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A semiannual radiocarbon record of a modern coral from the Solomon Islands

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Abstract

Radiocarbon records from modern corals have long been recognized for their usefulness as a geochemical tracer of surface ocean waters and oceanic upwelling. Pacific corals are especially interesting because of their potential relevance to El Niño – Southern Oscillation (ENSO) events. At present, the Pacific Ocean is undersampled with respect to radiocarbon time series. This study establishes a ^{14}C time series for a coral from the Solomon Islands, located near the center of the Western Pacific Warm Pool (WPWP). We present radiocarbon results from a *Porites* colony which grew in Marau Sound, on the east coast of Guadalcanal. A semiannual record of ^{14}C was constructed from measurements of alternating bands which grew continuously from 1944 to 1994. The record reflects the uptake of atmospheric bomb-produced ^{14}C since the late 1950s with superimposed subannual radiocarbon variations, presumably related to changes in ocean circulation. Although the coral radiocarbon is influenced by ENSO events, the record is not closely correlated with the Southern Oscillation Index (SOI) for the same period.

PACS: 92.20.–h
Keywords: Accelerator mass spectrometry; Radiocarbon; Coral

1. Introduction

Skeletons of Scleractinian corals preserve a continuous record of the radiocarbon content of dissolved inorganic carbon (DIC) in surface waters of the ocean [1]. The purpose of this study is to document the radiocarbon record in a Solomon Island coral and to understand this record in terms of the physical oceanography of the region. The long-term goal of the work is to use this information to understand sub-annual records from fossil corals collected from the same region.

The Solomon Islands stretch 900 km across the South Pacific, centered at about 8 °S and 159 °E (Fig. 1). Collectively these islands have over 5000 km of coastline, much of which is populated by coral. The entire country is located within the Western Pacific Warm Pool, where mean annual sea surface temperatures exceed 28 °C. The WPWP has been the focus of extensive climatological research in recent years, as part of the Tropical Oceans Global Atmosphere Coupled Ocean-Atmosphere Response Experiment (TOGA COARE). This interest stems from the importance

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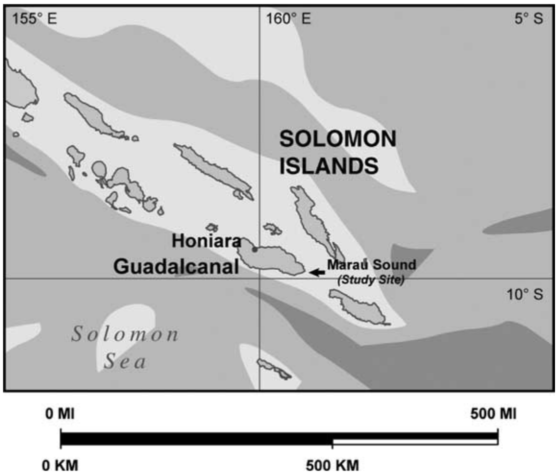

Fig. 1. Site map of the Solomon Islands and Marau Sound, Guadalcanal.

of the region as a source of latent heat and moisture to the atmosphere, and its central role in the development of ENSO events [2]. This association motivated us to sample from the Solomon Islands with the intent of using geochemical climate proxies such as elemental Sr/Ca and δ^{18}O ratios [3,4].

Since the original sampling took place, the potential for ^{14}C as a geochemical tracer in ENSO events has become clear from several studies. In some Pacific localities, the DIC ^{14}C record in surface ocean waters is strongly linked to ENSO. Two examples include the Galapagos Islands [5–8] and Christmas Island [4]. In contrast, there is no clear relationship to ENSO in corals from the Indonesian throughflow [9]. At other sites, such as at the Great Barrier Reef [10] and Raratonga [11], the relationship is variable.

The potential for ^{14}C to track ENSO in the Solomon Islands was particularly attractive since its tectonic setting makes it possible to sample fossil corals there, with a wide range of ages. This is true because of the complicated tectonics of the region [12]. The Solomon Island chain is located along a plate boundary. Different islands, or even different parts of the same island are being uplifted at different rates. In some places this produces a suite of fossil corals with variable ages at the same topographic height. This means that coral radiocarbon records from numerous time periods are readily accessible with careful site selection.

