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# Influence of resonance on tide and storm surge in the Gulf of Thailand

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ABSTRACT

A numerical simulation is used to determine the effective resonance period, quality factor Q and linear friction coefficient and mechanism of tide and storm surge in the Gulf of Thailand. The results indicated that the resonance response is triggered by the forced wave with the period of 20.25 hours. The *Q* factor and linear friction coefficient are approximately 3.15 and $2.76 \times 10^{-5}\ \mathrm{ms}^{-1}$, respectively. The gulf is regarded as a moderately dissipative system, which may yield small amplification for the oscillating forced wave. The resonance structure of the basin can play an important role in spatial distribution and amplification of tidal waves in the Gulf of Thailand and nearby area. Distance from the effective resonance period and the corresponding *Q* factor can be employed in characterizing of tidal amplification in the gulf. The study found that phase difference in the incoming tidal waves can induce the distortion of a nodal band to the normal mode analysis results. The resonance in the north–south direction is the principal mechanism to control tidal waves, specifically for the upper part of the gulf (the Gulf of Thailand). However, significant effect of resonance in the west–east direction on the amplification of tidal waves near the southern part of the gulf (Vietnam, Malaysia and Singapore coast) may be pronounced. From the reproduced historic storm surge and hypothetical results, the spatial distribution of storm surge elevation and the response ratio are in good agreement with the resonance mode and *Q* factor of the basin. Individually, the contribution of resonance factor to induce severe storm surge (positive surge) tends to be insignificant. Conversely, the interaction process between the disturbance system and the propagating surge wave in the gulf can induce large positive surge near the landfall location significantly.


## 1. Introduction

For many decades, the Gulf of Thailand (GOT), the major bay of the Sunda Shelf (SS) has been a significant factor for supporting the economic and social development of Southeast Asian countries. The sea has highly profitable and vital resources (fishery, mineral and petroleum); additionally, the transportation over this region is regarded as secure and comfortable. Hence, investments and overseas trade surrounding the gulf have continuously developed. Moreover, this region is well-known as a diverse coastal ecological system with a rich socio-culture. Thus, the tourism industry benefits to the region are also high. Another important issue in this region is the oceanic hazard induced by atmospheric disturbances. The region has been destroyed by severe tropical cyclones (TCs) in the past, such as Typhoon Harriet in 1962, Typhoon Gay in 1989 and Typhoon Linda in 1997. Comparing the typhoon reoccurrence between the GOT/SS and the South China Sea (SCS), shows that 4 storms per year occur in the GOT/SS following the period of monsoon trough, whereas more than 10 storms per year strike the coast of the SCS. The three severe storm surge situations in the SCS were found in 1902, 1937 and 1962, and the greatest area of risk was the Hong Kong coast. However, during the past several decades, a severe storm surge damage occurred on the GOT (1989 and 1997) instead of the SCS, whereas TC activity has intensified in the latter region. In fact, the basins are different with regards to their coastal configuration and seabed topography. The SCS is longer, wider and deeper than the GOT/SS. An important question is whether physical characteristics of the sea play an important role in the storm surge magnitude. The reasons behind that issue still need to be deeply investigated for both regions. It is evidenced that oscillation of long waves in complex natural coastal system can be effectively described by the resonance properties e.g. standing wave resonance (Garrett, 1972; Sutherland et al., 2005) and shelf resonance (Bertin et al., 2012).

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However, there is still lack of spatial dynamic identification and the corresponding physical processes through resonance response for the particular system with high geomorphic complexity such the GOT/SS. Improving knowledge of resonance response and the related physical processes of tides and storm surges dynamic for the GOT/SS and SCS system can be importance foundation for disaster preparation and improving in ocean prediction system in this region. However, in this study, we mainly consider the GOT/SS because of its importance and impact as mentioned previously. Therefore, our main objective is to investigate the resonance properties that characterize dynamics of long waves, especially tides and storm surges in the GOT/SS. Next, the geomorphic and hydrodynamic settings of this complex coastal bay shelves are presented.

## 2. Study area

### 2.1. Geomorphic setting

The GOT and adjacent areas, such as the Vietnam and Malaysia sea territories, comprise most of the Sunda Shelf (SS) in the Southeast Asia (Fig. 1). The shelf was formed during the end of the last glacial period as the second largest submerged extension of a continental margin in the world (Molengraaff, 1921 and Dickerson, 1941). Physically, the shelf is oriented primarily in the north–south direction. In overall, the shelf has a large basin, and the depth is regarded as moderately shallow. Furthermore, the shelf is characterized by a semi-enclosed bay or gulf with two open-ended connections to the South China Sea (SCS) and the Karimata Strait (KS). Its seabed topography is relatively shallow with an average depth of approximately 52 m enclosed by a slightly inclined bottom with the deepest bottom depth located in the middle of the gulf. Hence, this system may experience high friction inside. Specifically for the GOT/SS, the relationship between its geometry and the response hydrodynamic behaviors for long waves seems to be less concern for the disaster prevention communities, although the evidences from the observation data such as amphidromic system obviously indicate the influence of the geometry to the characteristic of the standing wave. It is indeed necessary to determine the resonance properties of the gulf both for insightful understanding of the hydrodynamic mechanism and improving in ocean prediction system in this region. In the next section, the hydrodynamic mechanism of the propagating long waves in the GOT is presented.

