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# Cooling trend over the past 4 centuries in northeastern Hong Kong waters as revealed by alkenone-derived SST records

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ABSTRACT

The climate history over the past few centuries is important to be used to assess how regional climate responds to global forcing. Here we report three high-resolution alkenone-based sea surface temperature (SST) records over the past 4 centuries from three sediment cores collected in the Mirs Bay, northeastern Hong Kong. All three SST records consistently show a general cooling trend toward the present, with most of cooling occurring over the last century. Alkenone-derived SST values stayed around 26.5–27 °C at the three sites prior to 1900s and decreased into the range of 25–26 °C. The magnitude of cooling approximately from the Little Ice Age (LIA) to present tends to be dampened from ~2 °C nearshore to ~1 °C offshore. The cooling trend, as identified in all three SST records, is thus opposite to the global temperature rise over the last century. Assisted with modern observations, we interpret that the alkenone-derived SST reflects increasing upwelling in the Mirs Bay, which likely results from the strengthened East Asian summer monsoon, in the context of global warming over the last century.



## 1. Introduction

Climatic changes over the past few centuries have been used as key reference in the assessment and projection of climate change under anthropogenic impact (IPCC, 2013; Mann et al., 1998). The global climate is characterized with unprecedented temperature rise since the late 19th century as suggested by numerous instrumental records and the Intergovernmental Panel on Climate Change (IPCC) Assessment Report (IPCC, 2013). The start of global warming in the late 19th century is also the end of a relative cool period (~1450 to 1850 AD), namely the “Little Ice Age” (LIA) (Bradley and Jonest, 1993; Mann et al., 2009; Wanner et al., 2008). Rapid warming from the LIA to present has been extensively studied to test the response of regional climate and environment, such as monsoons, precipitation and regional surface temperature, to the global climate forcing (Bradley and Jonest, 1993; Jones and Mann, 2004; Mann, 2007; Oppo et al., 2009).

Despite of the overall warming on Earth’s surface, temperature variations are found in great divergence in various regions, and greatly affected by regional climatic processes (Bao and Ren, 2014; Mann et al., 1998, 1995). For instance, several long-chain alkenone-derived SSTs reveal notable cooling in the Yellow Sea and East China Sea over the last 3 centuries (He et al., 2014). In some coastal areas, proxy-based SSTs exhibit significant cooling during the 20th century (Gutiérrez et al., 2011; McGregor et al., 2007). Particularly, observations and model simulations suggest that surface temperatures over land rise more than over the ocean with a warming climate (Bakun, 1990; Dong et al., 2009; Sun et al., 2010; Sutton et al., 2007). It is proposed that this different warming over land and ocean could lead to stronger Asian summer monsoon (Hu et al., 2000; Wang et al., 2012a), although other studies suggest weaker wind speed and monsoon precipitation over China in recent several decades (Guo et al., 2011; Liu et al., 2011).

The South China Sea (SCS), a tropical marginal sea located between the western Pacific and the Asian continent, is strongly affected by the reversing East Asian monsoons. Paired Holocene SST records from open ocean and the coast of the northern SCS indicate a significant cooling trend at the coast toward the late Holocene, perhaps with maximum cooling during the LIA (Kong et al., 2014), suggesting that coastal regions might have responded to monsoonal changes more sensitively. However, due to limited data resolution, coastal SST changes at centennial timescales could

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not be assessed. To better understand coastal climatic changes over the past few centuries, we here reconstruct three high-resolution alkenone-derived SST records from the Mirs Bay, northeastern Hong Kong, and assess the possible effects of East Asian monsoons on coastal SST changes.

## 2. Oceanographic settings

The study region is located in the Mirs Bay (22.50°N, 114.70°E), a semi-enclosed bay in the northeast of Hong Kong, northern South China Sea (Fig. 1). The Mirs Bay is embedded into the terrene ~18 km between Hong Kong and Dapeng Peninsula in Shenzhen, covering an area ~320 $km^2$ (Li et al., 2014). The water depth is generally less than 22 m, relatively deep in the southwest and shallow in the northeast (Li et al., 2014). There is no big river discharging into the bay. The SST and salinity at the marine observation station MM17 in the bay (Fig.1) range between 16–31 °C and 20–34 psu, with annual mean at ~24 °C and ~32 psu respectively (Hong Kong EPD, www.wqrc.epd.gov.hk).