2. Methods

A sample of *Porites* was drilled from Marau Sound, on the eastern tip of Guadalcanal in September, 1994 (Fig. 1). The sample was obtained using an underwater hydraulic drill equipped with an 8 cm diameter bit. The vertical core was drilled parallel to the growth axis of the coral, from approximately the center of the top surface of the colony. The core was cut in half along its length with a diamond saw and a 5mm thick slab was made from one half of the core. The slab was X-rayed to identify subannual growth bands (Fig. 2). A year of growth corresponds to one light and dark band couplet. Annual layers varied from 12

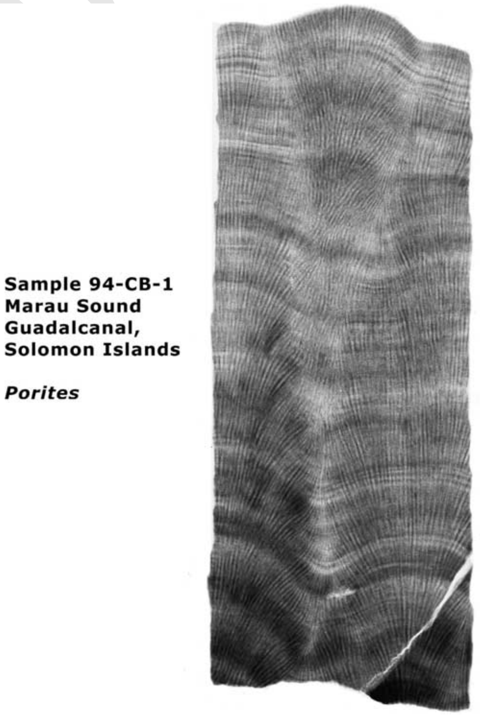

Fig. 2. X-radiograph of the top 20cm of *Porites* coral from the Solomon Islands, analyzed in the study. One light and one dark band couplet comprise one year of growth. The top portion of the core was living when it was collected in September, 1994. The core is 3 in. diameter.

Table 1
Radiocarbon results

year	F	Δ^{14}C (‰)	δ^{13}C (‰)
1994	1.0989 ± 0.0055	104.8 ± 5.5	−1.9
1993.5	1.0991 ± 0.0051	104.9 ± 5.1	−1.8
1993	1.0985 ± 0.0066	104.2 ± 6.6	(−1.0)
1992.5	1.0929 ± 0.0060	98.5 ± 6.0	(−1.0)
1992	1.1030 ± 0.0076	108.6 ± 7.6	(−1.0)
1991.5	1.0920 ± 0.0055	97.5 ± 5.5	−1.3
1991	1.1046 ± 0.0053	110.1 ± 5.3	−1.4
1990.5	1.1122 ± 0.0052	117.7 ± 5.2	−1.0
1990	1.1027 ± 0.0054	108.0 ± 5.4	(−1.0)
1989.5	1.1120 ± 0.0055	117.3 ± 5.5	(−1.0)
1989	1.1083 ± 0.0051	113.5 ± 5.1	(−1.0)
1988.5	1.1086 ± 0.0055	113.8 ± 5.5	(−1.0)
1988	1.0994 ± 0.0049	104.5 ± 4.9	(−1.0)
1987.5	1.1199 ± 0.0057	125.0 ± 5.7	(−1.0)
1987	1.1107 ± 0.0063	122.7 ± 6.3	(−1.0)
1986.5	1.1071 ± 0.0049	110.9 ± 4.9	(−1.0)
1986	1.1164 ± 0.0049	121.3 ± 4.9	−1.8
1985.5	1.1254 ± 0.0049	130.2 ± 4.9	−1.3
1985	1.1081 ± 0.0050	112.8 ± 5.0	−1.4
1984.5	1.1129 ± 0.0049	117.6 ± 4.9	−1.7
1984	1.1197 ± 0.0049	124.3 ± 4.9	−1.0
1983.5	1.1199 ± 0.0045	124.4 ± 4.5	−2.1
1983	1.1229 ± 0.0049	127.4 ± 4.9	(−1.0)
1982.5	1.1230 ± 0.0059	127.4 ± 5.9	−1.5
1982	1.1119 ± 0.0049	116.2 ± 4.9	(−1.0)
1981.5	1.1193 ± 0.0052	123.6 ± 5.2	−1.2
1981	1.1206 ± 0.0075	124.8 ± 7.5	−1.6
1980.5	1.1195 ± 0.0062	123.6 ± 6.2	−1.0
1980	1.1092 ± 0.0042	113.2 ± 4.2	−1.4
1979.5	1.1116 ± 0.0044	115.6 ± 4.4	−1.7
1979	1.1090 ± 0.0061	112.9 ± 6.1	−1.7
1978.5	1.1135 ± 0.0054	117.3 ± 5.4	−1.0
1978	1.1125 ± 0.0062	116.3 ± 6.2	−1.4
1977.5	1.1315 ± 0.0068	135.3 ± 6.8	−1.3
1977	1.1252 ± 0.0056	128.9 ± 5.6	−1.4
1976.5	1.1304 ± 0.0080	134.0 ± 8.0	−0.8
1976	1.1166 ± 0.0056	120.1 ± 5.6	−1.8
1975.5	1.1180 ± 0.0059	121.5 ± 5.9	−0.9
1975	1.1167 ± 0.0068	120.1 ± 6.8	−0.9
1974.5	1.1207 ± 0.0062	124.0 ± 6.2	−1.0
1974	1.1077 ± 0.0058	110.9 ± 5.8	−1.0
1973.5	1.1093 ± 0.0094	112.5 ± 9.4	−1.0
1973	1.0890 ± 0.0054	92.0 ± 5.4	−1.2
1972.5	1.1022 ± 0.0048	105.2 ± 4.8	−1.0
1972	1.1068 ± 0.0049	109.7 ± 4.9	−1.1
1971.5	1.0863 ± 0.0090	89.1 ± 9.0	−1.3
1971	1.0849 ± 0.0056	87.7 ± 5.6	−1.1
1970.5	1.0809 ± 0.0049	83.6 ± 4.9	−0.8
1970	1.0836 ± 0.0049	86.2 ± 4.9	−1.2
1969.5	1.0766 ± 0.0055	79.1 ± 5.5	−0.4
1968.5	1.0601 ± 0.0054	62.5 ± 5.4	−1.4
1968	1.0506 ± 0.0062	52.9 ± 6.2	−1.5
1967.5	1.0684 ± 0.0054	70.7 ± 5.4	−1.1

