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Chasing Interannual Marine Paleovariability

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Key Points:

- We briefly recount how scientists have reconstructed past year-to-year variations in marine temperatures

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Abstract

Several modes of tropical sea-surface temperature (SST) variability operate on year-to-year (interannual) timescales and profoundly shape seasonal precipitation patterns across adjacent landmasses. Substantial uncertainty remains in addressing how SST variability will become altered under sustained greenhouse warming. Paleoceanographic estimates of changes in variability under past climatic states have emerged as a powerful method to clarify the sensitivity of interannual variability to climate forcing. Several approaches have been developed to investigate interannual SST variability within and beyond the observational period, primarily using marine calcifiers that afford subannual-resolution sampling plans. Amongst these approaches, geochemical variations in coral skeletons are particularly attractive for their near-monthly, continuous sampling resolution, and capacity to focus on SST anomalies after removing an annual cycle calculated over many years (represented as geochemical oscillations). Here we briefly review the paleoceanographic pursuit of interannual variability. We additionally highlight recent research documented by Ong et al., (2022, https://doi.org/10.1029/2022PA004483) who demonstrate the utility of Sr/Ca variations in capturing SST variability using a difficult-to-sample meandroid coral species, *Colpophyllia natans*, which is widespread across the Caribbean region and can be used to generate records spanning multiple centuries.

1. Main Text

Year-to-year fluctuations in tropical sea-surface temperatures (SST) trigger anomalous weather patterns and long-lived extreme events over densely populated nations, resulting in severe socioeconomic distress (Cai et al., 2019). SST variations causing these events are typically associated with natural modes of climate variability such as the El Niño/Southern Oscillation (ENSO), the Atlantic Ocean Zonal mode, and the Indian Ocean Dipole (Birkett et al., 1999; Ropelewski & Halpert, 1986; Thirumalai et al., 2017; Towner et al., 2020), and exhibit distinct power spectral peaks within the interannual frequency band (1–9 year^{-1}). Temporally peaking during distinct seasons—that is, "phase-locked" to the annual cycle (Cane, 1986; Jin et al., 1994)—anomalous SST patterns diagnostic of these phenomena facilitate anomalous seasonal precipitation patterns around the globe (Cai et al., 2019; Ropelewski & Halpert, 1987). Accordingly, indices of SST variability characterizing these modes factor into seasonal climate prediction in many parts of the world (Goddard et al., 2001). Monitoring how year-to-year SST variability changes over time and examining its drivers and relationship with global and regional climate forcing are fundamental objectives of current climate science.

How will natural modes of interannual climate variability change under ongoing and future global warming due to increasing levels of greenhouse gases? Substantial uncertainties exist in addressing this question, partly due to the lack of long-term SST observations before the influence of radiative forcing from modern anthropogenic CO_2 emissions. Unfortunately, observational SST coverage was sparse before the 1960s, particularly in tropical regions (Deser et al., 2010), after which greenhouse forcing had already impacted SST trends. Therefore, the short and incomplete observational record precludes "*out-of-sample*" validations of simulated interannual variability using coupled general circulation models (GCMs)—our best available tools to anticipate future changes—under vastly different boundary conditions and forcings, resembling projected scenarios or otherwise (DiNezio et al., 2020). Fortunately, over the past six decades, geochemists, paleoceanographers, and paleoclimatologists have developed and fine-tuned several viable approaches to gain insights into interannual marine paleovariability.

The shells and skeletons accreted by calcareous marine biomineralizers are commonly utilized archives of seasonal and sub-seasonal temperature variations due to their ubiquity and preservation, relatively fast growth rates, and geochemical propensity to reflect environmental parameters. To resolve seasonal and interannual variability, one must work with archives that grew appreciably enough to be sampled (based on the choice of proxy/sensor) at subannual timescales (Fairbanks & Dodge, 1979; Shackleton, 1973), which include corals, mollusks, otoliths, sclerosponges, brachiopods etc. (collectively termed *"sclerochronological"* archives; *e.g.,* Buddemeier et al. (1974); Hudson et al. (1976)). Urey et al. (1951) first measured the stable oxygen isotope ratio ($\delta^{18}O$) across growth bands of a Jurassic belemnite and observed cyclic variations in $\delta^{18}O$ and interpreted them to be annual cycles of temperature. Epstein et al. (1953) presented a reconstruction of 1–2 years of subannually resolved $\delta^{18}O$ variations in live-collected abalone shells from the California coast, validated using in situ temperature observations. Twenty years later, Shackleton (1973) popularized this subannual sampling strategy in a pivotal study on limpet shells and pressed other "*paleotemperature laboratories*" to apply this approach to problems in archeology and paleoclimatology. Shackleton (1973) inferred the wintertime occupation of archeological sites in coastal South Africa by contrasting subannual $\delta^{18}O$ variations in recently dead limpet shells with those collected from nearby mid-Holocene-aged middens (albeit with a caveat: "*It is of course perfectly possible that during the summer the inhabitants simply did not eat shellfish, but considering how much more pleasant the very wet occupation of collecting shells at low water or below would be in summer than in winter, this seems improbable.*") In another preliminary study of interannual marine variability, Killingley and Berger (1979) reconstructed upwelling events offshore California using subannually sampled stable isotopes in accreted calcareous layers of mussel shells.

Generally, approaches of past interannual marine investigations fall into two broad (and sometimes overlapping) categories: (a) the generation of continuous subannually resolved geochemical measurements and estimating changes in variability via time- and frequency domain analysis (termed here as the *"temporal approach"*) and (b) by statistically contrasting changes in climate variance derived from subannually sampled archives between disparate climate states (the *"timeslice approach"*). Early examples of the *temporal approach* include the aforementioned study by Killingley and Berger (1979) and others resolving year-to-year variations using corals (E. Druffel, 1982; Dunbar & Wellington, 1981; Emiliani et al., 1978) and mollusks (Jones et al., 1983; Wefer & Killingley, 1980; Williams et al., 1982). Fast-accumulating sediments (primarily in anoxic settings) have also been used to furnish estimates of past interannual variability using a variety of enclosed proxy indicators, including foraminifera and biomarkers (Baumgartner et al., 1985; Hagadorn et al., 1995; Kennedy & Brassell, 1992; Soutar & Crill, 1977). The use of the *timeslice approach* to discern variability between periods, akin to that employed by Shackleton (1973), has been expanded to various archives—sclerochronological and otherwise (Beck et al., 1997; Jones et al., 1983; Tang & Stott, 1993)—proving useful in '*out-of-sample*' comparisons with climate simulations (Emile-Geay et al., 2015), as envisioned by Crowley et al. (1986).

