	8.811	0.888	-4.223
												86.49	1968.62	8.799	0.662	-4.239
												86.00	1968.70	8.788	0.436	-4.256
												85.51	1968.78	8.819	0.246	-4.075
												85.02	1968.87	8.851	0.056	-3.893
												84.50	1968.95	8.864	0.231	-3.986
												83.98	1969.03	8.876	0.421	-4.084
												83.49	1969.12	8.879	0.598	-4.048
												83.00	1969.20	8.882	0.775	-4.013
												82.51	1969.28	8.849	0.781	-4.115
												82.02	1969.37	8.816	0.787	-4.218
												81.50	1969.45	8.828	0.876	-4.289
												80.98	1969.53	8.840	0.954	-4.358
												80.49	1969.62	8.813	0.697	-4.398
												80.00	1969.70	8.786	0.440	-4.439
												78.96	1969.78	8.851	0.793	-4.255
												78.04	1969.87	8.838	0.280	-4.289
												77.00	1969.95	8.853	-0.351	-4.120
												75.96	1970.03	8.861	-0.301	-4.146
												75.04	1970.12	8.914	-0.003	-3.986
												74.00	1970.20	8.915	0.192	-4.039
												73.17	1970.28	8.887	0.570	-4.135
												72.33	1970.37	8.872	0.225	-4.243
												71.50	1970.45	8.854	-0.070	-4.452
												70.67	1970.53	8.848	-0.052	-4.447
												69.83	1970.62	8.857	0.077	-4.127
												69.00	1970.70	8.826	-0.295	-4.229
												68.17	1970.78	8.816	-0.264	-4.122
												67.33	1970.87	8.837	-0.667	-4.096
												66.50	1970.95	8.865	-0.634	-4.002
												65.67	1971.03	8.895	-0.249	-3.883
												64.83	1971.12	8.926	0.119	-3.818
												64.00	1971.20	8.935	0.482	-3.764
												63.51	1971.28	8.931	0.542	-3.859
												63.02	1971.37	8.927	0.602	-3.953
												62.50	1971.45	8.896	0.652	-4.103
												61.98	1971.53	8.863	0.702	-4.250
												61.49	1971.62	8.839	0.785	-4.276
												61.00	1971.70	8.814	0.867	-4.301
												60.17	1971.78	8.836	0.475	-4.279
												59.33	1971.87	8.835	0.301	-4.290
												58.50	1971.95	8.868	0.316	-4.077
												57.67	1972.03	8.905	0.266	-3.852
												56.83	1972.12	8.919	0.092	-3.843
												56.00	1972.20	8.951	0.330	-3.834
												55.51	1972.28	8.916	0.403	-3.850
												55.02	1972.37	8.880	0.475	-3.866
												54.50	1972.45	8.874	0.460	-3.973
												53.98	1972.53	8.868	0.440	-4.083
												53.49	1972.62	8.849	0.384	-4.206
												53.00	1972.70	8.829	0.328	-4.329
												52.36	1972.78	8.842	0.388	-4.396
												51.69	1972.87	8.848	0.339	-4.342
												51.00	1972.95	8.843	0.151	-4.134
												50.36	1973.03	8.896	0.407	-4.037
												49.69	1973.12	8.924	0.562	-3.919
												49.00	1973.20	8.923	0.589	-3.775
												48.36	1973.28	8.911	0.761	-3.855
												47.69	1973.37	8.902	0.883	-3.912
												47.00	1973.45	8.898	0.941	-3.940

Appendix A.2
oxygen isotope and trace element data for coral core from Guadeloupe (Gua 1, slabs B-F) and age model

							1st interpolation						2nd interpolation (monthly resolution)				
sample ID	new no.	Sr/ Ca	d13-C	d18-O	timemarker	anchor	new no.	Sr/ Ca	d13-C	d18-O	timemarker	new no.	timemarker	Sr/ Ca	d13-C	d18-O
		(mmol/mol)	(per mil)	(per mil)	year.month	High/Low		(mmol/mol)	(per mil)	(per mil)	year.month		year.month	(mmol/mol)	(per mil)	(per mil)
												46.36	1973.53	8.878	0.699	-4.127
												45.69	1973.62	8.865	0.454	-4.199
												45.00	1973.70	8.859	0.206	-4.123
												44.51	1973.78	8.884	0.164	-4.167
												44.02	1973.87	8.909	0.123	-4.211
												43.50	1973.95	8.920	-0.064	-3.998
												42.98	1974.03	8.930	-0.245	-3.782
												42.49	1974.12	8.942	-0.144	-3.754
												42.00	1974.20	8.954	-0.043	-3.726
												41.36	1974.28	8.957	0.081	-3.768
												40.69	1974.37	8.943	0.291	-3.870
												40.00	1974.45	8.908	0.608	-4.047
												39.36	1974.53	8.896	0.858	-4.119
												38.69	1974.62	8.877	0.847	-4.219
												38.00	1974.70	8.846	0.503	-4.356
												37.51	1974.78	8.877	0.124	-4.259
												37.02	1974.87	8.908	-0.255	-4.163
												36.50	1974.95	8.912	-0.024	-4.069
												35.98	1975.03	8.915	0.215	-3.976
												35.49	1975.12	8.942	0.012	-3.936
												35.00	1975.20	8.969	-0.191	-3.896
												33.96	1975.28	8.907	0.172	-3.806
												33.04	1975.37	8.920	0.258	-3.862
												32.00	1975.45	8.933	0.444	-4.022
												30.96	1975.53	8.892	0.188	-4.140
												30.04	1975.62	8.857	0.506	-4.261
												29.00	1975.70	8.853	-0.171	-4.129
												28.51	1975.78	8.861	-0.348	-3.996
												28.02	1975.87	8.869	-0.525	-3.862
												27.50	1975.95	8.892	-0.457	-3.792
												26.98	1976.03	8.915	-0.369	-3.722
												26.49	1976.12	8.940	-0.056	-3.629
												26.00	1976.20	8.965	0.256	-3.535
												25.17	1976.28	8.933	0.412	-3.743
												24.33	1976.37	8.898	0.372	-3.956
												23.50	1976.45	8.887	0.375	-4.093
												22.67	1976.53	8.874	0.427	-4.177
												21.83	1976.62	8.837	0.340	-4.250
												21.00	1976.70	8.814	-0.243	-4.281
												20.36	1976.78	8.856	-0.033	-4.143
												19.69	1976.87	8.889	0.030	-4.006
												19.00	1976.95	8.909	-0.092	-3.873
												18.36	1977.03	8.946	0.242	-3.788
												17.69	1977.12	8.955	0.363	-3.742
												17.00	1977.20	8.928	0.212	-3.747
												15.96	1977.28	8.929	0.734	-3.905
												15.04	1977.37	8.935	0.552	-3.982
												14.00	1977.45	8.820	1.172	-4.045
												12.96	1977.53	8.879	0.744	-4.204
												12.04	1977.62	8.849	0.490	-4.432
												11.00	1977.70	8.778	-0.133	-4.334
												10.36	1977.78	8.811	-0.490	-4.285
												9.69	1977.87	8.845	-0.709	-4.164
												9.00	1977.95	8.881	-0.752	-3.951
												8.36	1978.03	8.934	-0.717	-3.953
												7.69	1978.12	8.957	-0.427	-3.942
												7.00	1978.20	8.941	0.190	-3.914
												5.96	1978.28	8.914	0.195	-4.017
												5.04	1978.37	8.896	0.248	-4.091
												4.00	1978.45	8.892	0.206	-4.386
												2.96	1978.53	8.870	0.154	-4.379
												2.04	1978.62	8.869	-0.103	-4.424
												1.00	1978.70	8.859	-0.053	-4.516

Appendix B.1
oxygen isotope data for coral core from Archipelago Los Roques (Roq6) and age model

core Roq6 (2004-1917)
d18O

					1st interpolation			2nd interpolation (monthly resolution)		
sample ID	new no.	d18O (per mil)	timemarker year.month	anchor High/Low	new no.	d18O (per mil)	timemarker year.month	new no.	timemarker year.month	d18O (per mil)
1	1	-4.581	2004.79	H	1087	-3.812	1917.79	1087.00	1917.79	-3.812
2	2	-4.356			1086	-3.724	1917.88	1086.07	1917.87	-3.731
3	3	-4.352			1085	-3.750	1917.96	1085.04	1917.96	-3.749
4	4	-4.298			1084	-3.666	1918.04	1084.00	1918.04	-3.666
5	5	-4.122	2004.12	L	1083	-3.706	1918.12	1082.97	1918.12	-3.700
6	6	-4.242			1082	-3.522	1918.22	1082.13	1918.21	-3.546
7	7	-4.227			1081	-3.768	1918.32	1081.30	1918.29	-3.694
8	8	-4.416			1080	-3.696	1918.41	1080.41	1918.37	-3.725
9	9	-4.561	2003.79	H	1079	-3.820	1918.51	1079.53	1918.46	-3.754
10	10	-4.489			1078	-3.760	1918.60	1078.67	1918.54	-3.800
11	11	-4.435			1077	-3.915	1918.70	1077.77	1918.62	-3.796
12	12	-4.280			1076	-3.846	1918.79	1076.93	1918.71	-3.909
13	13	-4.277			1075	-3.776	1918.84	1076.00	1918.79	-3.846
14	14	-4.313			1074	-3.700	1918.89	1074.33	1918.87	-3.726
15	15	-4.091	2003.12	L	1073	-3.523	1918.93	1072.47	1918.96	-3.555
21	16	-4.028			1072	-3.584	1918.98	1070.80	1919.04	-3.502
22	17	-3.946			1071	-3.461	1919.03	1068.98	1919.12	-3.657
23	18	-3.861			1070	-3.666	1919.08	1068.38	1919.21	-3.691
24	19	-4.008			1069	-3.656	1919.12	1067.77	1919.29	-3.777
25	20	-4.073			1068	-3.714	1919.26	1067.13	1919.37	-3.954
26	21	-4.193			1067	-3.989	1919.39	1066.52	1919.46	-4.002
27	22	-4.304			1066	-4.016	1919.53	1065.92	1919.54	-4.011
28	23	-4.432	2002.79	H	1065	-3.954	1919.66	1065.28	1919.62	-3.971
29	24	-4.400			1064	-4.002	1919.79	1064.64	1919.71	-3.971
30	25	-4.372			1063	-4.009	1919.86	1064.00	1919.79	-4.002
31	26	-4.309			1062	-3.766	1919.93	1062.81	1919.87	-3.962
32	27	-4.291			1061	-3.667	1919.99	1061.56	1919.96	-3.722
33	28	-4.154			1060	-3.715	1920.06	1060.29	1920.04	-3.701
34	29	-4.104			1059	-3.580	1920.12	1058.98	1920.12	-3.578
35	30	-4.097			1058	-3.513	1920.26	1058.38	1920.21	-3.538
36	31	-4.146			1057	-3.529	1920.39	1057.77	1920.29	-3.516
37	32	-4.295	2002.12	L	1056	-3.638	1920.53	1057.13	1920.37	-3.527
38	33	-4.409			1055	-3.686	1920.66	1056.52	1920.46	-3.581
39	34	-4.385			1054	-3.785	1920.79	1055.92	1920.54	-3.641
40	35	-4.284			1053	-3.608	1920.86	1055.28	1920.62	-3.672
41	36	-4.378	2001.79	H	1052	-3.696	1920.93	1054.64	1920.71	-3.721
42	37	-4.405			1051	-3.705	1920.99	1054.00	1920.79	-3.785
43	38	-4.477			1050	-3.589	1921.06	1052.81	1920.87	-3.625
44	39	-4.228			1049	-3.602	1921.12	1051.56	1920.96	-3.700
45	40	-4.088			1048	-3.620	1921.19	1050.29	1921.04	-3.622
46	41	-4.042			1047	-3.629	1921.26	1048.95	1921.12	-3.603
47	42	-3.932	2001.12	L	1046	-3.630	1921.33	1047.76	1921.21	-3.622
48	43	-3.763			1045	-3.818	1921.39	1046.57	1921.29	-3.629
49	44	-3.859			1044	-3.689	1921.46	1045.28	1921.37	-3.766
50	45	-4.064			1043	-3.904	1921.53	1044.05	1921.46	-3.695
51	46	-4.137			1042	-3.987	1921.59	1042.83	1921.54	-3.918
52	47	-4.303	2000.79	H	1041	-4.040	1921.66	1041.52	1921.62	-4.012
53	48	-4.323			1040	-4.136	1921.73	1040.33	1921.71	-4.104
54	49	-4.380			1039	-4.389	1921.79	1039.00	1921.79	-4.389
55	50	-4.253			1038	-4.231	1921.88	1038.07	1921.87	-4.242
56	51	-4.103			1037	-3.980	1921.96	1037.04	1921.96	-3.990
57	52	-4.009			1036	-3.889	1922.04	1036.00	1922.04	-3.889
58	53	-3.929	2000.12	L	1035	-3.777	1922.12	1034.98	1922.12	-3.776
59	54	-3.989			1034	-3.710	1922.26	1034.38	1922.21	-3.735
60	55	-3.951			1033	-3.871	1922.39	1033.77	1922.29	-3.747
61	56	-4.172			1032	-3.972	1922.53	1033.13	1922.37	-3.850
62	57	-4.136			1031	-4.117	1922.66	1032.52	1922.46	-3.919
63	58	-4.297			1030	-4.329	1922.79	1031.92	1922.54	-3.983
64	59	-4.336			1029	-4.381	1922.85	1031.28	1922.62	-4.076
65	60	-4.274	1999.79	H	1028	-4.378	1922.90	1030.64	1922.71	-4.193
66	61	-4.303			1027	-4.090	1922.96	1030.00	1922.79	-4.329
67	62	-4.304			1026	-3.888	1923.01	1028.53	1922.87	-4.379
68	63	-4.148			1025	-3.772	1923.07	1027.06	1922.96	-4.106
69	64	-4.037			1024	-3.534	1923.12	1025.50	1923.04	-3.830
70	65	-3.940			1023	-3.649	1923.24	1023.97	1923.12	-3.538
71	66	-3.921	1999.12	L	1022	-3.903	1923.35	1023.28	1923.21	-3.617

Appendix B.1
oxygen isotope data for coral core from Archipelago Los Roques (Roq6) and age model

					1st interpolation			2nd interpolation (monthly resolution)		
sample ID	new no.	d18O	timemarker	anchor	new no.	d18O	timemarker	new no.	timemarker	d18O
		(per mil)	year.month	High/Low		(per mil)	year.month		year.month	(per mil)
72	67	-4.110			1021	-3.868	1923.46	1022.55	1923.29	-3.764
73	68	-4.186			1020	-4.060	1923.57	1021.79	1923.37	-3.895
74	69	-4.296			1019	-4.149	1923.68	1021.03	1923.46	-3.869
75	70	-4.328			1018	-3.921	1923.79	1020.27	1923.54	-4.008
76	71	-4.459			1017	-3.897	1923.88	1019.52	1923.62	-4.103
77	72	-4.479	1998.79	H	1016	-3.915	1923.96	1018.76	1923.71	-4.093
78	73	-4.469			1015	-3.774	1924.04	1018.00	1923.79	-3.921
79	74	-4.436			1014	-3.828	1924.12	1017.07	1923.87	-3.899
80	75	-4.355			1013	-3.787	1924.24	1016.04	1923.96	-3.914
81	76	-4.410			1012	-3.980	1924.35	1015.00	1924.04	-3.774
82	77	-4.069			1011	-3.989	1924.46	1013.97	1924.12	-3.827
83	78	-4.033	1998.12	L	1010	-4.239	1924.57	1013.28	1924.21	-3.798
84	79	-3.939			1009	-4.249	1924.68	1012.55	1924.29	-3.874
85	80	-3.992			1008	-4.331	1924.79	1011.79	1924.37	-3.982
86	81	-4.144			1007	-4.220	1924.85	1011.03	1924.46	-3.989
87	82	-4.354			1006	-4.152	1924.90	1010.27	1924.54	-4.171
88	83	-4.397			1005	-3.892	1924.96	1009.52	1924.62	-4.244
89	84	-4.175			1004	-3.706	1925.01	1008.76	1924.71	-4.269
90	85	-4.199	1997.79	H	1003	-3.471	1925.07	1008.00	1924.79	-4.331
91	86	-4.106			1002	-3.763	1925.12	1006.53	1924.87	-4.188
92	87	-4.047			1001	-3.729	1925.26	1005.06	1924.96	-3.907
93	88	-4.131			1000	-3.881	1925.39	1003.50	1925.04	-3.588
94	89	-4.115			999	-4.166	1925.53	1001.98	1925.12	-3.762
95	90	-4.099			998	-4.142	1925.66	1001.38	1925.21	-3.742
96	91	-3.947			997	-4.118	1925.79	1000.77	1925.29	-3.764
97	92	-3.904	1997.12	L	996	-4.106	1925.86	1000.13	1925.37	-3.861
98	93	-3.845			995	-4.168	1925.93	999.52	1925.46	-4.017
99	94	-4.033			994	-3.896	1925.99	998.92	1925.54	-4.165
100	95	-4.085			993	-3.902	1926.06	998.28	1925.62	-4.149
101	96	-4.282			992	-3.701	1926.12	997.64	1925.71	-4.134
102	97	-4.308			991	-3.616	1926.20	997.00	1925.79	-4.118
103	98	-4.384	1996.79	H	990	-3.785	1926.27	995.81	1925.87	-4.117
104	99	-4.320			989	-3.763	1926.35	994.56	1925.96	-4.047
105	100	-4.272			988	-3.903	1926.42	993.29	1926.04	-3.900
106	101	-4.205			987	-4.009	1926.50	991.96	1926.12	-3.697
107	102	-4.109			986	-4.157	1926.57	990.91	1926.21	-3.632
114	103	-4.119			985	-4.198	1926.64	989.75	1926.29	-3.780
115	104	-4.044			984	-4.306	1926.72	988.67	1926.37	-3.810
116	105	-3.851	1996.12	L	983	-4.244	1926.79	987.54	1926.46	-3.952
117	106	-4.266			982	-4.344	1926.86	986.43	1926.54	-4.093
118	107	-4.343			981	-4.113	1926.93	985.24	1926.62	-4.188
119	108	-4.530			980	-3.841	1926.99	984.17	1926.71	-4.288
120	109	-4.535			979	-3.855	1927.06	983.00	1926.79	-4.244
121	110	-4.630	1995.79	H	978	-3.876	1927.12	981.81	1926.87	-4.300
122	111	-4.556			977	-3.795	1927.22	980.56	1926.96	-3.992
123	112	-4.515			976	-3.876	1927.32	979.29	1927.04	-3.851
124	113	-4.455			975	-4.043	1927.41	977.97	1927.12	-3.873
125	114	-4.298			974	-4.056	1927.51	977.13	1927.21	-3.806
126	115	-4.263			973	-4.221	1927.60	976.30	1927.29	-3.851
127	116	-4.295			972	-4.162	1927.70	975.41	1927.37	-3.975
128	117	-4.208			971	-4.369	1927.79	974.53	1927.46	-4.049
129	118	-4.167			970	-4.184	1927.88	973.67	1927.54	-4.111
130	119	-3.959			969	-4.022	1927.96	972.77	1927.62	-4.207
131	120	-4.075			968	-3.891	1928.04	971.93	1927.71	-4.177
132	121	-3.878	1995.12	L	967	-3.832	1928.12	971.00	1927.79	-4.369
133	122	-4.183			966	-3.776	1928.21	970.07	1927.87	-4.197
134	123	-4.142			965	-3.662	1928.29	969.04	1927.96	-4.028
135	124	-4.328			964	-3.651	1928.38	968.00	1928.04	-3.891
136	125	-4.299			963	-3.809	1928.46	966.96	1928.12	-3.830
137	126	-4.480			962	-3.983	1928.54	966.04	1928.21	-3.778
138	127	-4.441			961	-4.153	1928.63	965.00	1928.29	-3.662
139	128	-4.570			960	-4.096	1928.71	964.07	1928.37	-3.652
140	129	-4.418	1994.79	H	959	-4.066	1928.79	963.04	1928.46	-3.802
141	130	-4.496			958	-3.927	1928.88	962.00	1928.54	-3.983
142	131	-4.249			957	-3.887	1928.96	961.07	1928.62	-4.141
143	132	-4.170			956	-3.744	1929.04	960.04	1928.71	-4.098
144	133	-3.862			955	-3.566	1929.12	959.00	1928.79	-4.066
145	134	-4.017			954	-3.707	1929.26	958.07	1928.87	-3.937
146	135	-3.856			953	-3.687	1929.39	957.04	1928.96	-3.889

Appendix B.1
oxygen isotope data for coral core from Archipelago Los Roques (Roq6) and age model

					1st interpolation			2nd interpolation (monthly resolution)		
sample ID	new no.	d18O (per mil)	timemarker year.month	anchor High/Low	new no.	d18O (per mil)	timemarker year.month	new no.	timemarker year.month	d18O (per mil)
147	136	-3.743	1994.12	L	952	-3.893	1929.53	956.00	1929.04	-3.744
148	137	-3.749			951	-3.914	1929.66	954.98	1929.12	-3.569
149	138	-3.812			950	-4.039	1929.79	954.38	1929.21	-3.653
150	139	-3.876			949	-4.061	1929.85	953.77	1929.29	-3.702
151	140	-4.009			948	-4.098	1929.90	953.13	1929.37	-3.690
152	141	-4.197			947	-3.985	1929.96	952.52	1929.46	-3.785
153	142	-4.199			946	-3.757	1930.01	951.92	1929.54	-3.894
154	143	-4.106			945	-3.593	1930.07	951.28	1929.62	-3.908
155	144	-4.255	1993.79	H	944	-3.725	1930.12	950.64	1929.71	-3.959
156	145	-4.292			943	-3.618	1930.22	950.00	1929.79	-4.039
157	146	-4.194			942	-3.813	1930.32	948.53	1929.87	-4.078
158	147	-4.235			941	-3.717	1930.41	947.06	1929.96	-3.991
159	148	-4.124			940	-3.847	1930.51	945.50	1930.04	-3.675
160	149	-4.042			939	-3.929	1930.60	943.97	1930.12	-3.721
161	150	-4.104			938	-3.931	1930.70	943.13	1930.21	-3.632
162	151	-3.958			937	-3.951	1930.79	942.30	1930.29	-3.755
163	152	-3.866			936	-3.932	1930.86	941.41	1930.37	-3.756
164	153	-4.006			935	-3.981	1930.93	940.53	1930.46	-3.778
165	154	-3.809	1993.12	L	934	-3.912	1930.99	939.67	1930.54	-3.874
166	155	-3.943			933	-3.911	1931.06	938.77	1930.62	-3.929
167	156	-4.056			932	-3.838	1931.12	937.93	1930.71	-3.932
168	157	-4.249			931	-3.871	1931.29	937.00	1930.79	-3.951
169	158	-4.258			930	-4.093	1931.46	935.81	1930.87	-3.942
170	159	-4.296			929	-4.171	1931.63	934.56	1930.96	-3.950
171	160	-4.321			928	-4.134	1931.79	933.29	1931.04	-3.911
172	161	-4.336	1992.79	H	927	-3.894	1931.83	931.98	1931.12	-3.838
173	162	-4.318			926	-4.129	1931.87	931.49	1931.21	-3.855
174	163	-4.303			925	-4.111	1931.90	931.00	1931.29	-3.871
175	164	-4.401			924	-4.086	1931.94	930.51	1931.37	-3.980
176	165	-4.209			923	-4.165	1931.98	930.02	1931.46	-4.089
177	166	-4.154			922	-4.201	1932.01	929.53	1931.54	-4.130
178	167	-4.162			921	-4.123	1932.05	929.04	1931.62	-4.168
179	168	-4.019	1992.12	L	920	-4.056	1932.09	928.52	1931.71	-4.153
180	169	-3.849			919	-3.800	1932.12	928.00	1931.79	-4.134
181	170	-3.832			918	-3.903	1932.24	925.89	1931.87	-4.127
182	171	-3.806			917	-4.029	1932.35	923.58	1931.96	-4.119
183	172	-3.780			916	-3.944	1932.46	921.25	1932.04	-4.143
184	173	-4.059			915	-4.244	1932.57	918.97	1932.12	-3.803
185	174	-3.961			914	-4.304	1932.68	918.28	1932.21	-3.875
186	175	-4.202			913	-4.520	1932.79	917.55	1932.29	-3.960
187	176	-4.199			912	-4.584	1932.85	916.79	1932.37	-4.011
188	177	-4.077	1991.79	H	911	-4.401	1932.90	916.03	1932.46	-3.946
189	178	-4.201			910	-4.237	1932.96	915.27	1932.54	-4.162
190	179	-4.102			909	-4.067	1933.01	914.52	1932.62	-4.273
191	180	-4.025			908	-4.006	1933.07	913.76	1932.71	-4.356
192	181	-4.080			907	-4.008	1933.12	913.00	1932.79	-4.520
193	182	-4.063			906	-4.019	1933.24	911.53	1932.87	-4.499
194	183	-3.880	1991.12	L	905	-4.209	1933.35	910.06	1932.96	-4.246
195	184	-3.879			904	-4.209	1933.46	908.50	1933.04	-4.037
196	185	-3.827			903	-4.259	1933.57	906.97	1933.12	-4.008
197	186	-3.921			902	-4.459	1933.68	906.28	1933.21	-4.016
198	187	-4.035			901	-4.357	1933.79	905.55	1933.29	-4.105
199	188	-4.264			900	-4.369	1933.86	904.79	1933.37	-4.209
200	189	-4.430			899	-4.194	1933.93	904.03	1933.46	-4.209
201	190	-4.328			898	-4.230	1933.99	903.27	1933.54	-4.245
202	191	-4.347	1990.79	H	897	-3.971	1934.06	902.52	1933.62	-4.356
203	192	-4.184			896	-3.827	1934.12	901.76	1933.71	-4.434
204	193	-4.188			895	-3.830	1934.20	901.00	1933.79	-4.357
205	194	-4.049			894	-4.150	1934.27	899.81	1933.87	-4.336
206	195	-4.049			893	-4.011	1934.35	898.56	1933.96	-4.210
207	196	-3.897			892	-3.892	1934.42	897.29	1934.04	-4.045
208	197	-3.926			891	-4.036	1934.50	895.96	1934.12	-3.827
209	198	-3.883	1990.12	L	890	-4.245	1934.57	894.91	1934.21	-3.860
210	199	-3.842			889	-4.081	1934.64	893.75	1934.29	-4.115
211	200	-3.837			888	-4.178	1934.72	892.67	1934.37	-3.971
212	201	-4.109			887	-4.160	1934.79	891.54	1934.46	-3.958
213	202	-3.911			886	-4.127	1934.88	890.43	1934.54	-4.155
214	203	-3.976			885	-4.086	1934.96	889.24	1934.62	-4.120
215	204	-4.168			884	-4.082	1935.04	888.17	1934.71	-4.162

Appendix B.1
oxygen isotope data for coral core from Archipelago Los Roques (Roq6) and age model

