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IMPACTS OF POTENTIAL FUTURE SEA LEVEL RISE ON THE NORTH BRANCH OF THE CHANGJIANG RIVER ESTUARY: QUANTIFYING THE SALINE WATER INTRUSION IN THE DRY SEASON

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ABSTRACT: The phenomenon of global sea level rise (SLR) is undeniable; the 4th IPCC report summaries that the average rise rate of global is 1.8 mm/y since 1961. It is widely taken for granted that SLR will have a severe impact on saline water intrusion processes in estuarine areas. In this paper, by using a two-dimensional hydrodynamic model (MIKE21) and SLR scenarios of 0.5m, 1m and 2m, the impacts of potential future SLR on the North Branch of the Changjiang River Estuary are evaluated by quantifying salinity changes in the dry season. The field data of tidal levels, flow velocities and salinities are employed to validate the model, and the computed results match the observed values well, which indicates that the validated model can provide reliable performances in reproducing the hydrodynamic and saline water intrusion processes in the Changjiang River Estuary, then this validated numerical model was run with present sea level as well as 0.5m, 1m and 2 m SLR scenarios in the dry season respectively. The computations show that: i)the amplification of tidal levels in the upper reach of the South Branch is greater than that in the upper reach of the North Branch with SLR; ii)the ebb and flood discharges in the upper cross-section of the North Branch both respond to SLR with a significant increase trend, with the ebb flow split ratio of the North Branch increasing from 3.8% to 10.3% in 2m SLR scenario; iii)the salinity in the North Branch presents a decrease trend with SLR, and the decreasing extent in the upper reach is 11.4%-33.4%, which is obvious greater than that in the middle and lower reaches. Consequently, it can be concluded that SLR enhances the ebb hydrodynamics and alleviates the saline water intrusion in the North Branch.

Keywords: SLR, saline water intrusion, hydrodynamic model, North Branch, Changjiang River Estuary.

INTRODUCTION

The North Branch is the first tidal inlet of the three-bifurcation Changjiang River Estuary (Fig.1). It was once the main channel of runoff transforming into sea. After the mid-18th century, the main channel of the Changjiang River Estuary turned to the South Branch, meanwhile the North Branch became branch channel. In 1915, the runoff of the North Branch accounted 25% of the total runoff in the Changjiang River Estuary. Since 1950s, the flow split ratio of the North Branch became smaller and smaller, only 1.4% in 2001, and the saline water of the North Branch spilling into the South Branch often happens.

There are many researches focusing on saline water spilling over from the North Branch. During the spring tide, the intensity of saline water sailing upstream increases and it aggravates saline water spilling into the South Branch. The spilling over saline water could spread to as far as the diversion of the North Channel and the South Channel (Cao et al., 2012.). Water quality in Qincaosha reservoir and Dongfengxisha reservoir are both influenced by saline water spilling over from the North Branch (Mao et al., 2001; Tang et al., 2012.). The formation of saline water spilling over has a close relation to the amount of upstream runoff (Wu et al., 2006; Xiao et al., 2000.). For transport mechanism of the saline water spilling over from the North Branch, the Lagrange residual and the tidal pump are found as the main dynamic factors (Wu et al., 2007.). In order to protect the water source in the South Branch, the Changjiang Institute of Survey, Planning, Design and Research designed five narrowing schemes in the North Branch, and Gu et al. (2009) deemed that the middle narrowing scheme without plugging the right branch of Xinlongsha is the optimum one for reducing the saline water spilling from the North Branch to the South Branch.

