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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 ¹⁴C 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 ¹⁴C was constructed from measurements of alternating bands which grew continuously from 1944 to 1994. The record reflects the uptake of atmospheric bomb-produced ¹⁴C 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.

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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 infor-

mation 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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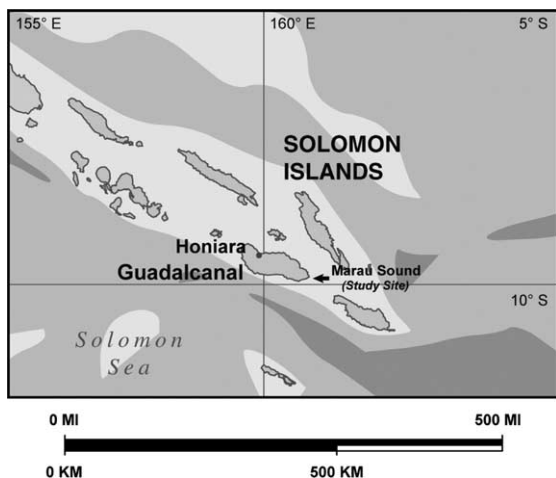


Fig. 1. Site map of the Solomon Islands and Marau Sound, Guadalcanal.

44 of the region as a source of latent heat and mois-
 45 ture to the atmosphere, and its central role in the
 46 development of ENSO events [2]. This association
 47 motivated us to sample from the Solomon Islands
 48 with the intent of using geochemical climate
 49 proxies such as elemental Sr/Ca and $\delta^{18}\text{O}$ ratios
 50 [3,4].

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

62 The potential for ^{14}C to track ENSO in the
 63 Solomon Islands was particularly attractive since
 64 its tectonic setting makes it possible to sample
 65 fossil corals there, with a wide range of ages. This
 66 is true because of the complicated tectonics of the
 67 region [12]. The Solomon Island chain is located
 68 along a plate boundary. Different islands, or even
 69 different parts of the same island are being uplifted
 70 at different rates. In some places this produces a
 71 suite of fossil corals with variable ages at the same
 72 topographic height. This means that coral radio-

73 carbon records from numerous time periods are
 74 readily accessible with careful site selection.

2. Methods

75
 76 A sample of *Porites* was drilled from Marau
 77 Sound, on the eastern tip of Guadalcanal in Sep-
 78 tember, 1994 (Fig. 1). The sample was obtained
 79 using an underwater hydraulic drill equipped with
 80 an 8 cm diameter bit. The vertical core was drilled
 81 parallel to the growth axis of the coral, from
 82 approximately the center of the top surface of the
 83 colony. The core was cut in half along its length
 84 with a diamond saw and a 5mm thick slab was
 85 made from one half of the core. The slab was X-
 86 rayed to identify subannual growth bands (Fig. 2).
 87 A year of growth corresponds to one light and
 88 dark band couplet. Annual layers varied from 12

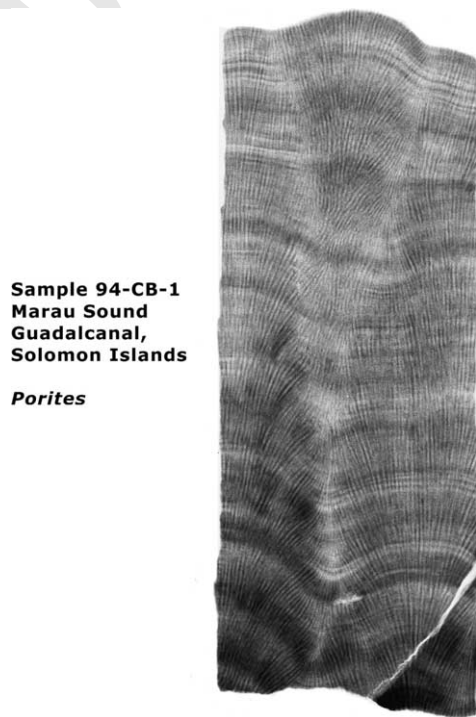


Fig. 2. X-radiograph of the top 20cm of *Porites* coral from the Solomon Islands, analyzed in the study. One light and one dark band couplet comprise one year of growth. The top portion of the core was living when it was collected in September, 1994. The core is 3 in. diameter.