Both stable isotopes and trace metal ratios measured in carbonates are routinely used as proxies for past seawater temperatures. Covariation between temperature and the trace metal composition and mineralogy of marine calcareous invertebrates was recognized by Clarke and Wheeler (1922) and Bøggild (1930), building on foundational studies such as Silliman (1846), who first reported on the chemistry of corals. Studies addressing the thermodynamical basis of elemental partitioning (such as Mg^{2+} and Sr^{2+}) during calcification provided breakthroughs for the emergence of trace metal paleothermometry (Chave, 1954; Dodd, 1967; Lowenstam, 1961). Influential early studies in the 1970s also addressed the thermodynamics of stable isotope fractionation in corals (Keith & Weber, 1965; Land et al., 1975; Weber & Woodhead, 1970, 1972). At this time, the annual nature of banding in corals was confirmed by radionuclide geochemistry (Dodge & Thomson, 1974; Moore et al., 1973), and several approaches to date modern and fossil corals began to be developed (Ku, 1976; E. M. Druffel & Linick, 1978). Expanding on these lines of research, and using annual layer counting for chronology, Goreau (1977) and Emiliani et al. (1978) generated the first continuous subannual $\delta^{18}O$ timeseries in slabs of massive Atlantic corals. Fairbanks and Dodge (1979) additionally showed that subannual geochemical variations provide more robust chronological constraints than coral growth rates and outlined a model for chronology and paleotemperature inference from coral archives. These and other studies (Brand & Veizer, 1980; Carriker et al., 1980; Dodd & Crisp, 1982; Papadopoulou et al., 1980; Swart, 1981) laid the foundations for subannually resolved paleotemperature applications throughout the Phanerozoic.

The "maverick" El Niño event of 1982–1983—a strong Eastern Pacific event unprecedented in observational coverage at the time—heralded significant progress in ENSO theory (Cane, 1983; Cane & Zebiak, 1985) and stimulated paleo-ENSO research (E. Druffel, 1985; Rollins et al., 1987; Carriquiry et al., 1988; Shen, 1993). Targeting paleo-ENSO reconstruction, several subannual-resolution coral records were generated from across the Pacific Ocean in the 1990s (Cole & Fairbanks, 1990; Cole, Fairbanks, & Shen, 1993; E. Druffel et al., 1990; Dunbar et al., 1994; Evans et al., 1998; Linn et al., 1990; Linsley et al., 1994; McCulloch et al., 1994; Quinn et al., 1993; Shen, 1993; Shen et al., 1991; Tudhope et al., 1995). This led to key advances such as preliminary

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forays into isotope-enabled model-data comparisons (Cole, Rind, & Fairbanks, 1993) and the development of coral-based SST field reconstructions (Evans et al., 2000). Additionally, the *timeslice approach* was extended to a variety of archives including mollusks (Carré et al., 2005; Perrier et al., 1992; Rollins et al., 1987), corals (Cobb et al., 2003; Gagan et al., 1998; McGregor & Gagan, 2004; Tudhope et al., 2001), and foraminifera (Koutavas et al., 2006) to estimate past ENSO variability. Subsequently, it was recognized that both *temporal* and *timeslice* approaches necessitated the isolation of the interannual (1–9 years) band of variability from subannual measurements for accurate assessments of past changes (Charles et al., 1997; Cobb et al., 2001; Dunbar et al., 1994), as ENSO and other natural modes are typically "phase-locked" to the annual cycle (Cane, 1986; Jin et al., 1994). Whereas seasonality may be estimated accurately from mollusks (Ivany, 2012; Jones & Allmon, 1995; Judd et al., 2018) and foraminifera (Tang & Stott, 1993; Thirumalai & Clemens, 2020; Thirumalai et al., 2013), the ability to separate subannual anomalies from the annual cycle over several years of data (≥a decade) renders coral geochemistry as a particularly suitable approach for the pursuit of past interannual variability.

Numerous extinct and extant coral taxa have been employed in paleoclimate reconstructions, with most studies of protracted interannual variability relying on massive stony corals. By our count, subannually resolved, continuous geochemical records have been generated from upwards of 14 different extant hermatypic coral genera, including *Montastrea/Orbicella* (Goreau, 1977), *Pocillopora* (Dunbar & Wellington, 1981), *Porites* (Schneider & Smith, 1982), *Pavona* (E. Druffel, 1985), *Platygyra* (Quinn et al., 1993), *Favia* (Chakraborty & Ramesh, 1998), *Diploastrea* (Watanabe et al., 2003), *Acropora* (Gallup et al., 2006), *Diploria/Pseudodiploria* (Hetzinger et al., 2006), *Siderastrea* (Maupin et al., 2008), *Isopora* (Lemley, 2012), *Stylophora* (Ross et al., 2019), *Turbinaria* (Ross et al., 2019), and *Cladocora* (Spreter et al., 2020). More recent work has also attempted to develop subannual geochemical records from ahermatypic and deep-sea corals (Montagna et al., 2005; Saenger et al., 2017; Serrato Marks et al., 2017; Thresher et al., 2009). By far, the most popular choice for tropical SST reconstructions has been the stony coral genus, *Porites*, partly owing to the regular growth patterns of certain species and their ability to form massive structures over several decades to centuries. However, we note that coral species from other genera also reliably fit these criteria and can also facilitate robust chronologies (Sadler et al., 2014). *Porites spp.* commonly used for paleoclimate are found only in particular basins across the tropical oceans and only within specific habitats; moreover, they are typically not as long-lived as corals with slower growth rates, the latter of which have the potential to yield records spanning longer than 5–6 centuries (Sadler et al., 2014; Watanabe et al., 2003). In addition, discrete pieces of coral collected from marine sediments and drill cores, outcrops, or storm deposits can span several years and belong to multiple genera besides *Porites* (Brenner et al., 2017; Marshall & Davies, 1982). Thus, paleothermometry developed across a plethora of coral taxa can improve our understanding of interannual climate variability by exploring oceanic environments and time periods commonly out of reach for *Porites*.

Several studies have begun a pivot, refocusing on expanding the coral paleoclimate toolkit beyond Indo-Pacific *Porites spp.*, developing calibrations for non-massive as well as slower-growing massive coral species, for example, Sadler et al. (2014), Sadler et al. (2016), Pereira et al. (2016, 2017), Brenner et al. (2017), Evangelista et al. (2018), Ross et al. (2019), and Spreter et al. (2020). Here we highlight recent work by Ong et al. (2022) who introduce a new genus to the toolkit: *Colpophyllia*. Specifically, these authors use *Colpophyllia natans* (Houttuyn, 1772; Figure 1) samples collected from the island of Tobago in the southeastern Caribbean region and demonstrate that its skeletal geochemistry can accurately record paleotemperature variations. *Colpophyllia natans* is a meandroid (brain) coral that can form massive colonies and is found throughout the northern tropical–subtropical Atlantic Ocean and Caribbean Sea (Goreau, 1959; Lewis, 1960; Roos, 1971). Linear growth rates for *C. natans* are typically less than 1 cm year^{-1} and reduce with increasing depth habitat of colonies (Huston, 1985). After deciphering optimal pathways for sampling this species, Ong et al. (2022) measured Sr/Ca ratios in powders continuously micro-milled from slabs of *C. natans*—a challenging task for corals with slow growth rates and complicated, intricate morphologies (Figure 1b) (Giry et al., 2010; Goodkin et al., 2005; Maupin et al., 2008; Watanabe et al., 2003)—achieving a resolution of around 40–50 samples year^{-1} (see Fig. S3 in Ong et al. (2022), for X-radiograph images of their sampling paths). They also measured Sr/Ca variations in a nearby *Siderastrea siderea* specimen to compare their measurements with a more established coral species in paleoclimate literature (DeLong et al., 2014; Flannery et al., 2017; Fowell et al., 2016; Maupin et al., 2008).

