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Numerical Study on Effects of Coastline Change on Salinity variation in the Liao River Estuary

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Abstract. A 3D numerical model is used to simulate the effect of coastline change on salinity distribution variation in the Liao River Estuary (LHE), China, consists of shallow channel and extensive tidal flat. Simulations are run with reclamation and land-ocean interaction to evaluate their effects on salinity transport for LHE. It is so evident to express the salinity diurnal varying with tide rather than the amount of runoff discharge; the LHE is always the rising tide advantage free of reclamation. To succinctly quantify the asymmetry degree of salinity distribution across the Gaizhou beach (GZB), the calculated parameter of low-salinity area is chosen. For dry seasons, such as May, the amplitude of its scale is from 209.54 km^2 reducing to 185.6 km^2. More interestingly, it demonstrates the variation shape divided into increasing at the west of GZB and decreasing in the east, varying from 7.4 to 20.9 km^2, especially the east of GZB. Despite the trend is basically consistent with flood seasons, the scale is 1.6 times higher than dry seasons. Reclamation has impact on low-salinity area variation enhanced coastal change influences on salinity distribution are less distinctive, but significant in ecological sustainability just like fishery breeding stability.

1. Introduction

Obviously, the estuary itself is the interface between extension of the basin and stretch of the ocean. The interface is a narrow zone of enhanced horizontal gradients of water properties that separates broader areas with physical and chemical attribute [1]; the most significant difference is salinity [8]. Cross-frontal differences in sea surface salinity are often limited by variable factors, behaved as complicacy and instability because of land-ocean mixing, climate, and other abrupt nature. Such the feature of salinity distribution varied faster for the runoff discharged in dry season [13]; but the mass exchange in flood season is relatively stable. Moreover, the estuary interface it also can be characterized as land-ocean interaction barrier of the river-carried sediment, nutrients, heavy mental and so on, which contributed to the ecological health [5, 12].

Recently mass and energy exchange have been become more and more sensitive to variable non-natural process developed off the coast, particularly prominent of coastline migration and topographic change due to man-made reclamation. From 1979 to 2013, the LHE has been drastically taken place coastal development including salt-development field, aquaculture, and port construction instead of natural muddy coastline [6]. By continuity the rate of coastal level decrease rising, the territory increases by 410 km^2 [7], and the length of current coastline is 298 km, which increases 63 km compared to 1979 [10]. The variation of reclamation proportion and length during recent decades in Figure 1.

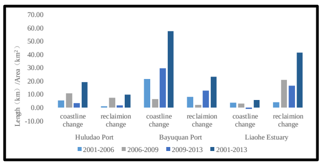

Figure 1. Coastline change in length (km) and area (km^2) in LHE. [14]

Depending on the coastline alteration in LHE, the tidal propagation will be varied and the blending with high-salinity oceanic water and lower-salinity runoff changed thereupon. Specifically, in order to better emphasize at the influence of coastline change on the low-salinity area variation, the presented study analyzes the two typical coastline respectively in 1990 and 2013. The organization of the paper is as follows. The 3D FVCOM (Finite-Volume Community Ocean Model) and varying parameters are described in Section 2. Methodology of model output analysis and model characteristics accuracy validation in Section 3. The implications of the results along with a summary and conclusions are presented in Section 4.

2. Model configuration and verification

The hydrodynamics of the LHE are simulated using a three-dimensional, free-surface primitive equations model (FVCOM) originally developed by Chen et al. [3]. The model uses unstructured triangular grids in the horizontal and σ-coordinate transformation in the vertical for a better representation of the irregular topography. This finite-volume approach makes use of the advantages of finite-element methods with geometric flexibility and finite-difference methods with simple discrete structures and computational efficiency.

2.1. General simulation description

The computational domain includes the main estuaries in the north of Liaodong Bay as shown in Figure 2. The horizontal grid spacing is ~2200 m at the open boundary (located in the ocean) and varies between 80 and 100 m in the tidal reaching channels of the estuary. The total number of new coastline horizontal elements is 10676, while it for old is 11047; the total number of grid nodes are respectively 5885 and 5722. The model utilizes 5 layers in the vertical direction. The water depth at each of the numerical elements consisting of measurement data from the latest version of the People's Liberation Army Navy Command Department of navigation (No.11500).