Table 1 (*continued*)

year	F	Δ^{14}C (‰)	δ^{13}C (‰)
1967	1.0627 ± 0.0074	64.9 ± 7.4	−1.2
1966.5	1.0623 ± 0.0055	64.4 ± 5.5	−0.6
1966	1.0518 ± 0.0054	53.8 ± 5.4	−1.5
1965.5	1.0352 ± 0.0086	37.1 ± 8.6	−1.5
1965	1.0443 ± 0.0053	46.2 ± 5.3	−1.9
1964.5	1.0377 ± 0.0071	39.5 ± 7.1	−1.0
1964	1.0241 ± 0.0053	25.8 ± 5.3	−2.2
1963.5	1.0188 ± 0.0038	20.5 ± 3.8	−2.6
1963	1.0144 ± 0.0054	16.0 ± 5.4	−1.7
1962.5	1.0163 ± 0.0047	17.8 ± 4.7	−1.3
1962	1.0040 ± 0.0052	5.5 ± 5.2	−2.0
1961.5	1.0030 ± 0.0037	4.4 ± 3.7	−0.8
1961	0.9784 ± 0.0048	−20.3 ± 4.8	−1.0
1960.5	0.9782 ± 0.0036	−20.6 ± 3.6	−1.5
1960	0.9744 ± 0.0036	−24.4 ± 3.6	−2.8
1959.5	0.9811 ± 0.0060	−17.8 ± 6.0	−3.1
1959	0.9764 ± 0.0036	−22.5 ± 3.6	−2.6
1958.5	0.9885 ± 0.0046	−10.5 ± 4.6	−2.6
1958	0.9767 ± 0.0036	−22.4 ± 3.6	−1.2
1957.5	0.9677 ± 0.0036	−31.4 ± 3.6	−2.0
1957	0.9678 ± 0.0036	−31.4 ± 3.6	−1.3
1956.5	0.9585 ± 0.0036	−40.7 ± 3.6	−1.7
1956	0.9527 ± 0.0065	−46.6 ± 6.5	−1.1
1955.5	0.9487 ± 0.0037	−50.7 ± 3.7	−1.1
1955	0.9417 ± 0.0048	−57.7 ± 4.8	−0.5
1954.5	0.9417 ± 0.0038	−57.8 ± 3.8	−0.7
1954	0.9483 ± 0.0051	−51.2 ± 5.1	−1.0
1953.5	0.9374 ± 0.0048	−62.2 ± 4.8	−1.0
1953	0.9467 ± 0.0049	−53.0 ± 4.9	−1.3
1952.5	0.9428 ± 0.0049	−56.9 ± 4.9	−1.6
1952	0.9467 ± 0.0049	−53.1 ± 4.9	−1.3
1951.5	0.9436 ± 0.0065	−56.2 ± 6.5	−1.5
1951	0.9433 ± 0.0059	−56.6 ± 5.9	−1.9
1950.5	0.9416 ± 0.0047	−58.3 ± 4.7	−1.1
1950	0.9505 ± 0.0058	−49.5 ± 5.8	−1.5
1949.5	0.9390 ± 0.0049	−69.2 ± 4.9	−1.4
1949	0.9497 ± 0.0050	−50.4 ± 5.0	−1.1
1948.5	0.9370 ± 0.0075	−63.2 ± 7.5	−1.6
1948	0.9376 ± 0.0052	−62.6 ± 5.2	−1.4
1947.5	0.9352 ± 0.0055	−65.1 ± 5.5	−1.2
1947	0.9417 ± 0.0056	−58.6 ± 5.6	−1.3
1946.5	0.9306 ± 0.0089	−69.8 ± 8.9	−1.2
1946	0.9378 ± 0.0047	−62.7 ± 4.7	−1.4
1945.5	0.9343 ± 0.0061	−66.2 ± 6.1	−1.3
1945	0.9359 ± 0.0050	−64.7 ± 5.0	−1.8
1944.5	0.9357 ± 0.0070	−64.9 ± 7.0	−1.8
1944	0.9344 ± 0.0055	−66.3 ± 5.5	−2.7