					1st interpolation			2nd interpolation (monthly resolution)		
sample ID	new no.	d18O (per mil)	timemarker year.month	anchor High/Low	new no.	d18O (per mil)	timemarker year.month	new no.	timemarker year.month	d18O (per mil)
216	205	-4.375			883	-4.183	1935.12	887.00	1934.79	-4.160
217	206	-4.267	1989.79	H	882	-4.064	1935.26	886.07	1934.87	-4.129
218	207	-4.070			881	-4.043	1935.39	885.04	1934.96	-4.088
219	208	-3.966			880	-4.078	1935.53	884.00	1935.04	-4.082
220	209	-3.987	1989.12	L	879	-4.190	1935.66	882.98	1935.12	-4.180
221	210	-3.872			878	-4.513	1935.79	882.38	1935.21	-4.109
222	211	-3.606			877	-4.377	1935.86	881.77	1935.29	-4.059
223	212	-3.709			876	-4.123	1935.93	881.13	1935.37	-4.046
224	213	-3.923			875	-4.100	1935.99	880.52	1935.46	-4.060
225	214	-4.080			874	-4.016	1936.06	879.92	1935.54	-4.087
226	215	-4.399	1988.79	H	873	-3.953	1936.12	879.28	1935.62	-4.158
227	216	-4.332			872	-4.026	1936.24	878.64	1935.71	-4.306
228	217	-4.320			871	-4.034	1936.35	878.00	1935.79	-4.513
229	218	-4.179			870	-4.234	1936.46	876.81	1935.87	-4.329
230	219	-4.263			869	-4.228	1936.57	875.56	1935.96	-4.113
231	220	-4.221	1988.12	L	868	-4.234	1936.68	874.29	1936.04	-4.040
232	221	-4.085			867	-4.459	1936.79	872.97	1936.12	-3.955
233	222	-3.900			866	-4.181	1936.88	872.28	1936.21	-4.006
234	223	-4.025			865	-3.982	1936.96	871.55	1936.29	-4.030
235	224	-3.997			864	-3.727	1937.04	870.79	1936.37	-4.076
236	225	-4.009			863	-3.682	1937.12	870.03	1936.46	-4.228
237	226	-4.043			862	-3.683	1937.22	869.27	1936.54	-4.230
238	227	-3.993			861	-3.865	1937.32	868.52	1936.62	-4.231
239	228	-3.980			860	-3.988	1937.41	867.76	1936.71	-4.289
240	229	-4.148			859	-4.144	1937.51	867.00	1936.79	-4.459
241	230	-4.227	1987.79	H	858	-4.409	1937.60	866.07	1936.87	-4.202
242	231	-4.213			857	-4.408	1937.70	865.04	1936.96	-3.990
243	232	-4.259			856	-4.443	1937.79	864.00	1937.04	-3.727
244	233	-4.394			855	-4.333	1937.88	862.97	1937.12	-3.682
245	234	-4.199			854	-4.052	1937.96	862.13	1937.21	-3.683
246	235	-3.981			853	-3.748	1938.04	861.30	1937.29	-3.810
247	236	-4.012	1987.12	L	852	-3.711	1938.12	860.41	1937.37	-3.938
248	237	-3.823			851	-3.938	1938.24	859.53	1937.46	-4.061
249	238	-3.824			850	-3.953	1938.35	858.67	1937.54	-4.232
250	239	-3.692			849	-4.038	1938.46	857.77	1937.62	-4.409
251	240	-3.887			848	-4.054	1938.57	856.93	1937.71	-4.411
252	241	-4.014			847	-4.286	1938.68	856.00	1937.79	-4.443
253	242	-4.144			846	-4.122	1938.79	855.07	1937.87	-4.341
254	243	-4.084			845	-4.302	1938.86	854.04	1937.96	-4.064
255	244	-4.075			844	-4.100	1938.93	853.00	1938.04	-3.748
256	245	-4.117	1986.79	H	843	-3.745	1938.99	851.97	1938.12	-3.717
257	246	-4.351			842	-3.693	1939.06	851.28	1938.21	-3.875
258	247	-4.120			841	-3.659	1939.12	850.55	1938.29	-3.945
259	248	-3.957			840	-3.733	1939.24	849.79	1938.37	-3.971
260	249	-3.811			839	-3.771	1939.35	849.03	1938.46	-4.035
261	250	-3.814			838	-3.933	1939.46	848.27	1938.54	-4.050
262	251	-3.827			837	-3.976	1939.57	847.52	1938.62	-4.166
263	252	-3.704			836	-4.062	1939.68	846.76	1938.71	-4.246
264	253	-3.690	1986.12	L	835	-4.179	1939.79	846.00	1938.79	-4.122
265	254	-4.194			834	-4.026	1939.88	844.81	1938.87	-4.264
266	255	-4.046			833	-3.994	1939.96	843.56	1938.96	-3.942
267	256	-4.136			832	-3.915	1940.04	842.29	1939.04	-3.708
268	257	-4.208			831	-3.892	1940.12	840.97	1939.12	-3.661
269	258	-4.090	1985.79	H	830	-3.934	1940.22	840.28	1939.21	-3.712
270	259	-4.167			829	-3.939	1940.32	839.55	1939.29	-3.750
271	260	-4.377			828	-3.920	1940.41	838.79	1939.37	-3.805
272	261	-4.048			827	-3.951	1940.51	838.03	1939.46	-3.928
273	262	-4.097			826	-3.988	1940.60	837.27	1939.54	-3.964
274	263	-3.921			825	-4.228	1940.70	836.52	1939.62	-4.018
275	264	-3.939			824	-4.345	1940.79	835.76	1939.71	-4.090
276	265	-3.815	1985.12	L	823	-4.248	1940.86	835.00	1939.79	-4.179
277	266	-3.852			822	-4.223	1940.93	834.07	1939.87	-4.037
278	267	-3.931			821	-4.083	1940.99	833.04	1939.96	-3.995
279	268	-4.175			820	-4.197	1941.06	832.00	1940.04	-3.915
280	269	-4.159	1984.79	H	819	-3.912	1941.12	830.97	1940.12	-3.893
281	270	-4.107			818	-4.117	1941.24	830.13	1940.21	-3.928
282	271	-4.106			817	-4.092	1941.35	829.30	1940.29	-3.938
283	272	-4.085			816	-4.195	1941.46	828.41	1940.37	-3.928
284	273	-4.024			815	-4.139	1941.57	827.53	1940.46	-3.934

Appendix B.1
oxygen isotope data for coral core from Archipelago Los Roques (Roq6) and age model

sample ID	new no.	d18O (per mil)	timemarker year.month	anchor High/Low	1st interpolation new no.	d18O (per mil)	timemarker year.month	2nd interpolation (monthly resolution) new no.	timemarker year.month	d18O (per mil)
285	274	-3.965			814	-4.340	1941.68	826.67	1940.54	-3.963
286	275	-3.897			813	-4.322	1941.79	825.77	1940.62	-4.044
287	276	-3.906			812	-4.204	1941.86	824.93	1940.71	-4.237
288	277	-3.887			811	-4.261	1941.93	824.00	1940.79	-4.345
289	278	-3.978	1984.12	L	810	-4.409	1941.99	822.81	1940.87	-4.243
290	279	-3.792			809	-4.060	1942.06	821.56	1940.96	-4.161
291	280	-3.994			808	-3.953	1942.12	820.29	1941.04	-4.164
292	281	-4.061			807	-4.003	1942.29	818.97	1941.12	-3.918
293	282	-4.159			806	-3.958	1942.46	818.28	1941.21	-4.060
294	283	-4.126			805	-4.126	1942.63	817.55	1941.29	-4.106
295	284	-4.063			804	-4.234	1942.79	816.79	1941.37	-4.114
296	285	-4.208	1983.79	H	803	-4.350	1942.84	816.03	1941.46	-4.192
297	286	-4.244			802	-4.311	1942.89	815.27	1941.54	-4.154
298	287	-4.299			801	-4.440	1942.93	814.52	1941.62	-4.236
299	288	-4.290			800	-4.327	1942.98	813.76	1941.71	-4.336
300	289	-4.152			799	-4.445	1943.03	813.00	1941.79	-4.322
301	290	-4.163			798	-4.186	1943.08	811.81	1941.87	-4.215
302	291	-4.117			797	-4.019	1943.12	810.56	1941.96	-4.327
303	292	-3.900			796	-3.869	1943.21	809.29	1942.04	-4.160
304	293	-3.870			795	-3.983	1943.29	807.98	1942.12	-3.954
305	294	-3.906			794	-4.000	1943.38	807.49	1942.21	-3.978
306	295	-3.894	1983.12	L	793	-4.143	1943.46	807.00	1942.29	-4.003
307	296	-3.986			792	-4.120	1943.54	806.51	1942.37	-3.981
308	297	-4.007			791	-4.342	1943.63	806.02	1942.46	-3.959
309	298	-4.007			790	-4.289	1943.71	805.53	1942.54	-4.037
310	299	-4.052			789	-4.334	1943.79	805.04	1942.62	-4.119
311	300	-4.172	1982.79	H	788	-4.311	1943.88	804.52	1942.71	-4.178
312	301	-4.219			787	-4.121	1943.96	804.00	1942.79	-4.234
313	302	-4.087			786	-4.000	1944.04	802.33	1942.87	-4.324
314	303	-4.095			785	-3.953	1944.12	800.47	1942.96	-4.380
315	304	-4.037			784	-3.980	1944.22	798.80	1943.04	-4.393
316	305	-3.963			783	-3.927	1944.32	796.96	1943.12	-4.013
317	306	-3.901			782	-4.050	1944.41	796.04	1943.21	-3.875
318	307	-3.781	1982.12	L	781	-4.203	1944.51	795.00	1943.29	-3.983
319	308	-3.834			780	-4.196	1944.60	794.07	1943.37	-3.999
320	309	-3.949			779	-4.257	1944.70	793.04	1943.46	-4.137
321	310	-4.234			778	-4.167	1944.79	792.00	1943.54	-4.120
322	311	-4.291			777	-4.252	1944.88	791.07	1943.62	-4.326
323	312	-4.325			776	-4.120	1944.96	790.04	1943.71	-4.291
324	313	-4.217			775	-4.080	1945.04	789.00	1943.79	-4.334
325	314	-4.279	1981.79	H	774	-4.042	1945.12	788.07	1943.87	-4.313
326	315	-4.317			773	-4.046	1945.26	787.04	1943.96	-4.129
327	316	-4.363			772	-4.235	1945.39	786.00	1944.04	-4.000
328	317	-4.408			771	-4.319	1945.53	784.97	1944.12	-3.954
329	318	-4.353			770	-4.425	1945.66	784.13	1944.21	-3.976
330	319	-4.103			769	-4.425	1945.79	783.30	1944.29	-3.943
331	320	-4.192			768	-4.404	1945.85	782.41	1944.37	-4.000
332	321	-4.151			767	-4.180	1945.90	781.53	1944.46	-4.121
333	322	-4.102			766	-4.107	1945.96	780.67	1944.54	-4.201
334	323	-4.162			765	-3.959	1946.01	779.77	1944.62	-4.210
335	324	-4.021	1981.12	L	764	-3.872	1946.07	778.93	1944.71	-4.250
336	325	-3.983			763	-3.849	1946.12	778.00	1944.79	-4.167
337	326	-4.037			762	-3.999	1946.26	777.07	1944.87	-4.246
338	327	-4.024			761	-4.085	1946.39	776.04	1944.96	-4.126
339	328	-3.960			760	-4.300	1946.53	775.00	1945.04	-4.080
340	329	-4.028			759	-4.336	1946.66	773.98	1945.12	-4.042
341	330	-4.007			758	-4.382	1946.79	773.38	1945.21	-4.044
342	331	-4.055			757	-4.289	1946.88	772.77	1945.29	-4.090
343	332	-4.090			756	-4.341	1946.96	772.13	1945.37	-4.211
344	333	-4.203			755	-3.961	1947.04	771.52	1945.46	-4.275
345	334	-4.245			754	-3.824	1947.12	770.92	1945.54	-4.327
346	335	-4.107			753	-3.855	1947.29	770.28	1945.62	-4.395
347	336	-4.267	1980.79	H	752	-3.940	1947.46	769.64	1945.71	-4.425
348	337	-4.166			751	-4.260	1947.63	769.00	1945.79	-4.425
349	338	-4.182			750	-4.292	1947.79	767.53	1945.87	-4.299
350	339	-4.051			749	-4.352	1947.86	766.06	1945.96	-4.111
351	340	-4.053			748	-4.222	1947.93	764.50	1946.04	-3.916
352	341	-3.980			747	-4.060	1947.99	762.98	1946.12	-3.853
353	342	-3.951			746	-4.072	1948.06	762.38	1946.21	-3.942

Appendix B.1
oxygen isotope data for coral core from Archipelago Los Roques (Roq6) and age model

sample ID	new no.	d18O (per mil)	timemarker year.month	anchor High/Low	1st interpolation new no.	d18O (per mil)	timemarker year.month	2nd interpolation (monthly resolution) new no.	timemarker year.month	d18O (per mil)
354	343	-3.934			745	-3.957	1948.12	761.77	1946.29	-4.019
355	344	-3.901	1980.12	L	744	-4.110	1948.24	761.13	1946.37	-4.074
356	345	-3.850			743	-4.169	1948.35	760.52	1946.46	-4.187
357	346	-3.947			742	-4.182	1948.46	759.92	1946.54	-4.303
358	347	-4.089			741	-4.355	1948.57	759.28	1946.62	-4.326
359	348	-4.177			740	-4.433	1948.68	758.64	1946.71	-4.353
360	349	-4.329			739	-4.303	1948.79	758.00	1946.79	-4.382
361	350	-4.505	1979.79	H	738	-4.265	1948.85	757.07	1946.87	-4.296
362	351	-4.288			737	-4.047	1948.90	756.04	1946.96	-4.339
363	352	-4.416			736	-3.882	1948.96	755.00	1947.04	-3.961
364	353	-4.215			735	-3.604	1949.01	753.98	1947.12	-3.825
365	354	-4.180			734	-3.766	1949.07	753.49	1947.21	-3.840
366	355	-4.088			733	-3.691	1949.12	753.00	1947.29	-3.855
367	356	-4.132			732	-3.745	1949.26	752.51	1947.37	-3.897
368	357	-4.161			731	-4.038	1949.39	752.02	1947.46	-3.938
369	358	-3.968			730	-3.963	1949.53	751.53	1947.54	-4.091
370	359	-3.992	1979.12	L	729	-3.994	1949.66	751.04	1947.62	-4.247
371	360	-3.854			728	-4.294	1949.79	750.52	1947.71	-4.275
372	361	-4.154			727	-4.161	1949.86	750.00	1947.79	-4.292
373	362	-4.144			726	-4.005	1949.93	748.81	1947.87	-4.327
374	363	-4.262			725	-4.003	1949.99	747.56	1947.96	-4.150
375	364	-4.270			724	-3.883	1950.06	746.29	1948.04	-4.069
376	365	-4.217			723	-4.009	1950.12	744.97	1948.12	-3.961
377	366	-4.135			722	-3.988	1950.26	744.28	1948.21	-4.068
378	367	-4.041	1978.79	H	721	-4.262	1950.39	743.55	1948.29	-4.137
379	368	-3.975			720	-4.399	1950.53	742.79	1948.37	-4.172
380	369	-3.919			719	-4.466	1950.66	742.03	1948.46	-4.182
381	370	-3.957			718	-4.398	1950.79	741.27	1948.54	-4.308
382	371	-3.886			717	-4.201	1950.90	740.52	1948.62	-4.393
383	372	-3.868			716	-4.077	1951.01	739.76	1948.71	-4.401
384	373	-3.947			715	-3.821	1951.12	739.00	1948.79	-4.303
385	374	-3.857			714	-4.039	1951.24	737.53	1948.87	-4.163
386	375	-3.897			713	-4.017	1951.35	736.06	1948.96	-3.891
387	376	-3.700	1978.12	L	712	-4.153	1951.46	734.50	1949.04	-3.685
388	377	-3.739			711	-4.120	1951.57	732.98	1949.12	-3.692
389	378	-3.818			710	-4.114	1951.68	732.38	1949.21	-3.724
390	379	-3.917			709	-4.197	1951.79	731.77	1949.29	-3.813
391	380	-3.913			708	-4.302	1951.86	731.13	1949.37	-4.000
392	381	-4.101			707	-4.114	1951.93	730.52	1949.46	-4.002
393	382	-4.113	1977.79	H	706	-3.936	1951.99	729.92	1949.54	-3.965
394	383	-4.148			705	-3.758	1952.06	729.28	1949.62	-3.985
395	384	-4.252			704	-3.839	1952.12	728.64	1949.71	-4.102
396	385	-4.110			703	-4.112	1952.26	728.00	1949.79	-4.294
397	386	-3.977			702	-4.008	1952.39	726.81	1949.87	-4.131
398	387	-3.988			701	-4.148	1952.53	725.56	1949.96	-4.004
399	388	-3.797			700	-4.350	1952.66	724.29	1950.04	-3.917
400	389	-3.759			699	-4.345	1952.79	722.98	1950.12	-4.009
401	390	-3.785			698	-4.160	1952.88	722.38	1950.21	-3.996
402	391	-3.795	1977.12	L	697	-4.096	1952.96	721.77	1950.29	-4.051
403	392	-3.672			696	-3.834	1953.04	721.13	1950.37	-4.227
404	393	-3.717			695	-3.811	1953.12	720.52	1950.46	-4.327
405	394	-3.947			694	-4.011	1953.24	719.92	1950.54	-4.404
406	395	-4.192			693	-3.991	1953.35	719.28	1950.62	-4.447
407	396	-4.260	1976.79	H	692	-4.171	1953.46	718.64	1950.71	-4.442
408	397	-4.256			691	-4.201	1953.57	718.00	1950.79	-4.398
409	398	-4.090			690	-4.218	1953.68	717.24	1950.87	-4.249
410	399	-4.108			689	-4.144	1953.79	716.49	1950.96	-4.137
411	400	-4.167			688	-4.138	1953.86	715.73	1951.04	-4.007
412	401	-3.935			687	-4.011	1953.93	714.97	1951.12	-3.827
413	402	-4.105			686	-3.997	1953.99	714.28	1951.21	-3.978
414	403	-3.800			685	-4.125	1954.06	713.55	1951.29	-4.029
415	404	-3.796	1976.12	L	684	-4.133	1954.12	712.79	1951.37	-4.046
416	405	-3.791			683	-3.965	1954.24	712.03	1951.46	-4.149
417	406	-3.664			682	-4.125	1954.35	711.27	1951.54	-4.129
418	407	-3.749			681	-4.245	1954.46	710.52	1951.62	-4.117
419	408	-3.643			680	-4.267	1954.57	709.76	1951.71	-4.134
420	409	-3.825			679	-4.375	1954.68	709.00	1951.79	-4.197
421	410	-3.923			678	-4.353	1954.79	707.81	1951.87	-4.266
422	411	-4.195			677	-4.272	1954.86	706.56	1951.96	-4.035

Appendix B.1
oxygen isotope data for coral core from Archipelago Los Roques (Roq6) and age model

					1st interpolation			2nd interpolation (monthly resolution)		
sample ID	new no.	d18O (per mil)	timemarker year.month	anchor High/Low	new no.	d18O (per mil)	timemarker year.month	new no.	timemarker year.month	d18O (per mil)
423	412	-4.401	1975.79	H	676	-4.152	1954.93	705.29	1952.04	-3.809
424	413	-4.187			675	-4.118	1954.99	703.98	1952.12	-3.846
425	414	-4.144			674	-4.036	1955.06	703.38	1952.21	-4.008
426	415	-4.104			673	-4.068	1955.12	702.77	1952.29	-4.088
427	416	-3.895			672	-4.229	1955.26	702.13	1952.37	-4.021
428	417	-3.822			671	-4.260	1955.39	701.52	1952.46	-4.075
429	418	-3.807			670	-4.464	1955.53	700.92	1952.54	-4.164
430	419	-3.951			669	-4.681	1955.66	700.28	1952.62	-4.293
431	420	-3.632	1975.12	L	668	-4.478	1955.79	699.64	1952.71	-4.348
432	421	-3.728			667	-4.587	1955.86	699.00	1952.79	-4.345
433	422	-3.607			666	-4.350	1955.93	698.07	1952.87	-4.174
434	423	-3.858			665	-4.148	1955.99	697.04	1952.96	-4.099
435	424	-4.202			664	-3.898	1956.06	696.00	1953.04	-3.834
436	425	-3.899			663	-3.904	1956.12	694.97	1953.12	-3.817
437	426	-3.995			662	-3.985	1956.24	694.28	1953.21	-3.955
438	427	-4.059			661	-4.077	1956.35	693.55	1953.29	-4.002
439	428	-4.033			660	-4.046	1956.46	692.79	1953.37	-4.029
440	429	-4.136	1974.79	H	659	-3.880	1956.57	692.03	1953.46	-4.166
441	430	-3.941			658	-4.303	1956.68	691.27	1953.54	-4.193
442	431	-3.938			657	-4.227	1956.79	690.52	1953.62	-4.209
443	432	-4.034			656	-4.300	1956.85	689.76	1953.71	-4.200
444	433	-3.861			655	-4.373	1956.90	689.00	1953.79	-4.144
445	434	-3.636			654	-4.200	1956.96	687.81	1953.87	-4.114
446	435	-3.701			653	-4.018	1957.01	686.56	1953.96	-4.005
447	436	-3.651	1974.12	L	652	-3.792	1957.07	685.29	1954.04	-4.088
448	437	-3.636			651	-3.693	1957.12	683.97	1954.12	-4.128
449	438	-3.897			650	-3.644	1957.22	683.28	1954.21	-4.012
450	439	-3.620			649	-3.763	1957.32	682.55	1954.29	-4.038
451	440	-3.799			648	-3.745	1957.41	681.79	1954.37	-4.150
452	441	-3.882			647	-3.995	1957.51	681.03	1954.46	-4.241
453	442	-3.922			646	-3.939	1957.60	680.27	1954.54	-4.261
454	443	-3.998			645	-4.108	1957.70	679.52	1954.62	-4.319
455	444	-4.143			644	-4.105	1957.79	678.76	1954.71	-4.370
456	445	-4.079	1973.79	H	643	-4.176	1957.88	678.00	1954.79	-4.353
457	446	-4.082			642	-4.038	1957.96	676.81	1954.87	-4.249
458	447	-4.109			641	-3.900	1958.04	675.56	1954.96	-4.137
459	448	-3.934			640	-3.907	1958.12	674.29	1955.04	-4.059
460	449	-3.846			639	-3.958	1958.26	672.98	1955.12	-4.072
466	450	-3.869			638	-4.165	1958.39	672.38	1955.21	-4.168
467	451	-3.879			637	-4.111	1958.53	671.77	1955.29	-4.236
468	452	-3.720	1973.12	L	636	-4.320	1958.66	671.13	1955.37	-4.256
469	453	-3.747			635	-4.269	1958.79	670.52	1955.46	-4.357
470	454	-3.811			634	-4.215	1958.85	669.92	1955.54	-4.481
471	455	-3.969			633	-4.143	1958.90	669.28	1955.62	-4.620
472	456	-4.166			632	-4.025	1958.96	668.64	1955.71	-4.608
473	457	-4.247			631	-3.962	1959.01	668.00	1955.79	-4.478
474	458	-4.307	1972.79	H	630	-3.871	1959.07	666.81	1955.87	-4.542
475	459	-4.393			629	-3.757	1959.12	665.56	1955.96	-4.260
476	460	-4.269			628	-3.869	1959.22	664.29	1956.04	-3.969
477	461	-4.192			627	-3.971	1959.32	662.97	1956.12	-3.906
478	462	-4.039			626	-3.980	1959.41	662.28	1956.21	-3.963
479	463	-4.010			625	-4.149	1959.51	661.55	1956.29	-4.027
480	464	-3.951			624	-4.174	1959.60	660.79	1956.37	-4.070
481	465	-3.856			623	-4.241	1959.70	660.03	1956.46	-4.047
482	466	-3.860	1972.12	L	622	-4.202	1959.79	659.27	1956.54	-3.925
483	467	-3.708			621	-4.105	1959.85	658.52	1956.62	-4.085
484	468	-3.755			620	-4.039	1959.90	657.76	1956.71	-4.285
485	469	-3.861			619	-4.128	1959.96	657.00	1956.79	-4.227
486	470	-4.095			618	-4.059	1960.01	655.53	1956.87	-4.334
487	471	-4.086	1971.79	H	617	-4.011	1960.07	654.06	1956.96	-4.210
488	472	-4.051			616	-4.090	1960.12	652.50	1957.04	-3.905
489	473	-4.083			615	-4.045	1960.24	650.97	1957.12	-3.691
490	474	-3.949			614	-4.063	1960.35	650.13	1957.21	-3.651
491	475	-3.892			613	-4.059	1960.46	649.30	1957.29	-3.727
492	476	-3.909			612	-4.388	1960.57	648.41	1957.37	-3.752
493	477	-3.920			611	-4.099	1960.68	647.53	1957.46	-3.862
494	478	-3.855	1971.12	L	610	-4.098	1960.79	646.67	1957.54	-3.976
495	479	-3.958			609	-4.187	1960.86	645.77	1957.62	-3.978
496	480	-3.953			608	-4.055	1960.93	644.93	1957.71	-4.108

Appendix B.1
oxygen isotope data for coral core from Archipelago Los Roques (Roq6) and age model

					1st interpolation			2nd interpolation (monthly resolution)		
sample ID	new no.	d18O	timemarker	anchor	new no.	d18O	timemarker	new no.	timemarker	d18O
		(per mil)	year.month	High/Low		(per mil)	year.month		year.month	(per mil)
497	481	-3.965			607	-3.901	1960.99	644.00	1957.79	-4.105
498	482	-4.179			606	-3.904	1961.06	643.07	1957.87	-4.171
499	483	-4.186			605	-3.719	1961.12	642.04	1957.96	-4.044
500	484	-4.318			604	-3.899	1961.24	641.00	1958.04	-3.900
501	485	-4.210	1970.79	H	603	-3.974	1961.35	639.98	1958.12	-3.908
502	486	-4.248			602	-3.934	1961.46	639.38	1958.21	-3.939
503	487	-4.216			601	-4.122	1961.57	638.77	1958.29	-4.006
504	488	-4.090			600	-4.290	1961.68	638.13	1958.37	-4.138
505	489	-3.943			599	-4.198	1961.79	637.52	1958.46	-4.139
506	490	-4.015	1970.12	L	598	-4.193	1961.85	636.92	1958.54	-4.127
507	491	-3.776			597	-4.145	1961.90	636.28	1958.62	-4.261
508	492	-3.927			596	-3.947	1961.96	635.64	1958.71	-4.302
509	493	-3.960			595	-4.013	1962.01	635.00	1958.79	-4.269
510	494	-4.171			594	-3.898	1962.07	633.53	1958.87	-4.181
511	495	-4.278			593	-3.740	1962.12	632.06	1958.96	-4.032
512	496	-4.488			592	-3.833	1962.22	630.50	1959.04	-3.917
513	497	-4.242			591	-3.925	1962.32	628.97	1959.12	-3.761
514	498	-4.266	1969.79	H	590	-4.108	1962.41	628.13	1959.21	-3.854
515	499	-4.227			589	-4.251	1962.51	627.30	1959.29	-3.940
516	500	-4.204			588	-4.240	1962.60	626.41	1959.37	-3.976
517	501	-4.178			587	-4.394	1962.70	625.53	1959.46	-4.059
518	502	-4.225			586	-4.288	1962.79	624.67	1959.54	-4.157
519	503	-4.096			585	-4.168	1962.85	623.77	1959.62	-4.190
520	504	-3.975			584	-4.083	1962.90	622.93	1959.71	-4.238
521	505	-3.977			583	-4.107	1962.96	622.00	1959.79	-4.202
522	506	-4.106	1969.12	L	582	-4.138	1963.01	620.53	1959.87	-4.074
523	507	-4.149			581	-3.911	1963.07	619.06	1959.96	-4.123
524	508	-4.206			580	-3.877	1963.12	617.50	1960.04	-4.035
525	509	-4.278			579	-4.021	1963.22	615.97	1960.12	-4.089
526	510	-4.235	1968.79	H	578	-4.046	1963.32	615.28	1960.21	-4.058
527	511	-4.230			577	-4.117	1963.41	614.55	1960.29	-4.053
528	512	-4.220			576	-4.278	1963.51	613.79	1960.37	-4.062
529	513	-4.210			575	-4.245	1963.60	613.03	1960.46	-4.059
530	514	-4.004			574	-4.220	1963.70	612.27	1960.54	-4.298
531	515	-4.060			573	-4.265	1963.79	611.52	1960.62	-4.248
532	516	-3.865	1968.12	L	572	-4.005	1963.88	610.76	1960.71	-4.099
533	517	-3.869			571	-3.956	1963.96	610.00	1960.79	-4.098
534	518	-3.955			570	-3.841	1964.04	608.81	1960.87	-4.162
535	519	-4.011			569	-3.903	1964.12	607.56	1960.96	-3.987
536	520	-4.150			568	-4.088	1964.26	606.29	1961.04	-3.903
537	521	-4.250	1967.79	H	567	-4.124	1964.39	604.97	1961.12	-3.724
538	522	-4.198			566	-4.394	1964.53	604.28	1961.21	-3.849
539	523	-4.063			565	-4.432	1964.66	603.55	1961.29	-3.933
540	524	-4.051			564	-4.428	1964.79	602.79	1961.37	-3.966
541	525	-4.044			563	-4.143	1964.86	602.03	1961.46	-3.935
542	526	-4.032			562	-4.205	1964.93	601.27	1961.54	-4.071
543	527	-3.851			561	-3.915	1964.99	600.52	1961.62	-4.203
544	528	-3.854			560	-3.823	1965.06	599.76	1961.71	-4.268
545	529	-3.922			559	-3.662	1965.12	599.00	1961.79	-4.198
546	530	-4.058			558	-3.834	1965.22	597.53	1961.87	-4.171
547	531	-3.772	1967.12	L	557	-4.015	1965.32	596.06	1961.96	-3.958
548	532	-3.875			556	-4.258	1965.41	594.50	1962.04	-3.956
549	533	-3.935			555	-4.174	1965.51	592.97	1962.12	-3.743
550	534	-4.020			554	-4.261	1965.60	592.13	1962.21	-3.820
551	535	-4.253			553	-4.253	1965.70	591.30	1962.29	-3.897
552	536	-4.430			552	-4.377	1965.79	590.41	1962.37	-4.033
553	537	-4.426			551	-4.136	1965.85	589.53	1962.46	-4.175
554	538	-4.368			550	-4.120	1965.90	588.67	1962.54	-4.247
555	539	-4.213	1966.79	H	549	-4.008	1965.96	587.77	1962.62	-4.276
556	540	-4.312			548	-4.042	1966.01	586.93	1962.71	-4.386
557	541	-4.278			547	-3.830	1966.07	586.00	1962.79	-4.288
558	542	-4.091			546	-3.799	1966.12	584.53	1962.87	-4.128
559	543	-4.154			545	-3.858	1966.22	583.06	1962.96	-4.106
560	544	-4.043			544	-4.043	1966.32	581.50	1963.04	-4.025
561	545	-3.858			543	-4.154	1966.41	579.97	1963.12	-3.882
562	546	-3.799	1966.12	L	542	-4.091	1966.51	579.13	1963.21	-4.002
563	547	-3.830			541	-4.278	1966.60	578.30	1963.29	-4.039
564	548	-4.042			540	-4.312	1966.70	577.41	1963.37	-4.088
565	549	-4.008			539	-4.213	1966.79	576.53	1963.46	-4.192

Appendix B.1
oxygen isotope data for coral core from Archipelago Los Roques (Roq6) and age model