The 4th IPCC report summaries that the average rise rate of global is 1.8 mm/y since 1961 (IPCC, 2007). The impacts of SLR attract many researchers’ attentions, especially focusing on the salinity change caused by SLR in estuaries. Bhuiyan et al. (2012) assessed the

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saline water intrusion in the Gorai river network of Bangladesh with 59cm SLR, and the results indicated that SLR of 59 cm produced a change of 0.9‰ at a distance of 80 km upstream of the river mouth; Alyssa et al. (2005) indicated that the saline water interface moves inland about 1.5 km at the base of the surficial aquifer system after 160 years with 48.26cm SLR; Karen et al. (2010) used a three dimensional Hydrodynamic Eutrophication Model (HEM-3D) as well as SLR scenarios of 30 cm, 50 cm and100 cm, and evaluated the salinity change with respect to the magnitude of SLR on two tributaries of Chesapeake Bay, the James and Chickahominy Rivers, and the model results indicated that salinity increases in the entire river with SLR and the salinity increase in a dry year is greater than that in a typical year; Mohsen et al. (1999) based on a 2D-FED model to investigate the effect of likely climate change on saline water intrusion in Nile Delta aquifer and Bay of Bengal, and the results indicated that a 50 cm rise in the Mediterranean sea level would cause intrusion of 9.0 km in the Nile Delta aquifer, while the same rise in water level in the Bay of Bengal would cause an additional intrusion of 0.4 km.

In China, there are only a few studies on the salinity changes regarding SLR, and most of these focus on the Pearl River Estuary. In Modaomen, the salty boundary shift distance is roughly 6.8 km for 10 cm SLR (He et al., 2012). During a high tide of the dry season, the maximum distance of saline water intrusion increases 4km, 3km and 5km in Humen, Modaomen and Huangmaohai respectively (Li et al., 2000). However, there is little information about the saline water intrusion in the North Branch of the Changjiang River Estuary due to SLR.

Fig.1 Layout of the Changjiang River Estuary

This paper applies MIKE21 model to set up a depth-averaged hydrodynamic and salinity transport model in the Changjiang River Estuary in order to simulate the tidal current and salinity processes. In the light of the future SLR scenarios summarized by Nicholls et al. (2011), and scenarios of 0.5m, 1m and 2 m SLR in a general dry season are simulated with the calibrated model. We focus on the analysis of model results on February 24 in the general dry season, and the changes of hydrodynamics and salinity caused by SLR in the North Branch are studied.

HYDRODYNAMIC MODELING OF THE CHANGJIANG RIVER ESTUARY

MIKE21 Flow Model FM is based on a flexible unstructured mesh approach and it has been developed for applications within oceanographic, coastal and estuarine environments. The system is based on the numerical solution of the two dimensional incompressible Reynolds averaged Navier-Stokes equations in the assumptions of Boussinesq and hydrostatic pressure. The spatial discretization of the primitive equations is performed using a element-centred finite volume method. The spatial domain is discretized by subdivision of the continuum into non-overlapping elements. In the 2D model the elements can be triangles or quadrilateral elements (DHI, 2011).

Grid and domain of hydrodynamic model

The computational area is about 210km in east-west direction from Jiangyin to the -40m hydroisohypse and 280km in south-north direction from Hangzhou Bay to Lianxing Harbor. The SMS (Surface Water Model System) software is used to create the unstructured triangular grids, with 13613 nodes and 25420 elements (Fig. 2), ranging from 140 m to 13750m.

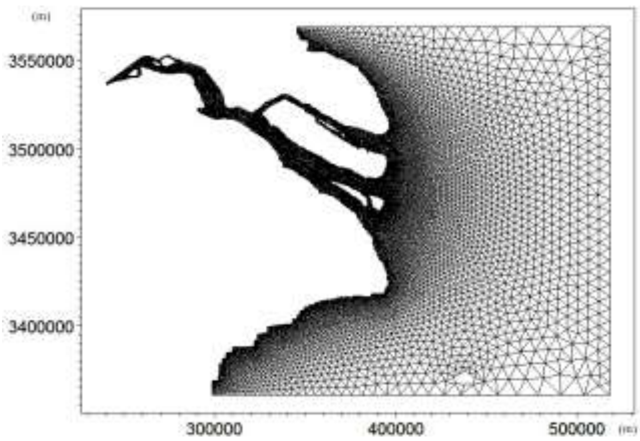


Fig.2 Grids of computational area

Boundary conditions and parameter settings

The upstream boundary employs the monthly mean runoff at Jiangyin, while the open sea boundary adopts tidal levels derived from 8 tidal constituents, i.e. M_2, K_2, S_2, N_2, K_1, P_1, O_1, Q_1. The time steps self-regulated at the range from 0.01s to 30s. The initial tidal levels and flow velocity are defined as 2 m and 0 m/s respectively, and the roughness coefficient adopts in a range of 74 to 90.

