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# Eastern tropical North Pacific coral radiocarbon reveals North Pacific Gyre Oscillation (NPGO) variability

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ABSTRACT

Fluctuations in oceanic circulation and upwelling associated with the North Pacific Gyre Oscillation (NPGO) are the largest source of salinity and nutrient concentration variability across the Pacific basin. Recent observations suggest NPGO-like variability is intensifying, but longer, “pre-instrumental” records are required to improve our understanding of NPGO amplitude and phase change. Here, using measurements of coral skeletal chemistry from San Benedicto Island in the Eastern Tropical North Pacific (ETNP), we assess this region's suitability for reconstructing NPGO behavior. We find that coral geochemical proxy measurements of ETNP salinity and dissolved inorganic carbon radiocarbon ($\Delta^{14}C$) content reflect NPGO-driven gyre circulation and regional coastal upwelling. These results provide the basis for reconstructing NPGO-related ocean conditions hundreds of years prior to the modern observational record.



## 1. Introduction

Low frequency ocean-atmosphere interactions are an influential component of the Pacific climate system (Mantua et al., 1997). One recognized mode of decadal to multi-decadal variability is the North Pacific Gyre Oscillation (NPGO), the second most dominant form of sea surface temperature variability (Di Lorenzo et al., 2008). Physically, the NPGO index describes the strength of the clockwise North Pacific surface circulation, which has a profound impact on ocean temperature, salinity, and nutrient concentrations (Di Lorenzo et al., 2008, 2009; Chhak et al., 2009). Furthermore, NPGO-related atmospheric variability (i.e., the North Pacific Oscillation) influences North American hydroclimate (Kilduff et al., 2015; Wang et al., 2014; Sanchez et al., 2016).

Recent work suggests that NPGO-like variability has intensified in recent decades, but the mechanism behind this amplification is still uncertain (Di Lorenzo et al., 2015). Many arguments center around the impacts of anthropogenic forcing (Di Lorenzo et al., 2008), in particular, the increased activity of the central equatorial Pacific (Di Lorenzo et al., 2010) or enhanced thermodynamic feedbacks (Di Lorenzo et al., 2015; Di Lorenzo and Mantua, 2016). As the recognition of the NPGO's influence grows, it becomes essential to identify the characteristics of this oscillation and the means by which this mode of variability might be changing.

However, it is difficult to understand the true characteristics of a predominantly decadal cycle, such as the NPGO, without long-term observations. This motivates the reconstruction of “pre-instrumental” sea surface conditions using the geological archives (e.g., sediments and corals). The thrust of this study is to demonstrate how longer period, circulation-driven phenomena, such as the NPGO, operate in the North Pacific by deciphering the geochemical record available in these archives. To date, three published studies provide insight to “pre-instrumental” NPGO variability. Nurhati et al. (2011) used a 112 year long record of central tropical Pacific coral geochemistry to show that the NPGO has a strong influence on local sea surface temperature (SST). A sedimentary record was used by Roach et al. (2013), to show that California coastal basin ventilation bears the imprint of NPGO. Finally, the recently published coral record of Sanchez et al. (2016) provides evidence of amplified NPGO-like variability during the early 19th century.

In our study, we have focused our attention on the Eastern Tropical North Pacific (ETNP) where the NPGO has a strong,

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predictable influence on circulation, upwelling, salinity, and nutrients (Di Lorenzo et al., 2008; Chhak et al., 2009; Di Lorenzo et al., 2009). Some sedimentary basins in this region allow for a relatively high-resolution (annual to semi-annual) reconstruction of ocean conditions (Herguera et al., 2010), but coastal North American oceanography can be complicated by the competing influence of other modes of climatic variability, such as the El Niño-Southern Oscillation (ENSO). For instance, even though Roach et al. (2013) found a relationship with the NPGO in Santa Barbara Basin sediment proxy measurements, this signal was overprinted by the migration of coastally trapped Kelvin waves associated with ENSO.

To circumvent this problem, we focus our attention on the Revillagigedo Archipelago, which lies near the terminus of the California Current System roughly 240 miles southwest of Baja California, Mexico (Fig. 1). Here we expect local surface ocean properties to be influenced by higher latitude NPGO-induced variability, such as increased salinity and upwelling within the California Current during positive NPGO conditions (Di Lorenzo et al., 2008; Chhak et al., 2009). The ETNP also experiences changes in sea surface height associated with NPGO (Di Lorenzo et al., 2008, Fig. 1C). Finally, the relatively warm waters of the ETNP provide favorable conditions for the growth of scleractinian corals (Villaescusa and Carriquiry, 2004), which can be used to reconstruct tropical Pacific ocean-atmospheric variability (e.g., Druffel and Linick (1978); Guilderson and Schrag (1998); Cobb et al. (2003); McGregor et al. (2008)).