					1st interpolation			2nd interpolation (monthly resolution)		
sample ID	new no.	d18O (per mil)	timemarker year.month	anchor High/Low	new no.	d18O (per mil)	timemarker year.month	new no.	timemarker year.month	d18O (per mil)
566	550	-4.120			538	-4.368	1966.83	575.67	1963.54	-4.267
567	551	-4.136			537	-4.426	1966.88	574.77	1963.62	-4.239
568	552	-4.377	1965.79	H	536	-4.430	1966.92	573.93	1963.71	-4.223
569	553	-4.253			535	-4.253	1966.96	573.00	1963.79	-4.265
570	554	-4.261			534	-4.020	1967.00	572.07	1963.87	-4.024
571	555	-4.174			533	-3.935	1967.04	571.04	1963.96	-3.958
572	556	-4.258			532	-3.875	1967.08	570.00	1964.04	-3.841
573	557	-4.015			531	-3.772	1967.12	568.98	1964.12	-3.907
574	558	-3.834			530	-4.058	1967.19	568.38	1964.21	-4.018
575	559	-3.662	1965.12	L	529	-3.922	1967.26	567.77	1964.29	-4.096
576	560	-3.823			528	-3.854	1967.33	567.13	1964.37	-4.119
577	561	-3.915			527	-3.851	1967.39	566.52	1964.46	-4.253
578	562	-4.205			526	-4.032	1967.46	565.92	1964.54	-4.397
579	563	-4.143			525	-4.044	1967.53	565.28	1964.62	-4.421
580	564	-4.428	1964.79	H	524	-4.051	1967.59	564.64	1964.71	-4.431
581	565	-4.432			523	-4.063	1967.66	564.00	1964.79	-4.428
582	566	-4.394			522	-4.198	1967.73	562.81	1964.87	-4.155
583	567	-4.124			521	-4.250	1967.79	561.56	1964.96	-4.076
584	568	-4.088			520	-4.150	1967.86	560.29	1965.04	-3.849
585	569	-3.903	1964.12	L	519	-4.011	1967.93	558.97	1965.12	-3.668
586	570	-3.841			518	-3.955	1967.99	558.13	1965.21	-3.811
587	571	-3.956			517	-3.869	1968.06	557.30	1965.29	-3.961
588	572	-4.005			516	-3.865	1968.12	556.41	1965.37	-4.159
589	573	-4.265	1963.79	H	515	-4.060	1968.24	555.53	1965.46	-4.219
590	574	-4.220			514	-4.004	1968.35	554.67	1965.54	-4.203
591	575	-4.245			513	-4.210	1968.46	553.77	1965.62	-4.259
592	576	-4.278			512	-4.220	1968.57	552.93	1965.71	-4.262
593	577	-4.117			511	-4.230	1968.68	552.00	1965.79	-4.377
594	578	-4.046			510	-4.235	1968.79	550.53	1965.87	-4.129
595	579	-4.021			509	-4.278	1968.88	549.06	1965.96	-4.014
596	580	-3.877	1963.12	L	508	-4.206	1968.96	547.50	1966.04	-3.936
597	581	-3.911			507	-4.149	1969.04	545.97	1966.12	-3.801
598	582	-4.138			506	-4.106	1969.12	545.13	1966.21	-3.850
599	583	-4.107			505	-3.977	1969.21	544.30	1966.29	-3.988
600	584	-4.083			504	-3.975	1969.29	543.41	1966.37	-4.109
601	585	-4.168			503	-4.096	1969.38	542.53	1966.46	-4.125
602	586	-4.288	1962.79	H	502	-4.225	1969.46	541.67	1966.54	-4.153
603	587	-4.394			501	-4.178	1969.54	540.77	1966.62	-4.286
604	588	-4.240			500	-4.204	1969.63	539.93	1966.71	-4.305
605	589	-4.251			499	-4.227	1969.71	539.00	1966.79	-4.213
606	590	-4.108			498	-4.266	1969.79	537.13	1966.87	-4.418
607	591	-3.925			497	-4.242	1969.83	535.08	1966.96	-4.268
608	592	-3.833			496	-4.488	1969.88	533.00	1967.04	-3.935
609	593	-3.740	1962.12	L	495	-4.278	1969.92	530.95	1967.12	-3.786
610	594	-3.898			494	-4.171	1969.96	529.76	1967.21	-4.026
611	595	-4.013			493	-3.960	1970.00	528.57	1967.29	-3.893
612	596	-3.947			492	-3.927	1970.04	527.28	1967.37	-3.852
613	597	-4.145			491	-3.776	1970.08	526.05	1967.46	-4.023
614	598	-4.193			490	-4.015	1970.12	524.83	1967.54	-4.045
615	599	-4.198	1961.79	H	489	-3.943	1970.26	523.52	1967.62	-4.057
616	600	-4.290			488	-4.090	1970.39	522.33	1967.71	-4.153
617	601	-4.122			487	-4.216	1970.53	521.00	1967.79	-4.250
618	602	-3.934			486	-4.248	1970.66	519.81	1967.87	-4.124
619	603	-3.974			485	-4.210	1970.79	518.56	1967.96	-3.986
620	604	-3.899			484	-4.318	1970.84	517.29	1968.04	-3.894
621	605	-3.719	1961.12	L	483	-4.186	1970.89	515.97	1968.12	-3.870
622	606	-3.904			482	-4.179	1970.93	515.28	1968.21	-4.006
623	607	-3.901			481	-3.965	1970.98	514.55	1968.29	-4.035
624	608	-4.055			480	-3.953	1971.03	513.79	1968.37	-4.048
625	609	-4.187			479	-3.958	1971.08	513.03	1968.46	-4.204
626	610	-4.098	1960.79	H	478	-3.855	1971.12	512.27	1968.54	-4.217
627	611	-4.099			477	-3.920	1971.22	511.52	1968.62	-4.225
628	612	-4.388			476	-3.909	1971.32	510.76	1968.71	-4.231
629	613	-4.059			475	-3.892	1971.41	510.00	1968.79	-4.235
630	614	-4.063			474	-3.949	1971.51	509.07	1968.87	-4.275
631	615	-4.045			473	-4.083	1971.60	508.04	1968.96	-4.209
632	616	-4.090	1960.12	L	472	-4.051	1971.70	507.00	1969.04	-4.149
633	617	-4.011			471	-4.086	1971.79	505.96	1969.12	-4.101
634	618	-4.059			470	-4.095	1971.86	505.04	1969.21	-3.982

Appendix B.1
oxygen isotope data for coral core from Archipelago Los Roques (Roq6) and age model

					1st interpolation			2nd interpolation (monthly resolution)		
sample ID	new no.	d18O (per mil)	timemarker year.month	anchor High/Low	new no.	d18O (per mil)	timemarker year.month	new no.	timemarker year.month	d18O (per mil)
635	619	-4.128			469	-3.861	1971.93	504.00	1969.29	-3.975
636	620	-4.039			468	-3.755	1971.99	503.07	1969.37	-4.087
637	621	-4.105			467	-3.708	1972.06	502.04	1969.46	-4.220
638	622	-4.202	1959.79	H	466	-3.860	1972.12	501.00	1969.54	-4.178
639	623	-4.241			465	-3.856	1972.21	500.07	1969.62	-4.202
640	624	-4.174			464	-3.951	1972.29	499.04	1969.71	-4.226
641	625	-4.149			463	-4.010	1972.38	498.00	1969.79	-4.266
642	626	-3.980			462	-4.039	1972.46	496.13	1969.87	-4.455
643	627	-3.971			461	-4.192	1972.54	494.08	1969.96	-4.180
644	628	-3.869			460	-4.269	1972.63	492.00	1970.04	-3.927
645	629	-3.757	1959.12	L	459	-4.393	1972.71	489.98	1970.12	-4.013
646	630	-3.871			458	-4.307	1972.79	489.38	1970.21	-3.970
647	631	-3.962			457	-4.247	1972.85	488.77	1970.29	-3.977
648	632	-4.025			456	-4.166	1972.90	488.13	1970.37	-4.071
649	633	-4.143			455	-3.969	1972.96	487.52	1970.46	-4.150
650	634	-4.215			454	-3.811	1973.01	486.92	1970.54	-4.218
651	635	-4.269	1958.79	H	453	-3.747	1973.07	486.28	1970.62	-4.239
652	636	-4.320			452	-3.720	1973.12	485.64	1970.71	-4.234
653	637	-4.111			451	-3.879	1973.22	485.00	1970.79	-4.210
654	638	-4.165			450	-3.869	1973.32	483.33	1970.87	-4.230
655	639	-3.958			449	-3.846	1973.41	481.47	1970.96	-4.065
656	640	-3.907	1958.12	L	448	-3.934	1973.51	479.80	1971.04	-3.954
657	641	-3.900			447	-4.109	1973.60	477.97	1971.12	-3.857
658	642	-4.038			446	-4.082	1973.70	477.13	1971.21	-3.911
659	643	-4.176			445	-4.079	1973.79	476.30	1971.29	-3.912
660	644	-4.105	1957.79	H	444	-4.143	1973.83	475.41	1971.37	-3.899
661	645	-4.108			443	-3.998	1973.87	474.53	1971.46	-3.919
662	646	-3.939			442	-3.922	1973.90	473.67	1971.54	-3.994
663	647	-3.995			441	-3.882	1973.94	472.77	1971.62	-4.076
664	648	-3.745			440	-3.799	1973.98	471.93	1971.71	-4.054
665	649	-3.763			439	-3.620	1974.01	471.00	1971.79	-4.086
666	650	-3.644			438	-3.897	1974.05	469.81	1971.87	-4.050
667	651	-3.693	1957.12	L	437	-3.636	1974.09	468.56	1971.96	-3.814
668	652	-3.792			436	-3.651	1974.12	467.29	1972.04	-3.721
669	653	-4.018			435	-3.701	1974.22	465.96	1972.12	-3.860
670	654	-4.200			434	-3.636	1974.32	465.04	1972.21	-3.856
671	655	-4.373			433	-3.861	1974.41	464.00	1972.29	-3.951
672	656	-4.300			432	-4.034	1974.51	463.07	1972.37	-4.006
673	657	-4.227	1956.79	H	431	-3.938	1974.60	462.04	1972.46	-4.038
674	658	-4.303			430	-3.941	1974.70	461.00	1972.54	-4.192
675	659	-3.880			429	-4.136	1974.79	460.07	1972.62	-4.263
681	660	-4.046			428	-4.033	1974.83	459.04	1972.71	-4.388
682	661	-4.077			427	-4.059	1974.87	458.00	1972.79	-4.307
683	662	-3.985			426	-3.995	1974.90	456.53	1972.87	-4.209
684	663	-3.904	1956.12	L	425	-3.899	1974.94	455.06	1972.96	-3.980
685	664	-3.898			424	-4.202	1974.98	453.50	1973.04	-3.779
686	665	-4.148			423	-3.858	1975.01	451.97	1973.12	-3.725
687	666	-4.350			422	-3.607	1975.05	451.13	1973.21	-3.858
688	667	-4.587			421	-3.728	1975.09	450.30	1973.29	-3.872
689	668	-4.478	1955.79	H	420	-3.632	1975.12	449.41	1973.37	-3.855
690	669	-4.681			419	-3.951	1975.21	448.53	1973.46	-3.887
691	670	-4.464			418	-3.807	1975.29	447.67	1973.54	-3.992
692	671	-4.260			417	-3.822	1975.38	446.77	1973.62	-4.103
693	672	-4.229			416	-3.895	1975.46	445.93	1973.71	-4.082
694	673	-4.068	1955.12	L	415	-4.104	1975.54	445.00	1973.79	-4.079
695	674	-4.036			414	-4.144	1975.63	442.89	1973.87	-3.990
696	675	-4.118			413	-4.187	1975.71	440.58	1973.96	-3.847
697	676	-4.152			412	-4.401	1975.79	438.25	1974.04	-3.828
698	677	-4.272			411	-4.195	1975.83	435.97	1974.12	-3.653
699	678	-4.353	1954.79	H	410	-3.923	1975.88	435.13	1974.21	-3.694
700	679	-4.375			409	-3.825	1975.92	434.30	1974.29	-3.656
701	680	-4.267			408	-3.643	1975.96	433.41	1974.37	-3.769
702	681	-4.245			407	-3.749	1976.00	432.53	1974.46	-3.942
703	682	-4.125			406	-3.664	1976.04	431.67	1974.54	-4.002
704	683	-3.965			405	-3.791	1976.08	430.77	1974.62	-3.939
705	684	-4.133	1954.12	L	404	-3.796	1976.12	429.93	1974.71	-3.955
706	685	-4.125			403	-3.800	1976.21	429.00	1974.79	-4.136
707	686	-3.997			402	-4.105	1976.29	426.89	1974.87	-4.052
708	687	-4.011			401	-3.935	1976.38	424.58	1974.96	-4.025

Appendix B.1
oxygen isotope data for coral core from Archipelago Los Roques (Roq6) and age model

					1st interpolation			2nd interpolation (monthly resolution)		
sample ID	new no.	d18O (per mil)	timemarker year.month	anchor High/Low	new no.	d18O (per mil)	timemarker year.month	new no.	timemarker year.month	d18O (per mil)
709	688	-4.138			400	-4.167	1976.46	422.25	1975.04	-3.670
710	689	-4.144	1953.79	H	399	-4.108	1976.54	419.96	1975.12	-3.644
711	690	-4.218			398	-4.090	1976.63	419.04	1975.21	-3.939
712	691	-4.201			397	-4.256	1976.71	418.00	1975.29	-3.807
713	692	-4.171			396	-4.260	1976.79	417.07	1975.37	-3.821
714	693	-3.991			395	-4.192	1976.86	416.04	1975.46	-3.892
715	694	-4.011			394	-3.947	1976.93	415.00	1975.54	-4.104
716	695	-3.811	1953.12	L	393	-3.717	1976.99	414.07	1975.62	-4.141
717	696	-3.834			392	-3.672	1977.06	413.04	1975.71	-4.185
718	697	-4.096			391	-3.795	1977.12	412.00	1975.79	-4.401
719	698	-4.160			390	-3.785	1977.20	410.13	1975.87	-3.959
720	699	-4.345	1952.79	H	389	-3.759	1977.27	408.08	1975.96	-3.658
721	700	-4.350			388	-3.797	1977.35	406.00	1976.04	-3.664
722	701	-4.148			387	-3.988	1977.42	403.96	1976.12	-3.796
723	702	-4.008			386	-3.977	1977.50	403.04	1976.21	-3.800
724	703	-4.112			385	-4.110	1977.57	402.00	1976.29	-4.105
725	704	-3.839	1952.12	L	384	-4.252	1977.64	401.07	1976.37	-3.948
726	705	-3.758			383	-4.148	1977.72	400.04	1976.46	-4.157
727	706	-3.936			382	-4.113	1977.79	399.00	1976.54	-4.108
728	707	-4.114			381	-4.101	1977.85	398.07	1976.62	-4.091
729	708	-4.302			380	-3.913	1977.90	397.04	1976.71	-4.249
730	709	-4.197	1951.79	H	379	-3.917	1977.96	396.00	1976.79	-4.260
731	710	-4.114			378	-3.818	1978.01	394.81	1976.87	-4.145
732	711	-4.120			377	-3.739	1978.07	393.56	1976.96	-3.845
733	712	-4.153			376	-3.700	1978.12	392.29	1977.04	-3.685
734	713	-4.017			375	-3.897	1978.20	390.96	1977.12	-3.795
735	714	-4.039			374	-3.857	1978.27	389.91	1977.21	-3.783
736	715	-3.821	1951.12	L	373	-3.947	1978.35	388.75	1977.29	-3.769
737	716	-4.077			372	-3.868	1978.42	387.67	1977.37	-3.861
738	717	-4.201			371	-3.886	1978.50	386.54	1977.46	-3.983
739	718	-4.398	1950.79	H	370	-3.957	1978.57	385.43	1977.54	-4.053
740	719	-4.466			369	-3.919	1978.64	384.24	1977.62	-4.218
741	720	-4.399			368	-3.975	1978.72	383.17	1977.71	-4.165
742	721	-4.262			367	-4.041	1978.79	382.00	1977.79	-4.113
743	722	-3.988			366	-4.135	1978.83	380.53	1977.87	-4.013
744	723	-4.009	1950.12	L	365	-4.217	1978.88	379.06	1977.96	-3.917
745	724	-3.883			364	-4.270	1978.92	377.50	1978.04	-3.779
750	725	-4.003			363	-4.262	1978.96	375.96	1978.12	-3.708
751	726	-4.005			362	-4.144	1979.00	374.91	1978.21	-3.893
752	727	-4.161			361	-4.154	1979.04	373.75	1978.29	-3.880
753	728	-4.294	1949.79	H	360	-3.854	1979.08	372.67	1978.37	-3.921
754	729	-3.994			359	-3.992	1979.12	371.54	1978.46	-3.876
755	730	-3.963			358	-3.968	1979.20	370.43	1978.54	-3.927
756	731	-4.038			357	-4.161	1979.27	369.24	1978.62	-3.928
757	732	-3.745			356	-4.132	1979.35	368.17	1978.71	-3.966
758	733	-3.691	1949.12	L	355	-4.088	1979.42	367.00	1978.79	-4.041
759	734	-3.766			354	-4.180	1979.50	365.13	1978.87	-4.206
760	735	-3.604			353	-4.215	1979.57	363.08	1978.96	-4.263
761	736	-3.882			352	-4.416	1979.64	361.00	1979.04	-4.154
762	737	-4.047			351	-4.288	1979.72	358.96	1979.12	-3.991
763	738	-4.265			350	-4.505	1979.79	357.91	1979.21	-3.986
764	739	-4.303	1948.79	H	349	-4.329	1979.85	356.75	1979.29	-4.154
765	740	-4.433			348	-4.177	1979.90	355.67	1979.37	-4.117
766	741	-4.355			347	-4.089	1979.96	354.54	1979.46	-4.130
767	742	-4.182			346	-3.947	1980.01	353.43	1979.54	-4.200
768	743	-4.169			345	-3.850	1980.07	352.24	1979.62	-4.368
769	744	-4.110			344	-3.901	1980.12	351.17	1979.71	-4.309
770	745	-3.957	1948.12	L	343	-3.934	1980.21	350.00	1979.79	-4.505
771	746	-4.072			342	-3.951	1980.29	348.53	1979.87	-4.258
772	747	-4.060			341	-3.980	1980.38	347.06	1979.96	-4.094
773	748	-4.222			340	-4.053	1980.46	345.50	1980.04	-3.899
774	749	-4.352			339	-4.051	1980.54	343.96	1980.12	-3.902
775	750	-4.292	1947.79	H	338	-4.182	1980.63	343.04	1980.21	-3.933
776	751	-4.260			337	-4.166	1980.71	342.00	1980.29	-3.951
777	752	-3.940			336	-4.267	1980.79	341.07	1980.37	-3.978
778	753	-3.855			335	-4.107	1980.82	340.04	1980.46	-4.050
779	754	-3.824	1947.12	L	334	-4.245	1980.85	339.00	1980.54	-4.051
780	755	-3.961			333	-4.203	1980.88	338.07	1980.62	-4.172
781	756	-4.341			332	-4.090	1980.90	337.04	1980.71	-4.167

Appendix B.1
oxygen isotope data for coral core from Archipelago Los Roques (Roq6) and age model

					1st interpolation			2nd interpolation (monthly resolution)		
sample ID	new no.	d18O (per mil)	timemarker year.month	anchor High/Low	new no.	d18O (per mil)	timemarker year.month	new no.	timemarker year.month	d18O (per mil)
782	757	-4.289			331	-4.055	1980.93	336.00	1980.79	-4.267
783	758	-4.382	1946.79	H	330	-4.007	1980.96	333.22	1980.87	-4.212
784	759	-4.336			329	-4.028	1980.99	330.11	1980.96	-4.012
785	760	-4.300			328	-3.960	1981.01	327.00	1981.04	-4.024
786	761	-4.085			327	-4.024	1981.04	323.95	1981.12	-4.028
787	762	-3.999			326	-4.037	1981.07	322.76	1981.21	-4.148
788	763	-3.849	1946.12	L	325	-3.983	1981.10	321.57	1981.29	-4.123
789	764	-3.872			324	-4.021	1981.12	320.28	1981.37	-4.181
790	765	-3.959			323	-4.162	1981.19	319.05	1981.46	-4.107
791	766	-4.107			322	-4.102	1981.26	317.83	1981.54	-4.362
792	767	-4.180			321	-4.151	1981.33	316.52	1981.62	-4.387
793	768	-4.404			320	-4.192	1981.39	315.33	1981.71	-4.332
794	769	-4.425	1945.79	H	319	-4.103	1981.46	314.00	1981.79	-4.279
795	770	-4.425			318	-4.353	1981.53	312.33	1981.87	-4.289
796	771	-4.319			317	-4.408	1981.59	310.47	1981.96	-4.261
797	772	-4.235			316	-4.363	1981.66	308.80	1982.04	-3.926
798	773	-4.046			315	-4.317	1981.73	306.97	1982.12	-3.785
799	774	-4.042	1945.12	L	314	-4.279	1981.79	306.13	1982.21	-3.885
800	775	-4.080			313	-4.217	1981.84	305.30	1982.29	-3.944
801	776	-4.120			312	-4.325	1981.89	304.41	1982.37	-4.007
802	777	-4.252			311	-4.291	1981.93	303.53	1982.46	-4.064
803	778	-4.167	1944.79	H	310	-4.234	1981.98	302.67	1982.54	-4.092
804	779	-4.257			309	-3.949	1982.03	301.77	1982.62	-4.118
805	780	-4.196			308	-3.834	1982.08	300.93	1982.71	-4.216
806	781	-4.203			307	-3.781	1982.12	300.00	1982.79	-4.172
807	782	-4.050			306	-3.901	1982.22	298.81	1982.87	-4.043
808	783	-3.927			305	-3.963	1982.32	297.56	1982.96	-4.007
809	784	-3.980			304	-4.037	1982.41	296.29	1983.04	-3.992
810	785	-3.953	1944.12	L	303	-4.095	1982.51	294.95	1983.12	-3.895
811	786	-4.000			302	-4.087	1982.60	293.76	1983.21	-3.897
812	787	-4.121			301	-4.219	1982.70	292.57	1983.29	-3.883
813	788	-4.311			300	-4.172	1982.79	291.28	1983.37	-4.057
814	789	-4.334	1943.79	H	299	-4.052	1982.86	290.05	1983.46	-4.161
815	790	-4.289			298	-4.007	1982.93	288.83	1983.54	-4.175
816	791	-4.342			297	-4.007	1982.99	287.52	1983.62	-4.294
817	792	-4.120			296	-3.986	1983.06	286.33	1983.71	-4.262
818	793	-4.143			295	-3.894	1983.12	285.00	1983.79	-4.208
819	794	-4.000			294	-3.906	1983.19	283.33	1983.87	-4.105
820	795	-3.983			293	-3.870	1983.26	281.47	1983.96	-4.107
821	796	-3.869			292	-3.900	1983.33	279.80	1984.04	-3.954
822	797	-4.019	1943.12	L	291	-4.117	1983.39	277.96	1984.12	-3.974
823	798	-4.186			290	-4.163	1983.46	276.91	1984.21	-3.889
824	799	-4.445			289	-4.152	1983.53	275.75	1984.29	-3.904
825	800	-4.327			288	-4.290	1983.59	274.67	1984.37	-3.920
826	801	-4.440			287	-4.299	1983.66	273.54	1984.46	-3.992
827	802	-4.311			286	-4.244	1983.73	272.43	1984.54	-4.059
828	803	-4.350			285	-4.208	1983.79	271.24	1984.62	-4.101
829	804	-4.234	1942.79	H	284	-4.063	1983.84	270.17	1984.71	-4.107
830	805	-4.126			283	-4.126	1983.89	269.00	1984.79	-4.159
831	806	-3.958			282	-4.159	1983.93	268.07	1984.87	-4.174
832	807	-4.003			281	-4.061	1983.98	267.04	1984.96	-3.941
833	808	-3.953	1942.12	L	280	-3.994	1984.03	266.00	1985.04	-3.852
834	809	-4.060			279	-3.792	1984.08	264.97	1985.12	-3.819
835	810	-4.409			278	-3.978	1984.12	264.13	1985.21	-3.922
836	811	-4.261			277	-3.887	1984.20	263.30	1985.29	-3.926
837	812	-4.204			276	-3.906	1984.27	262.41	1985.37	-4.025
838	813	-4.322	1941.79	H	275	-3.897	1984.35	261.53	1985.46	-4.074
839	814	-4.340			274	-3.965	1984.42	260.67	1985.54	-4.158
840	815	-4.139			273	-4.024	1984.50	259.77	1985.62	-4.328
841	816	-4.195			272	-4.085	1984.57	258.93	1985.71	-4.161
842	817	-4.092			271	-4.106	1984.64	258.00	1985.79	-4.090
843	818	-4.117			270	-4.107	1984.72	256.81	1985.87	-4.194
844	819	-3.912	1941.12	L	269	-4.159	1984.79	255.56	1985.96	-4.096
845	820	-4.197			268	-4.175	1984.88	254.29	1986.04	-4.152
846	821	-4.083			267	-3.931	1984.96	252.96	1986.12	-3.691
847	822	-4.223			266	-3.852	1985.04	252.04	1986.21	-3.703
848	823	-4.248			265	-3.815	1985.12	251.00	1986.29	-3.827
849	824	-4.345	1940.79	H	264	-3.939	1985.22	250.07	1986.37	-3.815
850	825	-4.228			263	-3.921	1985.32	249.04	1986.46	-3.811

Appendix B.1
oxygen isotope data for coral core from Archipelago Los Roques (Roq6) and age model

					1st interpolation			2nd interpolation (monthly resolution)		
sample ID	new no.	d18O	timemarker	anchor	new no.	d18O	timemarker	new no.	timemarker	d18O
		(per mil)	year.month	High/Low		(per mil)	year.month		year.month	(per mil)
851	826	-3.988			262	-4.097	1985.41	248.00	1986.54	-3.957
852	827	-3.951			261	-4.048	1985.51	247.07	1986.62	-4.108
853	828	-3.920			260	-4.377	1985.60	246.04	1986.71	-4.341
854	829	-3.939			259	-4.167	1985.70	245.00	1986.79	-4.117
855	830	-3.934			258	-4.090	1985.79	242.89	1986.87	-4.091
856	831	-3.892	1940.12	L	257	-4.208	1985.86	240.58	1986.96	-3.961
857	832	-3.915			256	-4.136	1985.93	238.25	1987.04	-3.791
858	833	-3.994			255	-4.046	1985.99	235.97	1987.12	-4.011
859	834	-4.026			254	-4.194	1986.06	235.28	1987.21	-3.990
860	835	-4.179	1939.79	H	253	-3.690	1986.12	234.55	1987.29	-4.080
861	836	-4.062			252	-3.704	1986.21	233.79	1987.37	-4.240
862	837	-3.976			251	-3.827	1986.29	233.03	1987.46	-4.388
863	838	-3.933			250	-3.814	1986.38	232.27	1987.54	-4.296
864	839	-3.771			249	-3.811	1986.46	231.52	1987.62	-4.237
868	840	-3.733			248	-3.957	1986.54	230.76	1987.71	-4.216
869	841	-3.659	1939.12	L	247	-4.120	1986.63	230.00	1987.79	-4.227
870	842	-3.693			246	-4.351	1986.71	227.56	1987.87	-3.986
871	843	-3.745			245	-4.117	1986.79	225.11	1987.96	-4.013
872	844	-4.100			244	-4.075	1986.83	222.67	1988.04	-3.983
873	845	-4.302			243	-4.084	1986.87	219.98	1988.12	-4.222
874	846	-4.122	1938.79	H	242	-4.144	1986.90	219.38	1988.21	-4.247
875	847	-4.286			241	-4.014	1986.94	218.77	1988.29	-4.244
876	848	-4.054			240	-3.887	1986.98	218.13	1988.37	-4.190
877	849	-4.038			239	-3.692	1987.01	217.52	1988.46	-4.246
878	850	-3.953			238	-3.824	1987.05	216.92	1988.54	-4.321
879	851	-3.938			237	-3.823	1987.09	216.28	1988.62	-4.329
880	852	-3.711	1938.12	L	236	-4.012	1987.12	215.64	1988.71	-4.356
881	853	-3.748			235	-3.981	1987.24	215.00	1988.79	-4.399
882	854	-4.052			234	-4.199	1987.35	213.53	1988.87	-4.007
883	855	-4.333			233	-4.394	1987.46	212.06	1988.96	-3.721
884	856	-4.443	1937.79	H	232	-4.259	1987.57	210.50	1989.04	-3.739
885	857	-4.408			231	-4.213	1987.68	208.99	1989.12	-3.987
886	858	-4.409			230	-4.227	1987.79	208.62	1989.21	-3.979
887	859	-4.144			229	-4.148	1987.83	208.26	1989.29	-3.971
888	860	-3.988			228	-3.980	1987.86	207.89	1989.37	-3.977
889	861	-3.865			227	-3.993	1987.89	207.52	1989.46	-4.016
890	862	-3.683			226	-4.043	1987.93	207.14	1989.54	-4.056
891	863	-3.682	1937.12	L	225	-4.009	1987.96	206.76	1989.62	-4.118
892	864	-3.727			224	-3.997	1987.99	206.38	1989.71	-4.192
893	865	-3.982			223	-4.025	1988.03	206.00	1989.79	-4.267
894	866	-4.181			222	-3.900	1988.06	204.13	1989.87	-4.196
895	867	-4.459	1936.79	H	221	-4.085	1988.09	202.08	1989.96	-3.916
896	868	-4.234			220	-4.221	1988.12	200.00	1990.04	-3.837
897	869	-4.228			219	-4.263	1988.26	197.97	1990.12	-3.884
898	870	-4.234			218	-4.179	1988.39	197.13	1990.21	-3.920
899	871	-4.034			217	-4.320	1988.53	196.30	1990.29	-3.906
900	872	-4.026			216	-4.332	1988.66	195.41	1990.37	-3.987
901	873	-3.953	1936.12	L	215	-4.399	1988.79	194.53	1990.46	-4.049
902	874	-4.016			214	-4.080	1988.85	193.67	1990.54	-4.095
903	875	-4.100			213	-3.923	1988.90	192.77	1990.62	-4.187
904	876	-4.123			212	-3.709	1988.96	191.93	1990.71	-4.196
905	877	-4.377			211	-3.606	1989.01	191.00	1990.79	-4.347
906	878	-4.513	1935.79	H	210	-3.872	1989.07	189.13	1990.87	-4.416
907	879	-4.190			209	-3.987	1989.12	187.08	1990.96	-4.054
908	880	-4.078			208	-3.966	1989.35	185.00	1991.04	-3.827
909	881	-4.043			207	-4.070	1989.57	182.97	1991.12	-3.885
910	882	-4.064			206	-4.267	1989.79	182.28	1991.21	-4.012
911	883	-4.183	1935.12	L	205	-4.375	1989.83	181.55	1991.29	-4.071
912	884	-4.082			204	-4.168	1989.88	180.79	1991.37	-4.068
913	885	-4.086			203	-3.976	1989.92	180.03	1991.46	-4.027
914	886	-4.127			202	-3.911	1989.96	179.27	1991.54	-4.081
915	887	-4.160	1934.79	H	201	-4.109	1990.00	178.52	1991.62	-4.150
916	888	-4.178			200	-3.837	1990.04	177.76	1991.71	-4.171
917	889	-4.081			199	-3.842	1990.08	177.00	1991.79	-4.077
918	890	-4.245			198	-3.883	1990.12	174.89	1991.87	-4.175
919	891	-4.036			197	-3.926	1990.22	172.58	1991.96	-3.943
920	892	-3.892			196	-3.897	1990.32	170.25	1992.04	-3.826
921	893	-4.011			195	-4.049	1990.41	167.97	1992.12	-4.024
922	894	-4.150			194	-4.049	1990.51	167.13	1992.21	-4.143