Ong et al. (2022) find strong correlations between observed surface-ocean temperature and Sr/Ca variations in reconstructions using *C. natans* and *S. siderea*. Though offset from each other in their mean Sr/Ca values—attributed to species-specific effects—variations reconstructed using both species significantly co-vary with each other and with 5–km-resolution satellite SST observations from 1988 to 2015 (see Fig. 3 in Ong et al. (2022)).

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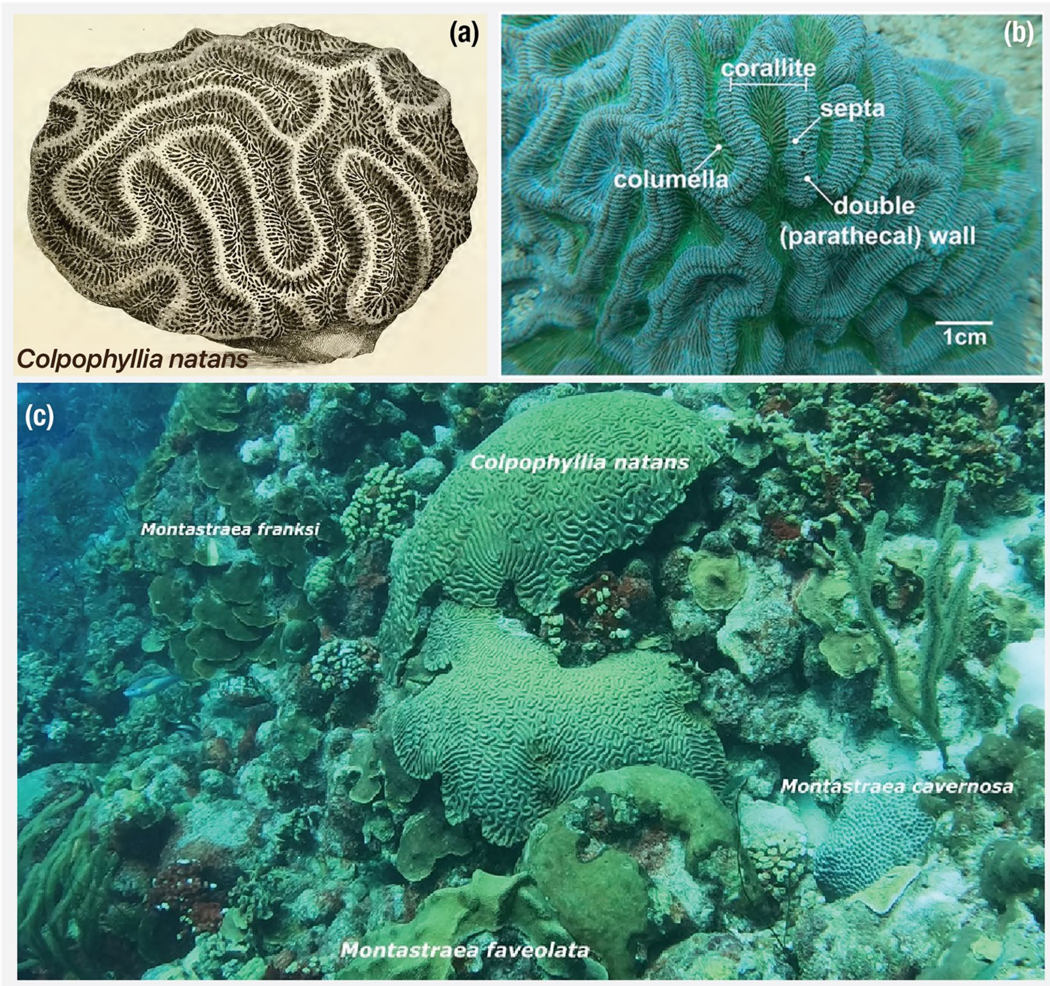

Figure 1. *Colpophyllia natans* (Houttuyn, 1772) through the ages. (a) Illustration of *C. natans* (originally listed as "*Madrepora gyrosa*") by Lamouroux (1816), (b) Photograph of *C. natans* and its morphology from Ong et al. (2022), (c) Photograph of *C. natans* colony in reefal habitat with other stony coral species (labeled), taken by one of the authors (CRM) in June 2023.

Debate persists regarding the exact mechanisms of temperature-mediated Sr^{2+} incorporation into coral aragonite and the size of nonthermal impacts on Sr/Ca variability related to growth kinetics (Allison, 1996; De Villiers et al., 1994; Grove et al., 2013; Hart & Cohen, 1996; Inoue et al., 2007). Nevertheless, several studies have shown that coral Sr/Ca has high reproducibility and skill in the retrieval of past paleotemperature variations (Smith et al., 2006; Stephans et al., 2004) [see also recent review by Thompson (2022)]. Using a careful subsampling strategy of corallites in slabs of *C. natans*, continuous Sr/Ca measurements performed by Ong et al. (2022) appear to be significantly (∼70%) explained by satellite-based SST variations. A ∼30–year stack using both coral records is fully consistent with observed seasonal and interannual SST variability—locally and with broader Atlantic Ocean climate indices. In essence, Ong et al. (2022) unlock the potential of *C. natans* Sr/Ca as a viable paleotemperature proxy in the tropical–subtropical Atlantic Ocean and Caribbean seas, with the ability to generate records spanning multiple centuries from recent or (sub)fossil specimens in the region. Applications of both *temporal* and *timeslice* approaches in the Indo-Pacific using non-traditional coral species may be targeted to address temporal gaps in available *Porites* datasets. Future calibration studies and applications using various coral taxa will furnish much-needed, long-term perspectives of tropical climate variability under various climatic regimes (Cai et al., 2019; DiNezio et al., 2020).

In 1979, a report prepared for the US National Science Foundation Climate Dynamics Program entitled "Paleoclimate Research: Status and Opportunities" contained this (then, open) question: *"Does the interannual variability*

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of climate change with time?" (Hecht et al., 1979). The rhetoric has significantly advanced since then, thanks to the persistence and curiosity of scientists across various disciplines and nations over the past 44 years. These efforts have since brought seemingly Promethean leaps and bounds to our understanding of interannual climate variability over Earth history, including testable theories for its nature of change.

Data Availability Statement

No new data were generated for this review paper.

