



# Coral Sr/Ca-based sea surface temperature and air temperature variability from the inshore and offshore corals in the Seribu Islands, Indonesia



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## ABSTRACT

The ability of massive *Porites* corals to faithfully record temperature is assessed. *Porites* corals from Kepulauan Seribu were sampled from one inshore and one offshore site and analyzed for their Sr/Ca variation. The results show that Sr/Ca of the offshore coral tracked SST, while Sr/Ca variation of the inshore coral tracked ambient air temperature. In particular, the inshore SST variation is related to air temperature anomalies of the urban center of Jakarta. The latter we relate to air–sea interactions modifying inshore SST associated with the land–sea breeze mechanism and/or monsoonal circulation. The correlation pattern of monthly coral Sr/Ca with the Niño3.4 index and SEIO-SST reveals that corals in the Seribu islands region respond differently to remote forcing. An opposite response is observed for inshore and offshore corals in response to El Niño onset, yet similar to El Niño mature phase (December to February). SEIO SSTs co-vary strongly with SST and air temperature variability across the Seribu island reef complex. The results of this study clearly indicate that locations of coral proxy record in Indonesia need to be chosen carefully in order to identify the seasonal climate response to local and remote climate and anthropogenic forcing.

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## 1. Introduction

The Seribu islands archipelago (also known as Thousand Islands or Kepulauan Seribu in Indonesian) is an archipelago that extends from the bay of Jakarta, a city of over 10 million inhabitants, to more than 80 km to the northwest in the Java sea. A popular tourist destination, the archipelago includes one of the first officially protected marine areas in Indonesia (Salm et al., 1982). The proximity of the Seribu Islands reef complex to Jakarta metropolitan city induced serious environmental problems, for example many of the inshore reefs, that were still thriving in the 1920s (Umbgrove and Verwey, 1929), are now effectively moribund, consisting of little else than sand, turf algae and the odd massive coral (Rachello-Dolmen and Cleary, 2007; Cleary et al., 2008; de Voogd and Cleary, 2008). Offshore the situation is better, but even here there has been a marked decline in coral cover over the last few decades (Cleary et al., 2008). The Seribu islands are an interesting

area to study the influence of large urban populations on reef communities and coastal waters because they are one of the few coral reef systems which are located close to a metropolitan city. Hence, the impact of a large-scale disturbance gradient (e.g. natural factor: El Niño–Southern Oscillation, Monsoon) on coral health in the Jakarta Bay and Seribu islands can be compared with its local-scale disturbance (e.g. anthropogenic factors).

A number of recent studies have assessed on-to-offshore variation in environmental conditions and biota of the Seribu islands (Cleary et al., 2006; Van der Meij et al., 2009). In addition to this, museum collections, dating back to the 1920s, were used to compare mollusc and coral composition over an eighty year period (Van der Meij et al., 2009, 2010).

Coral cores have been used to monitor changes in environmental conditions over long periods of time, importantly extending beyond the onset of the instrumental data collection (e.g.; Linsley et al., 2000; Zinke et al., 2004; Ourbak et al., 2006; Cahyarini et al., 2014). In the Seribu islands, coral cores have previously been used to compare fluorescence banding and Pb concentrations. Scoffin et al. (1989) concluded that fluorescence banding was brighter in inshore than in offshore corals. Inoue et al. (2006) presented five years of Pb concentrations which were shown to increase from the off- to inshore corals.

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In addition to the above, corals can also be used to monitor variation in temperature.