Table 1
Radiocarbon results

year	F	$\Delta^{14}\text{C}$ (‰)	$\delta^{13}\text{C}$ (‰)
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	$\Delta^{14}\text{C}$ (‰)	$\delta^{13}\text{C}$ (‰)
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 $\Delta^{14}\text{C}$ values [14]. All values corrected with measured or assumed $\delta^{13}\text{C}$ values. Assumed values are given in parentheses.

89 to 25 mm in thickness. Each band was sampled as
 90 one piece with a 0.5 mm thick carbide saw blade.
 91 The object of the sampling was to obtain a con-

tinuous semiannual integral record of ^{14}C . Each
 92 piece of coral was completely dissolved to produce
 93 CO_2 , which was reduced to graphite for analysis.
 94

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

98 3. Results

99 The radiocarbon and ^{13}C results are given in
 100 Table 1 and shown in Fig. 3. Radiocarbon values
 101 are quoted as fraction modern carbon (F) values
 102 [13] and as $\Delta^{14}\text{C}$ values [14]. The radiocarbon time
 103 series runs for 50 years. The uptake of atmospheric
 104 bomb-produced ^{14}C accounts for the rise in $\Delta^{14}\text{C}$
 105 observed in the record, from the late 1950s to the
 106 1970s. The total increase in coral $\Delta^{14}\text{C}$ is equivalent
 107 to changing seawater DIC ^{14}C [1] and in this
 108 case amounts to about 185‰. There are significant
 109 annual and subannual variations in the record as
 110 well, with frequencies of months to years, and
 111 amplitudes of less than ten permil to tens of permil
 112 $\Delta^{14}\text{C}$. The nature of these variations are considered
 113 below.

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

121 The initial uptake of atmospheric bomb-produced
 122 ^{14}C into the Pacific Ocean has been sum-

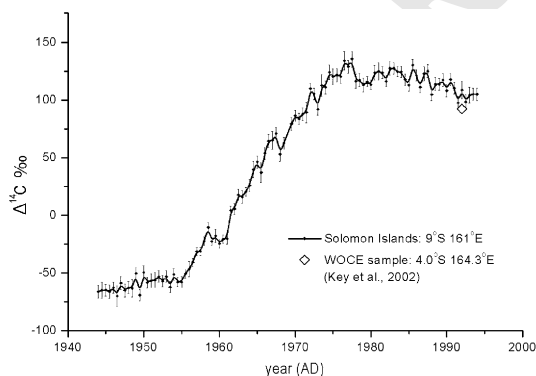


Fig. 3. $\Delta^{14}\text{C}$ results from Marau Sound, Guadalcanal coral. WOCE DIC ^{14}C result for surface sample from Cruise P13 (station 86) shown for comparison.

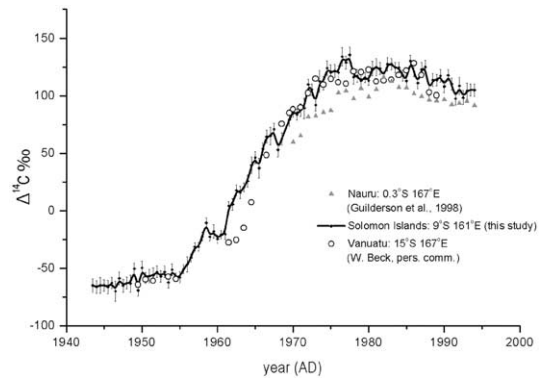


Fig. 4. N–S transect showing $\Delta^{14}\text{C}$ results from Nauru [19]; Vanuatu [24] and Marau Sound (this study).