Appendix B.1
oxygen isotope data for coral core from Archipelago Los Roques (Roq6) and age model

sample ID	new no.	d18O (per mil)	timemarker year.month	anchor High/Low	1st interpolation new no.	d18O (per mil)	timemarker year.month	2nd interpolation (monthly resolution) new no.	timemarker year.month	d18O (per mil)
923	895	-3.830			193	-4.188	1990.60	166.30	1992.29	-4.156
924	896	-3.827	1934.12	L	192	-4.184	1990.70	165.41	1992.37	-4.187
925	897	-3.971			191	-4.347	1990.79	164.53	1992.46	-4.299
926	898	-4.230			190	-4.328	1990.83	163.67	1992.54	-4.368
927	899	-4.194			189	-4.430	1990.88	162.77	1992.62	-4.307
928	900	-4.369			188	-4.264	1990.92	161.93	1992.71	-4.319
929	901	-4.357	1933.79	H	187	-4.035	1990.96	161.00	1992.79	-4.336
930	902	-4.459			186	-3.921	1991.00	159.33	1992.87	-4.304
931	903	-4.259			185	-3.827	1991.04	157.47	1992.96	-4.253
932	904	-4.209			184	-3.879	1991.08	155.80	1993.04	-4.033
933	905	-4.209			183	-3.880	1991.12	153.95	1993.12	-3.818
934	906	-4.019			182	-4.063	1991.24	152.76	1993.21	-3.973
935	907	-4.008	1933.12	L	181	-4.080	1991.35	151.57	1993.29	-3.905
936	908	-4.006			180	-4.025	1991.46	150.28	1993.37	-4.063
937	909	-4.067			179	-4.102	1991.57	149.05	1993.46	-4.045
938	910	-4.237			178	-4.201	1991.68	147.83	1993.54	-4.143
939	911	-4.401			177	-4.077	1991.79	146.52	1993.62	-4.215
940	912	-4.584			176	-4.199	1991.83	145.33	1993.71	-4.259
941	913	-4.520	1932.79	H	175	-4.202	1991.87	144.00	1993.79	-4.255
942	914	-4.304			174	-3.961	1991.90	142.13	1993.87	-4.187
943	915	-4.244			173	-4.059	1991.94	140.08	1993.96	-4.025
944	916	-3.944			172	-3.780	1991.98	138.00	1994.04	-3.812
945	917	-4.029			171	-3.806	1992.01	135.97	1994.12	-3.747
946	918	-3.903			170	-3.832	1992.05	135.13	1994.21	-3.841
947	919	-3.800	1932.12	L	169	-3.849	1992.09	134.30	1994.29	-3.969
948	920	-4.056			168	-4.019	1992.12	133.41	1994.37	-3.925
949	921	-4.123			167	-4.162	1992.22	132.53	1994.46	-4.006
950	922	-4.201			166	-4.154	1992.32	131.67	1994.54	-4.196
951	923	-4.165			165	-4.209	1992.41	130.77	1994.62	-4.307
952	924	-4.086			164	-4.401	1992.51	129.93	1994.71	-4.490
953	925	-4.111			163	-4.303	1992.60	129.00	1994.79	-4.418
954	926	-4.129			162	-4.318	1992.70	127.13	1994.87	-4.458
955	927	-3.894			161	-4.336	1992.79	125.08	1994.96	-4.314
956	928	-4.134	1931.79	H	160	-4.321	1992.84	123.00	1995.04	-4.142
957	929	-4.171			159	-4.296	1992.89	120.95	1995.12	-3.887
958	930	-4.093			158	-4.258	1992.93	119.72	1995.21	-4.043
959	931	-3.871			157	-4.249	1992.98	118.33	1995.29	-4.098
960	932	-3.838	1931.12	L	156	-4.056	1993.03	116.94	1995.37	-4.213
961	933	-3.911			155	-3.943	1993.08	115.56	1995.46	-4.281
962	934	-3.912			154	-3.809	1993.12	114.17	1995.54	-4.292
963	935	-3.981			153	-4.006	1993.19	112.78	1995.62	-4.468
964	936	-3.932			152	-3.866	1993.26	111.39	1995.71	-4.540
965	937	-3.951	1930.79	H	151	-3.958	1993.33	110.00	1995.79	-4.630
966	938	-3.931			150	-4.104	1993.39	108.81	1995.87	-4.534
967	939	-3.929			149	-4.042	1993.46	107.56	1995.96	-4.447
968	940	-3.847			148	-4.124	1993.53	106.29	1996.04	-4.288
969	941	-3.717			147	-4.235	1993.59	104.97	1996.12	-3.857
970	942	-3.813			146	-4.194	1993.66	104.13	1996.21	-4.018
971	943	-3.618			145	-4.292	1993.73	103.30	1996.29	-4.097
972	944	-3.725	1930.12	L	144	-4.255	1993.79	102.41	1996.37	-4.113
973	945	-3.593			143	-4.106	1993.83	101.53	1996.46	-4.154
974	946	-3.757			142	-4.199	1993.88	100.67	1996.54	-4.227
975	947	-3.985			141	-4.197	1993.92	99.77	1996.62	-4.283
976	948	-4.098			140	-4.009	1993.96	98.93	1996.71	-4.325
977	949	-4.061			139	-3.876	1994.00	98.00	1996.79	-4.384
978	950	-4.039	1929.79	H	138	-3.812	1994.04	96.53	1996.87	-4.296
979	951	-3.914			137	-3.749	1994.08	95.06	1996.96	-4.096
980	952	-3.893			136	-3.743	1994.12	93.50	1997.04	-3.939
981	953	-3.687			135	-3.856	1994.22	91.97	1997.12	-3.905
982	954	-3.707			134	-4.017	1994.32	91.13	1997.21	-3.941
983	955	-3.566	1929.12	L	133	-3.862	1994.41	90.30	1997.29	-4.053
984	956	-3.744			132	-4.170	1994.51	89.41	1997.37	-4.108
985	957	-3.887			131	-4.249	1994.60	88.53	1997.46	-4.122
986	958	-3.927			130	-4.496	1994.70	87.67	1997.54	-4.103
987	959	-4.066	1928.79	H	129	-4.418	1994.79	86.77	1997.62	-4.061
988	960	-4.096			128	-4.570	1994.83	85.93	1997.71	-4.113
989	961	-4.153			127	-4.441	1994.88	85.00	1997.79	-4.199
990	962	-3.983			126	-4.480	1994.92	83.33	1997.87	-4.323
991	963	-3.809			125	-4.299	1994.96	81.47	1997.96	-4.242

Appendix B.1
oxygen isotope data for coral core from Archipelago Los Roques (Roq6) and age model

					1st interpolation			2nd interpolation (monthly resolution)		
sample ID	new no.	d18O (per mil)	timemarker year.month	anchor High/Low	new no.	d18O (per mil)	timemarker year.month	new no.	timemarker year.month	d18O (per mil)
992	964	-3.651			124	-4.328	1995.00	79.80	1998.04	-3.981
993	965	-3.662			123	-4.142	1995.04	77.97	1998.12	-4.034
998	966	-3.776			122	-4.183	1995.08	77.28	1998.21	-4.059
999	967	-3.832	1928.12	L	121	-3.878	1995.12	76.55	1998.29	-4.224
1000	968	-3.891			120	-4.075	1995.19	75.79	1998.37	-4.398
1001	969	-4.022			119	-3.959	1995.25	75.03	1998.46	-4.357
1002	970	-4.184			118	-4.167	1995.31	74.27	1998.54	-4.414
1003	971	-4.369	1927.79	H	117	-4.208	1995.37	73.52	1998.62	-4.452
1004	972	-4.162			116	-4.295	1995.43	72.76	1998.71	-4.471
1005	973	-4.221			115	-4.263	1995.49	72.00	1998.79	-4.479
1006	974	-4.056			114	-4.298	1995.55	70.53	1998.87	-4.398
1007	975	-4.043			113	-4.455	1995.61	69.06	1998.96	-4.298
1008	976	-3.876			112	-4.515	1995.67	67.50	1999.04	-4.148
1009	977	-3.795			111	-4.556	1995.73	65.97	1999.12	-3.922
1010	978	-3.876	1927.12	L	110	-4.630	1995.79	65.28	1999.21	-3.935
1011	979	-3.855			109	-4.535	1995.86	64.55	1999.29	-3.984
1012	980	-3.841			108	-4.530	1995.93	63.79	1999.37	-4.061
1013	981	-4.113			107	-4.343	1995.99	63.03	1999.46	-4.145
1014	982	-4.344			106	-4.266	1996.06	62.27	1999.54	-4.261
1015	983	-4.244	1926.79	H	105	-3.851	1996.12	61.52	1999.62	-4.304
1016	984	-4.306			104	-4.044	1996.22	60.76	1999.71	-4.296
1017	985	-4.198			103	-4.119	1996.32	60.00	1999.79	-4.274
1018	986	-4.157			102	-4.109	1996.41	58.33	1999.87	-4.310
1019	987	-4.009			101	-4.205	1996.51	56.47	1999.96	-4.155
1020	988	-3.903			100	-4.272	1996.60	54.80	2000.04	-3.959
1021	989	-3.763			99	-4.320	1996.70	52.97	2000.12	-3.931
1022	990	-3.785			98	-4.384	1996.79	52.28	2000.21	-3.987
1023	991	-3.616			97	-4.308	1996.85	51.55	2000.29	-4.052
1024	992	-3.701	1926.12	L	96	-4.282	1996.90	50.79	2000.37	-4.135
1025	993	-3.902			95	-4.085	1996.96	50.03	2000.46	-4.248
1026	994	-3.896			94	-4.033	1997.01	49.27	2000.54	-4.345
1027	995	-4.168			93	-3.845	1997.07	48.52	2000.62	-4.352
1028	996	-4.106			92	-3.904	1997.12	47.76	2000.71	-4.318
1029	997	-4.118	1925.79	H	91	-3.947	1997.22	47.00	2000.79	-4.303
1030	998	-4.142			90	-4.099	1997.32	45.81	2000.87	-4.123
1031	999	-4.166			89	-4.115	1997.41	44.56	2000.96	-3.973
1032	1000	-3.881			88	-4.131	1997.51	43.29	2001.04	-3.790
1033	1001	-3.729			87	-4.047	1997.60	41.97	2001.12	-3.935
1034	1002	-3.763	1925.12	L	86	-4.106	1997.70	41.28	2001.21	-4.011
1035	1003	-3.471			85	-4.199	1997.79	40.55	2001.29	-4.063
1036	1004	-3.706			84	-4.175	1997.84	39.79	2001.37	-4.118
1037	1005	-3.892			83	-4.397	1997.89	39.03	2001.46	-4.224
1038	1006	-4.152			82	-4.354	1997.93	38.27	2001.54	-4.409
1039	1007	-4.220			81	-4.144	1997.98	37.52	2001.62	-4.442
1040	1008	-4.331	1924.79	H	80	-3.992	1998.03	36.76	2001.71	-4.398
1041	1009	-4.249			79	-3.939	1998.08	36.00	2001.79	-4.378
1042	1010	-4.239			78	-4.033	1998.12	35.07	2001.87	-4.291
1043	1011	-3.989			77	-4.069	1998.24	34.04	2001.96	-4.381
1044	1012	-3.980			76	-4.410	1998.35	33.00	2002.04	-4.409
1045	1013	-3.787			75	-4.355	1998.46	31.96	2002.12	-4.289
1046	1014	-3.828	1924.12	L	74	-4.436	1998.57	30.90	2002.21	-4.141
1047	1015	-3.774			73	-4.469	1998.68	29.75	2002.29	-4.099
1048	1016	-3.915			72	-4.479	1998.79	28.67	2002.37	-4.121
1049	1017	-3.897			71	-4.459	1998.85	27.54	2002.46	-4.217
1050	1018	-3.921	1923.79	H	70	-4.328	1998.90	26.43	2002.54	-4.301
1051	1019	-4.149			69	-4.296	1998.96	25.24	2002.62	-4.357
1052	1020	-4.060			68	-4.186	1999.01	24.17	2002.71	-4.395
1053	1021	-3.868			67	-4.110	1999.07	23.00	2002.79	-4.432
1054	1022	-3.903			66	-3.921	1999.12	21.13	2002.87	-4.208
1055	1023	-3.649			65	-3.940	1999.24	19.08	2002.96	-4.013
1056	1024	-3.534	1923.12	L	64	-4.037	1999.35	17.00	2003.04	-3.946
1057	1025	-3.772			63	-4.148	1999.46	14.97	2003.12	-4.097
1058	1026	-3.888			62	-4.304	1999.57	14.28	2003.21	-4.251
1059	1027	-4.090			61	-4.303	1999.68	13.55	2003.29	-4.297
1060	1028	-4.378			60	-4.274	1999.79	12.79	2003.37	-4.278
1061	1029	-4.381			59	-4.336	1999.84	12.03	2003.46	-4.280
1062	1030	-4.329	1922.79	H	58	-4.297	1999.89	11.27	2003.54	-4.393
1063	1031	-4.117			57	-4.136	1999.93	10.52	2003.62	-4.461
1064	1032	-3.972			56	-4.172	1999.98	9.76	2003.71	-4.506

Appendix B.1
oxygen isotope data for coral core from Archipelago Los Roques (Roq6) and age model

					1st interpolation			2nd interpolation (monthly resolution)		
sample ID	new no.	d18O	timemarker	anchor	new no.	d18O	timemarker	new no.	timemarker	d18O
		(per mil)	year.month	High/Low		(per mil)	year.month		year.month	(per mil)
1065	1033	-3.871			55	-3.951	2000.03	9.00	2003.79	-4.561
1066	1034	-3.710			54	-3.989	2000.08	8.07	2003.87	-4.427
1067	1035	-3.777	1922.12	L	53	-3.929	2000.12	7.04	2003.96	-4.235
1068	1036	-3.889			52	-4.009	2000.24	6.00	2004.04	-4.242
1069	1037	-3.980			51	-4.103	2000.35	4.98	2004.12	-4.125
1070	1038	-4.231			50	-4.253	2000.46	4.49	2004.21	-4.212
1071	1039	-4.389	1921.79	H	49	-4.380	2000.57	4.00	2004.29	-4.298
1072	1040	-4.136			48	-4.323	2000.68	3.51	2004.37	-4.324
1073	1041	-4.040			47	-4.303	2000.79	3.02	2004.46	-4.351
1074	1042	-3.987			46	-4.137	2000.86	2.53	2004.54	-4.354
1081	1043	-3.904			45	-4.064	2000.93	2.04	2004.62	-4.356
1082	1044	-3.689			44	-3.859	2000.99	1.52	2004.71	-4.464
1083	1045	-3.818			43	-3.763	2001.06	1.00	2004.79	-4.581
1084	1046	-3.630			42	-3.932	2001.12			
1085	1047	-3.629			41	-4.042	2001.24			
1086	1048	-3.620			40	-4.088	2001.35			
1087	1049	-3.602	1921.12	L	39	-4.228	2001.46			
1088	1050	-3.589			38	-4.477	2001.57			
1089	1051	-3.705			37	-4.405	2001.68			
1090	1052	-3.696			36	-4.378	2001.79			
1091	1053	-3.608			35	-4.284	2001.88			
1092	1054	-3.785	1920.79	H	34	-4.385	2001.96			
1093	1055	-3.686			33	-4.409	2002.04			
1094	1056	-3.638			32	-4.295	2002.12			
1095	1057	-3.529			31	-4.146	2002.20			
1096	1058	-3.513			30	-4.097	2002.27			
1097	1059	-3.580	1920.12	L	29	-4.104	2002.35			
1098	1060	-3.715			28	-4.154	2002.42			
1099	1061	-3.667			27	-4.291	2002.50			
1100	1062	-3.766			26	-4.309	2002.57			
1101	1063	-4.009			25	-4.372	2002.64			
1102	1064	-4.002	1919.79	H	24	-4.400	2002.72			
1103	1065	-3.954			23	-4.432	2002.79			
1104	1066	-4.016			22	-4.304	2002.83			
1105	1067	-3.989			21	-4.193	2002.88			
1106	1068	-3.714			20	-4.073	2002.92			
1107	1069	-3.656	1919.12	L	19	-4.008	2002.96			
1108	1070	-3.666			18	-3.861	2003.00			
1109	1071	-3.461			17	-3.946	2003.04			
1110	1072	-3.584			16	-4.028	2003.08			
1111	1073	-3.523			15	-4.091	2003.12			
1112	1074	-3.700			14	-4.313	2003.24			
1113	1075	-3.776			13	-4.277	2003.35			
1114	1076	-3.846	1918.79	H	12	-4.280	2003.46			
1115	1077	-3.915			11	-4.435	2003.57			
1116	1078	-3.760			10	-4.489	2003.68			
1117	1079	-3.820			9	-4.561	2003.79			
1118	1080	-3.696			8	-4.416	2003.88			
1119	1081	-3.768			7	-4.227	2003.96			
1120	1082	-3.522			6	-4.242	2004.04			
1121	1083	-3.706	1918.12	L	5	-4.122	2004.12			
1122	1084	-3.666			4	-4.298	2004.29			
1123	1085	-3.750			3	-4.352	2004.46			
1124	1086	-3.724			2	-4.356	2004.63			
1125	1087	-3.812	1917.79	H	1	-4.581	2004.79			

Appendix B.2
trace elemental data for coral core from Archipelago Los Roques (Roq6) and age model

core Roq6 (2004-1917)
Sr/Ca

						1st interpolation				2nd interpolation			
sample ID	new no.	Mg/Ca (mmol/mol)	Sr/Ca (mmol/mol)	timemarker year.month	anchor High/Low	new no.	Mg/Ca (mmol/mol)	Sr/Ca (mmol/mol)	timemarker year.month	new no.	timemarker year.month	Sr/Ca (mmol/mol)	Mg/Ca (mmol/mol)
1	1	7.072	8.921	2004.79	H	1094	5.431	8.920	1917.79	1094.00	1917.79	8.920	5.431
2	2	5.696	8.986			1093	5.630	8.937	1917.88	1093.07	1917.87	8.936	5.615
3	3	5.654	8.976			1092	5.534	8.945	1917.96	1092.04	1917.96	8.945	5.538
4	4	6.187	9.017			1091	5.349	8.919	1918.04	1091.00	1918.04	8.919	5.349
5	5	6.452	9.027	2004.12	L	1090	5.056	8.982	1918.12	1089.97	1918.12	8.982	5.068
6	6	6.367	9.026			1089	5.402	8.981	1918.22	1089.13	1918.21	8.981	5.356
7	7	5.479	9.025			1088	4.991	8.928	1918.32	1088.30	1918.29	8.944	5.114
8	8	5.194	8.937			1087	4.780	8.929	1918.41	1087.41	1918.37	8.929	4.866
9	9	4.908	8.915	2003.79	H	1086	5.080	8.943	1918.51	1086.53	1918.46	8.936	4.920
10	10	5.320	8.922			1085	4.721	8.885	1918.60	1085.67	1918.54	8.924	4.960
11	11	5.598	8.951			1084	4.688	8.878	1918.70	1084.77	1918.62	8.883	4.713
12	12	5.839	8.959			1083	4.979	8.861	1918.79	1083.93	1918.71	8.877	4.710
13	13	5.803	8.942			1082	5.072	8.906	1918.84	1083.00	1918.79	8.861	4.979
14	14	6.909	8.960			1081	5.106	8.912	1918.89	1081.33	1918.87	8.910	5.095
15	15	6.387	9.018	2003.12	L	1080	5.230	8.922	1918.93	1079.47	1918.96	8.934	5.184
21	16	6.144	8.964			1079	5.143	8.944	1918.98	1077.80	1919.04	8.954	5.071
22	17	6.029	8.960			1078	5.107	8.964	1919.03	1075.98	1919.12	9.016	4.952
23	18	7.231	8.927			1077	4.929	8.913	1919.08	1075.38	1919.21	8.973	5.107
24	19	6.682	8.934			1076	4.946	9.018	1919.12	1074.77	1919.29	8.935	5.168
25	20	6.379	8.898			1075	5.206	8.946	1919.26	1074.13	1919.37	8.905	5.064
26	21	6.205	8.877			1074	5.043	8.899	1919.39	1073.52	1919.46	8.894	4.911
27	22	5.861	8.876			1073	4.765	8.889	1919.53	1072.92	1919.54	8.889	4.762
28	23	5.517	8.779	2002.79	H	1072	4.720	8.893	1919.66	1072.28	1919.62	8.892	4.733
29	24	8.284	8.804			1071	4.674	8.895	1919.79	1071.64	1919.71	8.894	4.703
30	25	5.395	8.867			1070	4.933	8.894	1919.86	1071.00	1919.79	8.895	4.674
31	26	5.332	8.866			1069	4.714	8.939	1919.93	1069.81	1919.87	8.903	4.891
32	27	4.797	8.908			1068	4.719	9.000	1919.99	1068.56	1919.96	8.966	4.716
33	28	4.785	8.926			1067	4.697	9.007	1920.06	1067.29	1920.04	9.005	4.703
34	29	5.453	8.926			1066	4.640	9.037	1920.12	1065.98	1920.12	9.036	4.645
35	30	6.462	8.913			1065	4.830	9.009	1920.26	1065.38	1920.21	9.020	4.758
36	31	7.223	8.926			1064	4.696	9.027	1920.39	1064.77	1920.29	9.013	4.799
37	32	6.806	8.954	2002.12	L	1063	5.326	8.997	1920.53	1064.13	1920.37	9.025	4.713
38	33	7.305	8.901			1062	4.898	9.022	1920.66	1063.52	1920.46	9.013	4.996
39	34	7.080	8.871			1061	4.704	8.954	1920.79	1062.92	1920.54	8.999	5.293
40	35	6.069	8.849			1060	5.198	8.969	1920.86	1062.28	1920.62	9.015	5.019
41	36	5.854	8.778	2001.79	H	1059	4.597	8.950	1920.93	1061.64	1920.71	8.998	4.828
42	37	5.767	8.798			1058	4.842	8.964	1920.99	1061.00	1920.79	8.954	4.704
43	38	5.355	8.822			1057	4.605	8.967	1921.06	1059.81	1920.87	8.965	5.084
44	39	5.542	8.838			1056	5.293	8.998	1921.12	1058.56	1920.96	8.956	4.706
45	40	5.408	8.908			1055	4.814	8.990	1921.19	1057.29	1921.04	8.966	4.673
46	41	5.336	8.963			1054	5.144	8.980	1921.26	1055.95	1921.12	8.998	5.270
47	42	5.953	8.976	2001.12	L	1053	4.820	8.939	1921.33	1054.76	1921.21	8.988	4.893
48	43	6.805	8.939			1052	4.610	8.964	1921.39	1053.57	1921.29	8.962	5.005
49	44	6.713	8.947			1051	4.720	8.939	1921.46	1052.28	1921.37	8.957	4.668
50	45	6.109	8.910			1050	4.683	8.929	1921.53	1051.05	1921.46	8.940	4.715
51	46	6.068	8.838			1049	4.744	8.876	1921.59	1049.83	1921.54	8.920	4.693
52	47	5.450	8.799	2000.79	H	1048	4.777	8.873	1921.66	1048.52	1921.62	8.875	4.760
53	48	5.320	8.849			1047	5.073	8.840	1921.73	1047.33	1921.71	8.851	4.974
54	49	5.452	8.831			1046	5.022	8.803	1921.79	1046.00	1921.79	8.803	5.022
55	50	5.404	8.890			1045	4.806	8.849	1921.88	1045.07	1921.87	8.846	4.822
56	51	5.449	8.886			1044	4.391	8.868	1921.96	1044.04	1921.96	8.867	4.408
57	52	5.688	8.879			1043	5.132	8.886	1922.04	1043.00	1922.04	8.886	5.132
58	53	5.419	8.945	2000.12	L	1042	4.451	8.992	1922.12	1041.98	1922.12	8.991	4.451
59	54	5.560	8.919			1041	4.445	8.942	1922.26	1041.38	1922.21	8.961	4.447
60	55	5.641	8.926			1040	4.539	8.920	1922.39	1040.77	1922.29	8.937	4.467
61	56	5.593	8.888			1039	4.565	8.906	1922.53	1040.13	1922.37	8.923	4.527
62	57	6.162	8.878			1038	4.845	8.838	1922.66	1039.52	1922.46	8.913	4.551
63	58	5.734	8.844			1037	5.073	8.776	1922.79	1038.92	1922.54	8.901	4.587
64	59	5.573	8.835			1036	5.165	8.806	1922.85	1038.28	1922.62	8.857	4.766
65	60	5.423	8.803	1999.79	H	1035	4.969	8.770	1922.90	1037.64	1922.71	8.816	4.927
66	61	5.118	8.843			1034	4.976	8.826	1922.96	1037.00	1922.79	8.776	5.073
67	62	4.940	8.853			1033	4.815	8.846	1923.01	1035.53	1922.87	8.789	5.074
68	63	5.222	8.856			1032	5.057	8.881	1923.07	1034.06	1922.96	8.823	4.976
69	64	5.401	8.963			1031	5.253	8.923	1923.12	1032.50	1923.04	8.864	4.936
70	65	5.164	8.961			1030	5.166	8.909	1923.24	1030.97	1923.12	8.923	5.251
71	66	5.369	8.987	1999.12	L	1029	5.204	8.882	1923.35	1030.28	1923.21	8.913	5.190
72	67	5.219	8.954			1028	5.034	8.876	1923.46	1029.55	1923.29	8.897	5.183
73	68	5.285	8.927			1027	5.237	8.884	1923.57	1028.79	1923.37	8.881	5.168
74	69	5.327	8.910			1026	5.189	8.885	1923.68	1028.03	1923.46	8.876	5.039
75	70	5.305	8.900			1025	5.055	8.848	1923.79	1027.27	1923.54	8.882	5.182
76	71	4.950	8.815			1024	5.025	8.854	1923.88	1026.52	1923.62	8.884	5.214
77	72	5.041	8.815	1998.79	H	1023	4.930	8.846	1923.96	1025.76	1923.71	8.876	5.157
78	73	5.359	8.821			1022	4.902	8.879	1924.04	1025.00	1923.79	8.848	5.055
79	74	5.334	8.856			1021	4.685	8.891	1924.12	1024.07	1923.87	8.854	5.027
80	75	5.698	8.887			1020	5.129	8.888	1924.24	1023.04	1923.96	8.846	4.934
81	76	5.537	8.908			1019	4.914	8.818	1924.35	1022.00	1924.04	8.879	4.902
82	77	5.347	8.964			1018	5.090	8.803	1924.46	1020.97	1924.12	8.891	4.697
83	78	5.861	8.992	1998.12	L	1017	4.931	8.773	1924.57	1020.28	1924.21	8.889	5.006
84	79	5.798	8.963			1016	5.030	8.799	1924.68	1019.55	1924.29	8.856	5.031
85	80	5.970	8.971			1015	5.110	8.798	1924.79	1018.79	1924.37	8.815	4.951
86	81	6.124	8.906			1014	5.143	8.780	1924.85	1018.03	1924.46	8.803	5.085
87	82	5.855	8.898			1013	5.146	8.793	1924.90	1017.27	1924.54	8.781	4.974
88	83	5.375	8.878			1012	5.243	8.845	1924.96	1016.52	1924.62	8.786	4.979
89	84	5.784	8.892			1011	5.000	8.902	1925.01	1015.76	1924.71	8.799	5.049
90	85	5.561	8.891	1997.79	H	1010	5.092	8.922	1925.07	1015.00	1924.79	8.798	5.110
91	86	5.625	8.883			1009	5.113	8.939	1925.12	1013.53	1924.87	8.786	5.144
92	87	6.095	8.936			1008	4.969	8.888	1925.26	1012.06	1924.96	8.842	5.238
93	88	6.066	8.942			1007	4.782	8.884	1925.39	1010.50	1925.04	8.912	5.046
94	89	6.194	8.915			1006	4.986	8.872	1925.53	1008.98	1925.12	8.938	5.110
95	90	5.975	8.922			1005	4.857	8.891	1925.66	1008.38	1925.21	8.907	5.024
96	91	6.559	8.957			1004	5.022	8.869	1925.79	1007.77	1925.29	8.887	4.926

trace elemental data for coral core from Archipelago Los Roques (Roq6) and age model