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References

Allison, N. (1996). Geochemical anomalies in coral skeletons and their possible implications for palaeoenvironmental analyses. *Marine Chemistry*, *55*(3–4), 367–379. https://doi.org/10.1016/s0304-4203(96)00060-6

Baumgartner, T., Ferreira-Bartrina, V., Schrader, H., & Soutar, A. (1985). A 20-year varve record of siliceous phytoplankton variability in the central Gulf of California. *Marine Geology*, *64*(1–2), 113–129. https://doi.org/10.1016/0025-3227(85)90163-x

Beck, J. W., Récy, J., Taylor, F., Edwards, R. L., & Cabioch, G. (1997). Abrupt changes in early Holocene tropical sea surface temperature derived from coral records. *Nature*, *385*(6618), 705–707. https://doi.org/10.1038/385705a0

Birkett, C., Murtugudde, R., & Allan, T. (1999). Indian ocean climate event brings floods to east Africa's lakes and the Sudd marsh. *Geophysical Research Letters*, *26*(8), 1031–1034. https://doi.org/10.1029/1999gl900165

Bøggild, O. B. (1930). The shell structure of the mollusks. Det Kongelige Danske Videnskabernes Selskabs Skrifter. *Naturvidenskabelig og Mathematisk Afdeling, Raekke*, *9*(2), 231–326.

Brand, U., & Veizer, J. (1980). Chemical diagenesis of a multicomponent carbonate system; 1, trace elements. *Journal of Sedimentary Research*, *50*(4), 1219–1236.

Brenner, L. D., Linsley, B. K., & Potts, D. C. (2017). A modern sr/ca-δ18o-sea surface temperature calibration for isopora corals on the Great Barrier Reef. *Paleoceanography*, *32*(2), 182–194. https://doi.org/10.1002/2016pa002973

Buddemeier, R. W., Maragos, J. E., & Knutson, D. W. (1974). Radiographic studies of reef coral exoskeletons: Rates and patterns of coral growth. *Journal of Experimental Marine Biology and Ecology*, *14*(2), 179–199. https://doi.org/10.1016/0022-0981(74)90024-0

Cai, W., Wu, L., Lengaigne, M., Li, T., McGregor, S., Kug, J., et al. (2019). Pantropical climate interactions. *Science*, *363*(6430). https://doi.org/10.1126/science.aav4236

Cane, M. (1983). Oceanographic events during El Nino. *Science*, *222*(4629), 1189–1195. https://doi.org/10.1126/science.222.4629.1189

Cane, M. (1986). El Niño. *Annual Review of Earth and Planetary Sciences*, *14*(1), 43–70. https://doi.org/10.1146/annurev.ea.14.050186.000355

Cane, M., & Zebiak, S. (1985). A theory for El Nino and the southern oscillation. *Science*, *228*(4703), 1085–1087. https://doi.org/10.1126/science.228.4703.1085

Carré, M., Bentaleb, I., Fontugne, M., & Lavallée, D. (2005). Strong El Niño events during the early Holocene: Stable isotope evidence from Peruvian sea shells. *The Holocene*, *15*(1), 42–47. https://doi.org/10.1191/0959683605h1782rp

Carriker, M. R., Palmer, R. E., Sick, L. V., & Johnson, C. C. (1980). Interaction of mineral elements in sea water and shell of oysters (Crassostrea virginica (Gmelin)) cultured in controlled and natural systems. *Journal of Experimental Marine Biology and Ecology*, *46*(2), 279–296. https://doi.org/10.1016/0022-0981(80)90036-2

Carriquiry, J., Risk, M., & Schwarcz, H. (1988). Timing and temperature record from stable isotopes of the 1982-1983 El Nino warming event in eastern pacific corals. *PALAIOS*, *3*(3), 359–364. https://doi.org/10.2307/3514665

Chakraborty, S., & Ramesh, R. (1998). Stable isotope variations in a coral (*Favia speciosa*) from the Gulf of Kutch during 1948–1989 ad: Environmental implications. *Proceedings of the Indiana Academy of Science*, *107*(4), 331–341. https://doi.org/10.1007/bf02841599

Charles, C. D., Hunter, D. E., & Fairbanks, R. G. (1997). Interaction between the ENSO and the ASIAN monsoon in a coral record of tropical climate. *Science*, *277*(5328), 1–5. https://doi.org/10.1126/science.277.5328.925

Chave, K. E. (1954). Aspects of the biogeochemistry of magnesium 2. calcareous sediments and rocks. *The Journal of Geology*, *62*(6), 587–599. https://doi.org/10.1086/626208

Clarke, F. W., & Wheeler, W. C. (1922). *The inorganic constituents of marine invertebrates* (Vol. 124). US Government Printing Office.

Cobb, K. M., Charles, C. D., Cheng, H., & Edwards, R. L. (2003). El Niño/Southern Oscillation and tropical pacific climate during the last millennium. *Nature*, *424*(6946), 271–276. https://doi.org/10.1038/nature01779

Cobb, K. M., Charles, C. D., & Hunter, D. E. (2001). A central tropical pacific coral demonstrates Pacific, Indian, and Atlantic decadal climate connections. *Geophysical Research Letters*, *28*(11), 2209–2212. https://doi.org/10.1029/2001gl012919

Cole, J., & Fairbanks, R. (1990). The southern oscillation recorded in the δ^{18}o of corals from Tarawa Atoll. *Paleoceanography*, *5*(5), 669–683. https://doi.org/10.1029/pa005i005p00669

Cole, J., Fairbanks, R., & Shen, G. (1993). Recent variability in the southern oscillation: Isotopic results from a Tarawa Atoll coral. *Science*, *260*(5115), 1790–1793. https://doi.org/10.1126/science.260.5115.1790

Cole, J., Rind, D., & Fairbanks, R. (1993). Isotopic responses to interannual climate variability simulated by an atmospheric general circulation model. *Quaternary Science Reviews*, *12*(6), 387–406. https://doi.org/10.1016/s0277-3791(05)80004-6

Crowley, T., Short, D., Mengel, J., & North, G. (1986). Role of seasonality in the evolution of climate during the last 100 million years. *Science*, *231*(4738), 579–584. https://doi.org/10.1126/science.231.4738.579

DeLong, K. L., Flannery, J. A., Poore, R. Z., Quinn, T. M., Maupin, C. R., Lin, K., & Shen, C. C. (2014). A reconstruction of sea surface temperature variability in the southeastern Gulf of Mexico from 1734 to 2008 CE using cross-dated Sr/Ca records from the coral. *Paleoceanography*, *29*(5), 403–422. https://doi.org/10.1002/2013pa002524

Deser, C., Alexander, M. A., Xie, S.-P., & Phillips, A. S. (2010). Sea surface temperature variability: Patterns and mechanisms. *Annual Review of Marine Science*, *2*(1), 115–143. https://doi.org/10.1146/annurev-marine-120408-151453

De Villiers, S., Shen, G. T., & Nelson, B. K. (1994). The SRCA-temperature relationship in coralline aragonite: Influence of variability in (SRCA) seawater and skeletal growth parameters. *Geochimica et Cosmochimica Acta*, *58*(1), 197–208. https://doi.org/10.1016/0016-7037(94)90457-x

DiNezio, P. N., Puy, M., Thirumalai, K., Jin, F.-F., & Tierney, J. E. (2020). Emergence of an equatorial mode of climate variability in the Indian Ocean. *Science Advances*, *6*(19), eaay7684. https://doi.org/10.1126/sciadv.aay7684

Dodd, J. (1967). Magnesium and strontium in calcareous skeletons: A review. *Journal of Paleontology*, *41*(6), 1313–1329.