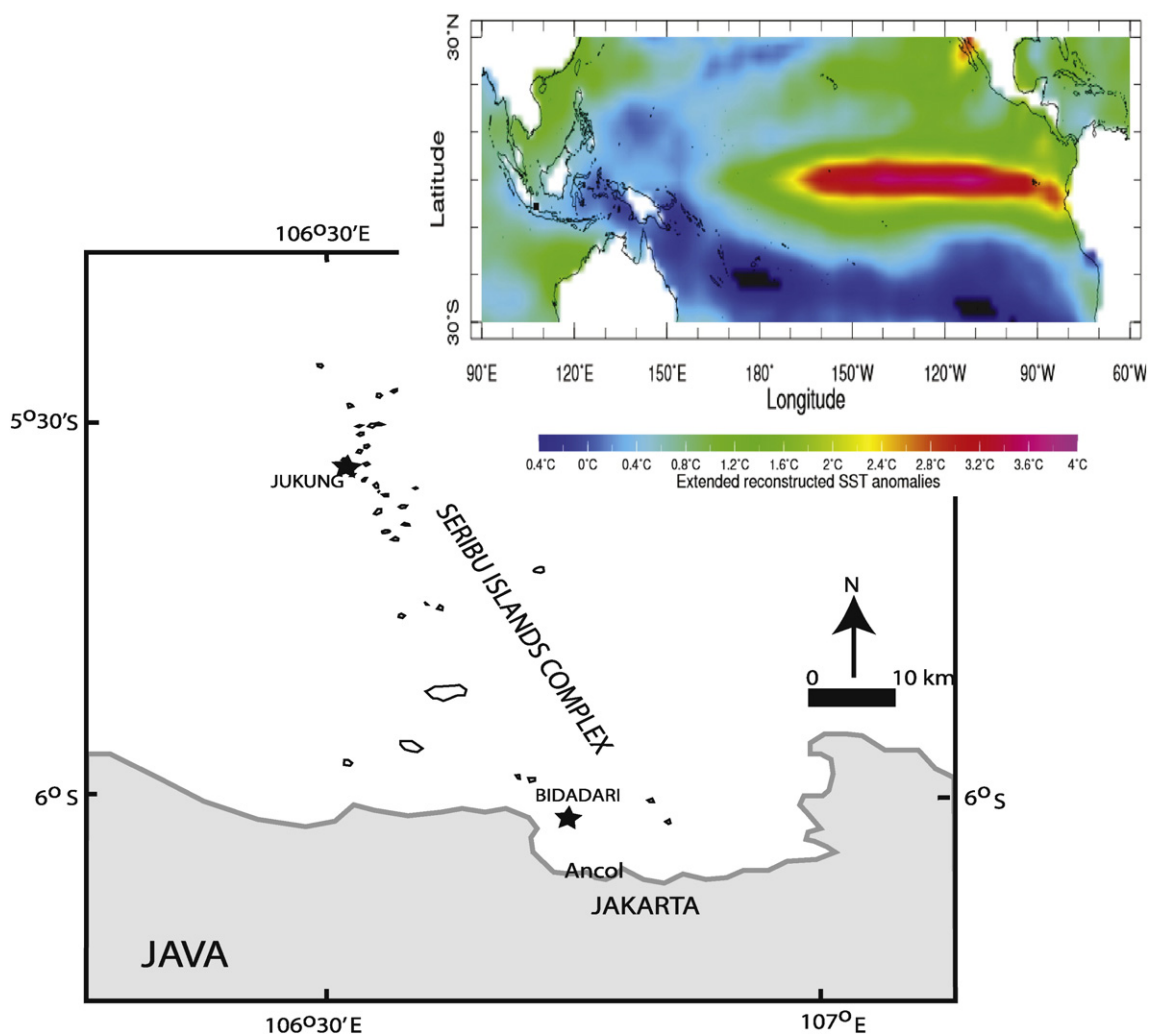
Coral Sr/Ca is presently the most promising sea surface temperature proxy in paleoclimatology. Several studies have shown that Sr/Ca is influenced only by sea surface temperature (SST; e.g., Zinke et al., 2004; Corrège, 2006; Hetzinger et al., 2006; Cahyarini et al., 2009).

In the present study Sr/Ca ratios in coral cores were determined from massive *Porites* corals in order to reconstruct variations in SST from an inshore and offshore coral reef. Comparing corals from inshore and offshore environments allows us to ascertain to what extent nearshore conditions influence environmental variables such as temperature. We hypothesise that inshore corals are influenced by air temperature over the adjacent land through air–sea interaction while the offshore corals provide truer records of open sea conditions. In addition to this, we will also assess whether there is evidence of a link between the temperature variations at the Seribu islands and remote climate forcing, i.e. El Niño–Southern Oscillation (ENSO) events and/or South Eastern Indian Ocean (SEIO) SST.

## 2. Climate setting at the Seribu islands reef complex

The Seribu islands reef complex (Fig. 1) extends from Jakarta Bay more than 80 km to the northwest in the Java Sea. Natural factors such as the Asian monsoon, ENSO and Indian Ocean Dipole (IOD)

influence the waters surrounding the Seribu islands (Haylock and McBride, 2001; Aldrian and Susanto, 2003; Aldrian and Djamil, 2008). During El Niño years, the August SST anomaly shows colder temperature over the Indonesia region including the Seribu Islands than the eastern Pacific Ocean, as exemplified for 2015 (Fig. 1). The seasonal movement of freshwater from the South China Sea to the Java sea steered by the monsoonal climate controls seasonal changes of sea surface temperature (SST) and salinity in the Java Sea, and thus influences the Seribu islands waters (Gordon et al., 2004). During the wet season, intensive rainfall feeds freshwater runoff into Jakarta bay. The prevailing monsoon winds distribute the freshwater plume within Jakarta bay affecting the Seribu reef complex with varying intensity. In addition to this, El Niño events cause droughts and have led to recorded warmer sea surface temperature anomalies in several locations across the Seribu islands (Brown and Suharsono, 1990; Suharsono, 1998). Based on monthly average SST data taken from ERSST data for period of 1992–2005, SST shows two peaks (April and October) and two troughs (August and January). Maximum SST is observed in April (29.81 °C) and the minimum (28.63 °C) in January (Fig. 2). The absolute maxima (May; 28.54 °C) and minima (January; 27.06 °C) of air temperature at Jakarta are in-phase with ERSST, while the secondary maxima (September) and minima (July) occur 1–2 months earlier. Air temperature follows solar radiation as expected, with similar bimodal seasonal cycle (Fig. 2d).



**Fig. 1.** Map of SST anomaly in November 2015, which is known El Niño year 2015, black square is the location of Seribu Islands—Indonesia. SST data anomaly map is taken from ERSST v3b, Jan. 1854 to Jan. 2016 (<http://iridl.ldeo.columbia.edu/>) (inset-colours). The Seribu islands complex in more detail showing drilling sites of Jukung and Bidadari island (Star).

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