The salinity at the upstream open boundary is set to zero, while at the sea open boundary it was interpolated based on the measured data, 31 ‰～35 ‰ from west to east in the north boundary, 35 ‰～36 ‰ from north to south in the east boundary, 36 ‰～15 ‰ from east to west in the south boundary (Sun et al., 2008). The initial salinity is adopted as 5 ‰. The salinity diffusion coefficient is 300 m^2/s.

Model verification

The tidal levels, flow velocities and salinities in this model have been validated with the observed data from 6:00 on May 5 to 5:00 on May 6, 2004 (period of spring tide, observed data from Sun, 2009). The comparisons (Fig.3, Fig.4 and Fig.5) show that the computed results match well with the measured results so that the model can be applied to simulate hydrodynamics and saline water intrusion processes in the North Branch caused by SLR.

Fig.3 Schematic diagram of survey stations, represented stations and cross-sections

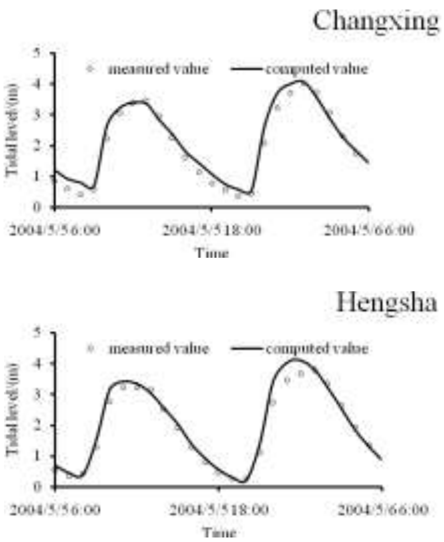


Fig. 4 Comparisons of measured and computed tidal levels

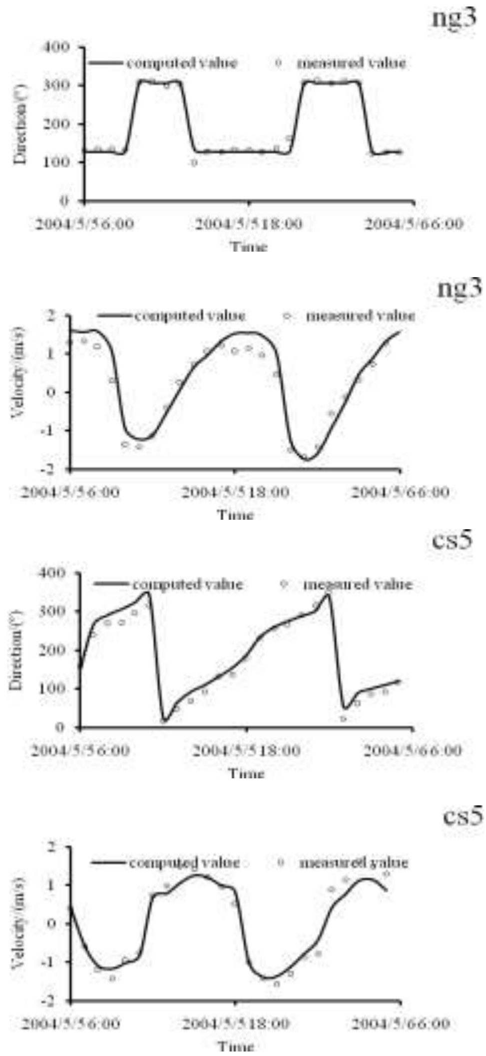
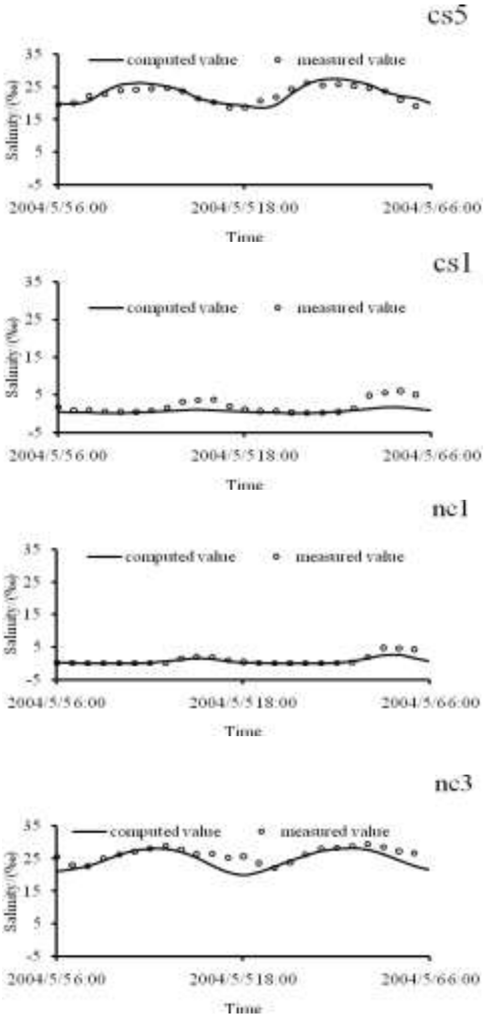