sample ID	new no.	Mg/Ca (mmol/mol)	Sr/Ca (mmol/mol)	timemarker year.month	anchor High/Low	1st interpolation new no.	Mg/Ca (mmol/mol)	Sr/Ca (mmol/mol)	timemarker year.month	2nd interpolation new no.	timemarker year.month	Sr/Ca (mmol/mol)	Mg/Ca (mmol/mol)
97	92	6.199	8.995	1997.12	L	1003	4.909	8.923	1925.86	1007.13	1925.37	8.885	4.806
98	93	6.833	8.985			1002	5.010	8.895	1925.93	1006.52	1925.46	8.878	4.879
99	94	6.453	8.950			1001	4.727	8.925	1925.99	1005.92	1925.54	8.873	4.976
100	95	6.591	8.950			1000	4.876	8.931	1926.06	1005.28	1925.62	8.886	4.893
101	96	5.866	8.873			999	4.775	8.994	1926.12	1004.64	1925.71	8.883	4.916
102	97	5.586	8.876			998	4.770	8.941	1926.20	1004.00	1925.79	8.869	5.022
103	98	5.482	8.872	1996.79	H	997	4.924	8.944	1926.27	1002.81	1925.87	8.918	4.928
104	99	5.509	8.922			996	4.767	8.928	1926.35	1001.56	1925.96	8.908	4.884
105	100	5.538	8.919			995	5.032	8.894	1926.42	1000.29	1926.04	8.929	4.833
106	101	5.471	8.935			994	5.231	8.898	1926.50	998.96	1926.12	8.992	4.775
107	102	5.220	8.911			993	5.127	8.871	1926.57	997.91	1926.21	8.941	4.785
114	103	5.813	9.013			992	5.272	8.840	1926.64	996.75	1926.29	8.940	4.885
115	104	6.393	8.977			991	5.161	8.828	1926.72	995.67	1926.37	8.917	4.855
116	105	7.558	9.078	1996.12	L	990	5.274	8.817	1926.79	994.54	1926.46	8.896	5.123
117	106	6.431	8.901			989	5.161	8.845	1926.86	993.43	1926.54	8.883	5.172
118	107	6.221	8.824			988	4.836	8.907	1926.93	992.24	1926.62	8.847	5.237
119	108	5.884	8.793			987	4.815	8.949	1926.99	991.17	1926.71	8.830	5.180
120	109	5.892	8.773			986	5.015	8.968	1927.06	990.00	1926.79	8.817	5.274
121	110	5.971	8.777	1995.79	H	985	4.697	8.976	1927.12	988.81	1926.87	8.857	5.099
122	111	5.762	8.822			984	4.818	8.910	1927.22	987.56	1926.96	8.926	4.827
123	112	5.643	8.841			983	4.983	8.914	1927.32	986.29	1927.04	8.963	4.958
124	113	5.993	8.840			982	4.978	8.921	1927.41	984.97	1927.12	8.974	4.701
125	114	5.757	8.873			981	5.133	8.868	1927.51	984.13	1927.21	8.919	4.802
126	115	5.754	8.885			980	4.902	8.894	1927.60	983.30	1927.29	8.913	4.934
127	116	6.434	8.951			979	5.280	8.831	1927.70	982.41	1927.37	8.918	4.980
128	117	6.295	8.946			978	4.930	8.805	1927.79	981.53	1927.46	8.896	5.050
129	118	6.674	8.963			977	5.571	8.818	1927.88	980.67	1927.54	8.877	5.056
130	119	6.971	8.971			976	5.137	8.863	1927.96	979.77	1927.62	8.879	4.990
131	120	6.376	8.966			975	5.111	8.932	1928.04	978.93	1927.71	8.829	5.254
132	121	6.578	8.980	1995.12	L	974	5.085	8.991	1928.12	978.00	1927.79	8.805	4.930
133	122	6.314	8.911			973	4.928	8.927	1928.21	977.07	1927.87	8.817	5.524
134	123	6.773	8.877			972	5.162	8.949	1928.29	976.04	1927.96	8.861	5.155
135	124	6.320	8.842			971	4.905	8.941	1928.38	975.00	1928.04	8.932	5.111
136	125	6.676	8.894			970	4.860	8.903	1928.46	973.96	1928.12	8.989	5.079
137	126	6.450	8.890			969	4.910	8.872	1928.54	973.04	1928.21	8.929	4.934
138	127	6.465	8.859			968	4.978	8.833	1928.63	972.00	1928.29	8.949	5.162
139	128	6.178	8.738			967	4.830	8.874	1928.71	971.07	1928.37	8.942	4.924
140	129	6.578	8.729	1994.79	H	966	5.177	8.806	1928.79	970.04	1928.46	8.905	4.862
141	130	6.877	8.873			965	5.050	8.864	1928.88	969.00	1928.54	8.872	4.910
142	131	6.783	8.911			964	5.148	8.864	1928.96	968.07	1928.62	8.836	4.973
143	132	5.946	8.928			963	5.487	8.931	1929.04	967.04	1928.71	8.872	4.836
144	133	6.356	8.991			962	4.812	8.961	1929.12	966.00	1928.79	8.806	5.177
145	134	6.628	9.001			961	5.157	8.912	1929.26	965.07	1928.87	8.860	5.059
146	135	7.341	9.041			960	5.580	8.848	1929.39	964.04	1928.96	8.864	5.144
147	136	7.638	9.049	1994.12	L	959	5.521	8.826	1929.53	963.00	1929.04	8.931	5.487
148	137	6.800	9.047			958	5.467	8.877	1929.66	961.98	1929.12	8.960	4.820
149	138	6.609	8.972			957	5.534	8.822	1929.79	961.38	1929.21	8.931	5.026
150	139	6.416	8.970			956	5.282	8.851	1929.85	960.77	1929.29	8.897	5.255
151	140	6.166	8.911			955	5.301	8.830	1929.90	960.13	1929.37	8.856	5.526
152	141	5.942	8.897			954	5.052	8.855	1929.96	959.52	1929.46	8.838	5.552
153	142	5.985	8.872			953	5.035	8.871	1930.01	958.92	1929.54	8.830	5.517
154	143	5.784	8.894			952	5.371	8.935	1930.07	958.28	1929.62	8.863	5.482
155	144	5.581	8.878	1993.79	H	951	5.122	8.937	1930.12	957.64	1929.71	8.857	5.491
156	145	5.736	8.884			950	5.268	8.918	1930.22	957.00	1929.79	8.822	5.534
157	146	5.510	8.886			949	5.480	8.922	1930.32	955.53	1929.87	8.841	5.291
158	147	6.306	8.891			948	5.284	8.914	1930.41	954.06	1929.96	8.854	5.066
159	148	6.185	8.878			947	5.275	8.863	1930.51	952.50	1930.04	8.903	5.203
160	149	6.369	8.890			946	5.135	8.850	1930.60	950.97	1930.12	8.936	5.127
161	150	6.554	8.899			945	5.165	8.864	1930.70	950.13	1930.21	8.921	5.249
162	151	6.738	8.943			944	5.081	8.833	1930.79	949.30	1930.29	8.921	5.416
163	152	6.712	8.951			943	5.305	8.839	1930.86	948.41	1930.37	8.917	5.364
164	153	7.024	8.952			942	5.388	8.837	1930.93	947.53	1930.46	8.890	5.280
165	154	7.406	8.973	1993.12	L	941	4.736	8.877	1930.99	946.67	1930.54	8.859	5.228
166	155	7.118	8.932			940	4.974	8.865	1931.06	945.77	1930.62	8.853	5.142
167	156	6.581	8.917			939	5.487	8.888	1931.12	944.93	1930.71	8.862	5.159
168	157	6.242	8.860			938	5.211	8.849	1931.29	944.00	1930.79	8.833	5.081
169	158	6.498	8.858			937	5.155	8.815	1931.46	942.81	1930.87	8.839	5.321
170	159	7.171	8.828			936	5.081	8.797	1931.63	941.56	1930.96	8.855	5.098
171	160	6.819	8.847			935	4.983	8.812	1931.79	940.29	1931.04	8.868	4.906
172	161	7.038	8.807	1992.79	H	934	4.858	8.816	1931.83	938.98	1931.12	8.887	5.482
173	162	6.094	8.821			933	5.068	8.832	1931.87	938.49	1931.21	8.868	5.346
174	163	6.326	8.824			932	5.123	8.864	1931.90	938.00	1931.29	8.849	5.211
175	164	6.307	8.870			931	5.646	8.865	1931.94	937.51	1931.37	8.832	5.184
176	165	6.214	8.865			930	5.287	8.812	1931.98	937.02	1931.46	8.816	5.156
177	166	6.154	8.878			929	5.375	8.837	1932.01	936.53	1931.54	8.807	5.120
178	167	6.703	8.929			928	5.466	8.839	1932.05	936.04	1931.62	8.798	5.084
179	168	6.956	8.938	1992.12	L	927	5.069	8.849	1932.09	935.52	1931.71	8.804	5.034
180	169	7.052	8.925			926	5.224	8.879	1932.12	935.00	1931.79	8.812	4.983
181	170	8.014	8.929			925	4.803	8.878	1932.24	932.89	1931.87	8.836	5.074
182	171	6.518	8.932			924	5.007	8.854	1932.35	930.58	1931.96	8.843	5.496
183	172	7.228	8.923			923	5.334	8.836	1932.46	928.25	1932.04	8.839	5.443
184	173	7.937	8.892			922	5.251	8.880	1932.57	925.97	1932.12	8.879	5.212
185	174	8.647	8.911			921	5.211	8.846	1932.68	925.28	1932.21	8.878	4.920
186	175	6.670	8.851			920	5.131	8.769	1932.79	924.55	1932.29	8.867	4.896
187	176	6.295	8.830			919	5.504	8.804	1932.85	923.79	1932.37	8.850	5.076
188	177	6.992	8.816	1991.79	H	918	5.386	8.799	1932.90	923.03	1932.46	8.837	5.324
189	178	5.887	8.823			917	5.411	8.839	1932.96	922.27	1932.54	8.868	5.274
190	179	6.013	8.855			916	5.312	8.863	1933.01	921.52	1932.62	8.864	5.232
191	180	6.139	8.860			915	5.609	8.912	1933.07	920.76	1932.71	8.827	5.192
192	181	5.919	8.875			914	5.137	8.917	1933.12	920.00	1932.79	8.769	5.131
193	182	5.838	8.917			913	5.333	8.869	1933.24	918.53	1932.87	8.802	5.449
194	183	6.037	8.973	1991.12	L	912	5.428	8.842	1933.35	917.06	1932.96	8.837	5.410
195	184	5.943	8.966			911	5.284	8.818	1933.46	915.50	1933.04	8.888	5.461
196	185	5.761	8.967			910	5.289	8.803	1933.57	913.97	1933.12	8.916	5.142

Appendix B.2
trace elemental data for coral core from Archipelago Los Roques (Roq6) and age model

						1st interpolation				2nd interpolation			
sample ID	new no.	Mg/Ca (mmol/mol)	Sr/Ca (mmol/mol)	timemarker year.month	anchor High/Low	new no.	Mg/Ca (mmol/mol)	Sr/Ca (mmol/mol)	timemarker year.month	new no.	timemarker year.month	Sr/Ca (mmol/mol)	Mg/Ca (mmol/mol)
197	186	5.936	8.933			909	5.313	8.777	1933.68	913.28	1933.21	8.882	5.279
198	187	6.078	8.867			908	5.231	8.745	1933.79	912.55	1933.29	8.857	5.376
199	188	6.149	8.779			907	5.050	8.777	1933.86	911.79	1933.37	8.837	5.397
200	189	5.619	8.805			906	5.363	8.781	1933.93	911.03	1933.46	8.819	5.288
201	190	6.040	8.831			905	5.507	8.822	1933.99	910.27	1933.54	8.807	5.288
202	191	5.518	8.781	1990.79	H	904	4.912	8.854	1934.06	909.52	1933.62	8.790	5.301
203	192	5.530	8.845			903	4.728	8.961	1934.12	908.76	1933.71	8.769	5.293
204	193	5.480	8.828			902	4.982	8.928	1934.20	908.00	1933.79	8.745	5.231
205	194	6.147	8.867			901	4.894	8.875	1934.27	906.81	1933.87	8.778	5.110
206	195	5.625	8.904			900	4.836	8.916	1934.35	905.56	1933.96	8.799	5.427
207	196	5.669	8.913			899	4.704	8.869	1934.42	904.29	1934.04	8.845	5.082
208	197	6.141	8.950			898	4.698	8.887	1934.50	902.96	1934.12	8.960	4.739
209	198	5.851	8.968	1990.12	L	897	4.740	8.867	1934.57	901.91	1934.21	8.923	4.974
210	199	6.029	8.928			896	4.920	8.839	1934.64	900.75	1934.29	8.885	4.880
211	200	6.131	8.942			895	4.784	8.856	1934.72	899.67	1934.37	8.900	4.792
212	201	5.833	8.874			894	4.715	8.799	1934.79	898.54	1934.46	8.877	4.701
213	202	5.987	8.887			893	4.659	8.873	1934.88	897.43	1934.54	8.876	4.722
214	203	6.151	8.895			892	4.751	8.820	1934.96	896.24	1934.62	8.846	4.877
215	204	5.939	8.861			891	4.818	8.874	1935.04	895.17	1934.71	8.853	4.807
216	205	5.512	8.896			890	5.237	8.899	1935.12	894.00	1934.79	8.799	4.715
217	206	5.544	8.841	1989.79	H	889	4.743	8.896	1935.26	893.07	1934.87	8.868	4.663
218	207	5.908	8.896			888	4.920	8.892	1935.39	892.04	1934.96	8.822	4.747
219	208	5.692	8.895			887	5.234	8.884	1935.53	891.00	1935.04	8.874	4.818
220	209	6.309	8.933	1989.12	L	886	4.911	8.810	1935.66	889.98	1935.12	8.899	5.225
221	210	7.193	8.895			885	4.931	8.814	1935.79	889.38	1935.21	8.897	4.931
222	211	7.348	8.856			884	5.024	8.832	1935.86	888.77	1935.29	8.895	4.784
1126	212	6.832	8.908			883	5.162	8.880	1935.93	888.13	1935.37	8.893	4.897
1127	213	6.091	8.887			882	5.209	8.888	1935.99	887.52	1935.46	8.888	5.070
1128	214	6.194	8.909			881	5.002	8.944	1936.06	886.92	1935.54	8.878	5.209
1129	215	5.557	8.864	1988.79	H	880	5.126	8.963	1936.12	886.28	1935.62	8.831	5.002
1130	216	5.794	8.867			879	5.346	8.924	1936.24	885.64	1935.71	8.811	4.918
1131	217	5.629	8.902			878	4.997	8.886	1936.35	885.00	1935.79	8.814	4.931
1132	218	5.470	8.933			877	5.087	8.887	1936.46	883.81	1935.87	8.841	5.050
1133	219	5.485	8.954			876	5.351	8.809	1936.57	882.56	1935.96	8.884	5.183
1134	220	5.094	9.044	1988.12	L	875	5.407	8.824	1936.68	881.29	1936.04	8.928	5.061
1135	221	5.218	9.023			874	5.618	8.808	1936.79	879.97	1936.12	8.962	5.132
1136	222	5.421	8.999			873	5.019	8.843	1936.88	879.28	1936.21	8.935	5.285
1137	223	5.354	8.996			872	5.440	8.863	1936.96	878.55	1936.29	8.907	5.187
1138	224	5.237	8.988			871	5.047	8.916	1937.04	877.79	1936.37	8.886	5.016
1139	225	5.488	8.939			870	5.063	8.974	1937.12	877.03	1936.46	8.887	5.084
1140	226	7.413	8.943			869	4.857	8.955	1937.22	876.27	1936.54	8.830	5.279
1141	227	5.850	8.890			868	4.860	8.931	1937.32	875.52	1936.62	8.816	5.378
1142	228	5.725	8.933			867	4.625	8.925	1937.41	874.76	1936.71	8.820	5.458
1143	229	5.593	8.884			866	4.744	8.867	1937.51	874.00	1936.79	8.808	5.618
1144	230	5.460	8.850	1987.79	H	865	5.079	8.819	1937.60	873.07	1936.87	8.840	5.063
1145	231	5.577	8.841			864	5.062	8.747	1937.70	872.04	1936.96	8.862	5.422
1146	232	5.395	8.870			863	4.948	8.742	1937.79	871.00	1937.04	8.916	5.047
1147	233	5.476	8.884			862	4.870	8.764	1937.88	869.97	1937.12	8.973	5.056
1148	234	5.786	8.920			861	5.419	8.860	1937.96	869.13	1937.21	8.958	4.884
1149	235	6.053	8.940			860	5.491	8.930	1938.04	868.30	1937.29	8.938	4.859
1150	236	5.566	8.989	1987.12	L	859	5.187	8.960	1938.12	867.41	1937.37	8.927	4.721
1151	237	5.444	8.952			858	5.148	8.930	1938.24	866.53	1937.46	8.898	4.681
1152	238	5.480	8.967			857	5.153	8.953	1938.35	865.67	1937.54	8.851	4.856
1153	239	5.335	8.985			856	5.064	8.905	1938.46	864.77	1937.62	8.802	5.075
1154	240	5.498	8.949			855	4.995	8.876	1938.57	863.93	1937.71	8.747	5.054
1155	241	5.358	8.928			854	5.220	8.871	1938.68	863.00	1937.79	8.742	4.948
1156	242	6.151	8.919			853	5.196	8.829	1938.79	862.07	1937.87	8.762	4.876
1157	243	5.521	8.870			852	5.328	8.861	1938.86	861.04	1937.96	8.856	5.396
1158	244	5.523	8.868			851	5.547	8.894	1938.93	860.00	1938.04	8.930	5.491
1159	245	5.502	8.849	1986.79	H	850	5.311	8.937	1938.99	858.97	1938.12	8.959	5.186
1160	246	5.595	8.888			849	5.629	8.974	1939.06	858.28	1938.21	8.938	5.159
1161	247	6.246	8.897			848	5.365	9.017	1939.12	857.55	1938.29	8.940	5.150
1162	248	5.754	8.933			847	5.002	8.998	1939.24	856.79	1938.37	8.943	5.134
1163	249	5.430	8.933			846	5.865	9.004	1939.35	856.03	1938.46	8.906	5.067
1164	250	5.675	8.910			845	5.288	8.922	1939.46	855.27	1938.54	8.884	5.014
1165	251	5.349	8.927			844	5.109	8.925	1939.57	854.52	1938.62	8.874	5.104
263	252	5.911	8.920			843	5.122	8.909	1939.68	853.76	1938.71	8.861	5.214
264	253	6.320	8.966	1986.12	L	842	5.246	8.854	1939.79	853.00	1938.79	8.829	5.196
265	254	6.947	8.924			841	5.061	8.846	1939.88	851.81	1938.87	8.867	5.370
266	255	6.263	8.844			840	5.306	8.891	1939.96	850.56	1938.96	8.913	5.442
267	256	5.897	8.836			839	5.353	8.927	1940.04	849.29	1939.04	8.963	5.538
268	257	5.482	8.813			838	5.034	8.967	1940.12	847.97	1939.12	9.016	5.355
269	258	5.194	8.825	1985.79	H	837	5.087	8.948	1940.22	847.28	1939.21	9.003	5.103
270	259	6.018	8.841			836	5.165	8.903	1940.32	846.55	1939.29	9.001	5.394
271	260	5.480	8.833			835	5.063	8.914	1940.41	845.79	1939.37	8.987	5.743
272	261	5.740	8.828			834	5.045	8.893	1940.51	845.03	1939.46	8.924	5.305
273	262	5.677	8.858			833	4.896	8.915	1940.60	844.27	1939.54	8.924	5.158
274	263	5.619	8.909			832	4.782	8.875	1940.70	843.52	1939.62	8.917	5.115
275	264	6.046	8.921			831	4.904	8.823	1940.79	842.76	1939.71	8.896	5.152
276	265	6.120	8.960	1985.12	L	830	4.971	8.814	1940.86	842.00	1939.79	8.854	5.246
277	266	7.200	8.953			829	4.958	8.904	1940.93	841.07	1939.87	8.847	5.075
278	267	5.775	8.869			828	4.928	8.860	1940.99	840.04	1939.96	8.889	5.296
279	268	5.469	8.827			827	4.882	8.937	1941.06	839.00	1940.04	8.927	5.353
280	269	5.355	8.787	1984.79	H	826	4.954	8.959	1941.12	837.97	1940.12	8.966	5.036
281	270	5.519	8.797			825	4.729	8.910	1941.24	837.13	1940.21	8.951	5.080
282	271	5.604	8.817			824	4.792	8.939	1941.35	836.30	1940.29	8.917	5.142
283	272	5.984	8.848			823	5.098	8.914	1941.46	835.41	1940.37	8.910	5.105
284	273	5.795	8.880			822	5.148	8.896	1941.57	834.53	1940.46	8.904	5.055
285	274	5.626	8.890			821	5.203	8.893	1941.68	833.67	1940.54	8.900	4.995
286	275	5.968	8.933			820	4.992	8.883	1941.79	832.77	1940.62	8.906	4.869
287	276	5.556	8.948			819	5.055	8.897	1941.86	831.93	1940.71	8.871	4.791
288	277	5.762	8.942			818	5.065	8.868	1941.93	831.00	1940.79	8.823	4.904
289	278	6.286	8.959	1984.12	L	817	5.251	8.877	1941.99	829.81	1940.87	8.831	4.969
290	279	6.276	8.888			816	5.478	8.896	1942.06	828.56	1940.96	8.884	4.945

Appendix B.2
trace elemental data for coral core from Archipelago Los Roques (Roq6) and age model

sample ID	new no.	Mg/Ca (mmol/mol)	Sr/Ca (mmol/mol)	timemarker year.month	anchor High/Low	1st interpolation new no.	Mg/Ca (mmol/mol)	Sr/Ca (mmol/mol)	timemarker year.month	2nd interpolation new no.	timemarker year.month	Sr/Ca (mmol/mol)	Mg/Ca (mmol/mol)
291	280	5.435	8.900			815	5.283	8.960	1942.12	827.29	1941.04	8.915	4.895
292	281	5.602	8.910			814	5.451	8.940	1942.29	825.97	1941.12	8.958	4.948
293	282	5.426	8.901			813	5.389	8.936	1942.46	825.28	1941.21	8.924	4.792
294	283	5.261	8.841			812	5.331	8.855	1942.63	824.55	1941.29	8.923	4.758
295	284	4.976	8.838			811	5.205	8.817	1942.79	823.79	1941.37	8.934	4.857
296	285	4.748	8.803	1983.79	H	810	5.163	8.846	1942.84	823.03	1941.46	8.915	5.089
297	286	4.839	8.827			809	5.326	8.836	1942.89	822.27	1941.54	8.901	5.134
298	287	5.125	8.818			808	5.365	8.836	1942.93	821.52	1941.62	8.895	5.175
299	288	5.294	8.811			807	5.576	8.832	1942.98	820.76	1941.71	8.891	5.152
300	289	5.847	8.881			806	5.347	8.830	1943.03	820.00	1941.79	8.883	4.992
301	290	6.060	8.886			805	5.580	8.822	1943.08	818.81	1941.87	8.891	5.057
302	291	5.529	8.904			804	5.519	8.883	1943.12	817.56	1941.96	8.872	5.148
303	292	5.930	8.912			803	5.461	8.881	1943.21	816.29	1942.04	8.891	5.413
304	293	6.289	8.940			802	5.514	8.878	1943.29	814.98	1942.12	8.960	5.286
305	294	6.149	8.912			801	5.411	8.865	1943.38	814.49	1942.21	8.950	5.369
306	295	5.912	8.957	1983.12	L	800	5.326	8.852	1943.46	814.00	1942.29	8.940	5.451
307	296	5.559	8.937			799	5.369	8.843	1943.54	813.51	1942.37	8.938	5.421
308	297	6.302	8.917			798	5.343	8.815	1943.63	813.02	1942.46	8.936	5.390
309	298	6.128	8.953			797	5.503	8.813	1943.71	812.53	1942.54	8.898	5.362
310	299	6.337	8.887			796	5.184	8.781	1943.79	812.04	1942.62	8.858	5.333
311	300	5.580	8.805	1982.79	H	795	5.269	8.816	1943.88	811.52	1942.71	8.837	5.271
312	301	5.333	8.892			794	5.388	8.838	1943.96	811.00	1942.79	8.817	5.205
313	302	5.390	8.907			793	5.150	8.845	1944.04	809.33	1942.87	8.839	5.272
314	303	4.925	8.879			792	5.372	8.887	1944.12	807.47	1942.96	8.834	5.478
315	304	5.224	8.896			791	5.042	8.883	1944.22	805.80	1943.04	8.828	5.394
316	305	5.208	8.927			790	5.218	8.885	1944.32	803.96	1943.12	8.883	5.517
317	306	5.642	8.927			789	5.345	8.866	1944.41	803.04	1943.21	8.881	5.463
318	307	6.607	8.979	1982.12	L	788	5.006	8.851	1944.51	802.00	1943.29	8.878	5.514
319	308	6.108	8.935			787	5.164	8.865	1944.60	801.07	1943.37	8.866	5.419
320	309	6.049	8.922			786	5.048	8.849	1944.70	800.04	1943.46	8.853	5.330
321	310	5.399	8.874			785	5.373	8.827	1944.79	799.00	1943.54	8.843	5.369
322	311	5.921	8.870			784	5.179	8.822	1944.88	798.07	1943.62	8.817	5.345
323	312	5.620	8.838			783	5.499	8.886	1944.96	797.04	1943.71	8.813	5.496
324	313	5.629	8.814			782	6.174	8.947	1945.04	796.00	1943.79	8.781	5.184
325	314	5.972	8.802	1981.79	H	781	5.550	9.003	1945.12	795.07	1943.87	8.813	5.263
326	315	5.787	8.831			780	5.611	8.994	1945.26	794.04	1943.96	8.837	5.383
327	316	5.808	8.824			779	5.428	8.956	1945.39	793.00	1944.04	8.845	5.150
328	317	5.610	8.823			778	5.241	8.901	1945.53	791.97	1944.12	8.887	5.361
329	318	5.799	8.831			777	5.109	8.839	1945.66	791.13	1944.21	8.884	5.086
330	319	5.834	8.877			776	5.060	8.840	1945.79	790.30	1944.29	8.884	5.165
331	320	5.934	8.887			775	5.259	8.844	1945.85	789.41	1944.37	8.874	5.293
332	321	6.186	8.872			774	5.371	8.908	1945.90	788.53	1944.46	8.859	5.187
333	322	6.082	8.887			773	5.218	8.904	1945.96	787.67	1944.54	8.856	5.059
334	323	6.226	8.872			772	5.119	8.936	1946.01	786.77	1944.62	8.861	5.137
335	324	6.620	8.971	1981.12	L	771	5.330	8.955	1946.07	785.93	1944.71	8.847	5.072
336	325	5.907	8.945			770	5.103	8.957	1946.12	785.00	1944.79	8.827	5.373
337	326	6.800	8.923			769	5.308	8.845	1946.26	784.07	1944.87	8.822	5.193
338	327	6.970	8.906			768	5.150	8.863	1946.39	783.04	1944.96	8.883	5.486
339	328	6.286	8.956			767	5.100	8.857	1946.53	782.00	1945.04	8.947	6.174
340	329	7.076	8.897			766	5.202	8.857	1946.66	780.98	1945.12	9.003	5.551
341	330	6.593	8.929			765	5.236	8.829	1946.79	780.38	1945.21	8.997	5.588
342	331	5.946	8.912			764	5.483	8.838	1946.88	779.77	1945.29	8.985	5.569
343	332	5.775	8.884			763	6.012	8.854	1946.96	779.13	1945.37	8.961	5.451
344	333	5.732	8.856			762	5.685	8.919	1947.04	778.52	1945.46	8.930	5.339
345	334	5.951	8.849			761	6.128	9.015	1947.12	777.92	1945.54	8.896	5.231
346	335	6.438	8.884			760	6.115	8.976	1947.29	777.28	1945.62	8.856	5.146
347	336	5.917	8.816	1980.79	H	759	5.499	8.959	1947.46	776.64	1945.71	8.839	5.091
348	337	5.748	8.854			758	5.158	8.872	1947.63	776.00	1945.79	8.840	5.060
349	338	5.401	8.816			757	4.970	8.824	1947.79	774.53	1945.87	8.874	5.311
350	339	5.695	8.878			756	5.264	8.845	1947.86	773.06	1945.96	8.904	5.227
351	340	5.364	8.867			755	4.995	8.875	1947.93	771.50	1946.04	8.946	5.225
352	341	5.334	8.935			754	4.822	8.879	1947.99	769.98	1946.12	8.954	5.108
353	342	5.528	8.883			753	5.045	8.882	1948.06	769.38	1946.21	8.888	5.230
354	343	5.741	8.954			752	5.393	9.020	1948.12	768.77	1946.29	8.849	5.272
355	344	5.530	8.990	1980.12	L	751	5.111	8.874	1948.24	768.13	1946.37	8.861	5.170
356	345	5.391	8.907			750	4.965	8.872	1948.35	767.52	1946.46	8.860	5.126
357	346	5.607	8.899			749	5.099	8.854	1948.46	766.92	1946.54	8.857	5.108
358	347	5.471	8.837			748	5.023	8.836	1948.57	766.28	1946.62	8.857	5.173
359	348	5.373	8.847			747	4.996	8.829	1948.68	765.64	1946.71	8.847	5.214
360	349	5.318	8.870			746	5.092	8.807	1948.79	765.00	1946.79	8.829	5.236
361	350	5.274	8.838	1979.79	H	745	5.450	8.857	1948.85	764.07	1946.87	8.837	5.465
362	351	5.034	8.843			744	5.501	8.843	1948.90	763.04	1946.96	8.853	5.990
363	352	5.846	8.841			743	5.222	8.914	1948.96	762.00	1947.04	8.919	5.685
364	353	5.274	8.864			742	5.253	8.935	1949.01	760.98	1947.12	9.014	6.128
365	354	5.753	8.865			741	5.705	8.923	1949.07	760.49	1947.21	8.995	6.121
366	355	5.470	8.912			740	5.390	8.960	1949.12	760.00	1947.29	8.976	6.115
367	356	5.090	8.884			739	5.236	8.925	1949.26	759.51	1947.37	8.968	5.813
368	357	5.139	8.871			738	5.078	8.875	1949.39	759.02	1947.46	8.959	5.511
369	358	5.634	8.916			737	5.261	8.892	1949.53	758.53	1947.54	8.918	5.339
370	359	5.352	8.974	1979.12	L	736	5.284	8.815	1949.66	758.04	1947.62	8.875	5.171
371	360	5.869	8.904			735	5.203	8.823	1949.79	757.52	1947.71	8.849	5.068
372	361	5.402	8.925			734	5.505	8.867	1949.86	757.00	1947.79	8.824	4.970
373	362	5.559	8.895			733	5.528	8.878	1949.93	755.81	1947.87	8.851	5.213
374	363	5.331	8.865			732	5.433	8.899	1949.99	754.56	1947.96	8.877	4.918
375	364	5.514	8.867			731	5.490	8.896	1950.06	753.29	1948.04	8.881	4.981
376	365	5.808	8.844			730	5.706	8.899	1950.12	751.97	1948.12	9.016	5.385
377	366	5.533	8.821			729	4.932	8.876	1950.26	751.28	1948.21	8.915	5.189
378	367	5.468	8.813	1978.79	H	728	5.234	8.876	1950.39	750.55	1948.29	8.873	5.045
379	368	5.526	8.836			727	5.331	8.852	1950.53	749.79	1948.37	8.868	4.993
380	369	5.511	8.880			726	5.265	8.838	1950.66	749.03	1948.46	8.855	5.095
381	370	5.356	8.897			725	5.448	8.812	1950.79	748.27	1948.54	8.841	5.044
382	371	5.195	8.873			724	5.518	8.857	1950.90	747.52	1948.62	8.833	5.010
383	372	5.170	8.902			723	5.390	8.930	1951.01	746.76	1948.71	8.824	5.019
384	373	5.081	8.907			722	5.420	8.954	1951.12	746.00	1948.79	8.807	5.092

