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# Reconstructing Ocean Circulation Using Coral $\Delta^{14}C$ Time Series:

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Project Overview

We utilize monthly $^{14}C$ data derived from coral archives in conjunction with ocean circulation models to address two questions: 1) how does the shallow circulation of the tropical Pacific vary on seasonal to decadal time scales and 2) which dynamic processes determine the mean vertical structure of the equatorial Pacific thermocline. Our results directly impact the understanding of global climate events such as the El Niño-Southern Oscillation (ENSO). To study changes in ocean circulation and water mass distribution involved in the genesis and evolution of ENSO and decadal climate variability, it is necessary to have records of climate variables several decades in length. Continuous instrumental records are limited because technology for continuous monitoring of ocean currents (*e.g*. satellites and moored arrays) has only recently been available, and ships of opportunity archives such as COADS contain large spatial and temporal biases. In addition, temperature and salinity in surface waters are not conservative and thus can not be independently relied upon to trace water masses, reducing the utility of historical observations. Radiocarbon in sea water is a quasi-conservative water mass tracer and is incorporated into coral skeletal material, thus coral $^{14}C$ records can be used to reconstruct changes in shallow circulation that would be difficult to characterize using instrumental data. High resolution $\Delta^{14}C$ timeseries such as ours, provide a powerful constraint on the rate of surface ocean mixing and hold great promise to augment onetime oceanographic surveys. $\Delta^{14}C$ timeseries such as these, not only provide fundamental information about the shallow circulation of the Pacific, but can also be directly used as a benchmark for the next generation of high resolution ocean models used in prognosticating climate.

The measurement of $\Delta^{14}C$ in biological archives such as tree rings and coral growth bands is a direct record of the invasion of fossil fuel $CO_2$ and bomb $^{14}C$ into the atmosphere and surface oceans. Therefore the $\Delta^{14}C$ data that are produced in this study can be used to validate the ocean uptake of fossil fuel $CO_2$ in coupled ocean-atmosphere models. This study takes advantage of the quasi-conservative nature of $^{14}C$ as a water mass tracer by using $\Delta^{14}C$ time series in corals to identify changes in the shallow circulation of the Pacific. Although the data itself provides fundamental information on surface water mass movement the true strength is a combined approach which is greater than the individual parts; the data helps uncover deficiencies in ocean circulation models and the model results place long $\Delta^{14}C$ time series in a dynamic framework which helps to identify those locations where additional observations are most needed.

Analytical Results

We have completed post-bomb time series from Nauru (166°E 0.5°S) and Guadalcanal (167°E, 7°S) in the western tropical Pacific, Rarotonga (21°S, 160°W) and Hawai'i (20°N, 156°E), the Galapagos (90°W, 0°), and at Bali (8°S, 115°E). A partial time-series is also available from Bunaken (1°N, 125°E) in the Sulawesi Sea. Exploratory analyses have been made on samples from Vanuatu, New Caledonia, Palmyra Island, Fitzroy Island, and Arno Atoll. In general, the subtropics (Rarotonga and Hawi'i) have higher $\Delta^{14}C$ reflecting longer mean residence time of surface water in the gyres and higher air-sea exchange. $\Delta^{14}C$ in eastern equatorial Pacific surface waters (Galapagos) are lower and due to the subsurface pathway of the Equatorial Undercurrent and entrainment of deeper thermocline waters which feed the upwelling in this region. Radiocarbon values in the warm pool region (Nauru, Guadalcanal) are intermediate between the higher subtropics and those in the east.

Our data show both the long term increase in $\Delta^{14}C$ reflecting oceanic uptake of bomb derived $^{14}C$ and high amplitude seasonal to interannual variations associated with changes in circulation. The post-bomb $^{14}C$ maxima in the subtropics occurs in the early 1970s whereas at Nauru, Guadalcanal, and Galapagos it is delayed by 10 years. The delay is a consequence of the subsurface history of waters upwelling in the east and the subsequent advection and mixing of these water in the west. Superimposed upon these long term trends is seasonal to interannual variability which reflect ocean dynamic processes. At Nauru and Guadalcanal these high amplitude variations reflect the cross basin advection of surface waters in the tropical Pacific in conjunction with ENSO whereas the Galapagos $\Delta^{14}C$ record reflects variations in upwelling intensity. Variability in the subtropics is related to winter Ekman pumping and the formation of subtropical modewaters.

Legacy

The data that resulted from this research endeavour is being used as a diagnostic tracer not only for coupled ocean general circulation experiments being undertaken at LLNL and with our own external collaborators, but recently has been placed in the context of the International Ocean Carbon Modeling Intercomparison Project (OCMIP). All future ocean circulation models used to understand and predict climate variability and the uptake of anthropogenic CO2 will have to pass a direct comparison with these data.

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