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Tidal characteristics of the gulf of Tonkin

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ABSTRACT

The Gulf of Tonkin, situated in the South China Sea, is a zone of strong ecological, touristic and economic interest. Improving our knowledge of its hydro-sedimentary processes is of great importance to the sustainable development of the area. The scientific objective of this study is to revisit the dominant physical processes that characterize tidal dynamics in the Gulf of Tonkin using a high-resolution model and combination of all available data. Particular attention is thus given to model-data cross-examination using tidal gauges and coastal satellite altimetry and to model calibration derived from a set of sensitivity experiments to model parameters. The tidal energy budget of the gulf (energy flux and dissipation) is then analyzed and its resonance properties are evaluated and compared with idealized models and observations. Then, the tidal residual flow in both Eulerian and Lagrangian frameworks is evaluated. Finally, the problem of tidal frontogenesis is addressed to explain the observed summer frontal structures in chlorophyll concentrations.

1. Introduction

The Gulf of Tonkin (16°10′–21°30′N, 105°40′–110°00′E; Fig. 1) is a shallow, tropical, crescent-shape, semi-enclosed basin located in the northwest of the South China Sea (SCS; also called East Vietnam Sea), which is the biggest marginal sea in the Northwest Pacific Ocean. Bounded by China and Vietnam to the north and west, the Gulf of Tonkin is 270 km wide and about 500 km long, connecting with the South China Sea through the gulf's mouth in the south and Hainan Strait (also called Leizhou strait) in the northeast. This strait is about 20-km wide and 100-m deep between the Hainan Island and Leizhou Peninsula (mainland China). The southern Gulf of Tonkin is a NW–SE trending shallow embayment from 50 to 100 m in depth. Many rivers feed the gulf, the largest being the Red River. The Red River flows from China, where it is known as the Yuan, then through Vietnam, where it mainly collects the waters of the Da and Lo rivers before emptying into the gulf through 9 distributaries in its delta. It provides the major riverine discharge into the gulf, along with some smaller rivers along the north and west coastal area. The Red River carries annually about 82×10^6 m^3 of sediment (Duc et al., 2007) and flows into a shallow shelf sea forming a river plume deflected southward by coastal currents.

Tides in the South China Sea have been studied since the 1940s. According to Wyrtki (1961), the four most important tidal constituents (O1, K1, M2 and S2) give a relatively complete picture of the tidal pattern of the region and are sufficient for a general description. However, the co-tidal and co-range charts (tidal phases and amplitudes of the main tidal constituents) shown before the 1980s had large discrepancies over the shelf areas. Numerical model later allowed substantial improvements, first on Chinese shelf zones (Fang et al., 1999; Cai et al., 2005; Zu et al., 2008; Chen et al., 2009). Zu et al. (2008) used data assimilation of TOPEX/POSEIDON altimeter data to improve predictions. With a shallow water model at relatively coarse resolution (quarter degree), Fang et al. (1999) showed that tides in the South China Sea are essentially maintained by the energy flux of both diurnal and semidiurnal tides from the Pacific Ocean through the Luzon Strait situated between Taiwan and Luzon (Luzon is the largest island in the Philippines, located in the northernmost region of the archipelago). The major branch of energy flux is southwestward passing through the deep basin. The branch toward the Gulf of Tonkin is weak for the semidiurnal tide but rather strong for the diurnal tide. Semi-diurnal tides are generally weaker than diurnal tides in the South China Sea.

Few studies (e.g., Nguyên Ngọc Thủy, 1984; Manh and Yanagi, 2000) have focused on the Gulf of Tonkin and generally at low resolution. They show that the tidal regime of the Gulf of Tonkin is diurnal (as in the SCS), with larger amplitudes in the north at the