Results are quoted as fraction modern carbon (F) values [13] and as Δ^{14}C values [14]. All values corrected with measured or assumed δ^{13}C values. Assumed values are given in parentheses.

to 25 mm in thickness. Each band was sampled as one piece with a 0.5 mm thick carbide saw blade. The object of the sampling was to obtain a continuous semiannual integral record of ^{14}C. Each piece of coral was completely dissolved to produce CO$_2$, which was reduced to graphite for analysis.

In most cases, a split of the CO_2 was taken to determine the $\delta^{13}C$ value of the sample using a conventional mass spectrometer.

3. Results

The radiocarbon and ^{13}C results are given in Table 1 and shown in Fig. 3. Radiocarbon values are quoted as fraction modern carbon (F) values [13] and as $\Delta^{14}C$ values [14]. The radiocarbon time series runs for 50 years. The uptake of atmospheric bomb-produced ^{14}C accounts for the rise in $\Delta^{14}C$ observed in the record, from the late 1950s to the 1970s. The total increase in coral $\Delta^{14}C$ is equivalent to changing seawater DIC ^{14}C [1] and in this case amounts to about 185‰. There are significant annual and subannual variations in the record as well, with frequencies of months to years, and amplitudes of less than ten permil to tens of permil $\Delta^{14}C$. The nature of these variations are considered below.

In 1992, a surface sample was collected for the World Ocean Circulation Experiment (WOCE) Cruise P13, station 86. This sample originated 650 km to the north and east of our Solomon Island coral. The $\Delta^{14}C$ result for this sample [15] is shown in Fig. 3 for comparison, and agrees well with our results.

The initial uptake of atmospheric bomb-produced ^{14}C into the Pacific Ocean has been summarized by Linick [16]. Linick plotted radiocarbon results from DIC ^{14}C measurements in seawater from 50 °N to 60 °S in the Central Pacific. A north–south $\Delta^{14}C$ gradient with maxima at about 30 °N and 30 °S, and a pronounced $\Delta^{14}C$ minima at the equator was observed. This gradient began in the late 1950s and peaked in the 1970s. The same basic structure was observed from results for both GEOSECS and WOCE crusies, with a gradual relaxation of the $\Delta^{14}C$ gradients since the 1970s [15,17,18]. Fig. 4 shows the Marau Sound coral data for this study, compared with data from Nauru [19] and Vanuatu. Nauru is located on the equator, and the radiocarbon record from Nauru lies consistently below the Solomon Island record (at 9 °S) as expected. The Vanuatu record (at 15 °S) is similar to the Solomon Island record with both higher and lower $\Delta^{14}C$ values for different time intervals.