Fig.5 Comparisons of measured and computed flow velocities

CHANGES OF TIDAL LEVELS DUE TO SLR

The most direct impact of SLR on estuaries is changes of tidal levels. Comparisons of tidal levels in base scenario and each SLR scenario at stations nb1 and sb6 are showed in Fig.7. Stations nb1 and sb6 locate at the North Branch and the South Branch respectively (in the vicinity of bifurcation of the North Branch and the South Branch, and positions of stations nb1 and sb6 shown in Fig.3). It can be seen that with SLR, the tidal levels increase significantly; the low tidal levels arrive early during ebb period, but the high tidal levels arrive without changes, so the period of flood is lengthen and the period of ebb is shorten. Table 1 shows amplifications of mean tidal level in each SLR scenario at stations nb1and sb6. Mean tidal level at nb1 increases by 19.4%, 41.4%, and 85.5% in 0.5m, 1m and 2m SLR scenarios, while at sb6 increases by 21.6%, 43.5% and 87.6% respectively. Mean tidal level shows more increase in the South Branch than in the North Branch. Under the impact of SLR, the South Branch attains stronger flood energy. It would give rise to hammed water in the upper reach of the South Branch and



increase of runoff in the North Branch.

Fig.6 Comparisons of measured and computed salinities

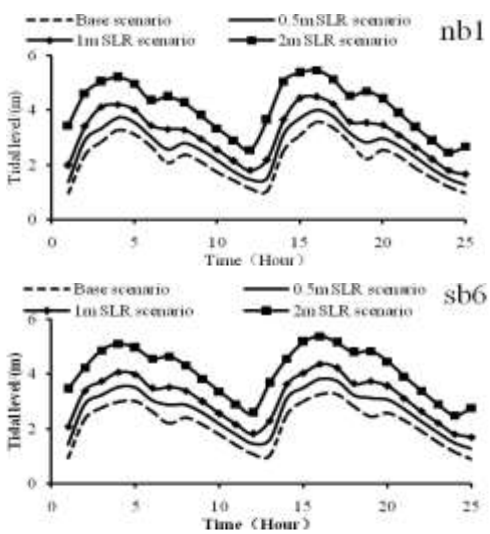


Fig.7 Comparisons of tidal levels in base scenario and each SLR scenario at stations nb1 (located at the North Branch) and sb6 (located at the South Branch) in the dry season

Table 1 Amplifications of mean tidal level in each SLR scenario at stations nb1 (located at the North Branch) and sb6 (located at the South Branch) in the dry season

SLR scenario / Station	0.5m	1m	2m
nb1	19.4%	41.4%	85.5%
sb6	21.6%	43.5%	87.6%

CHANGES OF DISCHARGE IN THE NORTH BRANCH DUE TO SLR

There is no doubt that SLR will trigger the changes of discharge. