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Baseline

Temporal variability and climatology of hydrodynamic, water property and water quality parameters in the West Johor Strait of Singapore

Manasa Ranjan Behera [a,b,*], Cui Chun [b], Sundarambal Palani [b], Pavel Tkalich [b]

[a] Department of Civil Engineering, Indian Institute of Technology Bombay, Powai, Mumbai 400076, India
[b] Physical Oceanography Research Laboratory, Tropical Marine Science Institute, National University of Singapore, S2S, 18 Kent Ridge Road 119227, Singapore

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ABSTRACT

The study presents a baseline variability and climatology study of measured hydrodynamic, water properties and some water quality parameters of West Johor Strait, Singapore at hourly-to-seasonal scales to uncover their dependency and correlation to one or more drivers. The considered parameters include, but not limited by sea surface elevation, current magnitude and direction, solar radiation and air temperature, water temperature, salinity, chlorophyll-a and turbidity. FFT (Fast Fourier Transform) analysis is carried out for the parameters to delineate relative effect of tidal and weather drivers. The group and individual correlations between the parameters are obtained by principal component analysis (PCA) and cross-correlation (CC) technique, respectively. The CC technique also identifies the dependency and time lag between driving natural forces and dependent water property and water quality parameters. The temporal variability and climatology of the driving forces and the dependent parameters are established at the hourly, daily, fortnightly and seasonal scales.

Understanding of coastal and estuarine processes is capturing much attention worldwide due to increasing utilisation of ocean resources and escalation of human impact. Being an interface between land, ocean and atmosphere, estuaries are affected by various phenomena typical for the encompassing media. The properties and the qualities of estuarine waters exhibit a complex interplay of anthropogenic impact, surface runoff, ocean fluxes and climatic extremes, each of which require understanding of separate and combined effects.

General important parameters considered in an impact assessment study are current velocity, water temperature, salinity, turbidity and chlorophyll-a (Chl-a) concentration. The tidal hydrodynamics, the water property and water quality parameters are also exposed to other atmospheric variables, e.g., solar irradiance, air temperature and rainfall (Lee and Lee, 1995; Blauw et al., 2012). Atmospheric and oceanic processes are interacting at a variety of time scales, particularly observed through a similar pattern in air and surface ocean temperature. The time scales range from the quite predictable diurnal variations caused by solar input and tides, to the much less predictable inter-decadal and centennial scale variability. Depending on the study objectives, the pattern could be studied at a broad range of temporal scales, from hourly to interannual (Cloern et al., 1989; Boesch et al., 2000; Sanderson and Taylor, 2003; Brodie et al., 2007; Madhu et al., 2010; Ruggieri et al., 2011; Blauw et al., 2012; Mulia et al., 2013).

In order to identify spatio-temporal variability and complex relationships between environmental parameters in empirical datasets, various multivariate statistical techniques such as principal component analysis (PCA), cross-correlation analysis (CC), frequency analysis (FA) and discriminant analysis (DA) are used (Shrestha et al., 2008; Prathumratana et al., 2008; Bengraine and Marhaba, 2003; Stefan et al., 2004; Sharma, 1996). Bengraine and Marhaba (2003) used PCA on physical, chemical and biological data to extract the factors associated with water quality variability. Similarly, Prathumratana et al. (2008) used PCA to analyse the correlation between climatic, hydrological and water quality of the lower Mekong River.

The above studies confirm the need for understanding of combined and separate hydrodynamic and atmospheric forces on water property and water quality parameters in an estuary. This is especially true for estuaries within Sunda Shelf of South East Asia (SEA), being affected by strong ocean- and weather-driven phenomena. The present study uses high resolution data resulting from monitoring buoys established in the West Johor Strait, Singapore. Water depths in the West Johor Strait range from a few meters along the boundaries to about 10–20 m along the center of the Strait and their width varies from about 0.5–2 km including the tidal flats on both sides of the Straits (Chan et al., 2006). The parameters of interest, including current velocity, water temperature, salinity, turbidity and Chl-a concentration are

* Corresponding author at: Department of Civil Engineering, Indian Institute of Technology Bombay, Powai, Mumbai 400076, India. Tel.: +91 22 25767313; fax: +91 22 25767302.
E-mail address: manasa.rb@iitb.ac.in (M.R. Behera).

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analysed to determine variability at hourly, daily, fortnightly and seasonal scales. Statistical techniques (FA, PCA and CC) are employed to uncover complex relationships between the water property parameters and met-ocean variables.

Majority of the atmospheric phenomena in the Southeast Asia (SEA, Fig. 1a) are regionally- or even globally-driven but modulated by local features; therefore, it is necessary to utilise knowledge of the climatic condition and oceanic flows of SEA for analysis of coastal processes in the West Johor Strait of Singapore (Fig. 1b). Southeast Asia encompasses twelve countries with notable marine features including the Indian Ocean, the Pacific Ocean, the Bay of Bengal, South China Sea and the Malacca Strait (Fig. 1a). Singapore is located at the confluence of two major tidally active water bodies, South China Sea (SCS) and Indian Ocean, via Malacca Strait (MS) and Singapore Strait. The climatology of Singapore, due to its geographical location, is characterised by uniform temperature and pressure, high humidity and abundant rainfall, and it is influenced strongly by the Asian monsoon. Being part of SEA, Singapore has two main monsoon seasons: the Northeast (NE) monsoon lasts from November to March and the Southwest (SW) monsoon lasts from June to September. These seasons are separated by two shorter inter-monsoon (IM) periods that last from April to May and October to November. Due to monsoonal forcing, the Singapore Strait receives inflow from the South China Sea during the NE monsoon and influx from the Java Sea and Malacca Strait during the SW monsoon.

