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POST-BOMB RADIOCARBON RECORDS OF SURFACE CORALS FROM THE TROPICAL ATLANTIC OCEAN

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ABSTRACT. $\Delta^{14}C$ records are reported for post-bomb corals from three sites in the tropical Atlantic Ocean. In corals from 18°S in the Brazil Current, $\Delta^{14}C$ values increased from *ca.* –58‰ in the early 1950s to +138‰ by 1974, then decreased to 110‰ by 1982. Shorter records from 8°S off Brazil and from the Cape Verde Islands (17°N) showed initially higher $\Delta^{14}C$ values before 1965 than those at 18°S, but showed lower rates of increase of $\Delta^{14}C$ during the early 1960s. There is general agreement between the coral results and $\Delta^{14}C$ of dissolved inorganic carbon (DIC) measured in seawater previously for locations in the tropical Atlantic Ocean. $\Delta^{14}C$ values at our tropical ocean sites increased at a slower rate than those observed previously in the temperate North Atlantic (Florida and Bermuda), owing to the latter's proximity to the bomb ^{14}C input source in the northern hemisphere. Model results show that from 1960–1980 the Cape Verde coral and selected DIC $\Delta^{14}C$ values from the North Equatorial Current agree with that calculated for the North Atlantic based on an isopycnal mixing model with a constant water mass renewal rate between surface and subsurface waters. This is in contrast to $\Delta^{14}C$ values in Bermuda corals that showed higher post-bomb values than those predicted using a constant water mass renewal rate, hence indicating that ventilation in the western north Atlantic Ocean had decreased by a factor of 3 during the 1960s and 1970s (Druffel 1989).

INTRODUCTION

Radiocarbon measurement of a banded coral reveals the $^{14}C/^{12}C$ ratio of the dissolved inorganic carbon (DIC) in the seawater that surrounded the coral at the time of accretion. Coral $\Delta^{14}C$ records for the past several hundred years have been reported previously for surface waters of the Atlantic and Pacific Oceans (Druffel and Linick 1978; Druffel 1987; Nozaki *et al.* 1978; Toggweiler, Dixon and Broecker 1991). Post-bomb records have been presented for a variety of locations in the Pacific (Druffel 1981; Druffel 1987; Konishi, Tanaka and Sakanoue, 1982; Toggweiler, Dixon and Broecker 1991), the Indian (Toggweiler 1983) and the Atlantic (Druffel and Linick 1978; Druffel 1989) oceans. Some of the information regarding ocean circulation obtained from coral $\Delta^{14}C$ records include the following: 1) a reduction in water mass renewal rate in the Sargasso Sea was observed during the 1960s and 1970s from coral $\Delta^{14}C$ records (Druffel 1989); 2) from the pre-bomb distribution of $\Delta^{14}C$ in the temperate and tropical Pacific it appears that Subantarctic Mode Water ventilates several features in the equatorial Pacific (Toggweiler *et al.* 1991); 3) seasonally varying transequatorial transport of surface waters in the mid-Pacific (Druffel 1987) controls the distribution of bomb ^{14}C in this area, as observed in coral $\Delta^{14}C$ records.

Time histories of $\Delta^{14}C$ from banded corals at three surface locations in the tropical Atlantic are presented here. Patterns reveal differences between these and previously published data sets from Florida (Druffel and Suess 1983) and Bermuda (Druffel 1989). Comparisons are presented between observed and model-calculated $\Delta^{14}C$ trends for the temperate and tropical North Atlantic.

METHODS

All corals used for this project were collected live from 3–4 m depth at locations well flushed by open ocean waters (see Fig. 1). A large coral colony (0.5 m diameter) of *Mussismilia braziliensis* (CABO) was collected from the southwest shore of the Timbabas Reefs located on the northwest Abrolhos Bank (17°30′S, 39°20′W) by S. Trumbore in December 1982. A small colony of *Mussismilia braziliensis* (CL17) was collected in July 1964 by J. Laborel from Sirbia Island in the Parcel dos Abrolhos Reefs (17°49′S, 30°44′W) (Bahia, Brazil). Small colonies were collected by J. Laborel from two other sites in the Atlantic: 1) *Montastrea cavernosa* (CL04) from Porto de Galinhas (Pernambuco, Brazil; 8°30′S, 35°00′E) on 3 December 1963; and 2) *Porites astreoides* ssp. *hentscheli* (CL19) from the north coast of São Vicente in the Islands of Cape Verde (17°N, 25°W) on 9 August 1970.

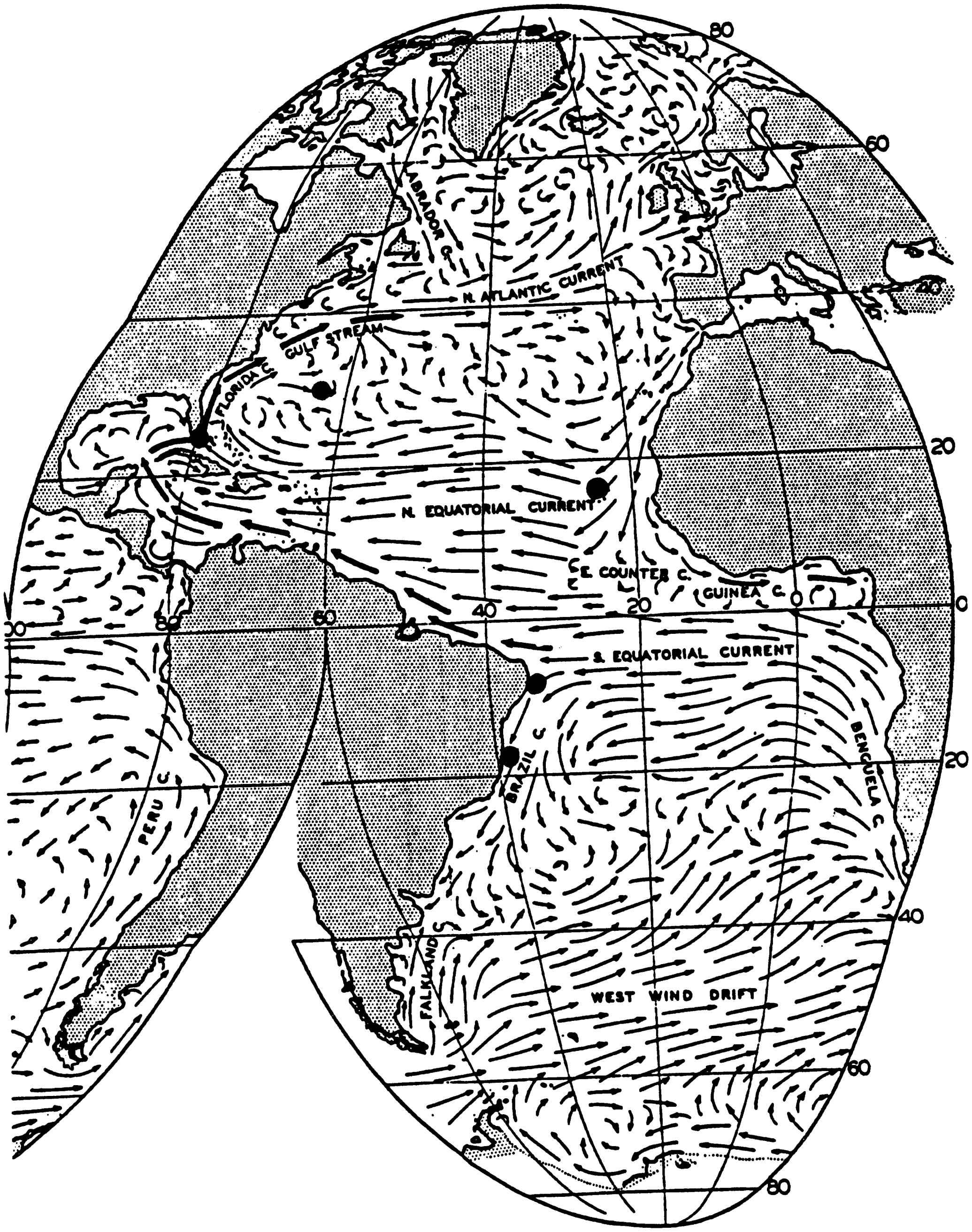

Fig. 1. Map of surface currents in the Atlantic (Sverdrup, Johnson and Fleming 1942). ● = locations of coral collection sites discussed in this paper. (Reprinted by permission of Prentice-Hall, Inc.)

Methods used to clean, X-ray and section the corals were reported previously (Griffin and Druffel 1985). Annual coral bands were taken from all specimens and subjected to ^{14}C analysis. Two bands from the small Abrolhos coral (CL17) were sectioned into half-year bands and analyzed for ^{14}C. Visual inspection of the X-radiographs indicate that the high-density bands for the southern hemisphere corals accreted during the beginning of the calendar year (January–March); the Cape Verde coral accreted its high-density band from about April through June of each year. The bands were drawn at the bottom of the high-density band for all the corals except the small Abrolhos coral, where they were drawn at the top of the high density band. Thus, the midpoint of each band was approximately the beginning of the calendar year for the small Abrolhos and Cape Verde corals (*i.e.*, 19xx.0) and in the middle of the year for the Porto de Galinhas and large Abrolhos corals (19xx.5).

We acidified *ca.* 25 g of coralline aragonite (a crystalline form of calcium carbonate) to produce 5.5 liters of CO_2 gas. The gas samples were converted to acetylene gas via a lithium carbide intermediate and purified through charcoal at 0°C. Samples from the large Abrolhos coral (CABO) were counted for 6–7 2-day periods in 1.5-liter quartz gas proportional beta counters at the WHOI Radiocarbon Laboratory in 1992 according to standard procedures (Druffel and Griffin 1993; Griffin and Druffel 1985). Samples from the three other corals were counted in 2.2-liter quartz gas proportional beta counters at the Mt. Soledad Radiocarbon Laboratory from 1980 to 1981.

Radiocarbon results for the annual coral samples are reported as $\Delta^{14}C$ in Table 1. Uncertainties for the $\Delta^{14}C$ measurements of the large Abrolhos coral (CABO) samples are ±3.0‰ and include counting statistics and laboratory reproducibility errors. The average statistical counting error of each analysis is ±2.1‰, and includes background and standard (HOxI) measurement errors. The laboratory reproducibility error was determined from multiple, high-precision analyses of a modern coral standard. The standard deviation of 10 results, each with a statistical error of 2.1‰, was 3.0‰. Thus, at this precision level, the laboratory error constitutes *ca.* 40% additional error. To obtain our total error, we multiply the statistical error by 1.4. The uncertainties of the $\Delta^{14}C$ results for the small coral heads (LJ numbers) was ±4–5‰ and was based only on the counting uncertainty of the sample, oxalic acid-1 standard and background. The $\delta^{13}C$ values were measured on the reburned acetylene gas and were used to correct the $\Delta^{14}C$ results according to standard techniques for age-corrected geochemical samples (Stuiver and Polach 1977).

RESULTS

Figure 2 presents the $\Delta^{14}C$ results for the four Atlantic corals. The Florida coral record is also shown for comparison (Druffel and Suess 1983). Prior to the introduction of bomb-produced ^{14}C to the oceans (~1956–1958), the average pre-bomb $\Delta^{14}C$ value from six measurements of the large Abrolhos coral (CABO) was –57.9 ± 4.5‰ (sd). All three of the pre-bomb $\Delta^{14}C$ values obtained from the small Abrolhos coral head (CL17) were –56‰. Two pre-bomb $\Delta^{14}C$ values from the coral 8°S off Brazil (–64‰, –49‰; CL04) averaged the same (–56 ± 4‰) as the Abrolhos corals, though the range (15‰) was high.

In all of the coral records, the $\Delta^{14}C$ values increased steadily after 1957–1958 due to the input of bomb ^{14}C from the atmosphere to surface ocean. There is also an initial leveling off of $\Delta^{14}C$ values in 1960–1961, similar to that found 1–2 yr earlier in the Florida corals (see Fig. 2) (Druffel and Suess 1983). Between 1962 and 1968, the long Abrolhos record (CABO) showed a large, steady rise of $\Delta^{14}C$ values, then a slower rise to 1974 when the highest value of 138‰ was attained. After 1974, $\Delta^{14}C$ values declined slowly to a low of 110‰ by 1982. There is agreement (within 2σ uncertainty) between the annual $\Delta^{14}C$ values for the two Abrolhos coral records. The two bands from CL17 that

TABLE 1. Radiocarbon Values for Two Abrolhos Reef Corals, and for the Porto de Galinhas and Cape Verde Island Corals Used in this Study

	Abrolhos, Brazil		Abrolhos, Brazil		Porto de Galinhas		Cape Verde	
Year (AD)	(CABO) $\Delta^{14}C$	WH#	(CL17) $\Delta^{14}C$	LJ#	(CL04) $\Delta^{14}C$	LJ#	(CL19) $\Delta^{14}C$	LJ#
1949.5	−66.3	1029						
1950.5	−54.2	846						
1951.5	−55.8	1031						
1952.5	−54.4	852			−64	5212		
1953.5	−58.7	1028						
1954.5								
1955.5	−57.9	1012						
1956.0			−56	5178				
1956.5	−53.1	1013			−49	5211		
1957.0			−56	5177				
1957.5	−51.3	1014						
1958.0			−56	5176				
1958.5	−51.7	1017			−34	5206		
1959.0			−29	5175				
1959.5	−35.2	1023			−20	5205		
1960.0			−25	5174				
1960.5	−24.8	1027			−16	5204		
1960.7			−27	5173				
1961.3			1	5171				
1961.5	−22.5	1025			−16	5203		
1962.0			−16	5172			15	5275
1962.5	−15.0	1018			9	5201		
1962.7			−12	5169				
1963.0						5202	20	5274
1963.3			17	5168				
1963.5	0.4	847			12			
1964.0			6	5170			40	5273
1964.5	26.2	1022						
1965.0							53	5272
1965.5	41.2	850						
1966.0							43	5271
1966.5	65.4	1019						
1967.0							58	5269
1967.5	80.2	1016						
1968.0								
1968.5	104.7	1024						
1969.0							53	5263
1969.5	108.0	1015						
1970.0							40	5264
1970.5	111.9	848						
1971.5	116.9	1034						
1972.5	125.4	1036						
1973.5	119.6	1092						
1974.5	137.8	1033						
1975.5	129.6	1040						
1976.5	124.5	1045						
1977.5	125.2	1030						
1978.5	123.7	1035						
1979.5	117.5	1042						
1980.5	124.0	1038						
1981.5	118.9	1032						
1982.5	110.0	849						

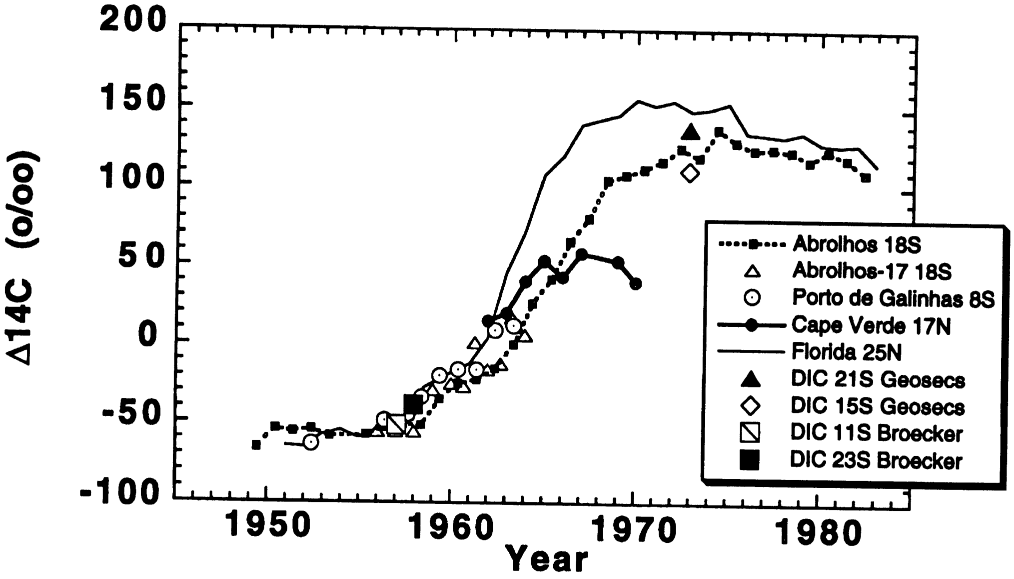

Fig. 2. $\Delta^{14}C$ measurements in annual coral bands from three locations in the tropical Atlantic Ocean: Abrolhos reefs (△) = CL17; (■)= CABO), Porto de Galinhas (○) and Cape Verde Islands (●). $\Delta^{14}C$ measurements for coral from Florida (23°43′N, 66°06′W) are included as an example of a temperate North Atlantic coral record. The $\Delta^{14}C$ results from seawater DIC were measured by two groups of investigators: 1) GEOSECS – November 1972, Stns. 56 and 54 (21°S, 33°W, 138 ± 4‰ at 25 m and 15°S, 30°W, 111 ± 4‰ at 20 m, respectively) (Stuiver and Ostlund, 1980); 2) Pre-bomb Atlantic study – January and December 1957, Stns. 35 and 36 (11°S, 32°W, −52 ± 7‰ at 0 m, and 23°S, 38°W, −39 ± 7‰ at 0 m, respectively) (Broecker *et al.* 1960). The size of the points is approximately equal to the 2 σ uncertainty of the $\Delta^{14}C$ measurements.

were split into half-year increments and analyzed separately revealed 28–29‰ higher values in the second half of the bands (midpoints 1961.3 and 1963.3) than in the first half. This illustrates that the minimum amplitude of the seasonal variability of the ^{14}C signature in the Brazil Current was at least 25‰ during the early 1960s, the period when the gradient between atmospheric CO_2 and surface ocean DIC $\Delta^{14}C$ values was highest.