Dodd, J., & Crisp, E. (1982). Non-linear variation with salinity of Sr/Ca and Mg/Ca ratios in water and aragonitic bivalve shells and implications for paleosalinity studies. *Palaeogeography, Palaeoclimatology, Palaeoecology*, *38*(1–2), 45–56. https://doi.org/10.1016/0031-0182(82)90063-3

Dodge, R. E., & Thomson, J. (1974). The natural radiochemical and growth records in contemporary hermatypic corals from the Atlantic and Caribbean. *Earth and Planetary Science Letters*, *23*(3), 313–322. https://doi.org/10.1016/0012-821x(74)90121-6

Druffel, E. (1982). Banded corals: Changes in oceanic carbon-14 during the little ice age. *Science*, *218*(4567), 13–19. https://doi.org/10.1126/science.218.4567.13

Druffel, E. (1985). Detection of El Nino and decade time scale variations of sea surface temperature from banded coral records: Implications for the carbon dioxide cycle. *The carbon cycle and atmospheric CO_2: Natural variations archean to present*, (Vol. 32, pp. 111–122).

Druffel, E., Dunbar, R., Wellington, G., & Minnis, S. (1990). Reef-building corals and identification of Enso warming episodes. In *Global ecological consequences of the 1982–83 El Nino—Southern Oscillation* (pp. 233–253). Elsevier.

Druffel, E. M., & Linick, T. W. (1978). Radiocarbon in annual coral rings of Florida. *Geophysical Research Letters*, *5*(11), 913–916. https://doi.org/10.1029/gl005i011p00913

Dunbar, R. B., & Wellington, G. M. (1981). Stable isotopes in a branching coral monitor seasonal temperature variation. *Nature*, *293*(5832), 453–455. https://doi.org/10.1038/293453a0

Dunbar, R. B., Wellington, G. M., Colgan, M. W., & Glynn, P. W. (1994). Eastern pacific sea surface temperature since 1600 ad: The δ^{18}o record of climate variability in galapagos corals. *Journal of Marine Research*, *9*(2), 291–315. https://doi.org/10.1029/93pa03501

Emile-Geay, J., Cobb, K. M., Carré, M., Braconnot, P., Leloup, J., Zhou, Y., et al. (2015). Links between tropical pacific seasonal, interannual and orbital variability during the Holocene. *Nature Geoscience*, *9*(2), 168–173. https://doi.org/10.1038/ngeo2608

Emiliani, C., Hudson, J., Shinn, E., & George, R. (1978). Oxygen and carbon isotopic growth record in a reef coral from the Florida keys and a deep-sea coral from Blake plateau. *Science*, *202*(4368), 627–629. https://doi.org/10.1126/science.202.4368.627

Epstein, S., Buchsbaum, R., Lowenstam, H. A., & Urey, H. C. (1953). Revised carbonate-water isotopic temperature scale. *Geological Society of America Bulletin*, *64*(11), 1315–1312. https://doi.org/10.1130/0016-7606(1953)64[1315:rcits]2.0.co;2

Evangelista, H., Sifeddine, A., Corrège, T., Servain, J., Dassié, E. P., Logato, R., et al. (2018). Climatic constraints on growth rate and geochemistry (Sr/Ca and U/Ca) of the coral *Siderastrea stellata* in the southwest equatorial Atlantic (Rocas Atoll, Brazil). *Geochemistry, Geophysics, Geosystems*, *19*(3), 772–786. https://doi.org/10.1002/2017gc007365

Evans, M. N., Fairbanks, R. G., & Rubenstone, J. L. (1998). A proxy index of ENSO teleconnections. *Nature*, *394*(6695), 732–733. https://doi.org/10.1038/29424

Evans, M. N., Kaplan, A., & Cane, M. A. (2000). Intercomparison of coral oxygen isotope data and historical sea surface temperature (SST): Potential for coral-based sst field reconstructions. *Paleoceanography*, *15*(5), 551–563. https://doi.org/10.1029/2000pa000498

Fairbanks, R. G., & Dodge, R. E. (1979). Annual periodicity of the 18o16o and 13c12c ratios in the coral Montastrea annularis. *Geochimica et Cosmochimica Acta*, *43*(7), 1009–1020. https://doi.org/10.1016/0016-7037(79)90090-5

Flannery, J. A., Richey, J. N., Thirumalai, K., Poore, R. Z., & DeLong, K. L. (2017). Multi-species coral Sr/Ca-based sea-surface temperature reconstruction using *Orbicella faveolata* and *Siderastrea siderea* from the Florida straits. *Palaeogeography, Palaeoclimatology, Palaeoecology*, *466*, 100–109. https://doi.org/10.1016/j.palaeo.2016.10.022

Fowell, S. E., Sandford, K., Stewart, J. A., Castillo, K. D., Ries, J. B., & Foster, G. L. (2016). Intrareef variations in li/mg and Sr/Ca sea surface temperature proxies in the Caribbean reef-building coral *Siderastrea siderea*. *Paleoceanography*, *31*(10), 1315–1329. https://doi.org/10.1002/2016pa002968

Gagan, M. K., Ayliffe, L. K., Hopley, D., Cali, J. A., Mortimer, G. E., Chappell, J., & Head, M. J. (1998). Temperature and surface-ocean water balance of the mid-Holocene tropical western pacific. *Science*, *279*(5353), 1014–1018. https://doi.org/10.1126/science.279.5353.1014

Gallup, C. D., Olson, D. M., Edwards, R. L., Gruhn, L. M., Winter, A., & Taylor, F. W. (2006). Sr/Ca-sea surface temperature calibration in the branching Caribbean coral *Acropora palmata*. *Geophysical Research Letters*, *33*(3), L03606. https://doi.org/10.1029/2005gl024935

Giry, C., Felis, T., Scheffers, S., & Fensterer, C. (2010). Assessing the potential of southern Caribbean corals for reconstructions of Holocene temperature variability. *IOP Conference Series: Earth and Environmental Science*, *9*, 012021–012010. https://doi.org/10.1088/1755-1315/9/1/012021

Goddard, L., Mason, S. J., Zebiak, S. E., Ropelewski, C. F., Basher, R., & Cane, M. A. (2001). Current approaches to seasonal to interannual climate predictions. *International Journal of Climatology*, *21*(9), 1111–1152. https://doi.org/10.1002/joc.636

Goodkin, N. F., Hughen, K. A., Cohen, A. L., & Smith, S. R. (2005). Record of little ice age sea surface temperatures at Bermuda using a growth-dependent calibration of coral Sr/Ca. *Paleoceanography*, *20*(4). https://doi.org/10.1029/2005pa001140

Goreau, T. (1959). The ecology of Jamaican coral reefs I. species composition and zonation. *Ecology*, *40*(1), 67–90. https://doi.org/10.2307/1929924

Goreau, T. (1977). Coral skeletal chemistry: Physiological and environmental regulation of stable isotopes and trace metals in *Montastrea annularis*. *Proceedings of the Royal Society of London - Series B: Biological Sciences*, *196*(1124), 291–315.