The temperature and salinity in the Mirs Bay and adjacent waters around Hong Kong are strongly influenced by the seasonally reversing monsoons. The East Asian summer monsoon (EASM) lasts from mid-May to mid-September, with maximum intensity in June, July and August (Chu and Wang, 2003; Yin, 2002). When summer monsoon prevails, southwest wind drives the surface water moving northeastward along the shore (Fang et al., 2012; Su, 2004). It causes an offshore movement in the surface water owing to the Ekman Effect. As a result, cooler and saltier bottom oceanic water intrudes shoreward and appears as a weak upwelling (Jing et al., 2009; Yin, 2002; Zu and Gan, 2015). Because of this upwelling effect, surface waters in the Mirs Bay, as well as the region to the northeast of Hainan Island, appear to be cooler by 1–2 °C, than surrounding waters (Jing et al., 2009). Despite the weak upwelling caused by summer monsoon, vertical temperature gradient in the Mirs Bay reaches the maximum in summer time. Meanwhile, bottom and middle layer salinity reach the maximum while surface salinity decreases apparently (Yin, 2002). In contrast to summer, the vertical distribution of temperature and salinity is almost homogenous in winter, due to the strong winter monsoon-induced mixing effect (Yuan et al., 2011).

## 3. Material and methods

Three short gravity cores, T3 (22°26′54″N, 114°15′43″E), T6 (22°28′24″N, 114°21′10″E) and M10 (22°27′55″N, 114°23′24″E), were collected from the Mirs Bay of Hong Kong in September 2012 (Fig.1). The water depth at sampling sites T3, T6 and M10 are 11, 15 and 20 m. The three core lengths are 66, 80 and 69 cm, respectively. All three cores were subsampled at 1 cm interval on board.

All the samples were freeze-dried and extracted following the standard procedure described in Kong et al. (2014). The lipid fraction containing alkenones was analyzed on an Agilent 7890 GC-FID at the University of Hong Kong. $C_{36}$ *n*-alkane was used as internal standard for quantification of alkenones. The alkenone unsaturation index ($U^{K'}_{37}$) is calculated based on the definition: $U^{K'}_{37} = C_{37:2}/(C_{37:2} + C_{37:3})$, where $C_{37:2}$ and $C_{37:3}$ are contents of the di- and tri-unsaturated $C_{37}$ alkenones respectively (Prahl et al., 1988). SST was calculated using the $U^{K'}_{37}$-SST calibration equation: $U^{K'}_{37} = 0.031 * SST + 0.092$ for the SCS region (Pelejero and Grimalt, 1997). Replicate injections of standards in different batches show analytical errors less than 0.3 °C for the calculated SST (Kong et al., 2014).

The chronologies of core T6 and M10 were established based on $^{210}Pb$ and $^{137}Cs$ dating. The radioactivity of $^{210}Pb$ and $^{137}Cs$ were detected using gamma spectrometry equipped with a germanium detector at the Institute of Polar Environment, the University of Science and technology, China. The detailed procedure and parameters used are described by Xu et al. (2010) and He et al. (2014). As $^{210}Pb$ dating failed at a nearby core, possibly due to sediment disturbance by human activities, $^{210}Pb$ and $^{137}Cs$ analyses were not conducted at core T3. Instead, the chronology of this core was tentatively assigned through correlation with core T6, based on identifiable common features in both SST records (Fig. 3).

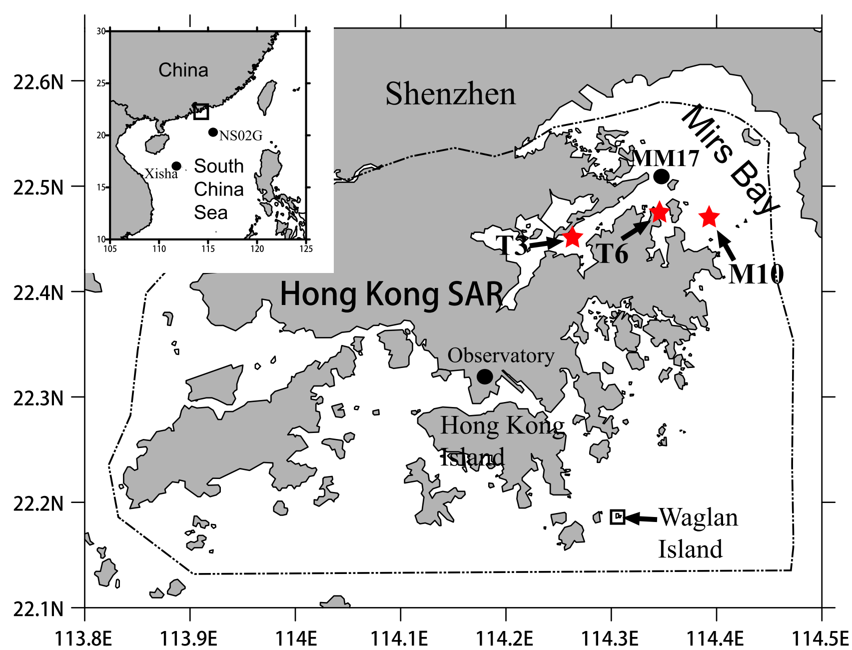


**Fig. 1.** Location map of the study area, the Mirs Bay, Hong Kong. Core sites T3, T6 and M10 are indicated by stars and the HK observatory and marine observation station MM17 by filled circles.