### 2.2. Hydrodynamic setting

Characteristic of tides in GOT/SS are mostly dominated by the two primary diurnal ($K_1$ and $O_1$) and semi-diurnal ($M_2$ and $S_2$) constituents. However, tidal regime along the coast is indeed different spatially. Specifically, the diurnal tides dominates in most of the upper GOT (except for the head-end region of the gulf) while almost of the rest are rather under influence of mixed and semi-diurnal tides. Tide range at the head-end of the GOT is observed to be smaller than that of the southern tip of the Ca Mau peninsula and the coast of Kuchin (Malaysia). This seems to be well conformed to spatial variation of the anti-nodal band of the amphidromic system for the SCS (Zu et al., 2007). One of the possible cause for the reduced range may involve with the energy dissipation of the incoming tidal waves which strongly depends on the geometry and seabed topography of the gulf. For GOT/SS, its shape is roughly rectangular with a length, $L$, and width, $l$, of approximately 1380 and 544 km, respectively. By estimating the basin aspect ratio defined by $L/l$ and the aperture ratio $b/l$ in which $b$ is the actual width of the mouth, this system cannot be defined

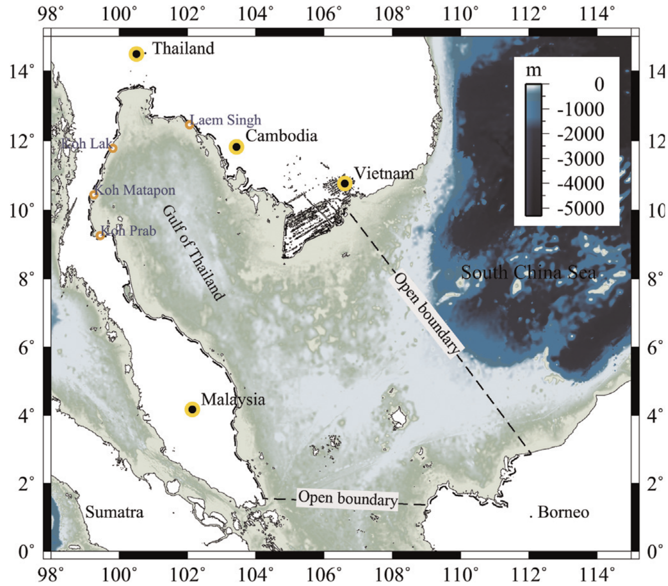


**Fig. 1.** Sea floor topography, tide stations and computational domain.

as an elongated semi-enclosed basin, which implies that much of the tidal energy is potentially dissipated to exterior regions. According to Zu et al. (2007), the work rate performed by the tidal generating force near the entrance of the GOT/SS is much more intense than the inside region. However, the effect of the aforementioned characteristic on the surge and tide inside the gulf is still not clear. In particular, the response of the basin on the propagating forced wave is still unclear. Yanagi and Takao (1998) proposed that the natural oscillation for the GOT is primarily the period of the diurnal tide, whereas Sirisup and Kitamoto (2012) indicated that natural oscillation periods of this region for the first through fourth mode are 56.61, 20.05, 15.6 and 13.64 hours. The latter result suggests that the higher modes are more topographic-dependent than the fundamental and the first mode. However, the effective resonant period of this gulf is not yet determined, which can explain the discrepancy regarding the long wave mechanism in this region.

The resonance period for semi-enclosed basins worldwide has been investigated through analytical and numerical experiments such as Garrett (1972), Greenberg (1979), Sutherland et al. (2005) and Zhong et al. (2008). In their investigations, a maximum response of the physical properties, such as amplitude gain, as well as the mean work rate across the boundary can be induced when the forcing frequency is close to the natural oscillation frequency of the basin. This phenomenon can be reasonably explained in terms of a physical mechanism; the propagating waves become amplified or depressed (dampened) due to the standing wave mechanism, the interaction between the bed topography and radiative energy loss to the exterior region. The first mentioned factor yields undulation patterns influenced by the shape and depth of the system, while the two latter factors mostly represent the energy loss properties (energy dissipation).

Another important property that is valuable in clarifying the resonance mechanism for the resonator system is a measure of energy damping in the system, or quality factor/dissipation parameter $Q$. Notably, for the resonance period, the stored energy inside the system is more than the dissipation rate. Therefore, large amplification can be produced. An example is the Bay of Fundy, on the North coast of British Columbia and the Gulf of California. On the other hand, a system with high energy loss will exhibit small amplification even at a resonance period, such as the Chesapeake Bay and the Juan De Fuca Strait of Georgia.