Grove, C. A., Kasper, S., Zinke, J., Pfeiffer, M., Garbe-Schönberg, D., & Brummer, G.-J. A. (2013). Confounding effects of coral growth and high SST variability on skeletal Sr/Ca: Implications for coral paleothermometry. *Geochemistry, Geophysics, Geosystems*, *14*(4), 1277–1293. https://doi.org/10.1002/ggge.20095

Hagadorn, J. W., Stott, L. D., Sinha, A., & Rincon, M. (1995). Geochemical and sedimentologic variations in inter-annually laminated sediments from Santa Monica basin. *Marine Geology*, *125*(1–2), 111–131. https://doi.org/10.1016/0025-3227(95)00012-n

Hart, S. R., & Cohen, A. L. (1996). An ion probe study of annual cycles of Sr/Ca and other trace elements in corals. *Geochimica et Cosmochimica Acta*, *60*(16), 3075–3084. https://doi.org/10.1016/0016-7037(96)00154-8

Hecht, A. D., Barry, R., Fritts, H., Imbrie, J., Kutzbach, J., Mitchell, J. M., & Savin, S. M. (1979). Paleoclimatic research: Status and opportunities. *Quaternary Research*, *12*(1), 6–17. https://doi.org/10.1016/0033-5894(79)90089-9

Hetzinger, S., Pfeiffer, M., Dullo, W.-C., Ruprecht, E., & Garbe-Schönberg, D. (2006). Sr/Ca and δ18o in a fast-growing *Diploria strigosa* coral: Evaluation of a new climate archive for the tropical Atlantic. *Geochemistry, Geophysics, Geosystems*, *7*(10). https://doi.org/10.1029/2006gc001347

Houttuyn, M. (1772). Natuurlyke historie of uitvoerige beschryving der dieren, planten en mineraalen, volgens het samenstel van den heer linnæus (Vol. *17*).

Hudson, J. H., Shinn, E. A., Halley, R. B., & Lidz, B. (1976). Sclerochronology: A tool for interpreting past environments. *Geology*, *4*(6), 361–364. https://doi.org/10.1130/0091-7613(1976)4<361:satfip>2.0.co;2

Huston, M. (1985). Variation in coral growth rates with depth at discovery bay, Jamaica. *Coral Reefs*, *4*(1), 19–25. https://doi.org/10.1007/bf00302200

Inoue, M., Suzuki, A., Nohara, M., Hibino, K., & Kawahata, H. (2007). Empirical assessment of coral sr/ca and mg/ca ratios as climate proxies using colonies grown at different temperatures. *Geophysical Research Letters*, *34*(12), L12611. https://doi.org/10.1029/2007gl029628

Ivany, L. C. (2012). Reconstructing paleoseasonality from accretionary skeletal carbonates—Challenges and opportunities. *Paleontological Society Papers*, *18*, 133–166. https://doi.org/10.1017/s108933260000259x

25724525, 2023, 8, Downloaded from https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2023PA004723, Wiley Online Library on [02/12/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

Jin, F. F., Neelin, J. D., & Ghil, M. (1994). El Niño on the devil's staircase: Annual subharmonic steps to chaos. *Science*, *264*(5155), 70–72. https://doi.org/10.1126/science.264.5155.70

Jones, D. S., & Allmon, W. D. (1995). Records of upwelling, seasonality and growth in stable-isotope profiles of Pliocene mollusk shells from Florida. *Lethaia*, *28*(1), 61–74. https://doi.org/10.1111/j.1502-3931.1995.tb01593.x

Jones, D. S., Williams, D. F., & Arthur, M. A. (1983). Growth history and ecology of the Atlantic surf clam, *Spisula solidissima* (dillwyn), as revealed by stable isotopes and annual shell increments. *Journal of Experimental Marine Biology and Ecology*, *73*(3), 225–242. https://doi.org/10.1016/0022-0981(83)90049-7

Judd, E. J., Wilkinson, B. H., & Ivany, L. C. (2018). The life and time of clams: Derivation of intra-annual growth rates from high-resolution oxygen isotope profiles. *Palaeogeography, Palaeoclimatology, Palaeoecology*, *490*, 70–83. https://doi.org/10.1016/j.palaeo.2017.09.034

Keith, M., & Weber, J. (1965). Systematic relationships between carbon and oxygen isotopes in carbonates deposited by modern corals and algae. *Science*, *150*(3695), 498–501. https://doi.org/10.1126/science.150.3695.498

Kennedy, J. A., & Brassell, S. C. (1992). Molecular records of twentieth-century El Niño events in laminated sediments from the Santa Barbara basin. *Nature*, *357*(6373), 62–64. https://doi.org/10.1038/357062a0

Killingley, J., & Berger, W. (1979). Stable isotopes in a mollusk shell: Detection of upwelling events. *Science*, *205*(4402), 186–188. https://doi.org/10.1126/science.205.4402.186

Koutavas, A., de Menocal, P. B., Olive, G. C., & Lynch-Stieglitz, J. (2006). Mid-Holocene El Niño–Southern Oscillation (ENSO) attenuation revealed by individual foraminifera in eastern tropical pacific sediments. *Geology*, *34*(12), 993–994. https://doi.org/10.1130/g22810a.1

Ku, T.-L. (1976). The uranium-series methods of age determination. *Annual Review of Earth and Planetary Sciences*, *4*(1), 347–379. https://doi.org/10.1146/annurev.ea.04.050176.002023

Lamouroux, J. V. F. (1816). *Histoire des polypiers coralligènes flexibles, vulgairement nommés zoophytes*. Imprimerie de F. Poisson.

Land, L., Lang, J., & Barnes, D. (1975). Extension rate: A primary control on the isotopic composition of West Indian (Jamaican) Scleractinian reef coral skeletons. *Marine Biology*, *33*(3), 221–233. https://doi.org/10.1007/bf00390926

Lemley, G. M. (2012). Assessing delta oxygen-18 in the coral genus Isopora for reconstructing indo-pacific regional and seasonal climate. *ProQuest Dissertations and Theses*, *76*. (Copyright - Database copyright ProQuest LLC; ProQuest does not claim copyright in the individual underlying works; Last updated - 2023-03-04).