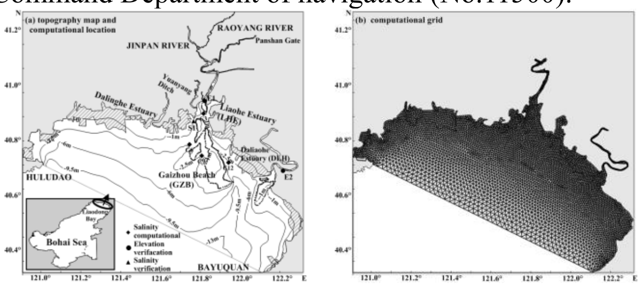

Figure 2. Schematic diagram of location and topography (a) and grid (b) in LHE.

The model is driven by the forecast elevation computed by amplitudes and phases from 4 major tidal constituents (M2, S2, O1, and K1) specified at the boundary. The water levels and current magnitudes within the domain are zero initially and the tidal forcing at the open boundary is ramped up to its actual value over two days to avoid any numerical instability. Although this estuary is primarily tidal driven, watershed and freshwater flow input is also included in the model from the gazette and monitored data. The open boundary of temperature and salinity is derived from the HYCOM data (http://hycom.org/); the salinity of the river is set to zero.

2.2. Model/measurement comparison

The numerical model output for each simulation is compared to previously acquired and published field data. Based measurements of current velocity profiles, water surface heights, and salinity were acquired from May and October cruises in 2015 along the LHE in Figure 2.

2.2.1 Tidal validation. The water elevation data is validated from a diurnal on September 31 and October 1, 2015. As shown in Figure 3, the mean absolute errors of water elevation at E1 and E2 are respectively 0.06 m and 0.07 m. To obtain a quantitative description of accuracy for the model results, a correlation type of skill score (CSS) is calculated between the measurements and simulations presented in *Table 1. The score is formulated as*

$$CSS = \frac{\sum_{t=1}^{25}\left[x(t)-\bar{x}\right]\left[y(t)-\bar{y}\right]}{\sqrt{\sum_{t=1}^{25}\left[x(t)-\bar{x}\right]^2 \sum_{t=1}^{25}\left[y(t)-\bar{y}\right]^2}} \in [-1,1] \tag{1}$$

where $x(t)$ is measured data at time index t, $y(t)$ is the model output, $\bar{x}$ and $\bar{y}$ are respectively behalf of the mean of $x(t)$ and $y(t)$,as used by *Timko et al. (2012)*. A value of $CSS = 1$ signifies model is related to the measurement by an increasing monotonic function while $CSS = 0$ signifies complete disagreement, and $CSS = -1$ signifies the model is related to the measurement by a decreasing monotonic function [2]. Overall, both the modeled water elevations agree well with the observed data, indicating that a relatively accurate hydrodynamic model results can be provided for the calculation of the salinity distribution.

Table 1. Simulation correlations skill scores (CSS) for E1 and E2predicted surface heights.

Verification position	Skill scores (CSS index)
E1	0.990
E2	0.987
S1	0.669

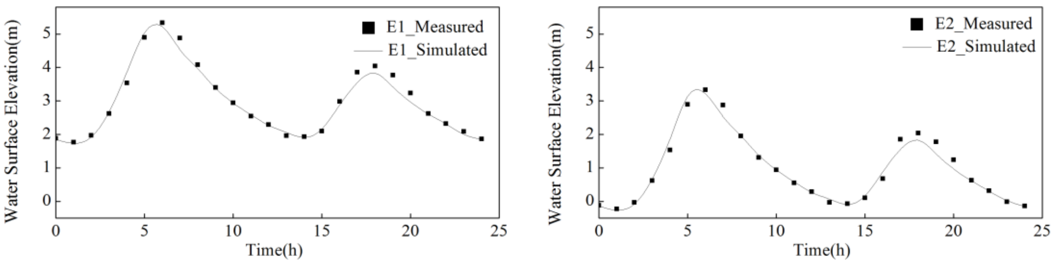

Figure 3. Comparisons between the measured and simulated surface elevations.

2.2.2 Salinity. The measured data from May cruise were taken at station S1 is in accordance with simulated seen in Figure 4, of which average error is just 1.02. Furthermore, the CSS index in Table 1 indicates the salinity computation results can be provided to reflect the variation of salinity distribution.

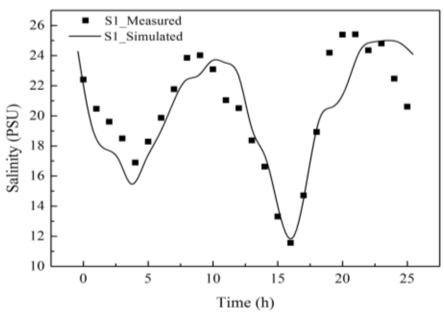

Figure 4. Comparisons between the measured and simulated salinity at station S1.

3. Results and discussions

3.1 Response of salinity variation to land-ocean interaction

The coastal scale affects the increasing or decreasing in tidal range to promote the exchange of runoff and ocean [4]. To analyze the influence of hydrodynamic force on the salinity distribution, plots of spring diurnal tide between salinity and water level from a representative dry season (May) and flood runoff (August) are shown in Figure 5. It is known that the land-ocean interaction effect of salinity diurnal variation is heavily dependent on the surface elevation in relation to rising and falling tide. The effect of the tidal wave on the salinity is the most obvious in river entrance while it wears off near the upstream. The general response of the LHE to basin runoff discharge is for the lower volume to be dominant. For C3 station, located in the mouth of LHE, the salinity is lower 4 ~ 6 units compared to other stations around the GZB. However, for the coastal reclamation it is less clear because the hydrodynamic is lower to a certain extent. To evaluate the effect of coastal change on the distortion, in terms of the salinity variation before and after reclamation at C6 and C12 stations can be see more apparent compared to others; the difference is about 2 ~ 3untis.

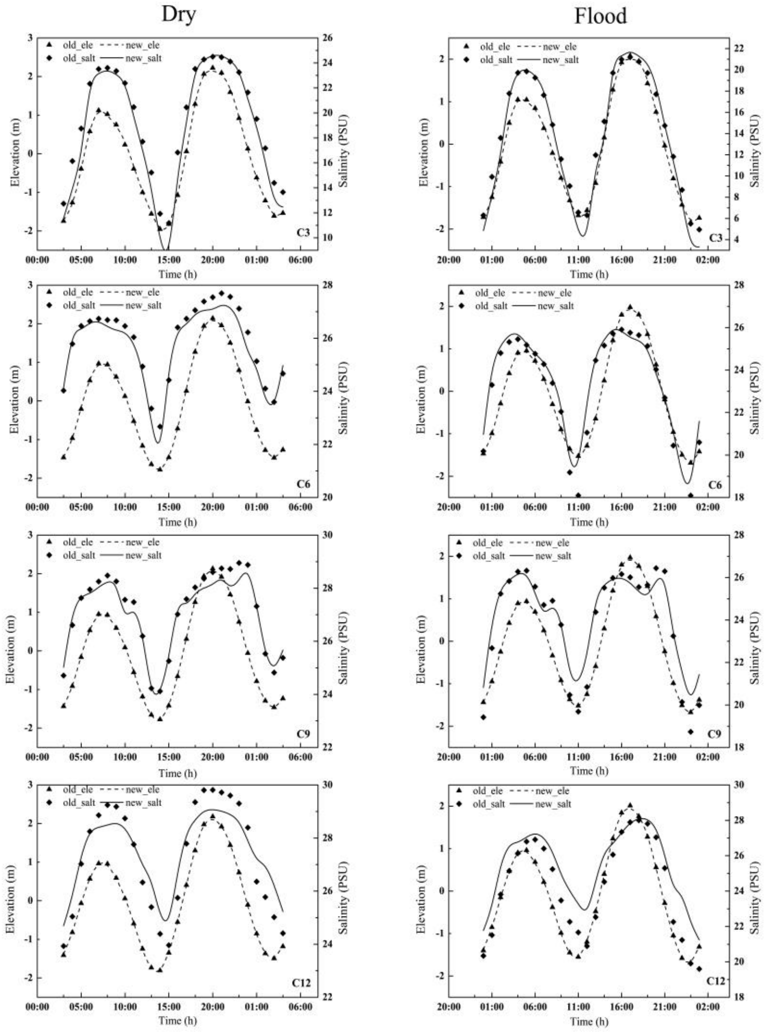

Figure 5. Diurnal water level and salinity time series effected by coastline change during dry season (left column) and flood season (right column) among the station (C3, C6, C9 and C12).

3.2 Response of low-salinity variation to reclamation

In view of horizontal scale, the low-salinity upstream correspondingly extended to the southwest off the mouth of LHE estuary whether coastal reclamation or not. It is clear from Figure 6 that the contour line performs roughly northwest-southeast tendency. Thus the salinity front prefers to being incline to the south. Furthermore, the salinity front is gradually stretching towards the inlet edge of Gaizhou beach (GZB). Notably the salinity variation is more apparent in southwest of Liao River estuary (LHE) and southeast of Daliao River estuary (DLH) resulting from terrible coastal development. Compared to old coastline, the salinity front of new is ranged from 22 to 27 instead of between 20 and 26. In addition the width of front gradient from 24 to 27 is about among 2.6～4.3 km, which rebound 0.3～0.6 km within old coastline.