The Porto de Galinhas (8°S) $\Delta^{14}C$ values were higher than the annual Abrolhos (18°S) values during the post-bomb period of 1956–1963. The offset ranges from 5–10‰ during most years and is 24‰ in 1962, a period when atmospheric values were near their peak. Porto de Galinhas $\Delta^{14}C$ values were lower than the values of the 6-month samples 1961.3 and 1963.3. The $\Delta^{14}C$ in 1952 (−64 ± 4‰) was lower (by 10‰) than that at Abrolhos (−54.4 ± 3.0‰), likely due to upwelling at the site nearer the equator (8°S).

The $\Delta^{14}C$ data from Cape Verde coral in the tropical North Atlantic (17°N) covers the post-bomb period from 1962–1970. The 1962 $\Delta^{14}C$ value (15 ± 4‰) is high and similar to that (4 ± 4‰) found at Florida (24°N) in the western North Atlantic. The $\Delta^{14}C$ values increase with time to 1967 when the highest value (58‰) is found. A decrease is apparent in the $\Delta^{14}C$ value of 1970 (40‰), at the same time that the Abrolhos coral $\Delta^{14}C$ values are still rising.

DISCUSSION

Surface Currents in the Tropical Atlantic. The coral $\Delta^{14}C$ records presented here are from three major surface current systems in the Atlantic (Fig. 1). First, the Abrolhos Banks corals (18°S) lie in the Brazil Current that travels southward along the Brazil coast. This current is the southern arm of the South Equatorial Current (SEC), which lies between 5°N and 8°S during most of the year. The SEC also flows through our second coral site, Porto de Galinhas (8°S). This major warm current travels westward along the equator and is influenced by equatorial upwelling of deeper waters that contain lower Δ^{14}C.

The third water mass is the North Equatorial Current (NEC) that flows through the Cape Verde Islands coral site (Fig. 1). This cool, dense water mass is transported from east to west between 30°N and 10°N. It is fed by the southwestern currents off the west coast of North Africa which originate in the northwest Atlantic. Wind-driven upwelling occurs close to the African coast, but its influence here is not as widespread as that off the west coasts of North and South America. The Cape Verde Islands are located 600 km west of northwest Africa, where upwelling is not strong.

Correlation with Seawater DIC Δ^{14}C Values. The coral results and Δ^{14}C of DIC in seawater from the tropical Atlantic are compared in Figure 2. The two Δ^{14}C values from surface seawater DIC (111‰, 138‰) collected from 15°S and 21°S, respectively, off the coast of Brazil during GEOSECS in 1972 (Stuiver and Ostlund 1980), bracket the two coral Δ^{14}C values for 1972 and 1973 (119.6 and 125.4‰, respectively) from the Abrolhos reefs (18°S). In addition, earlier Δ^{14}C measurements of surface DIC Δ^{14}C in 1957 by Broecker *et al.* (1960) from 11°S (–52 ± 7‰) and 23°S (–39 ± 7‰) agree with the Δ^{14}C values for Porto de Galinhas (–49 ± 5‰, 1956) and Abrolhos corals (–51 ± 3‰, 1957), respectively. This agreement confirms that the average annual coral Δ^{14}C record agrees with measurements of DIC Δ^{14}C in open ocean waters that feed the coastal areas off Brazil. No local seawater DIC Δ^{14}C values were available for comparison during the time period covered by the Cape Verde coral (1962–1970).

Broecker *et al.* (1960) reported that the pre-bomb DIC Δ^{14}C values in the surface Atlantic Ocean increased from the south to the north. The average Δ^{14}C value of 16 South Atlantic (0°–40°S) surface samples was –57‰ and that of 18 North Atlantic (15°–40°N) surface samples was –49‰. By correcting for a small amount of bomb ^{14}C that had already entered the ocean by the time these measurements were made, they estimated that the average pre-bomb Δ^{14}C values were –63‰ and –52‰ in the South and North Atlantic surface waters, respectively. The pre-bomb Δ^{14}C time histories from the South Atlantic corals (Abrolhos and Porto de Galinhas) averaged –56 to –58‰, agreeing within the measurement uncertainty with the average surface DIC Δ^{14}C value (–63‰) (Broecker *et al.* 1960). The North Atlantic corals from Florida and Bermuda had pre-bomb Δ^{14}C values of –59.5 ± 3.1‰ (sd, N = 6) and –45.8 ± 0.9‰ (sd, N = 3) (Druffel, in preparation), respectively, which compare well with the average pre-bomb surface DIC Δ^{14}C value (–52‰) for the North Atlantic.