123 marized by Linick [16]. Linick plotted radiocarbon
 124 results from DIC ^{14}C measurements in seawater
 125 from 50 °N to 60 °S in the Central Pacific. A
 126 north–south $\Delta^{14}\text{C}$ gradient with maxima at about
 127 30 °N and 30 °S, and a pronounced $\Delta^{14}\text{C}$ minima
 128 at the equator was observed. This gradient began
 129 in the late 1950s and peaked in the 1970s. The
 130 same basic structure was observed from results for
 131 both GEOSECS and WOCE cruises, with a
 132 gradual relaxation of the $\Delta^{14}\text{C}$ gradients since the
 133 1970s [15,17,18]. Fig. 4 shows the Marau Sound
 134 coral data for this study, compared with data from
 135 Nauru [19] and Vanuatu. Nauru is located on the
 136 equator, and the radiocarbon record from Nauru
 137 lies consistently below the Solomon Island record
 138 (at 9 °S) as expected. The Vanuatu record (at 15
 139 °S) is similar to the Solomon Island record with
 140 both higher and lower $\Delta^{14}\text{C}$ values for different
 141 time intervals.

142 4. Discussion

143 Radiocarbon in modern coral has long been
 144 recognized for its potential as a geochemical tracer
 145 in the oceans [20]. Radiocarbon time series have
 146 been used in the Pacific to investigate upwelling [5–
 147 8], horizontal advection of surface waters [9], vertical
 148 mixing [11] and to document the Sues effect
 149 [10]. Of particular interest is the observation that
 150 in some localities, radiocarbon time series parallel
 151 changes in sea surface temperature (SST) associated
 152 with ENSO [4,8]. To test for this association

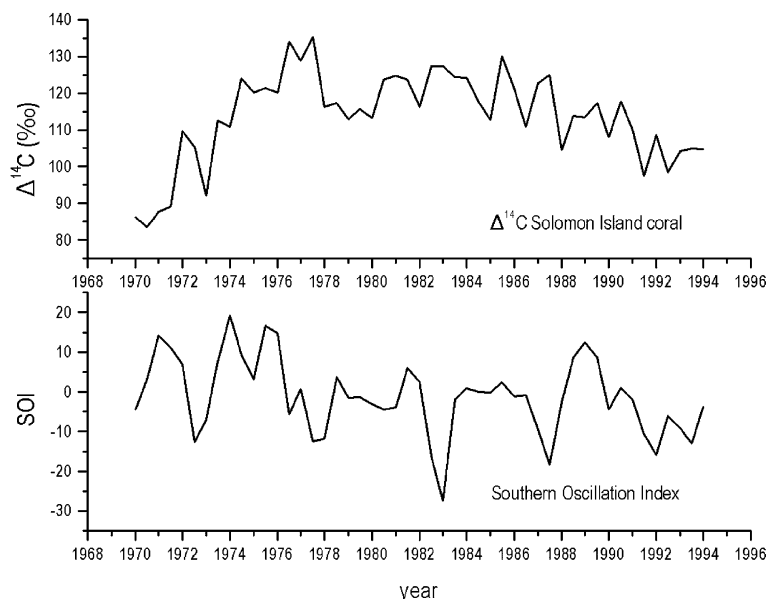


Fig. 5. Comparison of $\Delta^{14}\text{C}$ results with SOI data from 1970 to 1994. SOI data from the Australian Bureau of Meteorology, National Climate Centre, Climate Analysis Section.

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

162 The climatology and weather of the Solomon
 163 Island region can be understood in terms of its
 164 position between two persistent atmospheric fea-
 165 tures: the equatorial trough to the north and the
 166 subtropical ridge to the south. The equatorial
 167 trough is a zone of low pressure and the subtrop-
 168 ical ridge is a zone of high pressure. The equatorial
 169 trough migrates from south of the Solomon Is-
 170 lands in January to March, to the northern
 171 hemisphere between May and October. Between
 172 January and March, persistent West to North-
 173 westerly monsoonal winds blow across the region.
 174 Between May and October, Southeast trade winds
 175 dominate [21]. These two modes directly influence
 176 the surface ocean circulation in the region and this
 177 affects the radiocarbon content of the coral,
 178 bringing different source waters depending on the

time of year. This is shown in Fig. 6. Fig. 6(a) 179
 shows the surface ocean circulation during the 180
 austral winter, when the Southeast trade winds 181
 dominate. In this case, the dominant ocean circula- 182
 tion is from the east, towards the west. The 183
 source of ^{14}C is from the South Equatorial Current 184
 to the east. Fig. 6(b) shows the effect of the mon- 185
 soon season on surface ocean circulation during 186
 the austral summer. Surface ocean currents at this 187
 time of year reverse in direction, with the forma- 188
 tion of the South Equatorial Counter Current. 189
 Source waters carrying ^{14}C to the region come 190
 from the west/northwest instead of the east. In 191
 view of the strong north-south DIC ^{14}C gradient, it 192
 is easy to understand how this change could pro- 193
 duce substantial subannual radiocarbon varia- 194
 tions. 195