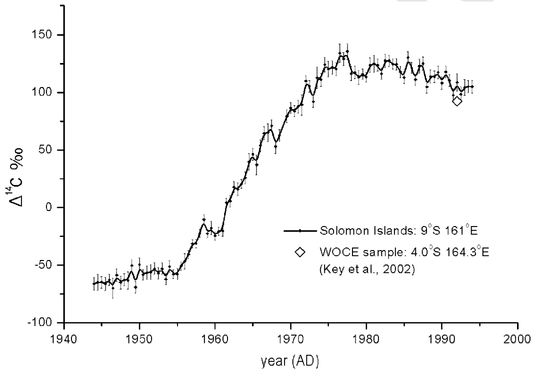

Fig. 3. $\Delta^{14}C$ results from Marau Sound, Guadalcanal coral. WOCE DIC ^{14}C result for surface sample from Cruise P13 (station 86) shown for comparison.

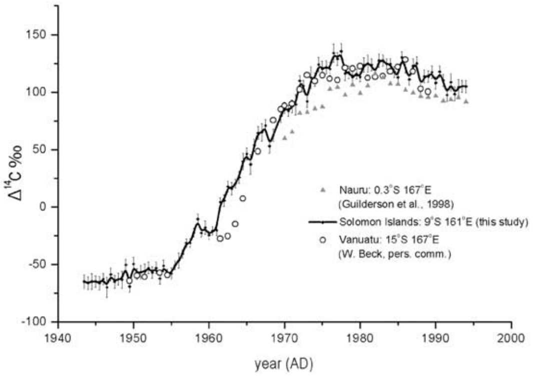

Fig. 4. N–S transect showing $\Delta^{14}C$ results from Nauru [19]; Vanuatu [24] and Marau Sound (this study).

4. Discussion

Radiocarbon in modern coral has long been recognized for its potential as a geochemical tracer in the oceans [20]. Radiocarbon time series have been used in the Pacific to investigate upwelling [5–8], horizontal advection of surface waters [9], vertical mixing [11] and to document the Suess effect [10]. Of particular interest is the observation that in some localities, radiocarbon time series parallel changes in sea surface temperature (SST) associated with ENSO [4,8]. To test for this association

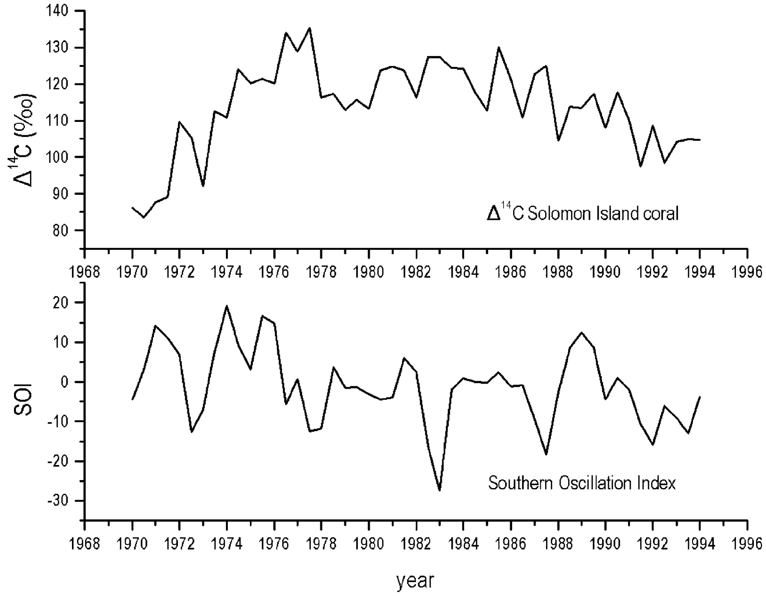

Fig. 5. Comparison of $\Delta^{14}C$ results with SOI data from 1970 to 1994. SOI data from the Australian Bureau of Meteorology, National Climate Centre, Climate Analysis Section.

in our record, we plot $\Delta^{14}C$ along with SOI values for the last 24 years of our record (Fig. 5). A linear regression between the two datasets yields a correlation coefficient (r^2 value) of 0.016. Hence, there is no direct relationship between SOI and $\Delta^{14}C$ at the Marau Sound site, as seen elsewhere in the Pacific. Other physical oceanographic factors must influence the coral radiocarbon record at the Marau Sound site.