Corals offer a relatively high-resolution archive for reconstructing past oceanic conditions throughout the tropical Pacific (Cobb et al., 2013; Nurhati et al., 2009, 2011; Carilli et al., 2014). Here, we introduce new measurements of $\delta^{18}O$ and $\Delta^{14}C$ alongside published Sr/Ca measurements of San Benedicto Island *Porites* coral from the Revillagigedo Archipelago (Fig. 1) from 1950 to 1998; a period that allows for direct comparison with the NPGO and other modes of ocean-atmosphere variability. The oxygen isotopic composition ($\delta^{18}O$) of a coral skeleton provides a mixed proxy record of SST and salinity variability (Erez, 1978). The Sr/Ca of coral skeleton provides a proxy for SST (Villaescusa and Carriquiry, 2004). The radiocarbon content ($\Delta^{14}C$) of coral skeleton records

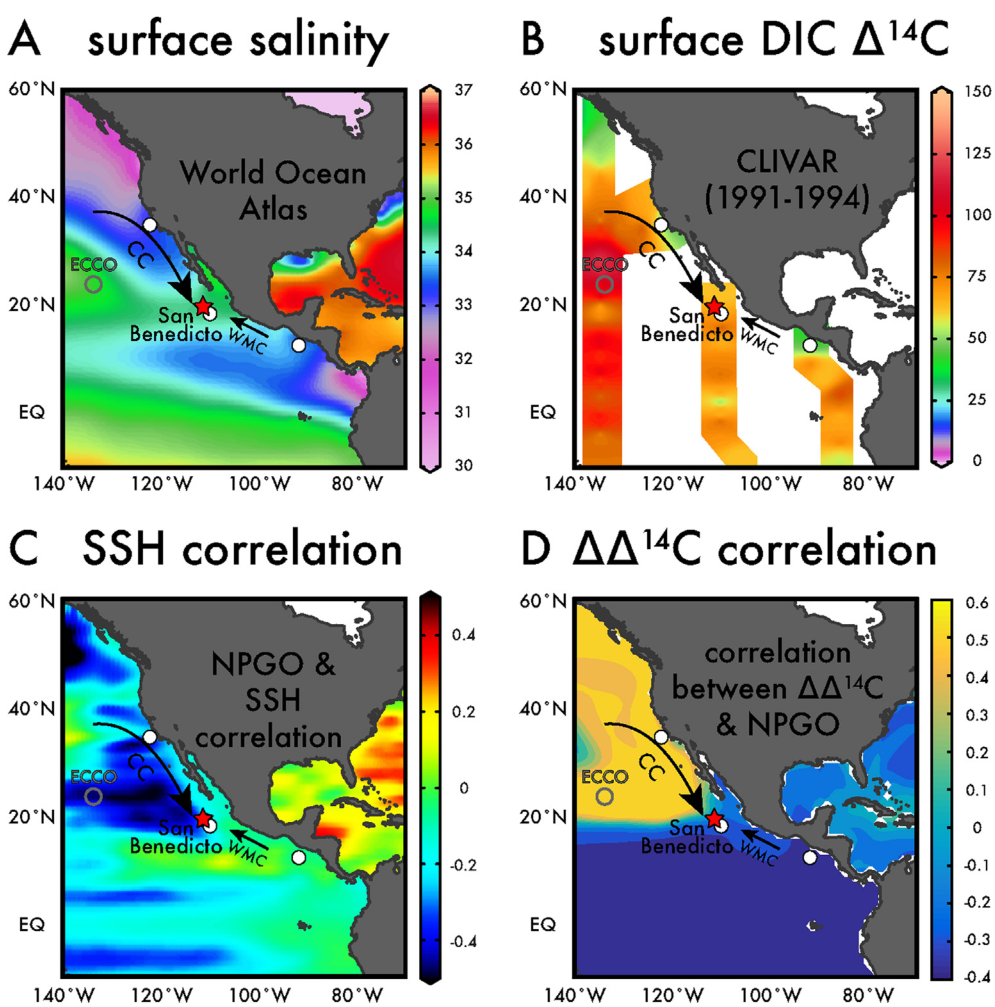


**Fig. 1.** (A) Climatological sea surface salinity and generalized surface circulation (based on Kessler (2006)). Red star indicates the coral sampling site at San Benedicto Island. White circles indicate the location of seawater measurements listed in Table 2. (B) Surface seawater dissolved inorganic carbon (DIC) radiocarbon content ($\Delta^{14}C$) between 1991 and 1994 in the northeast and tropical Pacific (Key et al., 2004). (C) The correlation between the North Pacific Gyre Oscillation (NPGO) index and sea surface height (SSH) anomalies (similar to Ceballos et al. (2009)). Note that San Benedicto Island and the Revillagigedo Archipelago appear to be located within a region of lower sea surface height (surface divergence) during positive phases of NPGO. (D) A map showing the correlation coefficient between NPGO and $\Delta\Delta^{14}C$ for all locations in the map ($\Delta\Delta^{14}C$ being the difference between ECCO model surface water DIC $\Delta^{14}C$ (Graven et al., 2012) and coral $\Delta^{14}C$). The map in (D) was created by first calculating the $\Delta\Delta^{14}C$ for each map location ($\approx$2000 $\Delta\Delta^{14}C$ time-series) and then calculating the correlation of each $\Delta\Delta^{14}C$ time series with NPGO. The correlation coefficient is shown by color. We ultimately chose the $\Delta\Delta^{14}C$ differencing for the site labeled "ECCO," but this map shows that the correlation is not overly sensitive to the chosen model site. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)