The Pre-Bomb Δ^{14}C Signature. There is an offset of *ca.* 10‰ between the average pre-bomb Δ^{14}C (–56‰ to –58‰) at three of the coral sites (Florida, Porto and Abrolhos; Fig. 2) and that of Bermuda (–46‰, Druffel, in preparation). This offset was not anticipated, considering the dissimilarities of the post-bomb records between Florida and Abrolhos (Fig. 1) and the similarities between the Abrolhos and Bermuda post-bomb records (Fig. 3). Nonetheless, the low pre-bomb Δ^{14}C values for Florida, Porto and Abrolhos are likely related to the fact that water supplying these regions originates from the SEC. The SEC is heavily influenced by upwelling associated with divergence at the equator, which brings low Δ^{14}C waters from subsurface layers to the surface. The water is transported relatively quickly (within 1 yr) from the SEC to the Florida Straits *via* the Gulf Stream and to the coast of Brazil *via* the Brazil Current (Fig. 1). In contrast, the Sargasso Sea is fed by several currents but is mainly an anticyclonic gyre whose main mixing mode throughout most of the year is downwelling of water to relatively shallow depths. A larger influence from atmospheric CO_2 is obtained under these conditions than for the locations closer to continents and influenced by SEC and upwelling.

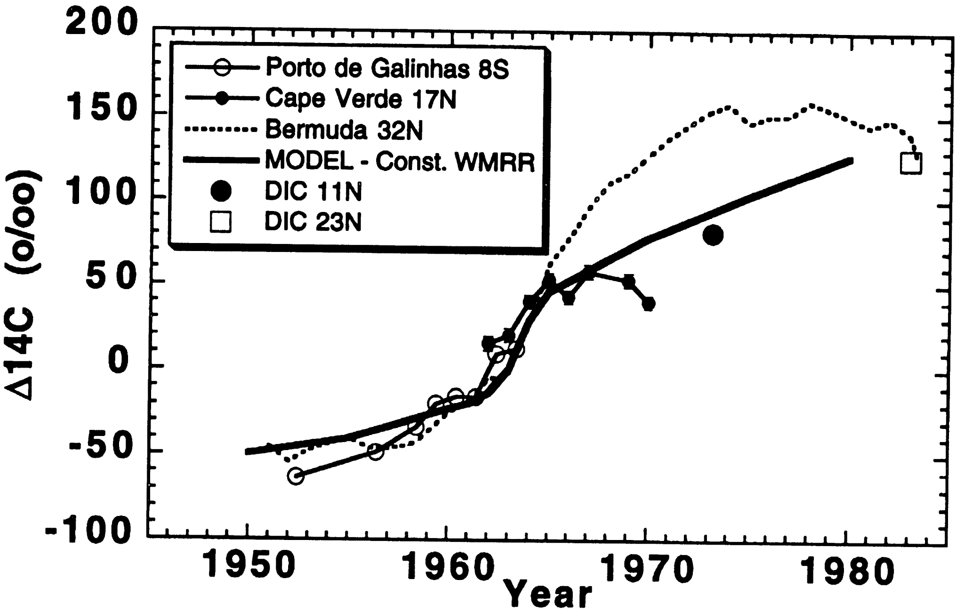

Fig. 3. Model calculated $\Delta^{14}C$ time history for the North Atlantic surface waters using model of Druffel (1989) with constant water mass renewal rate (WMRR) (▬), coral $\Delta^{14}C$ measurements for Cape Verde Islands (–●–), Porto de Galinhas (–⊖–), Bermuda coral (-----) (Druffel 1989) and DIC $\Delta^{14}C$ measurements made previously (single points) for the NEC: 1. GEOSECS, March 1973, Stn 113 (11°N, 21°W, 81‰, 1 m depth) (Stuiver and Ostlund 1980); 2. TTO, 1983, Stn 75 (23°N, 37°W, 126‰, surface) (Ostlund and Grall, 1992).