Appendix B.2
trace elemental data for coral core from Archipelago Los Roques (Roq6) and age model

						1st interpolation				2nd interpolation			
sample ID	new no.	Mg/Ca (mmol/mol)	Sr/Ca (mmol/mol)	timemarker year.month	anchor High/Low	new no.	Mg/Ca (mmol/mol)	Sr/Ca (mmol/mol)	timemarker year.month	new no.	timemarker year.month	Sr/Ca (mmol/mol)	Mg/Ca (mmol/mol)
385	374	5.118	8.915			721	5.740	8.937	1951.24	744.53	1948.87	8.850	5.474
386	375	5.666	8.904			720	6.017	8.888	1951.35	743.06	1948.96	8.910	5.238
387	376	5.642	8.959	1978.12	L	719	5.435	8.890	1951.46	741.50	1949.04	8.929	5.479
388	377	5.868	8.941			718	5.943	8.879	1951.57	739.98	1949.12	8.959	5.386
389	378	5.570	8.906			717	5.533	8.871	1951.68	739.38	1949.21	8.938	5.295
390	379	5.730	8.887			716	5.229	8.861	1951.79	738.77	1949.29	8.913	5.200
391	380	5.753	8.883			715	5.343	8.868	1951.86	738.13	1949.37	8.881	5.098
392	381	5.429	8.923			714	5.397	8.878	1951.93	737.52	1949.46	8.883	5.165
393	382	5.580	8.821	1977.79	H	713	5.139	8.926	1951.99	736.92	1949.54	8.886	5.263
394	383	5.637	8.886			712	4.987	8.988	1952.06	736.28	1949.62	8.837	5.278
395	384	5.793	8.833			711	5.377	9.012	1952.12	735.64	1949.71	8.818	5.255
396	385	5.855	8.924			710	5.267	8.927	1952.26	735.00	1949.79	8.823	5.203
397	386	5.954	8.915			709	5.479	8.924	1952.39	733.81	1949.87	8.869	5.509
398	387	5.755	8.888			708	5.470	8.877	1952.53	732.56	1949.96	8.887	5.486
399	388	5.665	8.955			707	5.210	8.838	1952.66	731.29	1950.04	8.897	5.474
400	389	6.084	8.935			706	5.441	8.784	1952.79	729.98	1950.12	8.898	5.688
401	390	5.983	8.949			705	5.434	8.812	1952.88	729.38	1950.21	8.885	5.227
402	391	5.703	8.987	1977.12	L	704	6.220	8.899	1952.96	728.77	1950.29	8.876	5.002
403	392	5.747	8.959			703	5.463	8.908	1953.04	728.13	1950.37	8.876	5.195
404	393	5.458	8.942			702	5.664	8.924	1953.12	727.52	1950.46	8.865	5.280
405	394	5.787	8.920			701	5.525	8.893	1953.24	726.92	1950.54	8.851	5.326
406	395	5.393	8.808			700	5.652	8.830	1953.35	726.28	1950.62	8.842	5.284
407	396	5.065	8.817	1976.79	H	699	5.528	8.857	1953.46	725.64	1950.71	8.829	5.331
408	397	5.198	8.842			698	6.100	8.911	1953.57	725.00	1950.79	8.812	5.448
409	398	5.549	8.869			697	5.248	8.847	1953.68	724.24	1950.87	8.846	5.501
410	399	5.808	8.844			696	6.044	8.826	1953.79	723.49	1950.96	8.895	5.452
411	400	5.428	8.853			695	6.375	8.883	1953.86	722.73	1951.04	8.937	5.398
412	401	5.342	8.886			694	6.091	8.902	1953.93	721.97	1951.12	8.954	5.429
413	402	5.481	8.945			693	6.178	8.945	1953.99	721.28	1951.21	8.942	5.651
414	403	5.223	8.928			692	5.950	8.966	1954.06	720.55	1951.29	8.915	5.866
415	404	5.281	8.943	1976.12	L	691	5.625	9.004	1954.12	719.79	1951.37	8.888	5.894
416	405	5.573	8.933			690	5.529	8.968	1954.24	719.03	1951.46	8.890	5.453
417	406	5.457	8.912			689	5.799	8.956	1954.35	718.27	1951.54	8.882	5.804
418	407	5.234	8.936			688	5.746	8.912	1954.46	717.52	1951.62	8.875	5.744
419	408	5.386	8.914			687	5.760	8.914	1954.57	716.76	1951.71	8.869	5.459
420	409	6.065	8.936			686	6.408	8.868	1954.68	716.00	1951.79	8.861	5.229
421	410	5.599	8.854			685	5.775	8.837	1954.79	714.81	1951.87	8.870	5.353
422	411	5.337	8.845			684	5.789	8.873	1954.86	713.56	1951.96	8.899	5.282
423	412	5.135	8.789	1975.79	H	683	5.517	8.883	1954.93	712.29	1952.04	8.970	5.030
424	413	5.348	8.816			682	5.885	8.913	1954.99	710.98	1952.12	9.010	5.374
425	414	5.934	8.863			681	6.353	8.984	1955.06	710.38	1952.21	8.959	5.309
426	415	5.915	8.866			680	5.474	8.989	1955.12	709.77	1952.29	8.926	5.316
427	416	5.762	8.881			679	5.446	8.957	1955.26	709.13	1952.37	8.924	5.452
428	417	5.553	8.947			678	5.821	8.935	1955.39	708.52	1952.46	8.902	5.475
429	418	5.873	8.960			677	5.610	8.847	1955.53	707.92	1952.54	8.874	5.450
430	419	5.939	8.977			676	5.474	8.838	1955.66	707.28	1952.62	8.849	5.283
431	420	5.888	9.053	1975.12	L	675	5.616	8.811	1955.79	706.64	1952.71	8.819	5.293
432	421	6.042	8.994			674	5.381	8.861	1955.86	706.00	1952.79	8.784	5.441
433	422	5.390	9.002			673	5.580	8.905	1955.93	705.07	1952.87	8.810	5.435
434	423	5.899	8.960			672	5.779	8.948	1955.99	704.04	1952.96	8.895	6.187
435	424	5.836	8.959			671	5.461	8.953	1956.06	703.00	1953.04	8.908	5.463
436	425	5.984	8.908			670	5.344	8.993	1956.12	701.97	1953.12	8.923	5.660
437	426	5.495	8.874			669	5.536	8.972	1956.24	701.28	1953.21	8.902	5.564
438	427	5.058	8.836			668	5.783	8.978	1956.35	700.55	1953.29	8.864	5.583
439	428	5.120	8.890			667	5.744	8.925	1956.46	699.79	1953.37	8.836	5.626
440	429	5.479	8.833	1974.79	H	666	4.742	8.892	1956.57	699.03	1953.46	8.856	5.532
441	430	5.299	8.882			665	5.205	8.834	1956.68	698.27	1953.54	8.896	5.944
442	431	5.340	8.927			664	5.292	8.815	1956.79	697.52	1953.62	8.880	5.687
443	432	5.622	8.958			663	5.364	8.833	1956.85	696.76	1953.71	8.842	5.441
444	433	5.283	8.945			662	5.484	8.801	1956.90	696.00	1953.79	8.826	6.044
445	434	5.171	9.012			661	5.846	8.862	1956.96	694.81	1953.87	8.887	6.321
446	435	5.518	9.013			660	7.272	8.887	1957.01	693.56	1953.96	8.921	6.130
447	436	5.275	9.017	1974.12	L	659	5.654	8.907	1957.07	692.29	1954.04	8.960	6.015
448	437	4.964	8.989			658	6.117	8.951	1957.12	690.97	1954.12	9.003	5.622
449	438	5.271	8.987			657	5.518	8.947	1957.22	690.28	1954.21	8.978	5.556
450	439	5.103	8.995			656	5.645	8.936	1957.32	689.55	1954.29	8.963	5.652
451	440	5.392	8.987			655	6.024	8.918	1957.41	688.79	1954.37	8.947	5.788
452	441	5.014	8.987			654	5.714	8.850	1957.51	688.03	1954.46	8.913	5.748
453	442	5.328	8.970			653	5.584	8.814	1957.60	687.27	1954.54	8.913	5.756
454	443	5.062	8.952			652	5.332	8.853	1957.70	686.52	1954.62	8.892	6.074
455	444	5.041	8.909			651	5.261	8.806	1957.79	685.76	1954.71	8.860	6.255
456	445	5.105	8.895	1973.79	H	650	5.313	8.813	1957.88	685.00	1954.79	8.837	5.775
457	446	5.132	8.904			649	5.511	8.835	1957.96	683.81	1954.87	8.875	5.737
458	447	5.204	8.942			648	5.410	8.874	1958.04	682.56	1954.96	8.896	5.681
459	448	5.270	9.009			647	5.623	8.884	1958.12	681.29	1955.04	8.964	6.219
460	449	5.083	9.022			646	5.820	8.884	1958.26	679.98	1955.12	8.988	5.473
461	450	5.782	9.031			645	5.488	8.863	1958.39	679.38	1955.21	8.969	5.457
462	451	5.908	9.024			644	5.455	8.841	1958.53	678.77	1955.29	8.952	5.533
463	452	5.827	9.033			643	5.362	8.779	1958.66	678.13	1955.37	8.938	5.773
464	453	6.104	9.036	1973.12	L	642	5.588	8.782	1958.79	677.52	1955.46	8.893	5.721
465	454	7.776	9.005			641	5.629	8.827	1958.85	676.92	1955.54	8.846	5.600
1256	455	5.570	8.963			640	5.392	8.887	1958.90	676.28	1955.62	8.841	5.512
1257	456	6.003	8.937			639	5.861	8.866	1958.96	675.64	1955.71	8.828	5.525
1258	457	5.888	8.887			638	5.492	8.859	1959.01	675.00	1955.79	8.811	5.616
1259	458	5.907	8.913			637	6.123	8.909	1959.07	673.81	1955.87	8.869	5.419
1260	459	5.616	8.870	1972.79	H	636	6.391	8.947	1959.12	672.56	1955.96	8.924	5.668
1261	460	5.578	8.877			635	6.255	8.943	1959.22	671.29	1956.04	8.952	5.552
1263	461	5.316	8.918			634	5.781	8.893	1959.32	669.97	1956.12	8.992	5.349
1264	462	5.345	8.955			633	5.747	8.839	1959.41	669.28	1956.21	8.978	5.483
1265	463	5.153	8.957			632	5.654	8.844	1959.51	668.55	1956.29	8.975	5.648
1266	464	5.075	8.946			631	5.409	8.837	1959.60	667.79	1956.37	8.967	5.775
1267	465	5.890	9.027			630	5.287	8.821	1959.70	667.03	1956.46	8.927	5.745
1268	466	5.418	9.017			629	5.252	8.804	1959.79	666.27	1956.54	8.901	5.015
1269	467	5.371	9.016			628	5.552	8.860	1959.85	665.52	1956.62	8.864	4.966

Appendix B.2
trace elemental data for coral core from Archipelago Los Roques (Roq6) and age model

						1st interpolation				2nd interpolation			
sample ID	new no.	Mg/Ca (mmol/mol)	Sr/Ca (mmol/mol)	timemarker year.month	anchor High/Low	new no.	Mg/Ca (mmol/mol)	Sr/Ca (mmol/mol)	timemarker year.month	new no.	timemarker year.month	Sr/Ca (mmol/mol)	Mg/Ca (mmol/mol)
1271	468	5.871	9.029			627	5.889	8.874	1959.90	664.76	1956.71	8.829	5.226
1272	469	6.193	9.056	1972.12	L	626	6.152	8.860	1959.96	664.00	1956.79	8.815	5.292
1273	470	6.060	9.047			625	5.774	8.884	1960.01	662.53	1956.87	8.818	5.420
1274	471	6.121	9.005			624	5.971	8.912	1960.07	661.06	1956.96	8.859	5.826
1275	472	6.340	9.016			623	6.081	8.933	1960.12	659.50	1957.04	8.897	6.463
1276	473	5.604	8.929			622	6.222	8.920	1960.24	657.97	1957.12	8.951	6.097
1277	474	5.536	8.888	1971.79	H	621	6.113	8.894	1960.35	657.13	1957.21	8.948	5.598
1278	475	5.446	8.900			620	6.172	8.859	1960.46	656.30	1957.29	8.939	5.607
1279	476	5.790	8.907			619	6.737	8.886	1960.57	655.41	1957.37	8.925	5.870
1280	477	5.595	8.965			618	5.283	8.880	1960.68	654.53	1957.46	8.886	5.879
1282	478	4.966	8.956			617	5.512	8.824	1960.79	653.67	1957.54	8.838	5.671
1283	479	5.417	8.971			616	5.456	8.858	1960.86	652.77	1957.62	8.823	5.525
1285	480	5.284	8.963			615	5.647	8.892	1960.93	651.93	1957.71	8.850	5.327
1286	481	5.309	8.959			614	5.693	8.896	1960.99	651.00	1957.79	8.806	5.261
1287	482	5.448	8.973	1971.12	L	613	5.468	8.876	1961.06	650.07	1957.87	8.812	5.309
1288	483	5.322	8.912			612	5.607	8.962	1961.12	649.04	1957.96	8.834	5.503
1289	484	5.389	8.939			611	5.772	8.938	1961.24	648.00	1958.04	8.874	5.410
1290	485	6.498	8.923			610	5.342	8.877	1961.35	646.98	1958.12	8.884	5.628
1291	486	5.751	8.879			609	5.333	8.900	1961.46	646.38	1958.21	8.884	5.745
1292	487	5.470	8.899			608	5.225	8.851	1961.57	645.77	1958.29	8.879	5.743
1293	488	5.312	8.889			607	5.169	8.829	1961.68	645.13	1958.37	8.866	5.531
1294	489	5.215	8.840			606	5.388	8.806	1961.79	644.52	1958.46	8.853	5.472
1295	490	5.327	8.799	1970.79	H	605	5.270	8.824	1961.85	643.92	1958.54	8.836	5.448
1296	491	5.518	8.822			604	5.647	8.842	1961.90	643.28	1958.62	8.796	5.388
1297	492	5.830	8.849			603	5.976	8.901	1961.96	642.64	1958.71	8.780	5.443
1298	493	6.027	8.887			602	5.442	8.910	1962.01	642.00	1958.79	8.782	5.588
1299	494	6.102	8.863			601	5.835	8.918	1962.07	640.53	1958.87	8.855	5.518
1300	495	5.907	8.892			600	6.263	8.957	1962.12	639.06	1958.96	8.867	5.835
1301	496	6.200	8.930			599	5.120	8.906	1962.22	637.50	1959.04	8.884	5.808
1302	497	6.745	8.996			598	5.130	8.910	1962.32	635.97	1959.12	8.947	6.386
505	498	5.338	9.012			597	5.065	8.879	1962.41	635.13	1959.21	8.944	6.273
506	499	5.682	9.045	1970.12	L	596	5.185	8.860	1962.51	634.30	1959.29	8.908	5.923
507	500	5.589	9.035			595	5.261	8.827	1962.60	633.41	1959.37	8.861	5.761
508	501	5.736	9.041			594	5.331	8.821	1962.70	632.53	1959.46	8.841	5.704
509	502	5.944	8.965			593	5.324	8.823	1962.79	631.67	1959.54	8.842	5.572
510	503	6.012	8.929			592	5.164	8.822	1962.85	630.77	1959.62	8.833	5.381
511	504	5.765	8.920			591	5.476	8.851	1962.90	629.93	1959.71	8.820	5.284
512	505	5.572	8.889	1969.79	H	590	5.909	8.884	1962.96	629.00	1959.79	8.804	5.252
514	506	4.773	8.909			589	5.781	8.944	1963.01	627.53	1959.87	8.867	5.709
516	507	4.788	8.926			588	5.595	8.961	1963.07	626.06	1959.96	8.861	6.137
517	508	5.556	8.923			587	5.498	8.977	1963.12	624.50	1960.04	8.898	5.873
518	509	4.953	8.927			586	5.297	8.954	1963.22	622.97	1960.12	8.933	6.085
519	510	5.408	8.940			585	4.994	8.947	1963.32	622.28	1960.21	8.924	6.183
520	511	5.328	8.967			584	5.028	8.943	1963.41	621.55	1960.29	8.908	6.172
521	512	5.247	8.994			583	5.045	8.923	1963.51	620.79	1960.37	8.887	6.126
522	513	4.956	9.009	1969.12	L	582	5.374	8.904	1963.60	620.03	1960.46	8.860	6.170
523	514	5.189	8.978			581	5.131	8.884	1963.70	619.27	1960.54	8.879	6.583
524	515	4.807	8.955			580	5.373	8.864	1963.79	618.52	1960.62	8.883	6.032
525	516	5.074	8.970			579	6.447	8.958	1963.88	617.76	1960.71	8.866	5.339
526	517	4.569	8.908	1968.79	H	578	6.635	8.985	1963.96	617.00	1960.79	8.824	5.512
527	518	4.620	8.945			577	6.823	9.011	1964.04	615.81	1960.87	8.864	5.492
528	519	4.960	8.923			576	5.902	9.021	1964.12	614.56	1960.96	8.894	5.667
529	520	4.871	8.995			575	5.752	8.944	1964.26	613.29	1961.04	8.882	5.532
530	521	4.840	9.035			574	5.375	8.908	1964.39	611.97	1961.12	8.961	5.612
531	522	4.956	9.042			573	5.137	8.865	1964.53	611.28	1961.21	8.945	5.726
532	523	6.287	9.059	1968.12	L	572	5.262	8.863	1964.66	610.55	1961.29	8.910	5.577
533	524	6.308	9.018			571	4.953	8.868	1964.79	609.79	1961.37	8.882	5.340
534	525	5.754	8.977			570	5.830	8.906	1964.86	609.03	1961.46	8.899	5.333
535	526	5.964	8.981			569	5.405	8.950	1964.93	608.27	1961.54	8.864	5.254
536	527	5.529	8.917			568	6.035	8.978	1964.99	607.52	1961.62	8.840	5.198
537	528	5.577	8.897	1967.79	H	567	6.208	8.984	1965.06	606.76	1961.71	8.823	5.222
538	529	5.142	8.921			566	6.902	9.022	1965.12	606.00	1961.79	8.806	5.388
539	530	5.482	8.944			565	5.815	8.972	1965.22	604.53	1961.87	8.832	5.446
540	531	5.083	8.960			564	5.613	8.939	1965.32	603.06	1961.96	8.898	5.958
541	532	5.198	8.959			563	5.409	8.895	1965.41	601.50	1962.04	8.914	5.639
542	533	5.061	9.014			562	5.539	8.851	1965.51	599.97	1962.12	8.955	6.225
543	534	4.991	8.985			561	5.345	8.876	1965.60	599.13	1962.21	8.913	5.272
544	535	4.937	8.982			560	5.282	8.889	1965.70	598.30	1962.29	8.909	5.127
545	536	4.936	8.979			559	5.514	8.869	1965.79	597.41	1962.37	8.892	5.091
546	537	5.051	9.003			558	5.205	8.865	1965.85	596.53	1962.46	8.870	5.121
547	538	4.942	9.015	1967.12	L	557	5.285	8.858	1965.90	595.67	1962.54	8.849	5.210
548	539	5.023	8.968			556	5.261	8.913	1965.96	594.77	1962.62	8.826	5.277
549	540	5.059	8.942			555	5.299	8.980	1966.01	593.93	1962.71	8.821	5.330
550	541	5.076	8.928			554	5.421	9.003	1966.07	593.00	1962.79	8.823	5.324
551	542	5.015	8.889			553	5.539	9.033	1966.12	591.53	1962.87	8.836	5.310
552	543	5.120	8.871			552	5.564	8.976	1966.22	590.06	1962.96	8.882	5.885
553	544	4.490	8.897			551	5.476	8.971	1966.32	588.50	1963.04	8.953	5.688
554	545	4.947	8.893			550	5.523	8.966	1966.41	586.97	1963.12	8.976	5.491
555	546	5.081	8.873	1966.79	H	549	5.777	8.980	1966.51	586.13	1963.21	8.957	5.324
556	547	5.053	8.885			548	5.357	8.921	1966.60	585.30	1963.29	8.949	5.085
557	548	5.357	8.921			547	5.053	8.885	1966.70	584.41	1963.37	8.945	5.014
558	549	5.777	8.980			546	5.081	8.873	1966.79	583.53	1963.46	8.934	5.036
559	550	5.523	8.966			545	4.947	8.893	1966.83	582.67	1963.54	8.917	5.155
560	551	5.476	8.971			544	4.490	8.897	1966.88	581.77	1963.62	8.899	5.317
561	552	5.564	8.976			543	5.120	8.871	1966.92	580.93	1963.71	8.883	5.149
562	553	5.539	9.033	1966.12	L	542	5.015	8.889	1966.96	580.00	1963.79	8.864	5.373
563	554	5.421	9.003			541	5.076	8.928	1967.00	579.07	1963.87	8.951	6.367
564	555	5.299	8.980			540	5.059	8.942	1967.04	578.04	1963.96	8.984	6.627
565	556	5.261	8.913			539	5.023	8.968	1967.08	577.00	1964.04	9.011	6.823
566	557	5.285	8.858			538	4.942	9.015	1967.12	575.98	1964.12	9.019	5.898
567	558	5.205	8.865			537	5.051	9.003	1967.19	575.38	1964.21	8.973	5.809
568	559	5.514	8.869	1965.79	H	536	4.936	8.979	1967.26	574.77	1964.29	8.936	5.665
569	560	5.282	8.889			535	4.937	8.982	1967.33	574.13	1964.37	8.913	5.423
570	561	5.345	8.876			534	4.991	8.985	1967.39	573.52	1964.46	8.888	5.262

Appendix B.2
trace elemental data for coral core from Archipelago Los Roques (Roq6) and age model

						1st interpolation				2nd interpolation			
sample ID	new no.	Mg/Ca (mmol/mol)	Sr/Ca (mmol/mol)	timemarker year.month	anchor High/Low	new no.	Mg/Ca (mmol/mol)	Sr/Ca (mmol/mol)	timemarker year.month	new no.	timemarker year.month	Sr/Ca (mmol/mol)	Mg/Ca (mmol/mol)
571	562	5.539	8.851			533	5.061	9.014	1967.46	572.92	1964.54	8.865	5.147
572	563	5.409	8.895			532	5.198	8.959	1967.53	572.28	1964.62	8.864	5.227
573	564	5.613	8.939			531	5.083	8.960	1967.59	571.64	1964.71	8.865	5.151
574	565	5.815	8.972			530	5.482	8.944	1967.66	571.00	1964.79	8.868	4.953
575	566	6.902	9.022	1965.12	L	529	5.142	8.921	1967.73	569.81	1964.87	8.914	5.749
576	567	6.208	8.984			528	5.577	8.897	1967.79	568.56	1964.96	8.962	5.685
577	568	6.035	8.978			527	5.529	8.917	1967.86	567.29	1965.04	8.982	6.159
578	569	5.405	8.950			526	5.964	8.981	1967.93	565.97	1965.12	9.020	6.866
579	570	5.830	8.906			525	5.754	8.977	1967.99	565.13	1965.21	8.979	5.960
580	571	4.953	8.868	1964.79	H	524	6.308	9.018	1968.06	564.30	1965.29	8.949	5.674
581	572	5.262	8.863			523	6.287	9.059	1968.12	563.41	1965.37	8.913	5.492
582	573	5.137	8.865			522	4.956	9.042	1968.24	562.53	1965.46	8.874	5.470
583	574	5.375	8.908			521	4.840	9.035	1968.35	561.67	1965.54	8.859	5.474
584	575	5.752	8.944			520	4.871	8.995	1968.46	560.77	1965.62	8.879	5.330
585	576	5.902	9.021	1964.12	L	519	4.960	8.923	1968.57	559.93	1965.71	8.888	5.299
586	577	6.823	9.011			518	4.620	8.945	1968.68	559.00	1965.79	8.869	5.514
587	578	6.635	8.985			517	4.569	8.908	1968.79	557.53	1965.87	8.862	5.242
588	579	6.447	8.958			516	5.074	8.970	1968.88	556.06	1965.96	8.910	5.262
589	580	5.373	8.864	1963.79	H	515	4.807	8.955	1968.96	554.50	1966.04	8.992	5.360
590	581	5.131	8.884			514	5.189	8.978	1969.04	552.97	1966.12	9.031	5.540
591	582	5.374	8.904			513	4.956	9.009	1969.12	552.13	1966.21	8.984	5.561
592	583	5.045	8.923			512	5.247	8.994	1969.21	551.30	1966.29	8.973	5.502
593	584	5.028	8.943			511	5.328	8.967	1969.29	550.41	1966.37	8.968	5.504
594	585	4.994	8.947			510	5.408	8.940	1969.38	549.53	1966.46	8.973	5.642
595	586	5.297	8.954			509	4.953	8.927	1969.46	548.67	1966.54	8.960	5.637
596	587	5.498	8.977	1963.12	L	508	5.556	8.923	1969.54	547.77	1966.62	8.913	5.286
597	588	5.595	8.961			507	4.788	8.926	1969.63	546.93	1966.71	8.884	5.055
598	589	5.781	8.944			506	4.773	8.909	1969.71	546.00	1966.79	8.873	5.081
599	590	5.909	8.884			505	5.572	8.889	1969.79	544.13	1966.87	8.896	4.551
600	591	5.476	8.851			504	5.765	8.920	1969.85	542.08	1966.96	8.888	5.024
601	592	5.164	8.822			503	6.012	8.929	1969.90	540.00	1967.04	8.942	5.059
602	593	5.324	8.823	1962.79	H	502	5.944	8.965	1969.96	537.95	1967.12	9.014	4.947
603	594	5.331	8.821			501	5.736	9.041	1970.01	536.76	1967.21	8.997	5.024
604	595	5.261	8.827			500	5.589	9.035	1970.07	535.57	1967.29	8.980	4.936
605	596	5.185	8.860			499	5.682	9.045	1970.12	534.28	1967.37	8.984	4.976
606	597	5.065	8.879			498	5.338	9.012	1970.20	533.05	1967.46	9.013	5.058
607	598	5.130	8.910			497	6.745	8.996	1970.27	531.83	1967.54	8.959	5.179
608	599	5.120	8.906			496	6.200	8.930	1970.35	530.52	1967.62	8.952	5.273
609	600	6.263	8.957	1962.12	L	495	5.907	8.892	1970.42	529.33	1967.71	8.929	5.255
610	601	5.835	8.918			494	6.102	8.863	1970.50	528.00	1967.79	8.897	5.577
611	602	5.442	8.910			493	6.027	8.887	1970.57	526.81	1967.87	8.929	5.612
612	603	5.976	8.901			492	5.830	8.849	1970.64	525.56	1967.96	8.979	5.871
613	604	5.647	8.842			491	5.518	8.822	1970.72	524.29	1968.04	9.006	6.150
614	605	5.270	8.824			490	5.327	8.799	1970.79	522.97	1968.12	9.059	6.250
615	606	5.388	8.806	1961.79	H	489	5.215	8.840	1970.83	522.28	1968.21	9.047	5.326
616	607	5.169	8.829			488	5.312	8.889	1970.88	521.55	1968.29	9.039	4.903
617	608	5.225	8.851			487	5.470	8.899	1970.92	520.79	1968.37	9.027	4.847
618	609	5.333	8.900			486	5.751	8.879	1970.96	520.03	1968.46	8.996	4.870
619	610	5.342	8.877			485	6.498	8.923	1971.00	519.27	1968.54	8.943	4.936
620	611	5.772	8.938			484	5.389	8.939	1971.04	518.52	1968.62	8.934	4.795
621	612	5.607	8.962	1961.12	L	483	5.322	8.912	1971.08	517.76	1968.71	8.936	4.608
622	613	5.468	8.876			482	5.448	8.973	1971.12	517.00	1968.79	8.908	4.569
623	614	5.693	8.896			481	5.309	8.959	1971.21	516.07	1968.87	8.965	5.037
624	615	5.647	8.892			480	5.284	8.963	1971.29	515.04	1968.96	8.956	4.818
625	616	5.456	8.858			479	5.417	8.971	1971.38	514.00	1969.04	8.978	5.189
626	617	5.512	8.824	1960.79	H	478	4.966	8.956	1971.46	512.96	1969.12	9.008	4.967
627	618	5.283	8.880			477	5.595	8.965	1971.54	512.04	1969.21	8.995	5.236
628	619	6.737	8.886			476	5.790	8.907	1971.63	511.00	1969.29	8.967	5.328
629	620	6.172	8.859			475	5.446	8.900	1971.71	510.07	1969.37	8.942	5.402
630	621	6.113	8.894			474	5.536	8.888	1971.79	509.04	1969.46	8.928	4.972
631	622	6.222	8.920			473	5.604	8.929	1971.86	508.00	1969.54	8.923	5.556
632	623	6.081	8.933	1960.12	L	472	6.340	9.016	1971.93	507.07	1969.62	8.926	4.845
633	624	5.971	8.912			471	6.121	9.005	1971.99	506.04	1969.71	8.910	4.774
634	625	5.774	8.884			470	6.060	9.047	1972.06	505.00	1969.79	8.889	5.572
635	626	6.152	8.860			469	6.193	9.056	1972.12	503.53	1969.87	8.924	5.880
636	627	5.889	8.874			468	5.871	9.029	1972.19	502.06	1969.96	8.963	5.948
637	628	5.552	8.860			467	5.371	9.016	1972.26	500.50	1970.04	9.038	5.663
638	629	5.252	8.804	1959.79	H	466	5.418	9.017	1972.33	498.96	1970.12	9.044	5.668
639	630	5.287	8.821			465	5.890	9.027	1972.39	497.91	1970.21	9.010	5.472
640	631	5.409	8.837			464	5.075	8.946	1972.46	496.75	1970.29	8.980	6.609
641	632	5.654	8.844			463	5.153	8.957	1972.53	495.67	1970.37	8.917	6.102
642	633	5.747	8.839			462	5.345	8.955	1972.59	494.54	1970.46	8.879	5.996
643	634	5.781	8.893			461	5.316	8.918	1972.66	493.43	1970.54	8.877	6.059
644	635	6.255	8.943			460	5.578	8.877	1972.73	492.24	1970.62	8.858	5.877
645	636	6.391	8.947	1959.12	L	459	5.616	8.870	1972.79	491.17	1970.71	8.827	5.570
646	637	6.123	8.909			458	5.907	8.913	1972.85	490.00	1970.79	8.799	5.327
647	638	5.492	8.859			457	5.888	8.887	1972.90	488.13	1970.87	8.882	5.299
648	639	5.861	8.866			456	6.003	8.937	1972.96	486.08	1970.96	8.881	5.728
649	640	5.392	8.887			455	5.570	8.963	1973.01	484.00	1971.04	8.939	5.389
650	641	5.629	8.827			454	7.776	9.005	1973.07	481.96	1971.12	8.972	5.443
651	642	5.588	8.782	1958.79	H	453	6.104	9.036	1973.12	481.04	1971.21	8.960	5.314
652	643	5.362	8.779			452	5.827	9.033	1973.21	480.00	1971.29	8.963	5.284
653	644	5.455	8.841			451	5.908	9.024	1973.29	479.07	1971.37	8.970	5.407
654	645	5.488	8.863			450	5.782	9.031	1973.38	478.04	1971.46	8.957	4.985
655	646	5.820	8.884			449	5.083	9.022	1973.46	477.00	1971.54	8.965	5.595
656	647	5.623	8.884	1958.12	L	448	5.270	9.009	1973.54	476.07	1971.62	8.911	5.776
657	648	5.410	8.874			447	5.204	8.942	1973.63	475.04	1971.71	8.900	5.460
658	649	5.511	8.835			446	5.132	8.904	1973.71	474.00	1971.79	8.888	5.536
659	650	5.313	8.813			445	5.105	8.895	1973.79	472.81	1971.87	8.946	5.744
660	651	5.261	8.806	1957.79	H	444	5.041	8.909	1973.83	471.56	1971.96	9.011	6.243
661	652	5.332	8.853			443	5.062	8.952	1973.87	470.29	1972.04	9.035	6.077
662	653	5.584	8.814			442	5.328	8.970	1973.90	468.95	1972.12	9.055	6.178
663	654	5.714	8.850			441	5.014	8.987	1973.94	467.76	1972.21	9.026	5.752
664	655	6.024	8.918			440	5.392	8.987	1973.98	466.57	1972.29	9.016	5.391