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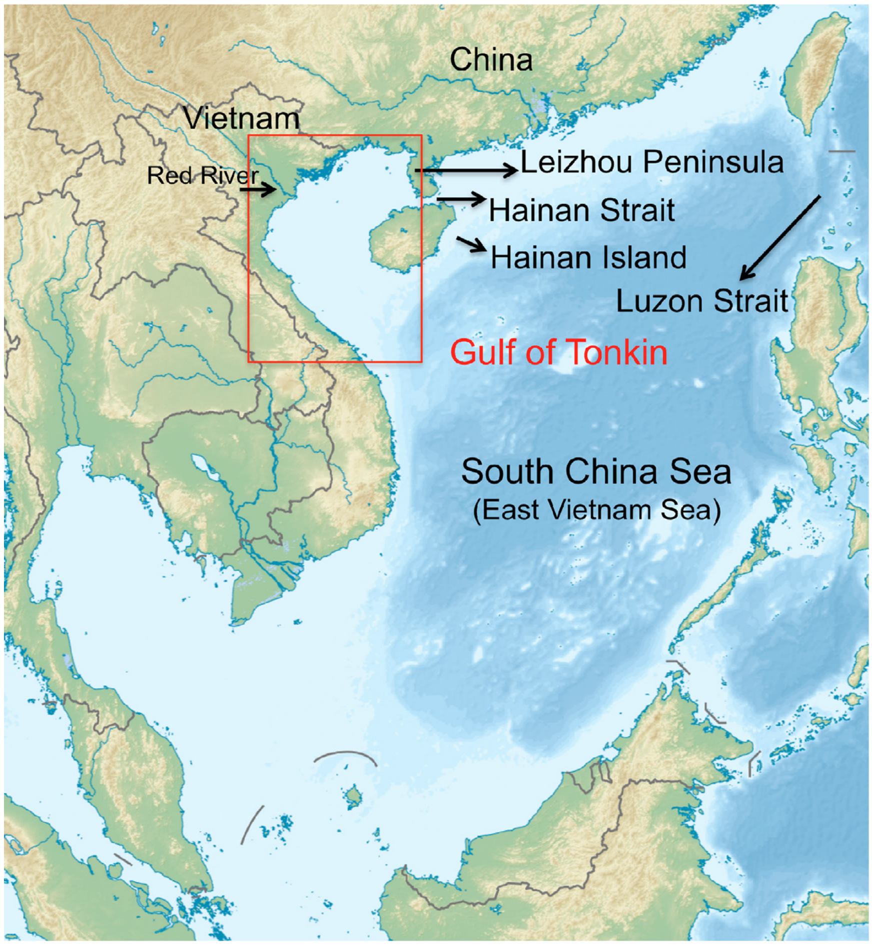

Fig. 1. Geography of the Gulf of Tonkin.

head of the gulf. Diurnal tidal regimes are commonly microtidal, but the Gulf of Tonkin is one of the few basins with a mesotidal, and locally even macrotidal diurnal regimes (van Maren et al., 2004). In open shelf areas, tidal amplification varies with the difference of squared frequencies between the tide and earth rotation (Clark and Battisti, 1981). The only possible configuration for large amplification of diurnal tides is thus coastal embayment. In such small bodies of water, the open ocean is the primary driver for tides. Their propagation is much slower as they enter shallower waters but remains influenced by earth rotation and is anticlockwise around the coasts (northern hemisphere). Amplification can occur by at least two processes. One is simply focusing: if the bay becomes progressively narrower along its length, the tide will be confined to a narrower channel as it propagates, thus concentrating its energy. The second process is resonance by constructive interference between the incoming tide and a component reflected from the coast. If the geometry of the bay is such that it takes one-quarter period for a wave to propagate its length, it will support a quarter-wavelength mode (zeroth or Helmholtz mode) at the forcing period, leading to large tides at the head of the bay. Tidal waves enter the Gulf of Tonkin from the adjacent South China Sea, and are partly reflected in the northern part of the Gulf. The geometry of the basin is believed to cause the diurnal components O1 and K1 to resonate. That would explain their pattern of amplitudes with an increase from the mouth to the head, where they reach their highest values in the whole of South China Sea (exceeding 90 cm for O1 and 80 cm for K1; Fang et al., 1999).

The Gulf of Tonkin is a zone of strong ecological, touristic and economic interest (Ha Long bay, Cat Ba island, Hai Phong harbor etc.). Improving our knowledge of its hydro-sedimentary processes (transport of suspended particles) is of great importance as we need to address major challenges, e.g., the silting up of Red River estuaries (Lefebvre et al., 2012), their contamination (Navarro et al., 2012) and the recent changes of coastline and mangrove forest coverage (Tanh et al., 2004). The scientific objective of this study is to revisit the dominant physical processes that characterize tidal dynamics in the Gulf of Tonkin using a high-resolution model and combination of all available data. Particular attention is thus given to model-data cross-examination using tidal gauges and coastal satellite altimetry and to model calibration derived from a set of sensitivity experiments to model parameters. The tidal energy budget of the gulf (energy flux and dissipation) is then analyzed and its resonance properties are evaluated using idealized models compared with a direct estimation by the numerical model. Next, the tidal residual flow in both Eulerian and Lagrangian frameworks is evaluated to assess its potential role in property transports. Finally, the problem of tidal frontogenesis and its relation to the observed summer frontal structures in chlorophyll concentrations is addressed.

2. Model setup

ROMS solves the primitive equations in an Earth-centered rotating environment, based on the Boussinesq approximation