Lag Time Between the Bomb Signal in North and South Atlantic. Compared to coral $\Delta^{14}C$ records from Florida in the Northwestern Atlantic, the Brazil (Abrolhos) $\Delta^{14}C$ record is delayed by *ca.* 1 yr during the late 1950s to 1960 and delayed 2–3 yr from the early 1960s to the mid-1970s (see Fig. 2). Maximum values were reached between 1970 and 1972 at Florida, whereas they were reached much later (1974) at the Abrolhos site. This delay agrees with measurements of tropospheric bomb $^{14}CO_2$ (Levin *et al.* 1985; Nydal and Lovseth 1983) that showed a similar delay between the northern hemisphere (where the bomb ^{14}C entered the troposphere) and the southern hemisphere owing to the 1–2 yr mixing time of CO_2 in the troposphere.

In addition to north-south differences, another trend is apparent in these data. In areas that are influenced by horizontal transport of water, and very little by upwelling, $\Delta^{14}C$ values rise more quickly. This is because surface waters are in contact with the atmosphere for a longer period of time and fewer subsurface waters low in ^{14}C are being entrained into the surface waters. The best example of this is in the Florida coral $\Delta^{14}C$ record, which rose faster than all of the other Atlantic records owing to its position in the fast-flowing Gulf Stream (Fig. 2). In contrast is the Bermuda record, whose $\Delta^{14}C$ values rose more slowly in the 1960s and achieved a maximum $\Delta^{14}C$ value 4 yr later than the Florida record (Druffel 1989) (Fig. 3). This delay is due to the dilution of surface ^{14}C levels in the Sargasso Sea by low $\Delta^{14}C$ subsurface waters during 18°C-mode water formation in late winter (Druffel 1989).

How do these trends in the temperate North Atlantic compare to the $\Delta^{14}C$ time histories reported here for the tropical Atlantic? There are two causes of differences in these $\Delta^{14}C$ records: 1) north-south differences caused by the lag in the atmospheric $^{14}CO_2$ signal, and 2) varying degrees of entrainment of low ^{14}C subsurface water into the surface, which causes differences in the slope of $\Delta^{14}C$ *vs.* time during the 1960s. The slopes of all five coral $\Delta^{14}C$ records in Figures 2 and 3 were measured for the most sensitive part of the ^{14}C rise, *i.e.*, between 1962 and 1965. This is also when atmospheric $\Delta^{14}C$ records rose the fastest (Levin *et al.* 1985; Nydal and Lovseth 1983). The slopes are as follows: Florida (34‰ yr^{-1}) > Bermuda (23‰ yr^{-1}) > Abrolhos (20‰ yr^{-1}) > Cape Verde (13‰ yr^{-1}) = Porto de Galinhas (14‰ yr^{-1}). The Porto de Galinhas slope was based only on three $\Delta^{14}C$ results because the coral was collected before the 1965 cutoff. Comparison of these slopes is a relative measure of the contribution of low ^{14}C subsurface waters into the surface layers where the corals lived. Porto de Galinhas (8°S) and Cape Verde (17°N) appear to have the largest amount of dilution of surface waters due to upwelling in the SEC and NEC, respectively.

Comparison of Tropical Atlantic Coral Records with Model-Calculated $\Delta^{14}C$. Bomb ^{14}C time histories in surface ocean waters provide a sensitive record of the balance between the three processes controlling ^{14}C in the surface ocean: 1) exchange of CO_2 between atmosphere and surface ocean; 2) vertical mixing between surface and subsurface water masses; and 3) lateral advection of waters from sources that contain different $\Delta^{14}C$ signatures.

It is useful to parameterize mixing in the Atlantic using the bomb $\Delta^{14}C$ time histories as a mixing constraint. The records reported here cover only parts of the post-bomb period, making it difficult to construct a complete ocean model at this time. Therefore, we compare the tropical results reported here with a model that was previously constructed for the North Atlantic (Druffel 1989).

A multibox isopycnal mixing model was used to estimate the ventilation rate of the upper water column in the Sargasso Sea (Druffel 1989). The reader is referred to the original paper for specific details of the model (Druffel 1989). In brief, high-precision $\Delta^{14}C$ from two sites in the North Atlantic, Florida (representative of Gulf Stream input) and Bermuda (representative of Sargasso Sea) were used to parameterize this mixing model. The model reproduced actual mixing processes that occur in the upper ocean, *i.e.*, transport of ocean water along isopycnals. There were three surface boxes (Gulf Stream, Slope Water to the north and Sargasso Sea) and seven subsurface boxes that mixed along surfaces of constant density (σ_Θ = 26.4–27.0) with the surface Sargasso Sea box. The CO_2 gas exchange rate was calculated as a function of the gas exchange piston velocity and was a function of wind speed (Jenkins 1988; Roether 1986). The atmospheric $\Delta^{14}C$ time history of Levin *et al.* (1985) was used. A 0.1-yr time interval was chosen on the basis of stability requirements. The water mass renewal rate (WMRR) was the ventilation or exchange rate between the surface Sargasso Sea box and each of the subsurface isopycnal boxes (in yr^{-1}).