Appendix B.2
trace elemental data for coral core from Archipelago Los Roques (Roq6) and age model

						1st interpolation				2nd interpolation			
sample ID	new no.	Mg/Ca (mmol/mol)	Sr/Ca (mmol/mol)	timemarker year.month	anchor High/Low	new no.	Mg/Ca (mmol/mol)	Sr/Ca (mmol/mol)	timemarker year.month	new no.	timemarker year.month	Sr/Ca (mmol/mol)	Mg/Ca (mmol/mol)
665	656	5.645	8.936			439	5.103	8.995	1974.01	465.28	1972.37	9.024	5.759
666	657	5.518	8.947			438	5.271	8.987	1974.05	464.05	1972.46	8.950	5.114
667	658	6.117	8.951	1957.12	L	437	4.964	8.989	1974.09	462.83	1972.54	8.957	5.185
668	659	5.654	8.907			436	5.275	9.017	1974.12	461.52	1972.62	8.937	5.331
669	660	7.272	8.887			435	5.518	9.013	1974.22	460.33	1972.71	8.891	5.491
670	661	5.846	8.862			434	5.171	9.012	1974.32	459.00	1972.79	8.870	5.616
671	662	5.484	8.801			433	5.283	8.945	1974.41	457.53	1972.87	8.901	5.898
672	663	5.364	8.833			432	5.622	8.958	1974.51	456.06	1972.96	8.934	5.997
673	664	5.292	8.815	1956.79	H	431	5.340	8.927	1974.60	454.50	1973.04	8.984	6.673
674	665	5.205	8.834			430	5.299	8.882	1974.70	452.96	1973.12	9.036	6.094
675	666	4.742	8.892			429	5.479	8.833	1974.79	452.04	1973.21	9.033	5.837
681	667	5.744	8.925			428	5.120	8.890	1974.83	451.00	1973.29	9.024	5.908
682	668	5.783	8.978			427	5.058	8.836	1974.87	450.07	1973.37	9.030	5.791
683	669	5.536	8.972			426	5.495	8.874	1974.90	449.04	1973.46	9.022	5.112
684	670	5.344	8.993	1956.12	L	425	5.984	8.908	1974.94	448.00	1973.54	9.009	5.270
685	671	5.461	8.953			424	5.836	8.959	1974.98	447.07	1973.62	8.947	5.209
686	672	5.779	8.948			423	5.899	8.960	1975.01	446.04	1973.71	8.906	5.135
687	673	5.580	8.905			422	5.390	9.002	1975.05	445.00	1973.79	8.895	5.105
688	674	5.381	8.861			421	6.042	8.994	1975.09	442.89	1973.87	8.954	5.092
689	675	5.616	8.811	1955.79	H	420	5.888	9.053	1975.12	440.58	1973.96	8.987	5.172
690	676	5.474	8.838			419	5.939	8.977	1975.21	438.25	1974.04	8.989	5.229
691	677	5.610	8.847			418	5.873	8.960	1975.29	435.97	1974.12	9.017	5.283
692	678	5.821	8.935			417	5.553	8.947	1975.38	435.13	1974.21	9.014	5.486
693	679	5.446	8.957			416	5.762	8.881	1975.46	434.30	1974.29	9.012	5.275
694	680	5.474	8.989	1955.12	L	415	5.915	8.866	1975.54	433.41	1974.37	8.972	5.237
695	681	6.353	8.984			414	5.934	8.863	1975.63	432.53	1974.46	8.951	5.441
696	682	5.885	8.913			413	5.348	8.816	1975.71	431.67	1974.54	8.948	5.528
697	683	5.517	8.883			412	5.135	8.789	1975.79	430.77	1974.62	8.917	5.330
698	684	5.789	8.873			411	5.337	8.845	1975.83	429.93	1974.71	8.878	5.312
699	685	5.775	8.837	1954.79	H	410	5.599	8.854	1975.88	429.00	1974.79	8.833	5.479
700	686	6.408	8.868			409	6.065	8.936	1975.92	426.89	1974.87	8.840	5.107
701	687	5.760	8.914			408	5.386	8.914	1975.96	424.58	1974.96	8.929	5.922
702	688	5.746	8.912			407	5.234	8.936	1976.00	422.25	1975.04	8.992	5.517
703	689	5.799	8.956			406	5.457	8.912	1976.04	419.96	1975.12	9.050	5.890
704	690	5.529	8.968			405	5.573	8.933	1976.08	419.04	1975.21	8.980	5.937
705	691	5.625	9.004	1954.12	L	404	5.281	8.943	1976.12	418.00	1975.29	8.960	5.873
706	692	5.950	8.966			403	5.223	8.928	1976.21	417.07	1975.37	8.948	5.577
707	693	6.178	8.945			402	5.481	8.945	1976.29	416.04	1975.46	8.884	5.753
708	694	6.091	8.902			401	5.342	8.886	1976.38	415.00	1975.54	8.866	5.915
709	695	6.375	8.883			400	5.428	8.853	1976.46	414.07	1975.62	8.863	5.933
710	696	6.044	8.826	1953.79	H	399	5.808	8.844	1976.54	413.04	1975.71	8.818	5.372
711	697	5.248	8.847			398	5.549	8.869	1976.63	412.00	1975.79	8.789	5.135
712	698	6.100	8.911			397	5.198	8.842	1976.71	410.13	1975.87	8.853	5.564
713	699	5.528	8.857			396	5.065	8.817	1976.79	408.08	1975.96	8.916	5.443
714	700	5.652	8.830			395	5.393	8.808	1976.86	406.00	1976.04	8.912	5.457
715	701	5.525	8.893			394	5.787	8.920	1976.93	403.96	1976.12	8.942	5.279
716	702	5.664	8.924	1953.12	L	393	5.458	8.942	1976.99	403.04	1976.21	8.929	5.225
717	703	5.463	8.908			392	5.747	8.959	1977.06	402.00	1976.29	8.945	5.481
718	704	6.220	8.899			391	5.703	8.987	1977.12	401.07	1976.37	8.890	5.352
719	705	5.434	8.812			390	5.983	8.949	1977.20	400.04	1976.46	8.854	5.424
720	706	5.441	8.784	1952.79	H	389	6.084	8.935	1977.27	399.00	1976.54	8.844	5.808
721	707	5.210	8.838			388	5.665	8.955	1977.35	398.07	1976.62	8.867	5.568
722	708	5.470	8.877			387	5.755	8.888	1977.42	397.04	1976.71	8.843	5.213
723	709	5.479	8.924			386	5.954	8.915	1977.50	396.00	1976.79	8.817	5.065
724	710	5.267	8.927			385	5.855	8.924	1977.57	394.81	1976.87	8.829	5.468
725	711	5.377	9.012	1952.12	L	384	5.793	8.833	1977.64	393.56	1976.96	8.930	5.641
726	712	4.987	8.988			383	5.637	8.886	1977.72	392.29	1977.04	8.954	5.664
727	713	5.139	8.926			382	5.580	8.821	1977.79	390.96	1977.12	8.985	5.715
728	714	5.397	8.878			381	5.429	8.923	1977.85	389.91	1977.21	8.948	5.993
729	715	5.343	8.868			380	5.753	8.883	1977.90	388.75	1977.29	8.940	5.979
730	716	5.229	8.861	1951.79	H	379	5.730	8.887	1977.96	387.67	1977.37	8.933	5.695
731	717	5.533	8.871			378	5.570	8.906	1978.01	386.54	1977.46	8.900	5.846
732	718	5.943	8.879			377	5.868	8.941	1978.07	385.43	1977.54	8.920	5.897
733	719	5.435	8.890			376	5.642	8.959	1978.12	384.24	1977.62	8.855	5.808
734	720	6.017	8.888			375	5.666	8.904	1978.20	383.17	1977.71	8.877	5.663
735	721	5.740	8.937			374	5.118	8.915	1978.27	382.00	1977.79	8.821	5.580
736	722	5.420	8.954	1951.12	L	373	5.081	8.907	1978.35	380.53	1977.87	8.904	5.580
737	723	5.390	8.930			372	5.170	8.902	1978.42	379.06	1977.96	8.887	5.731
738	724	5.518	8.857			371	5.195	8.873	1978.50	377.50	1978.04	8.924	5.719
739	725	5.448	8.812	1950.79	H	370	5.356	8.897	1978.57	375.96	1978.12	8.957	5.643
740	726	5.265	8.838			369	5.511	8.880	1978.64	374.91	1978.21	8.905	5.614
741	727	5.331	8.852			368	5.526	8.836	1978.72	373.75	1978.29	8.913	5.109
742	728	5.234	8.876			367	5.468	8.813	1978.79	372.67	1978.37	8.905	5.111
743	729	4.932	8.876			366	5.533	8.821	1978.83	371.54	1978.46	8.889	5.181
744	730	5.706	8.899	1950.12	L	365	5.808	8.844	1978.88	370.43	1978.54	8.887	5.287
745	731	5.490	8.896			364	5.514	8.867	1978.92	369.24	1978.62	8.884	5.474
750	732	5.433	8.899			363	5.331	8.865	1978.96	368.17	1978.71	8.843	5.524
751	733	5.528	8.878			362	5.559	8.895	1979.00	367.00	1978.79	8.813	5.468
752	734	5.505	8.867			361	5.402	8.925	1979.04	365.13	1978.87	8.841	5.771
753	735	5.203	8.823	1949.79	H	360	5.869	8.904	1979.08	363.08	1978.96	8.865	5.346
754	736	5.284	8.815			359	5.352	8.974	1979.12	361.00	1979.04	8.925	5.402
755	737	5.261	8.892			358	5.634	8.916	1979.20	358.96	1979.12	8.972	5.364
756	738	5.078	8.875			357	5.139	8.871	1979.27	357.91	1979.21	8.912	5.587
757	739	5.236	8.925			356	5.090	8.884	1979.35	356.75	1979.29	8.874	5.127
758	740	5.390	8.960	1949.12	L	355	5.470	8.912	1979.42	355.67	1979.37	8.893	5.217
759	741	5.705	8.923			354	5.753	8.865	1979.50	354.54	1979.46	8.890	5.600
760	742	5.253	8.935			353	5.274	8.864	1979.57	353.43	1979.54	8.864	5.479
761	743	5.222	8.914			352	5.846	8.841	1979.64	352.24	1979.62	8.846	5.710
762	744	5.501	8.843			351	5.034	8.843	1979.72	351.17	1979.71	8.843	5.169
763	745	5.450	8.857			350	5.274	8.838	1979.79	350.00	1979.79	8.838	5.274
764	746	5.092	8.807	1948.79	H	349	5.318	8.870	1979.85	348.53	1979.87	8.859	5.344
765	747	4.996	8.829			348	5.373	8.847	1979.90	347.06	1979.96	8.838	5.466
766	748	5.023	8.836			347	5.471	8.837	1979.96	345.50	1980.04	8.903	5.499
767	749	5.099	8.854			346	5.607	8.899	1980.01	343.96	1980.12	8.989	5.538

Appendix B.2
trace elemental data for coral core from Archipelago Los Roques (Roq6) and age model

						1st interpolation				2nd interpolation			
sample ID	new no.	Mg/Ca (mmol/mol)	Sr/Ca (mmol/mol)	timemarker year.month	anchor High/Low	new no.	Mg/Ca (mmol/mol)	Sr/Ca (mmol/mol)	timemarker year.month	new no.	timemarker year.month	Sr/Ca (mmol/mol)	Mg/Ca (mmol/mol)
768	750	4.965	8.872			345	5.391	8.907	1980.07	343.04	1980.21	8.955	5.733
769	751	5.111	8.874			344	5.530	8.990	1980.12	342.00	1980.29	8.883	5.528
770	752	5.393	9.020	1948.12	L	343	5.741	8.954	1980.21	341.07	1980.37	8.931	5.348
771	753	5.045	8.882			342	5.528	8.883	1980.29	340.04	1980.46	8.870	5.363
772	754	4.822	8.879			341	5.334	8.935	1980.38	339.00	1980.54	8.878	5.695
773	755	4.995	8.875			340	5.364	8.867	1980.46	338.07	1980.62	8.821	5.423
774	756	5.264	8.845			339	5.695	8.878	1980.54	337.04	1980.71	8.852	5.734
775	757	4.970	8.824	1947.79	H	338	5.401	8.816	1980.63	336.00	1980.79	8.816	5.917
776	758	5.158	8.872			337	5.748	8.854	1980.71	333.22	1980.87	8.854	5.781
777	759	5.499	8.959			336	5.917	8.816	1980.79	330.11	1980.96	8.927	6.521
778	760	6.115	8.976			335	6.438	8.884	1980.82	327.00	1981.04	8.906	6.970
779	761	6.128	9.015	1947.12	L	334	5.951	8.849	1980.85	323.95	1981.12	8.966	6.601
780	762	5.685	8.919			333	5.732	8.856	1980.88	322.76	1981.21	8.876	6.192
781	763	6.012	8.854			332	5.775	8.884	1980.90	321.57	1981.29	8.881	6.127
782	764	5.483	8.838			331	5.946	8.912	1980.93	320.28	1981.37	8.883	6.004
783	765	5.236	8.829	1946.79	H	330	6.593	8.929	1980.96	319.05	1981.46	8.877	5.839
784	766	5.202	8.857			329	7.076	8.897	1980.99	317.83	1981.54	8.830	5.768
785	767	5.100	8.857			328	6.286	8.956	1981.01	316.52	1981.62	8.823	5.704
786	768	5.150	8.863			327	6.970	8.906	1981.04	315.33	1981.71	8.829	5.794
787	769	5.308	8.845			326	6.800	8.923	1981.07	314.00	1981.79	8.802	5.972
788	770	5.103	8.957	1946.12	L	325	5.907	8.945	1981.10	312.33	1981.87	8.830	5.623
789	771	5.330	8.955			324	6.620	8.971	1981.12	310.47	1981.96	8.872	5.643
790	772	5.119	8.936			323	6.226	8.872	1981.19	308.80	1982.04	8.925	6.061
791	773	5.218	8.904			322	6.082	8.887	1981.26	306.97	1982.12	8.977	6.575
792	774	5.371	8.908			321	6.186	8.872	1981.33	306.13	1982.21	8.934	5.771
793	775	5.259	8.844			320	5.934	8.887	1981.39	305.30	1982.29	8.927	5.338
794	776	5.060	8.840	1945.79	H	319	5.834	8.877	1981.46	304.41	1982.37	8.909	5.217
795	777	5.109	8.839			318	5.799	8.831	1981.53	303.53	1982.46	8.888	5.084
796	778	5.241	8.901			317	5.610	8.823	1981.59	302.67	1982.54	8.888	5.080
797	779	5.428	8.956			316	5.808	8.824	1981.66	301.77	1982.62	8.904	5.377
798	780	5.611	8.994			315	5.787	8.831	1981.73	300.93	1982.71	8.886	5.351
799	781	5.550	9.003	1945.12	L	314	5.972	8.802	1981.79	300.00	1982.79	8.805	5.580
800	782	6.174	8.947			313	5.629	8.814	1981.84	298.81	1982.87	8.900	6.297
801	783	5.499	8.886			312	5.620	8.838	1981.89	297.56	1982.96	8.937	6.205
802	784	5.179	8.822			311	5.921	8.870	1981.93	296.29	1983.04	8.931	5.771
803	785	5.373	8.827	1944.79	H	310	5.399	8.874	1981.98	294.95	1983.12	8.955	5.923
804	786	5.048	8.849			309	6.049	8.922	1982.03	293.76	1983.21	8.919	6.182
805	787	5.164	8.865			308	6.108	8.935	1982.08	292.57	1983.29	8.928	6.135
806	788	5.006	8.851			307	6.607	8.979	1982.12	291.28	1983.37	8.906	5.640
807	789	5.345	8.866			306	5.642	8.927	1982.22	290.05	1983.46	8.887	6.035
808	790	5.218	8.885			305	5.208	8.927	1982.32	288.83	1983.54	8.869	5.755
809	791	5.042	8.883			304	5.224	8.896	1982.41	287.52	1983.62	8.814	5.214
810	792	5.372	8.887	1944.12	L	303	4.925	8.879	1982.51	286.33	1983.71	8.824	4.934
811	793	5.150	8.845			302	5.390	8.907	1982.60	285.00	1983.79	8.803	4.748
812	794	5.388	8.838			301	5.333	8.892	1982.70	283.33	1983.87	8.840	5.166
813	795	5.269	8.816			300	5.580	8.805	1982.79	281.47	1983.96	8.906	5.520
814	796	5.184	8.781	1943.79	H	299	6.337	8.887	1982.86	279.80	1984.04	8.898	5.603
815	797	5.503	8.813			298	6.128	8.953	1982.93	277.96	1984.12	8.958	6.264
816	798	5.343	8.815			297	6.302	8.917	1982.99	276.91	1984.21	8.943	5.742
817	799	5.369	8.843			296	5.559	8.937	1983.06	275.75	1984.29	8.944	5.659
818	800	5.326	8.852			295	5.912	8.957	1983.12	274.67	1984.37	8.919	5.854
819	801	5.411	8.865			294	6.149	8.912	1983.19	273.54	1984.46	8.885	5.703
820	802	5.514	8.878			293	6.289	8.940	1983.26	272.43	1984.54	8.862	5.903
821	803	5.461	8.881			292	5.930	8.912	1983.33	271.24	1984.62	8.824	5.694
822	804	5.519	8.883	1943.12	L	291	5.529	8.904	1983.39	270.17	1984.71	8.800	5.533
823	805	5.580	8.822			290	6.060	8.886	1983.46	269.00	1984.79	8.787	5.355
824	806	5.347	8.830			289	5.847	8.881	1983.53	268.07	1984.87	8.824	5.461
825	807	5.576	8.832			288	5.294	8.811	1983.59	267.04	1984.96	8.867	5.762
826	808	5.365	8.836			287	5.125	8.818	1983.66	266.00	1985.04	8.953	7.200
827	809	5.326	8.836			286	4.839	8.827	1983.73	264.97	1985.12	8.959	6.118
828	810	5.163	8.846			285	4.748	8.803	1983.79	264.13	1985.21	8.926	6.056
829	811	5.205	8.817	1942.79	H	284	4.976	8.838	1983.84	263.30	1985.29	8.913	5.747
830	812	5.331	8.855			283	5.261	8.841	1983.89	262.41	1985.37	8.879	5.653
831	813	5.389	8.936			282	5.426	8.901	1983.93	261.53	1985.46	8.844	5.706
832	814	5.451	8.940			281	5.602	8.910	1983.98	260.67	1985.54	8.830	5.653
833	815	5.283	8.960	1942.12	L	280	5.435	8.900	1984.03	259.77	1985.62	8.835	5.606
834	816	5.478	8.896			279	6.276	8.888	1984.08	258.93	1985.71	8.840	5.957
835	817	5.251	8.877			278	6.286	8.959	1984.12	258.00	1985.79	8.825	5.194
836	818	5.065	8.868			277	5.762	8.942	1984.20	256.81	1985.87	8.817	5.561
837	819	5.055	8.897			276	5.556	8.948	1984.27	255.56	1985.96	8.840	6.060
838	820	4.992	8.883	1941.79	H	275	5.968	8.933	1984.35	254.29	1986.04	8.901	6.752
839	821	5.203	8.893			274	5.626	8.890	1984.42	252.96	1986.12	8.964	6.305
840	822	5.148	8.896			273	5.795	8.880	1984.50	252.04	1986.21	8.922	5.926
841	823	5.098	8.914			272	5.984	8.848	1984.57	251.00	1986.29	8.927	5.349
842	824	4.792	8.939			271	5.604	8.817	1984.64	250.07	1986.37	8.911	5.651
843	825	4.729	8.910			270	5.519	8.797	1984.72	249.04	1986.46	8.932	5.440
844	826	4.954	8.959	1941.12	L	269	5.355	8.787	1984.79	248.00	1986.54	8.933	5.754
845	827	4.882	8.937			268	5.469	8.827	1984.88	247.07	1986.62	8.900	6.210
846	828	4.928	8.860			267	5.775	8.869	1984.96	246.04	1986.71	8.888	5.622
847	829	4.958	8.904			266	7.200	8.953	1985.04	245.00	1986.79	8.849	5.502
848	830	4.971	8.814			265	6.120	8.960	1985.12	242.89	1986.87	8.875	5.591
849	831	4.904	8.823	1940.79	H	264	6.046	8.921	1985.22	240.58	1986.96	8.937	5.416
850	832	4.782	8.875			263	5.619	8.909	1985.32	238.25	1987.04	8.972	5.444
851	833	4.896	8.915			262	5.677	8.858	1985.41	235.97	1987.12	8.988	5.580
852	834	5.045	8.893			261	5.740	8.828	1985.51	235.28	1987.21	8.954	5.918
853	835	5.063	8.914			260	5.480	8.833	1985.60	234.55	1987.29	8.931	5.932
854	836	5.165	8.903			259	6.018	8.841	1985.70	233.79	1987.37	8.912	5.720
855	837	5.087	8.948			258	5.194	8.825	1985.79	233.03	1987.46	8.885	5.485
856	838	5.034	8.967	1940.12	L	257	5.482	8.813	1985.86	232.27	1987.54	8.874	5.417
857	839	5.353	8.927			256	5.897	8.836	1985.93	231.52	1987.62	8.856	5.483
858	840	5.306	8.891			255	6.263	8.844	1985.99	230.76	1987.71	8.843	5.549
859	841	5.061	8.846			254	6.947	8.924	1986.06	230.00	1987.79	8.850	5.460
860	842	5.246	8.854	1939.79	H	253	6.320	8.966	1986.12	227.56	1987.87	8.914	5.781
861	843	5.122	8.909			252	5.911	8.920	1986.21	225.11	1987.96	8.939	5.702

Appendix B.2
trace elemental data for coral core from Archipelago Los Roques (Roq6) and age model