The surrounding water bodies and monsoon pattern dictate much of the region's climate and local hydrodynamics that influence water temperature, salinity, turbidity and Chl-a. The air temperature in Singapore ranges from 21.7 to 35.5 °C and annual average rainfall is 2075 mm (Department of Statistics, Singapore, 2012). Fig. 2a shows typical annual air temperature and rainfall pattern, where the mean air temperature ranges from 25.9 to 27.7 °C and mean monthly rainfall ranges from 159.3 to 287.4 mm. Heavy rains are observed from November to January and usually lowest average in July. The daily solar radiation pattern shows the maximum radiation at around 12 noon (Fig. 2b). The daily air temperature follows the solar radiation, which in turn governs the sea surface temperature (SST) as shown in Fig. 2c and d. The maximum air temperature and SST are observed at around 2 pm and 4 pm, respectively.

Analysis of water properties may provide a lot of information on state and dynamics of the coastal ocean waters. Water temperature and salinity are the most basic properties of water that influence and being influenced by many other water column variables, as well as modulate biological components of aquatic environments. Sea surface temperature (SST) is largely determined by the amount of solar energy absorbed by the water, but also indicative of vertical and lateral water mixing. Salinity is a dynamic water quality indicator of the nature of the exchange system. Salinity is influenced by high rainfall and by freshwater input from numerous rivers. Increases in precipitation and runoff combined with warmer sea surface temperatures and lower currents increase the intensity of stratification. This has the potential for both positive and negative environmental effects.

In the SEA region, the annual mean sea surface salinity is generally low and sea surface temperature is high, where the salinity ranges from 32.0–34.5 ppt and the water temperature ranges from 22.8–32.9 °C (NASA Aquarius and World Ocean Atlas, 2005). The adjoining water bodies, MS and SCS, are mostly affecting the water properties in Singapore Strait Region (SSR). However, MS has relatively higher effect on the West Johor Strait (WJS) due to a close proximity. Amiruddin et al. (2010) observed that there is significant low salinity input from the west coast of Peninsular Malaysia during the NE monsoon and intrusion of high saline water from the Andaman Sea during SW monsoon to the MS. The climatology of MS varies based on the monsoon seasons (Eng et al., 2000). Surface water temperature of MS is warmer during the SW monsoon, ranging from 28 °C to 30 °C, but drops 1–2 °C during the NE monsoon. The coastal salinity off Singapore may range 29–32 ppt (Din et al., 1996). The mean temperature and salinity in the Singapore Strait and Malacca Strait are approximately 29 °C and 29 ppt, respectively (Purnomohadi, 2003). The salinity in the Johor Strait is lower than the Singapore Strait due to fresh water discharge from two major rivers located in Malaysian territory, Sungai Johor on the east and the largest river Sungai Pulai on the west with a catchment area of 330 km^2. The mean annual runoff (from Malaysia and Singapore) into the West Johor Strait is approximately 45 m^3/s (DHI, 2004).

Chl-a biomass can be an indicator of nutrient enrichment and level of eutrophication in the water bodies that leads to algal blooms (Palani et al., 2008; Boyer et al., 2009). Chl-a content in the MS is strongly influenced by Asian monsoon (Tan et al., 2006). Generally, higher Chl-a concentration is observed during SW monsoon compared to the wetter and cooler NE monsoon. Surface chlorophyll in the MS varies from 0.51–0.95 μg/L (Chua et al., 1997). The Chl-a concentration is generally low in the open seas and high in the coastal regions. The Chl-a concentration of

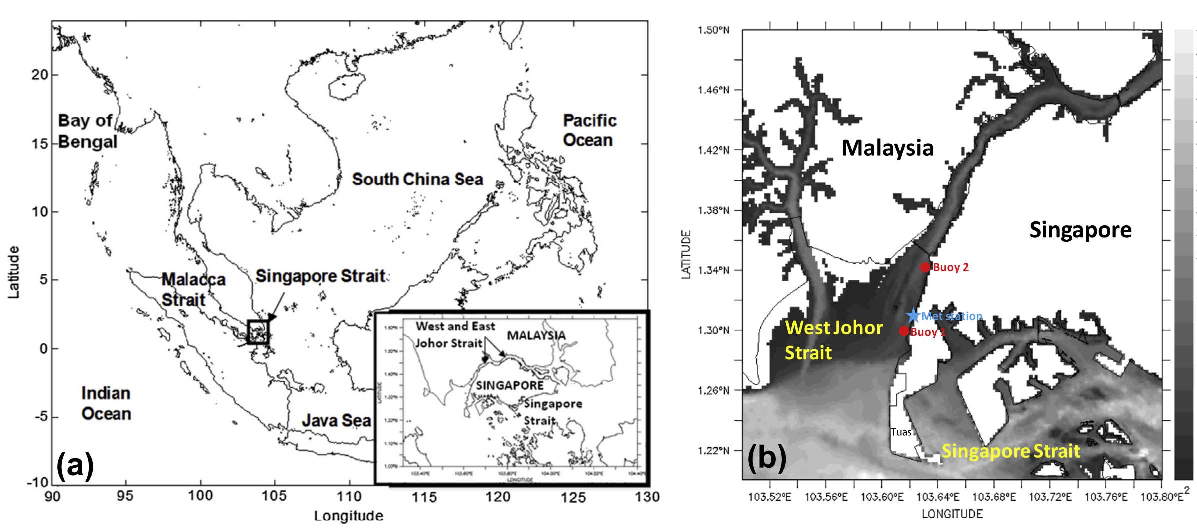

Fig. 1. (a) A geographical map of Southeast Asia, Singapore; (b) bathymetry map covering the study area in the West Johor Strait.