When a constant WMRR was used to estimate the ventilation of the upper water column in the Sargasso Sea surface box, disagreement between the calculated $\Delta^{14}C$ record and the actual record for the Sargasso Sea at Bermuda was obtained (Fig. 3). Therefore, an inverse model was used, *i.e.*, the WMRR was calculated for the post-bomb period in order to satisfy the post-bomb $\Delta^{14}C$ time history in the Bermuda corals. Results showed that the WMRR in the Sargasso Sea was high during 1963–1964, decreased by a factor of 3 during the late 1960s and remained low during most of the 1970s (Druffel 1989).

This model took into account mixing of water masses in the western North Atlantic. But what about waters in the eastern North Atlantic, such as the NEC that laves the Cape Verde Islands? The NEC is supplied mostly by waters from the north that originate in part, from the Gulf Stream. The NEC is also influenced by upwelling of waters from subsurface depths. In a sense, the waters feeding the NEC and the Sargasso Sea are similar, given the Gulf Stream source and the convective overturning during 18°C-mode water formation during late winter in the northern Sargasso Sea. Thus, it is instructive to compare the model estimates of $\Delta^{14}C$ for the Sargasso Sea (Bermuda) with the limited $\Delta^{14}C$ record obtained from the NEC (Cape Verde Islands).

Figure 3 shows the Bermuda and Cape Verde Islands $\Delta^{14}C$ records along with the model-calculated $\Delta^{14}C$ record for the Sargasso Sea using a constant WMRR of 0.44 yr^{-1} for the σ_{θ} 26.4 isopycnal. Of course, the Bermuda and the model-calculated records do not agree, owing to the fact that the WMRR varied by a factor of 3 during the post-bomb period (Druffel 1989). However, the Cape Verde Islands data, up to 1967, and subsequent DIC $\Delta^{14}C$ values agree with the model calculated $\Delta^{14}C$ records. This agreement may be fortuitous, or may indicate that the eastern fringes of the Sargasso Sea were not affected by a decrease in ventilation (WMRR) during the 1960s and 1970s. Druffel (1989) noted evidence suggesting that the western fringe of the Sargasso Sea may have also undergone a decrease in ventilation during the period 1960–1980. The evidence presented here suggests that this reduction in ventilation could have been restricted to the western North Atlantic and may not have extended into the eastern basin.

Correlation with ENSO. The ENSO signal in the Atlantic is not as well defined as it is in the Pacific. A correlation between low $\Delta^{14}C$ values in post-bomb corals from Florida and some ENSO events (1969, 1972–1973, 1976) is evident, whereas there is no apparent correlation with the Bermuda coral data. It is noted that a low $\Delta^{14}C$ value was obtained for the Abrolhos coral in 1973, coincident with the major ENSO event of 1972–1973 (Fig. 2). Also, low $\Delta^{14}C$ values for the 1969–1970 coral bands at Cape Verde were noticed (Fig. 2), and are coincident with the moderate ENSO event of 1969. It is difficult to discern lower $\Delta^{14}C$ values previous to 1970, owing to both the small signal expected in pre-bomb times (<1957) and the expected swamping of the signal during the time of maximum bomb ^{14}C input to the ocean (1957–1969). Druffel and Griffin (1993) attributed low ^{14}C in Australian corals during ENSO to the southward displacement of the Pacific SEC, which brought low-^{14}C waters directly into the Coral Sea. The origin of the low $\Delta^{14}C$ values during ENSO events in the Atlantic may be the diversion of low ^{14}C waters from areas of high divergence into the regions inhabited by the corals.

CONCLUSION

$\Delta^{14}C$ values at our Abrolhos site in the South Atlantic increased at a slower rate than those from corals in the northern hemisphere. This is attributed to the delayed bomb ^{14}C signal in atmospheric CO_2 and to the influence of upwelling in its source waters from the SEC. The calculated $\Delta^{14}C$ record for the surface ocean during the post-bomb period using an isopycnal mixing model of the North Atlantic (Druffel 1989) and constant WMRR agreed better with the Cape Verde coral $\Delta^{14}C$ time history than with that at Bermuda during the 1960s and 1970s. This agreement may indicate that the decrease in ventilation (WMRR) of the thermocline observed from 1963–1980 in the North Atlantic (Druffel 1989) was restricted to the western North Atlantic and may not have extended into the eastern basin.

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