						1st interpolation				2nd interpolation			
sample ID	new no.	Mg/Ca (mmol/mol)	Sr/Ca (mmol/mol)	timemarker year.month	anchor High/Low	new no.	Mg/Ca (mmol/mol)	Sr/Ca (mmol/mol)	timemarker year.month	new no.	timemarker year.month	Sr/Ca (mmol/mol)	Mg/Ca (mmol/mol)
862	844	5.109	8.925			251	5.349	8.927	1986.29	222.67	1988.04	8.997	5.376
863	845	5.288	8.922			250	5.675	8.910	1986.38	219.98	1988.12	9.042	5.103
864	846	5.865	9.004			249	5.430	8.933	1986.46	219.38	1988.21	8.988	5.336
868	847	5.002	8.998			248	5.754	8.933	1986.54	218.77	1988.29	8.949	5.482
869	848	5.365	9.017	1939.12	L	247	6.246	8.897	1986.63	218.13	1988.37	8.936	5.472
870	849	5.629	8.974			246	5.595	8.888	1986.71	217.52	1988.46	8.918	5.546
871	850	5.311	8.937			245	5.502	8.849	1986.79	216.92	1988.54	8.899	5.642
872	851	5.547	8.894			244	5.523	8.868	1986.83	216.28	1988.62	8.877	5.747
873	852	5.328	8.861			243	5.521	8.870	1986.87	215.64	1988.71	8.866	5.709
874	853	5.196	8.829	1938.79	H	242	6.151	8.919	1986.90	215.00	1988.79	8.864	5.557
875	854	5.220	8.871			241	5.358	8.928	1986.94	213.53	1988.87	8.899	6.146
876	855	4.995	8.876			240	5.498	8.949	1986.98	212.06	1988.96	8.907	6.791
877	856	5.064	8.905			239	5.335	8.985	1987.01	210.50	1989.04	8.876	7.271
878	857	5.153	8.953			238	5.480	8.967	1987.05	208.99	1989.12	8.932	6.300
879	858	5.148	8.930			237	5.444	8.952	1987.09	208.62	1989.21	8.919	6.077
880	859	5.187	8.960	1938.12	L	236	5.566	8.989	1987.12	208.26	1989.29	8.905	5.853
881	860	5.491	8.930			235	6.053	8.940	1987.24	207.89	1989.37	8.895	5.715
882	861	5.419	8.860			234	5.786	8.920	1987.35	207.52	1989.46	8.895	5.797
883	862	4.870	8.764			233	5.476	8.884	1987.46	207.14	1989.54	8.896	5.879
884	863	4.948	8.742	1937.79	H	232	5.395	8.870	1987.57	206.76	1989.62	8.883	5.820
885	864	5.062	8.747			231	5.577	8.841	1987.68	206.38	1989.71	8.862	5.682
886	865	5.079	8.819			230	5.460	8.850	1987.79	206.00	1989.79	8.841	5.544
887	866	4.744	8.867			229	5.593	8.884	1987.83	204.13	1989.87	8.866	5.882
888	867	4.625	8.925			228	5.725	8.933	1987.86	202.08	1989.96	8.888	6.001
889	868	4.860	8.931			227	5.850	8.890	1987.89	200.00	1990.04	8.942	6.131
890	869	4.857	8.955			226	7.413	8.943	1987.93	197.97	1990.12	8.967	5.861
891	870	5.063	8.974	1937.12	L	225	5.488	8.939	1987.96	197.13	1990.21	8.952	6.102
892	871	5.047	8.916			224	5.237	8.988	1987.99	196.30	1990.29	8.924	5.811
893	872	5.440	8.863			223	5.354	8.996	1988.03	195.41	1990.37	8.908	5.643
894	873	5.019	8.843			222	5.421	8.999	1988.06	194.53	1990.46	8.887	5.869
895	874	5.618	8.808	1936.79	H	221	5.218	9.023	1988.09	193.67	1990.54	8.854	5.925
896	875	5.407	8.824			220	5.094	9.044	1988.12	192.77	1990.62	8.832	5.492
897	876	5.351	8.809			219	5.485	8.954	1988.26	191.93	1990.71	8.840	5.529
898	877	5.087	8.887			218	5.470	8.933	1988.39	191.00	1990.79	8.781	5.518
899	878	4.997	8.886			217	5.629	8.902	1988.53	189.13	1990.87	8.808	5.675
900	879	5.346	8.924			216	5.794	8.867	1988.66	187.08	1990.96	8.860	6.084
901	880	5.126	8.963	1936.12	L	215	5.557	8.864	1988.79	185.00	1991.04	8.967	5.761
902	881	5.002	8.944			214	6.194	8.909	1988.85	182.97	1991.12	8.971	6.031
903	882	5.209	8.888			213	6.091	8.887	1988.90	182.28	1991.21	8.933	5.893
904	883	5.162	8.880			212	6.832	8.908	1988.96	181.55	1991.29	8.898	5.875
905	884	5.024	8.832			211	7.348	8.856	1989.01	180.79	1991.37	8.872	5.966
906	885	4.931	8.814	1935.79	H	210	7.193	8.895	1989.07	180.03	1991.46	8.860	6.132
907	886	4.911	8.810			209	6.309	8.933	1989.12	179.27	1991.54	8.856	6.047
908	887	5.234	8.884			208	5.692	8.895	1989.35	178.52	1991.62	8.839	5.952
909	888	4.920	8.892			207	5.908	8.896	1989.57	177.76	1991.71	8.821	6.155
910	889	4.743	8.896			206	5.544	8.841	1989.79	177.00	1991.79	8.816	6.992
911	890	5.237	8.899	1935.12	L	205	5.512	8.896	1989.83	174.89	1991.87	8.858	6.890
912	891	4.818	8.874			204	5.939	8.861	1989.88	172.58	1991.96	8.905	7.642
913	892	4.751	8.820			203	6.151	8.895	1989.92	170.25	1992.04	8.930	7.640
914	893	4.659	8.873			202	5.987	8.887	1989.96	167.97	1992.12	8.938	6.948
915	894	4.715	8.799	1934.79	H	201	5.833	8.874	1990.00	167.13	1992.21	8.930	6.737
916	895	4.784	8.856			200	6.131	8.942	1990.04	166.30	1992.29	8.893	6.319
917	896	4.920	8.839			199	6.029	8.928	1990.08	165.41	1992.37	8.870	6.190
918	897	4.740	8.867			198	5.851	8.968	1990.12	164.53	1992.46	8.867	6.257
919	898	4.698	8.887			197	6.141	8.950	1990.22	163.67	1992.54	8.855	6.313
920	899	4.704	8.869			196	5.669	8.913	1990.32	162.77	1992.62	8.823	6.272
921	900	4.836	8.916			195	5.625	8.904	1990.41	161.93	1992.71	8.820	6.164
922	901	4.894	8.875			194	6.147	8.867	1990.51	161.00	1992.79	8.807	7.038
923	902	4.982	8.928			193	5.480	8.828	1990.60	159.33	1992.87	8.834	7.054
924	903	4.728	8.961	1934.12	L	192	5.530	8.845	1990.70	157.47	1992.96	8.859	6.361
925	904	4.912	8.854			191	5.518	8.781	1990.79	155.80	1993.04	8.920	6.688
926	905	5.507	8.822			190	6.040	8.831	1990.83	153.95	1993.12	8.972	7.388
927	906	5.363	8.781			189	5.619	8.805	1990.88	152.76	1993.21	8.952	6.950
928	907	5.050	8.777			188	6.149	8.779	1990.92	151.57	1993.29	8.948	6.723
929	908	5.231	8.745	1933.79	H	187	6.078	8.867	1990.96	150.28	1993.37	8.911	6.605
930	909	5.313	8.777			186	5.936	8.933	1991.00	149.05	1993.46	8.890	6.378
931	910	5.289	8.803			185	5.761	8.967	1991.04	147.83	1993.54	8.880	6.205
932	911	5.284	8.818			184	5.943	8.966	1991.08	146.52	1993.62	8.889	5.927
933	912	5.428	8.842			183	6.037	8.973	1991.12	145.33	1993.71	8.885	5.661
934	913	5.333	8.869			182	5.838	8.917	1991.24	144.00	1993.79	8.878	5.581
935	914	5.137	8.917	1933.12	L	181	5.919	8.875	1991.35	142.13	1993.87	8.875	5.958
936	915	5.609	8.912			180	6.139	8.860	1991.46	140.08	1993.96	8.910	6.147
937	916	5.312	8.863			179	6.013	8.855	1991.57	138.00	1994.04	8.972	6.609
938	917	5.411	8.839			178	5.887	8.823	1991.68	135.97	1994.12	9.049	7.628
939	918	5.386	8.799			177	6.992	8.816	1991.79	135.13	1994.21	9.042	7.381
940	919	5.504	8.804			176	6.295	8.830	1991.83	134.30	1994.29	9.013	6.842
941	920	5.131	8.769	1932.79	H	175	6.670	8.851	1991.87	133.41	1994.37	8.995	6.467
942	921	5.211	8.846			174	8.647	8.911	1991.90	132.53	1994.46	8.962	6.165
943	922	5.251	8.880			173	7.937	8.892	1991.94	131.67	1994.54	8.922	6.225
944	923	5.334	8.836			172	7.228	8.923	1991.98	130.77	1994.62	8.902	6.805
945	924	5.007	8.854			171	6.518	8.932	1992.01	129.93	1994.71	8.862	6.855
946	925	4.803	8.878			170	8.014	8.929	1992.05	129.00	1994.79	8.729	6.578
947	926	5.224	8.879	1932.12	L	169	7.052	8.925	1992.09	127.13	1994.87	8.843	6.427
948	927	5.069	8.849			168	6.956	8.938	1992.12	125.08	1994.96	8.894	6.657
949	928	5.466	8.839			167	6.703	8.929	1992.22	123.00	1995.04	8.877	6.773
950	929	5.375	8.837			166	6.154	8.878	1992.32	120.95	1995.12	8.979	6.568
951	930	5.287	8.812			165	6.214	8.865	1992.41	119.72	1995.21	8.967	6.541
952	931	5.646	8.865			164	6.307	8.870	1992.51	118.33	1995.29	8.966	6.773
953	932	5.123	8.864			163	6.326	8.824	1992.60	116.94	1995.37	8.946	6.303
954	933	5.068	8.832			162	6.094	8.821	1992.70	115.56	1995.46	8.922	6.132
955	934	4.858	8.816			161	7.038	8.807	1992.79	114.17	1995.54	8.875	5.757
956	935	4.983	8.812	1931.79	H	160	6.819	8.847	1992.84	112.78	1995.62	8.840	5.915
957	936	5.081	8.797			159	7.171	8.828	1992.89	111.39	1995.71	8.829	5.716
958	937	5.155	8.815			158	6.498	8.858	1992.93	110.00	1995.79	8.777	5.971

Appendix B.2
trace elemental data for coral core from Archipelago Los Roques (Roq6) and age model

sample ID	new no.	Mg/Ca (mmol/mol)	Sr/Ca (mmol/mol)	timemarker year.month	anchor High/Low	1st interpolation new no.	Mg/Ca (mmol/mol)	Sr/Ca (mmol/mol)	timemarker year.month	2nd interpolation new no.	timemarker year.month	Sr/Ca (mmol/mol)	Mg/Ca (mmol/mol)
959	938	5.211	8.849			157	6.242	8.860	1992.98	108.81	1995.87	8.777	5.890
960	939	5.487	8.888	1931.12	L	156	6.581	8.917	1993.03	107.56	1995.96	8.807	6.034
961	940	4.974	8.865			155	7.118	8.932	1993.08	106.29	1996.04	8.879	6.371
962	941	4.736	8.877			154	7.406	8.973	1993.12	104.97	1996.12	9.075	7.519
963	942	5.388	8.837			153	7.024	8.952	1993.19	104.13	1996.21	8.990	6.548
964	943	5.305	8.839			152	6.712	8.951	1993.26	103.30	1996.29	9.002	5.987
965	944	5.081	8.833	1930.79	H	151	6.738	8.943	1993.33	102.41	1996.37	8.953	5.462
966	945	5.165	8.864			150	6.554	8.899	1993.39	101.53	1996.46	8.922	5.337
967	946	5.135	8.850			149	6.369	8.890	1993.46	100.67	1996.54	8.930	5.493
968	947	5.275	8.863			148	6.185	8.878	1993.53	99.77	1996.62	8.920	5.531
969	948	5.284	8.914			147	6.306	8.891	1993.59	98.93	1996.71	8.918	5.507
970	949	5.480	8.922			146	5.510	8.886	1993.66	98.00	1996.79	8.872	5.482
971	950	5.268	8.918			145	5.736	8.884	1993.73	96.53	1996.87	8.875	5.717
972	951	5.122	8.937	1930.12	L	144	5.581	8.878	1993.79	95.06	1996.96	8.946	6.551
973	952	5.371	8.935			143	5.784	8.894	1993.83	93.50	1997.04	8.968	6.643
974	953	5.035	8.871			142	5.985	8.872	1993.88	91.97	1997.12	8.994	6.211
975	954	5.052	8.855			141	5.942	8.897	1993.92	91.13	1997.21	8.962	6.511
976	955	5.301	8.830			140	6.166	8.911	1993.96	90.30	1997.29	8.933	6.150
977	956	5.282	8.851			139	6.416	8.970	1994.00	89.41	1997.37	8.918	6.105
978	957	5.534	8.822	1929.79	H	138	6.609	8.972	1994.04	88.53	1997.46	8.928	6.134
979	958	5.467	8.877			137	6.800	9.047	1994.08	87.67	1997.54	8.940	6.076
980	959	5.521	8.826			136	7.638	9.049	1994.12	86.77	1997.62	8.924	5.985
981	960	5.580	8.848			135	7.341	9.041	1994.22	85.93	1997.71	8.884	5.620
982	961	5.157	8.912			134	6.628	9.001	1994.32	85.00	1997.79	8.891	5.561
983	962	4.812	8.961	1929.12	L	133	6.356	8.991	1994.41	83.33	1997.87	8.883	5.511
984	963	5.487	8.931			132	5.946	8.928	1994.51	81.47	1997.96	8.902	5.998
985	964	5.148	8.864			131	6.783	8.911	1994.60	79.80	1998.04	8.969	5.936
986	965	5.050	8.864			130	6.877	8.873	1994.70	77.97	1998.12	8.991	5.847
987	966	5.177	8.806	1928.79	H	129	6.578	8.729	1994.79	77.28	1998.21	8.972	5.490
988	967	4.830	8.874			128	6.178	8.738	1994.83	76.55	1998.29	8.939	5.433
989	968	4.978	8.833			127	6.465	8.859	1994.88	75.79	1998.37	8.904	5.571
990	969	4.910	8.872			126	6.450	8.890	1994.92	75.03	1998.46	8.888	5.693
991	970	4.860	8.903			125	6.676	8.894	1994.96	74.27	1998.54	8.864	5.433
992	971	4.905	8.941			124	6.320	8.842	1995.00	73.52	1998.62	8.839	5.346
993	972	5.162	8.949			123	6.773	8.877	1995.04	72.76	1998.71	8.820	5.282
998	973	4.928	8.927			122	6.314	8.911	1995.08	72.00	1998.79	8.815	5.041
999	974	5.085	8.991	1928.12	L	121	6.578	8.980	1995.12	70.53	1998.87	8.855	5.116
1000	975	5.111	8.932			120	6.376	8.966	1995.19	69.06	1998.96	8.909	5.326
1001	976	5.137	8.863			119	6.971	8.971	1995.25	67.50	1999.04	8.941	5.252
1002	977	5.571	8.818			118	6.674	8.963	1995.31	65.97	1999.12	8.986	5.363
1003	978	4.930	8.805	1927.79	H	117	6.295	8.946	1995.37	65.28	1999.21	8.968	5.221
1004	979	5.280	8.831			116	6.434	8.951	1995.43	64.55	1999.29	8.962	5.272
1005	980	4.902	8.894			115	5.754	8.885	1995.49	63.79	1999.37	8.940	5.363
1006	981	5.133	8.868			114	5.757	8.873	1995.55	63.03	1999.46	8.859	5.227
1007	982	4.978	8.921			113	5.993	8.840	1995.61	62.27	1999.54	8.854	5.017
1008	983	4.983	8.914			112	5.643	8.841	1995.67	61.52	1999.62	8.848	5.026
1009	984	4.818	8.910			111	5.762	8.822	1995.73	60.76	1999.71	8.833	5.192
1010	985	4.697	8.976	1927.12	L	110	5.971	8.777	1995.79	60.00	1999.79	8.803	5.423
1011	986	5.015	8.968			109	5.892	8.773	1995.86	58.33	1999.87	8.841	5.680
1012	987	4.815	8.949			108	5.884	8.793	1995.93	56.47	1999.96	8.883	5.859
1013	988	4.836	8.907			107	6.221	8.824	1995.99	54.80	2000.04	8.925	5.625
1014	989	5.161	8.845			106	6.431	8.901	1996.06	52.97	2000.12	8.943	5.426
1015	990	5.274	8.817	1926.79	H	105	7.558	9.078	1996.12	52.28	2000.21	8.897	5.613
1016	991	5.161	8.828			104	6.393	8.977	1996.22	51.55	2000.29	8.882	5.579
1017	992	5.272	8.840			103	5.813	9.013	1996.32	50.79	2000.37	8.887	5.439
1018	993	5.127	8.871			102	5.220	8.911	1996.41	50.03	2000.46	8.890	5.405
1019	994	5.231	8.898			101	5.471	8.935	1996.51	49.27	2000.54	8.847	5.439
1020	995	5.032	8.894			100	5.538	8.919	1996.60	48.52	2000.62	8.840	5.388
1021	996	4.767	8.928			99	5.509	8.922	1996.70	47.76	2000.71	8.837	5.352
1022	997	4.924	8.944			98	5.482	8.872	1996.79	47.00	2000.79	8.799	5.450
1023	998	4.770	8.941			97	5.586	8.876	1996.85	45.81	2000.87	8.852	6.076
1024	999	4.775	8.994	1926.12	L	96	5.866	8.873	1996.90	44.56	2000.96	8.926	6.377
1025	1000	4.876	8.931			95	6.591	8.950	1996.96	43.29	2001.04	8.941	6.779
1026	1001	4.727	8.925			94	6.453	8.950	1997.01	41.97	2001.12	8.976	5.936
1027	1002	5.010	8.895			93	6.833	8.985	1997.07	41.28	2001.21	8.967	5.507
1028	1003	4.909	8.923			92	6.199	8.995	1997.12	40.55	2001.29	8.938	5.369
1029	1004	5.022	8.869	1925.79	H	91	6.559	8.957	1997.22	39.79	2001.37	8.893	5.436
1030	1005	4.857	8.891			90	5.975	8.922	1997.32	39.03	2001.46	8.840	5.538
1031	1006	4.986	8.872			89	6.194	8.915	1997.41	38.27	2001.54	8.826	5.406
1032	1007	4.782	8.884			88	6.066	8.942	1997.51	37.52	2001.62	8.810	5.555
1033	1008	4.969	8.888			87	6.095	8.936	1997.60	36.76	2001.71	8.793	5.788
1034	1009	5.113	8.939	1925.12	L	86	5.625	8.883	1997.70	36.00	2001.79	8.778	5.854
1035	1010	5.092	8.922			85	5.561	8.891	1997.79	35.07	2001.87	8.844	6.053
1036	1011	5.000	8.902			84	5.784	8.892	1997.84	34.04	2001.96	8.870	7.038
1037	1012	5.243	8.845			83	5.375	8.878	1997.89	33.00	2002.04	8.901	7.305
1038	1013	5.146	8.793			82	5.855	8.898	1997.93	31.96	2002.12	8.953	6.823
1039	1014	5.143	8.780			81	6.124	8.906	1997.98	30.90	2002.21	8.925	7.151
1040	1015	5.110	8.798	1924.79	H	80	5.970	8.971	1998.03	29.75	2002.29	8.916	6.210
1041	1016	5.030	8.799			79	5.798	8.963	1998.08	28.67	2002.37	8.926	5.230
1042	1017	4.931	8.773			78	5.861	8.992	1998.12	27.54	2002.46	8.918	4.791
1043	1018	5.090	8.803			77	5.347	8.964	1998.24	26.43	2002.54	8.884	5.103
1044	1019	4.914	8.818			76	5.537	8.908	1998.35	25.24	2002.62	8.867	5.380
1045	1020	5.129	8.888			75	5.698	8.887	1998.46	24.17	2002.71	8.815	7.803
1046	1021	4.685	8.891	1924.12	L	74	5.334	8.856	1998.57	23.00	2002.79	8.779	5.517
1047	1022	4.902	8.879			73	5.359	8.821	1998.68	21.13	2002.87	8.877	6.159
1048	1023	4.930	8.846			72	5.041	8.815	1998.79	19.08	2002.96	8.931	6.657
1049	1024	5.025	8.854			71	4.950	8.815	1998.85	17.00	2003.04	8.960	6.029
1050	1025	5.055	8.848	1923.79	H	70	5.305	8.900	1998.90	14.97	2003.12	9.016	6.402
1051	1026	5.189	8.885			69	5.327	8.910	1998.96	14.28	2003.21	8.976	6.764
1052	1027	5.237	8.884			68	5.285	8.927	1999.01	13.55	2003.29	8.952	6.406
1053	1028	5.034	8.876			67	5.219	8.954	1999.07	12.79	2003.37	8.946	5.811
1054	1029	5.204	8.882			66	5.369	8.987	1999.12	12.03	2003.46	8.958	5.838
1055	1030	5.166	8.909			65	5.164	8.961	1999.24	11.27	2003.54	8.953	5.664
1056	1031	5.253	8.923	1923.12	L	64	5.401	8.963	1999.35	10.52	2003.62	8.937	5.463

Appendix B.2
trace elemental data for coral core from Archipelago Los Roques (Roq6) and age model

						1st interpolation				2nd interpolation			
sample ID	new no.	Mg/Ca	Sr/Ca	timemarker	anchor	new no.	Mg/Ca	Sr/Ca	timemarker	new no.	timemarker	Sr/Ca	Mg/Ca
		(mmol/mol)	(mmol/mol)	year.month	High/Low		(mmol/mol)	(mmol/mol)	year.month		year.month	(mmol/mol)	(mmol/mol)
1057	1032	5.057	8.881			63	5.222	8.856	1999.46	9.76	2003.71	8.920	5.220
1058	1033	4.815	8.846			62	4.940	8.853	1999.57	9.00	2003.79	8.915	4.908
1059	1034	4.976	8.826			61	5.118	8.843	1999.68	8.07	2003.87	8.935	5.173
1060	1035	4.969	8.770			60	5.423	8.803	1999.79	7.04	2003.96	9.021	5.467
1061	1036	5.165	8.806			59	5.573	8.835	1999.84	6.00	2004.04	9.026	6.367
1062	1037	5.073	8.776	1922.79	H	58	5.734	8.844	1999.89	4.98	2004.12	9.027	6.447
1063	1038	4.845	8.838			57	6.162	8.878	1999.93	4.49	2004.21	9.022	6.317
1064	1039	4.565	8.906			56	5.593	8.888	1999.98	4.00	2004.29	9.017	6.187
1065	1040	4.539	8.920			55	5.641	8.926	2000.03	3.51	2004.37	8.997	5.926
1066	1041	4.445	8.942			54	5.560	8.919	2000.08	3.02	2004.46	8.977	5.664
1067	1042	4.451	8.992	1922.12	L	53	5.419	8.945	2000.12	2.53	2004.54	8.981	5.674
1068	1043	5.132	8.886			52	5.688	8.879	2000.24	2.04	2004.62	8.986	5.694
1069	1044	4.391	8.868			51	5.449	8.886	2000.35	1.52	2004.71	8.955	6.355
1070	1045	4.806	8.849			50	5.404	8.890	2000.46	1.00	2004.79	8.921	7.072
1071	1046	5.022	8.803	1921.79	H	49	5.452	8.831	2000.57				
1072	1047	5.073	8.840			48	5.320	8.849	2000.68				
1073	1048	4.777	8.873			47	5.450	8.799	2000.79				
1074	1049	4.744	8.876			46	6.068	8.838	2000.86				
1081	1050	4.683	8.929			45	6.109	8.910	2000.93				
1082	1051	4.720	8.939			44	6.713	8.947	2000.99				
1083	1052	4.610	8.964			43	6.805	8.939	2001.06				
1084	1053	4.820	8.939			42	5.953	8.976	2001.12				
1085	1054	5.144	8.980			41	5.336	8.963	2001.24				
1086	1055	4.814	8.990			40	5.408	8.908	2001.35				
1087	1056	5.293	8.998	1921.12	L	39	5.542	8.838	2001.46				
1088	1057	4.605	8.967			38	5.355	8.822	2001.57				
1089	1058	4.842	8.964			37	5.767	8.798	2001.68				
1090	1059	4.597	8.950			36	5.854	8.778	2001.79				
1091	1060	5.198	8.969			35	6.069	8.849	2001.88				
1092	1061	4.704	8.954	1920.79	H	34	7.080	8.871	2001.96				
1093	1062	4.898	9.022			33	7.305	8.901	2002.04				
1094	1063	5.326	8.997			32	6.806	8.954	2002.12				
1095	1064	4.696	9.027			31	7.223	8.926	2002.20				
1096	1065	4.830	9.009			30	6.462	8.913	2002.27				
1097	1066	4.640	9.037	1920.12	L	29	5.453	8.926	2002.35				
1098	1067	4.697	9.007			28	4.785	8.926	2002.42				
1099	1068	4.719	9.000			27	4.797	8.908	2002.50				
1100	1069	4.714	8.939			26	5.332	8.866	2002.57				
1101	1070	4.933	8.894			25	5.395	8.867	2002.64				
1102	1071	4.674	8.895	1919.79	H	24	8.284	8.804	2002.72				
1103	1072	4.720	8.893			23	5.517	8.779	2002.79				
1104	1073	4.765	8.889			22	5.861	8.876	2002.83				
1105	1074	5.043	8.899			21	6.205	8.877	2002.88				
1106	1075	5.206	8.946			20	6.379	8.898	2002.92				
1107	1076	4.946	9.018	1919.12	L	19	6.682	8.934	2002.96				
1108	1077	4.929	8.913			18	7.231	8.927	2003.00				
1109	1078	5.107	8.964			17	6.029	8.960	2003.04				
1110	1079	5.143	8.944			16	6.144	8.964	2003.08				
1111	1080	5.230	8.922			15	6.387	9.018	2003.12				
1112	1081	5.106	8.912			14	6.909	8.960	2003.24				
1113	1082	5.072	8.906			13	5.803	8.942	2003.35				
1114	1083	4.979	8.861	1918.79	H	12	5.839	8.959	2003.46				
1115	1084	4.688	8.878			11	5.598	8.951	2003.57				
1116	1085	4.721	8.885			10	5.320	8.922	2003.68				
1117	1086	5.080	8.943			9	4.908	8.915	2003.79				
1118	1087	4.780	8.929			8	5.194	8.937	2003.88				
1119	1088	4.991	8.928			7	5.479	9.025	2003.96				
1120	1089	5.402	8.981			6	6.367	9.026	2004.04				
1121	1090	5.056	8.982	1918.12	L	5	6.452	9.027	2004.12				
1122	1091	5.349	8.919			4	6.187	9.017	2004.29				
1123	1092	5.534	8.945			3	5.654	8.976	2004.46				
1124	1093	5.630	8.937			2	5.696	8.986	2004.63				
1125	1094	5.431	8.920	1917.79	H	1	7.072	8.921	2004.79				

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PERSONAL

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EDUCATION

03/2004 – present	**Ph.D. candidate, IFM-GEOMAR, Leibniz Institute for Marine Science, Kiel, Germany** *Dissertation title:* Stable oxygen isotopes and Sr/Ca-ratios in modern *Diploria strigosa* corals from different sites in the Caribbean Sea – evaluation of a new climate archive for the tropical Atlantic
10/1998 – 12/2003	**M.S. degree (Diplom-Geologe), Geology and Paleontology, University of Stuttgart, Germany** *Thesis title:* Acoustic mapping and sedimentology of Recent non-tropical carbonates in the Isla San Jose area, southwestern Gulf of California, Mexico.

AWARDS

2006	Japan Society for the Promotion of Science (JSPS) – Postdoctoral Fellowship (short-term)

PROFESSIONAL + FIELD EXPERIENCE

08-09/2006	JSPS Postdoctoral Fellow, Department of Natural History Sciences, Graduate School of Science, Hokkaido University, Japan
12/2004	Field trip to Caribbean (Venezuela), SCUBA based underwater drilling of modern corals and establishment of a SST monitoring program

06-07/2004	Field trip to Indonesia, SCUBA based underwater drilling of modern corals and collection of mollusc shells
05/2003	Internship at GEOMAR, Kiel
03-04/2003	Expedition in Gulf of California, Mexico, for acoustic sediment mapping and grab sampling survey (supported by the Volkswagen-Stiftung)
10/2000 – 07/2003	Internship at Ingenieurbüro Butscher + Partner, Stuttgart, Germany

LABORATORY EXPERIENCE

Mass Spectrometry, Stable isotope analyis ($\delta^{18}O$, $\delta^{13}C$), Trace element analysis (Sr/Ca, Mg/Ca), X-radiography, coral core preparation and sampling (hand-drill, automated drilling devices), Thin section preparation, geological interpretation of well logs.

PUBLICATIONS

Hetzinger, S., Pfeiffer, M., Dullo, W.-Chr., Ruprecht, E., and D. Garbe-Schönberg, 2006, Sr/Ca and $\delta^{18}O$ in a fast-growing *Diploria strigosa* coral: Evaluation of a new climate archive for the tropical Atlantic, *Geochemistry Geophysics Geosystems*, v. 7(10), doi:10.1029/2006GC001347.

Hetzinger, S., Halfar, J., Riegl, B., and Godinez-Orta, L., 2006, Sedimentology and acoustic mapping of modern rhodolith facies on a non-tropical carbonate shelf (Gulf of California, Mexico): *Journal of Sedimentary Research*, v.76, doi:10.2110/jsr.2006.053.

Hetzinger, S., Pfeiffer, M., Keenlyside, N., Dullo, W.-Chr., Latif, M., and Zinke, J., 2007, *subm.*, Caribbean coral tracks Atlantic Multidecadal Oscillation and past hurricane activity.

Hetzinger, S., Pfeiffer, M., Dullo, W.-Chr., Ruprecht, E., *in prep.*, Impact of remote climate forcings on the eastern Caribbean Sea as captured by a monthly resolved coral proxy record from Guadeloupe covering the entire 20th century.

Hetzinger, S., 2003, Acoustic mapping and sedimentology of Recent non-tropical carbonates in the Isla San Jose area, southwestern Gulf of California, Mexico, *unpublished Diploma thesis*, Universität Stuttgart, Germany.

ORAL PRESENTATIONS

Hetzinger, S., Pfeiffer, M., Keenlyside, N., Dullo, W.-Chr., Latif, M., and Zinke, J., 2007, Caribbean brain coral tracks Atlantic Multidecadal Oscillation and past hurricane intensity, Geophysical Research Abstracts, Vol. 9, EGU General Assembly, Vienna, Austria.

Hetzinger, S., Pfeiffer, M., Dullo, W.-Chr., and Ruprecht, E., 2006, First century-long reconstruction of past sea surface conditions from the Caribbean Sea using a new coral archive, International Society for Reef Studies European Meeting, Bremen, Germany.

Hetzinger, S., Pfeiffer, M., Dullo, W.-Chr., and Ruprecht, E., 2006, The Caribbean braincoral *Diploria strigosa* as climate archive for the tropical Atlantic, Ocean Research Institute, The University of Tokyo, Japan *(Invited)*.

Hetzinger, S., Pfeiffer, M., Dullo, W.-Chr., and Ruprecht, E., 2006, Reconstructing variability of past sea surface conditions using coral records from three sites in the Caribbean Sea, *EOS Trans. AGU*, 87(36), Ocean Sci. Meet. Suppl., Abstract OS23I-02, AGU Ocean Sciences Meeting, Honolulu, USA.

POSTER PRESENTATIONS

Hetzinger, S., Pfeiffer, M., Dullo, W.-Chr., and Ruprecht, E., 2006, Reconstructing variability of past sea surface conditions using coral records from three sites in the Caribbean Sea, Geophysical Research Abstracts, Vol. 8, 01910, 1607-7962/gra/EGU06-A-01910, EGU General Assembly, Vienna, Austria.

Hetzinger, S., Pfeiffer, M., Dullo, W.-Chr., and Ruprecht, E., 2005, Variability of past Caribbean sea surface conditions derived from a century-long coral record, *EOS Trans. AGU*, 86(52), Fall Meet. Suppl., Abstract PP51A-0579, AGU Fall Meeting, San Francisco, USA.

Hetzinger, S., Pfeiffer, M., Dullo, W.-Chr., and Ruprecht, E., 2005, Tracking tropical Atlantic climate variability of the last century using a 93-year monthly resolved $\delta^{18}O$ and Sr/Ca record from a Caribbean coral, Geophysical Research Abstracts, Vol. 7, 04678, 1607-7962/gra/EGU05-A-04678, EGU General Assembly, Vienna, Austria.

Hetzinger, S., Pfeiffer, M., Ruprecht, E., and Dullo, W.-Chr., 2005, Reconstructing past sea surface conditions using a 93-year high resolution Sr/Ca and $\delta^{18}O$ coral record from Guadeloupe, PAGES-DEKLIM conference, Mainz, Germany.

Hetzinger, S., Pfeiffer, M., Ruprecht, E., and Dullo, W.-Chr., 2004, Reconstruction of Caribbean sea-surface salinity using a combined analysis of Sr/Ca elemental ratios and oxygen isotope data from modern *Diploria strigosa* corals, 8th International Conference on Paleoceanography (ICP 8), Biarritz, France.