The climatology and weather of the Solomon Island region can be understood in terms of its position between two persistent atmospheric features: the equatorial trough to the north and the subtropical ridge to the south. The equatorial trough is a zone of low pressure and the subtropical ridge is a zone of high pressure. The equatorial trough migrates from south of the Solomon Islands in January to March, to the northern hemisphere between May and October. Between January and March, persistent West to Northwesterly monsoonal winds blow across the region. Between May and October, Southeast trade winds dominate [21]. These two modes directly influence the surface ocean circulation in the region and this affects the radiocarbon content of the coral, bringing different source waters depending on the time of year. This is shown in Fig. 6. Fig. 6(a) shows the surface ocean circulation during the austral winter, when the Southeast trade winds dominate. In this case, the dominant ocean circulation is from the east, towards the west. The source of ^{14}C is from the South Equatorial Current to the east. Fig. 6(b) shows the effect of the monsoon season on surface ocean circulation during the austral summer. Surface ocean currents at this time of year reverse in direction, with the formation of the South Equatorial Counter Current. Source waters carrying ^{14}C to the region come from the west/northwest instead of the east. In view of the strong north-south DIC ^{14}C gradient, it is easy to understand how this change could produce substantial subannual radiocarbon variations.

A number of coral radiocarbon records have now been published in the South Pacific. These include sites from the Great Barrier Reef [10,22,23], Raratonga [11], Nauru [19], Vanuatu [24], and the Solomon Islands ([25] and this study). To exploit the full potential of ^{14}C as a geochemical tracer, these records should be studied together, in the context of a dynamical model [26]. Considering the vast size of the Southwest Pacific,

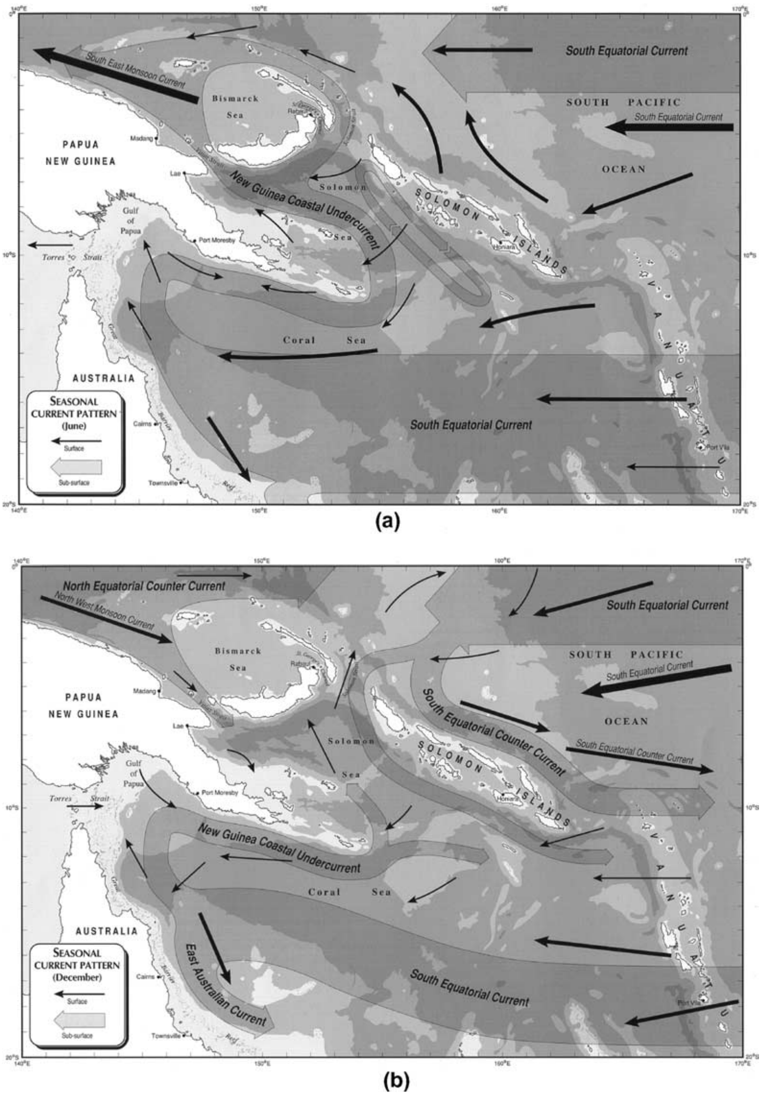

Fig. 6. Surface and subsurface ocean currents in the South Pacific (modified with permission from [27]). (a) June circulation—east to west, South Equatorial Current. (b) December circulation – northwest/west to east, South Equatorial Countercurrent.

many more coral records of this type warrant further study.

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