A number of coral radiocarbon records have 196
 now been published in the South Pacific. These 197
 include sites from the Great Barrier Reef 198
 [10,22,23], Raratonga [11], Nauru [19], Vanuatu 199
 [24], and the Solomon Islands ([25] and this study). 200
 To exploit the full potential of ^{14}C as a geochem- 201
 ical tracer, these records should be studied to- 202
 gether, in the context of a dynamical model [26]. 203
 Considering the vast size of the Southwest Pacific, 204

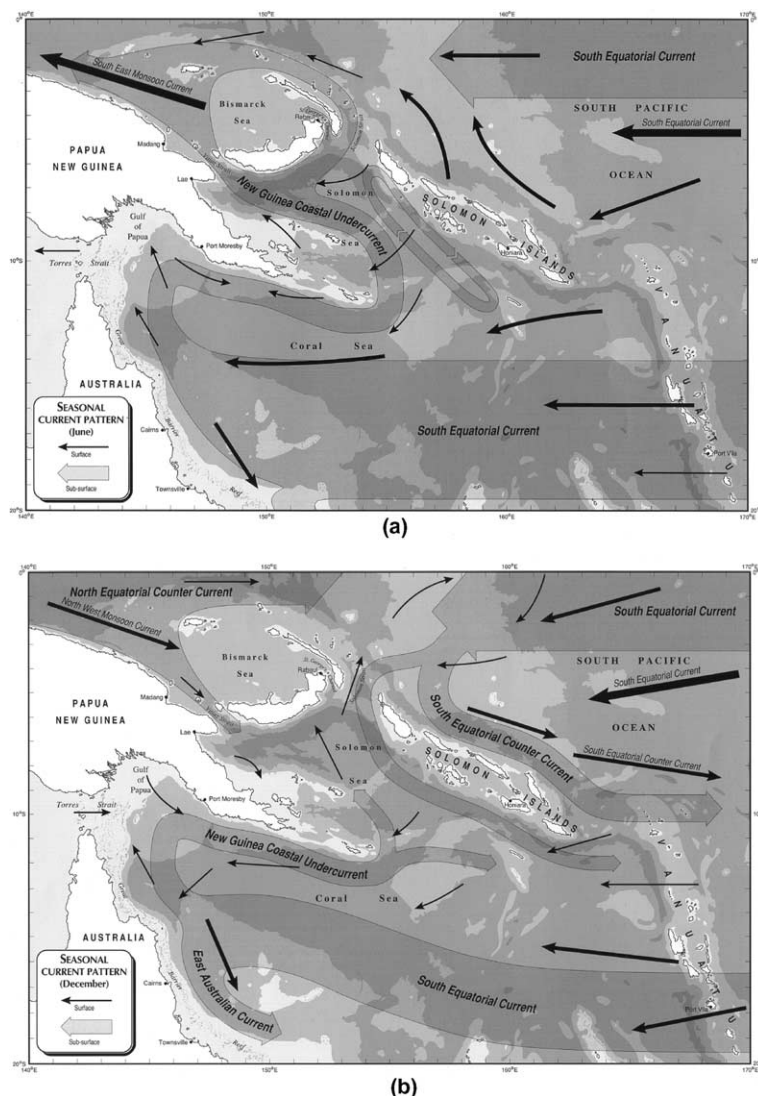


Fig. 6. Surface and subsurface ocean currents in the South Pacific (modified with permission from [27]). (a) June circulation—east to west, South Equatorial Current. (b) December circulation – northwest/west to east, South Equatorial Countercurrent.

205 many more coral records of this type warrant
 206 further study.

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