The quantative description of the salinity variation before and after reclamation is supported by low-salinity proportion calculations presented in Figure 7. Although the runoff discharge is much more at flood season leading to salinity gradient increasing, the core salinity value of estuary interface is still below 27 [11]. Thus the 27 isoline is provided by the oceanic boundary of low-salinity and the inner is limited by 0m isobath.

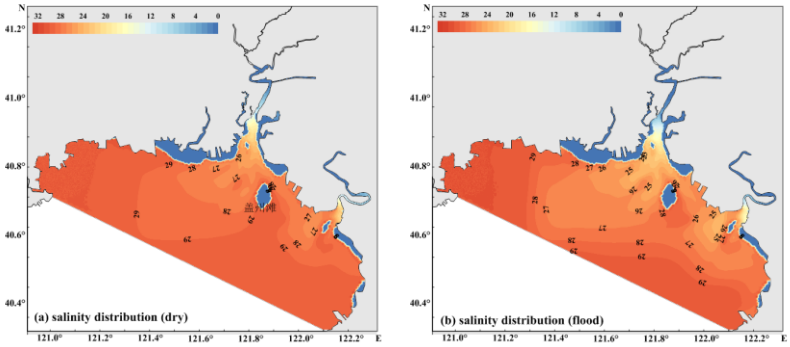

Figure 6. Surface salinity distribution at dry (a) and flood (b) season after reclamation.

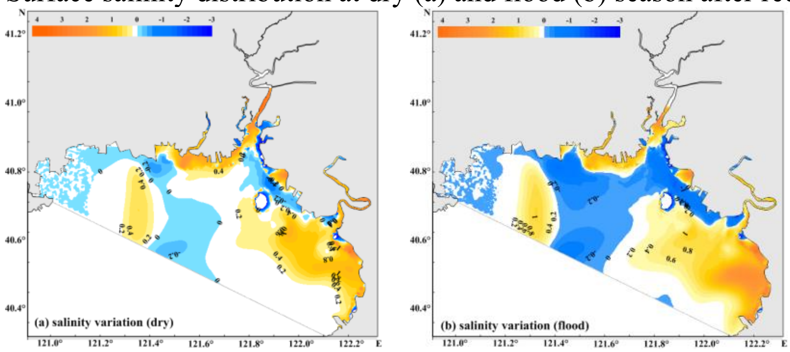

Figure 7. Salinity variation at dry (a) and flood (b)season due to reclamation (old minus new).

As shown in Figure 7 the hysteresis effect from the degree of discharge volume is more evident on low-salinity square, particularly at flood seasons. Similarly, the low-salinity boundary mainly concentrates on the tidal flat between LHE and GZB as well as the mouth of DLH; the tendency of low-salinity extends out along the west of GZB. On the contrary, the scope of dispersion range broadening towards the open sea is less than before. It can be referred to the mass exchange between estuaries is that the mass transport weights in DLH instead of LHE. For dry seasons, the amplitude of its scale is from 209.54 km^2 reducing to 185.6 km^2. More interestingly, it demonstrates the variation shape divided into increasing at the west of GZB and decreasing in the east. The actual change is from 7.4 to 20.9 km^2, especially the east of GZB. Despite the trend is basically consistent with flood seasons, the scale is 1.6 times higher than dry seasons.

Better yet, the eastern part is narrow down low-salinity in the LHE, which causing the water quality deteriorating more seriously. Besides, biological reproduction should ensure adequate low-salinity habitat. But it is far less than standard level after shoreline changes; therefore, it is emergent that the rational allocation of the upper runoff from Liao River guaranteeing shrimp and crabs reproduced to maintain ecosystem health.

4. Summary and conclusions

In this study a 3D numerical model was used to simulate the salinity variation due to reclamation of the LHE, characterized by land-ocean interaction. Such variation is known to be caused primarily by the hydrodynamic change. A summary of the results is presented below: this study provides specific links between coastal reclamation and resultant land-ocean balance. It is speculated that such relationships can be referred to the transport and exchange of sediment, nutrient, and others. The salinity distribution asymmetry is in accordance with the sediment flushing process where eroding in east and depositing in west. Meanwhile, the presented work showcasing smaller salinity field served as the mass transport is in favor of Daliao River estuary towards Liao River estuary.

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