Lewis, J. B. (1960). The coral reefs and coral communities of Barbados, W.I. *Canadian Journal of Zoology*, *38*(6), 1133–1145. https://doi.org/10.1139/z60-118

Linn, L., Delaney, M., & Druffel, E. (1990). Trace metals in contemporary and seventeenth-century galapagos coral: Records of seasonal and annual variations. *Geochimica et Cosmochimica Acta*, *54*(2), 387–394. https://doi.org/10.1016/0016-7037(90)90327-h

Linsley, B. K., Dunbar, R. B., Wellington, G. M., & Mucciarone, D. A. (1994). A coral-based reconstruction of intertropical convergence zone variability over central America since 1707. *Journal of Geophysical Research*, *99*(C5), 9977. https://doi.org/10.1029/94jc00360

Lowenstam, H. A. (1961). Mineralogy, o18/o16 ratios, and strontium and magnesium contents of recent and fossil brachiopods and their bearing on the history of the oceans. *The Journal of Geology*, *69*(3), 241–260. https://doi.org/10.1086/626740

Marshall, J. F., & Davies, P. J. (1982). Internal structure and Holocene evolution of one tree reef, southern great barrier reef. *Coral Reefs*, *1*(1), 21–28. https://doi.org/10.1007/bf00286536

Maupin, C. R., Quinn, T. M., & Halley, R. B. (2008). Extracting a climate signal from the skeletal geochemistry of the caribbean coral *Siderastrea siderea*. *Geochemistry, Geophysics, Geosystems*, *9*(12). https://doi.org/10.1029/2008gc002106

McCulloch, M. T., Gagan, M. K., Mortimer, G. E., Chivas, A. R., & Isdale, P. J. (1994). A high-resolution sr/ca and δ18o coral record from the Great Barrier Reef, Australia, and the 1982–1983 el niño. *Geochimica et Cosmochimica Acta*, *58*(12), 2747–2754. https://doi.org/10.1016/0016-7037(94)90142-2

McGregor, H. V., & Gagan, M. K. (2004). Western pacific coral δ^{18}o records of anomalous Holocene variability in the El Niño–southern oscillation. *Geophysical Research Letters*, *31*(11), L11204–4. https://doi.org/10.1029/2004gl019972

Montagna, P., McCulloch, M., Taviani, M., Remia, A., & Rouse, G. (2005). High-resolution trace and minor element compositions in deep-water Scleractinian corals (*Desmophyllum dianthus*) from the Mediterranean sea and the great Australian bight. In A. Freiwald & J. M. Roberts (Eds.), *Cold-water corals and ecosystems* (pp. 1109–1126). Springer Berlin Heidelberg.

Moore, W. S., Krishnaswami, S., & Bhat, S. (1973). Coral reef project—Papers in memory of Dr. Thomas F. Goreau. 6. Radiometric determinations of coral growth rates. *Bulletin of Marine Science*, *23*(2), 157–176.

Ong, M. R., Goodkin, N. F., Guppy, R., & Hughen, K. A. (2022). *Colpophyllia natans* from tobago, a novel paleoclimate archive for reconstructing sea surface temperature in the tropical Atlantic. *Paleoceanography and Paleoclimatology*, *37*(12). https://doi.org/10.1029/2022pa004483

Papadopoulou, C., Kanias, G., & Moraitopoulou-Kassimati, E. (1980). Trace element content in fish otoliths in relation to age and size. *Marine Pollution Bulletin*, *11*(3), 68–72. https://doi.org/10.1016/0025-326x(80)90546-9

Pereira, N., Sial, A., Frei, R., Ullmann, C., Korte, C., Kikuchi, R., & Kilbourne, K. (2017). The potential of the coral species *Porites astreoides* as a paleoclimate archive for the tropical South Atlantic Ocean. *Journal of South American Earth Sciences*, *77*, 276–285. https://doi.org/10.1016/j.jsames.2017.05.008

Pereira, N., Voegelin, A. R., Paulukat, C., Sial, A. N., Ferreira, V. P., & Frei, R. (2016). Chromium-isotope signatures in Scleractinian corals from the Rocas Atoll, tropical south Atlantic. *Geobiology*, *14*(1), 54–67. https://doi.org/10.1111/gbi.12155

Perrier, C., Hillaire-Marcel, C., & Ortlieb, L. (1992). *Isotopic record of recent and paleo-El Nino events on mollusk shells from nw Peru*. Peru.

Quinn, T. M., Taylor, F. W., & Crowley, T. J. (1993). A 173 year stable isotope record from a tropical south pacific coral. *Quaternary Science Reviews*, *12*(6), 407–418. https://doi.org/10.1016/s0277-3791(05)80005-8

Rollins, H. B., Sandweiss, D. H., Brand, U., & Rollins, J. C. (1987). Growth increment and stable isotope analysis of marine bivalves: Implications for the geoarchaeological record of El Niño. *Geoarchaeology*, *2*(3), 181–197. https://doi.org/10.1002/gea.3340020301

Roos, P. (1971). The shallow-water stony corals of The Netherlands Antilles. *Studies on the Fauna of Curacao and Other Caribbean Islands*, *37*(1), 1–108.

Ropelewski, C. F., & Halpert, M. S. (1986). North American precipitation and temperature patterns associated with the El Niño/Southern Oscillation (ENSO). *Monthly Weather Review*, *114*(12), 2352–2362. https://doi.org/10.1175/1520-0493(1986)114<2352:napatp>2.0.co;2

Ropelewski, C. F., & Halpert, M. S. (1987). Global and regional scale precipitation patterns associated with the El Niño/Southern Oscillation. *Monthly Weather Review*, *115*(8), 1606–1626. https://doi.org/10.1175/1520-0493(1987)115<1606:garspp>2.0.co;2

Ross, C. L., DeCarlo, T. M., & McCulloch, M. T. (2019). Calibration of Sr/Ca, Li/Mg and Sr-U paleothermometry in branching and foliose corals. *Paleoceanography and Paleoclimatology*, *34*(8), 1271–1291. https://doi.org/10.1029/2018pa003426

Sadler, J., Nguyen, A. D., Leonard, N. D., Webb, G. E., & Nothdurft, L. D. (2016). *Acropora* interbranch skeleton Sr/Ca ratios: Evaluation of a potential new high-resolution paleothermometer. *Paleoceanography*, *31*(4), 505–517. https://doi.org/10.1002/2015pa002898

25724525, 2023, 8, Downloaded from https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2023PA004723, Wiley Online Library on [02/12/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

10.1029/2023PA004723

Sadler, J., Webb, G. E., Nothdurft, L. D., & Dechnik, B. (2014). Geochemistry-based coral palaeoclimate studies and the potential of 'non-traditional' (non-massive porites) corals: Recent developments and future progression. *Earth-Science Reviews*, *139*(C), 291–316. https://doi.org/10.1016/j.earscirev.2014.10.002

Saenger, C., Gabitov, R. I., Farmer, J., Watkins, J. M., & Stone, R. (2017). Linear correlations in bamboo coral δ13c and δ18o sampled by sims and micromill: Evaluating paleoceanographic potential and biomineralization mechanisms using δ11b and δ47 composition. *Chemical Geology*, *454*, 1–14. https://doi.org/10.1016/j.chemgeo.2017.02.014

Schneider, R., & Smith, S. (1982). Skeletal Sr content and density in porites spp. in relation to environmental factors. *Marine Biology*, *66*(2), 121–131. https://doi.org/10.1007/bf00397185

Serrato Marks, G., LaVigne, M., Hill, T. M., Sauthoff, W., Guilderson, T. P., Roark, E. B., & Horner, T. J. (2017). Reproducibility of ba/ca variations recorded by northeast Pacific bamboo corals. *Paleoceanography*, *32*(9), 966–979. https://doi.org/10.1002/2017pa003178

Shackleton, N. J. (1973). Oxygen isotope analysis as a means of determining season of occupation of prehistoric midden sites. *Archaeometry*, *15*(1), 133–141. https://doi.org/10.1111/j.1475-4754.1973.tb00082.x

Shen, G. T. (1993). Reconstruction of El Niño history from reef corals. *Bulletin de l'Institut français d'études andines*, *22*(1), 125–158. https://doi.org/10.3406/bifea.1993.1108

Shen, G. T., Campbell, T. M., Dunbar, R. B., Wellington, G. M., Colgan, M. W., & Glynn, P. W. (1991). Paleochemistry of manganese in corals from the Galapagos Islands. *Coral Reefs*, *10*(2), 91–100. https://doi.org/10.1007/bf00571827

Silliman, B. (1846). Art. IV.–On the chemical composition of the calcareous corals. *American Journal of Science and Arts*, *1*(2), 189.

Smith, J., Quinn, T., Helmle, K., & Halley, R. (2006). Reproducibility of geochemical and climatic signals in the Atlantic coral *Montastraea faveolata*. *Paleoceanography*, *21*(1). https://doi.org/10.1029/2005pa001187

Soutar, A., & Crill, P. A. (1977). Sedimentation and climatic patterns in the Santa Barbara basin during the 19th and 20th centuries. *Geological Society of America Bulletin*, *88*(8), 1161–1172. https://doi.org/10.1130/0016-7606(1977)88<1161:sacpit>2.0.co;2

Spreter, P., Reuter, M., Brachert, T. C., & Kersting, D. K. (2020). Ultra-high-resolution stable isotope sampling of slow-growing and fragile coral skeletons. *Palaeogeography, Palaeoclimatology, Palaeoecology*, *560*, 109992. https://doi.org/10.1016/j.palaeo.2020.109992

Stephans, C. L., Quinn, T. M., Taylor, F. W., & Corrége, T. (2004). Assessing the reproducibility of coral-based climate records. *Geophysical Research Letters*, *31*(18), L18210–L18214. https://doi.org/10.1029/2004gl020343

Swart, P. K. (1981). The strontium, magnesium and sodium composition of recent scleractinian coral skeletons as standards for palaeoenvironmental analysis. *Palaeogeography, Palaeoclimatology, Palaeoecology*, *34*, 115–136. https://doi.org/10.1016/0031-0182(81)90060-2

Tang, C. M., & Stott, L. D. (1993). Seasonal salinity changes during mediterranean sapropel deposition 9000 years bp: Evidence from isotopic analyses of individual planktonic foraminifera. *Paleoceanography*, *8*(4), 473–493. https://doi.org/10.1029/93pa01319

Thirumalai, K., & Clemens, S. (2020). Monsoon reconstructions using bulk and individual foraminiferal analyses in marine sediments offshore India. *Current Science*, *119*(2), 328–334. https://doi.org/10.18520/cs/v119/i2/328-334

Thirumalai, K., DiNezio, P. N., Okumura, Y., & Deser, C. (2017). Extreme temperatures in Southeast Asia caused by El Niño and worsened by global warming. *Nature Communications*, *8*(1), ncomms15531. https://doi.org/10.1038/ncomms15531

Thirumalai, K., Partin, J. W., Jackson, C. S., & Quinn, T. M. (2013). Statistical constraints on El Niño southern oscillation reconstructions using individual foraminifera: A sensitivity analysis. *Paleoceanography*, *28*(3), 401–412. https://doi.org/10.1002/palo.20037

Thompson, D. M. (2022). Environmental records from coral skeletons: A decade of novel insights and innovation. *WIREs Climate Change*, *13*(1). https://doi.org/10.1002/wcc.745

Thresher, R. E., MacRae, C. M., Wilson, N. C., & Fallon, S. (2009). Feasibility of age determination of deep-water bamboo corals (Gorgonacea; Isididae) from annual cycles in skeletal composition. *Deep Sea Research Part I: Oceanographic Research Papers*, *56*(3), 442–449. https://doi.org/10.1016/j.dsr.2008.10.003

Towner, J., Cloke, H. L., Lavado, W., Santini, W., Bazo, J., Coughlan de Perez, E., & Stephens, E. M. (2020). Attribution of amazon floods to modes of climate variability: A review. *Meteorological Applications Meteorol Appl*, *27*(5), e1949. https://doi.org/10.1002/met.1949

Tudhope, A., Chilcott, C. P., McCulloch, M. T., Cook, E. R., Chappell, J., Ellam, R. M., et al. (2001). Variability in the El Nino-southern oscillation through a glacial-interglacial cycle. *Science*, *291*(5508), 1511–1517. https://doi.org/10.1126/science.1057969

Tudhope, A., Shimmield, G., Chilcott, C., Jebb, M., Fallick, A., & Dalgleish, A. (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*, *136*(3–4), 575–590. https://doi.org/10.1016/0012-821x(95)00156-7

Urey, H. C., Lowenstam, H. A., Epstein, S., & McKinney, C. R. (1951). Measurement of paleotemperatures and temperatures of the upper cretaceous of England, Denmark, and the southeastern United States. *Geological Society of America Bulletin*, *62*(4), 399–416. https://doi.org/10.1130/0016-7606(1951)62[399:mopato]2.0.co;2

Watanabe, T., Gagan, M. K., Corrége, T., Scott-Gagan, H., Cowley, J., & Hantoro, W. S. (2003). Oxygen isotope systematics in *Diploastrea heliopora*: New coral archive of tropical paleoclimate. *Geochimica et Cosmochimica Acta*, *67*(7), 1349–1358. https://doi.org/10.1016/s0016-7037(02)01221-8

Weber, J., & Woodhead, P. (1970). Carbon and oxygen isotope fractionation in the skeletal carbonate of reef-building corals. *Chemical Geology*, *6*, 93–117. https://doi.org/10.1016/0009-2541(70)90009-4

Weber, J., & Woodhead, P. (1972). Temperature dependence of oxygen-18 concentration in reef coral carbonates. *Journal of Geophysical Research*, *77*(3), 463–469. https://doi.org/10.1029/jc077i003p00463

Wefer, G., & Killingley, J. S. (1980). Growth histories of strombid snails from Bermuda recorded in their o-18 and c-13 profiles. *Marine Biology*, *60*(2–3), 129–135. https://doi.org/10.1007/bf00389156

Williams, D. F., Arthur, M. A., Jones, D. S., & Healy-Williams, N. (1982). Seasonality and mean annual sea surface temperatures from isotopic and sclerochronological records. *Nature*, *296*(5856), 432–434. https://doi.org/10.1038/296432a0

25724525, 2023, 8, Downloaded from https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2023PA004723, Wiley Online Library on [02/12/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License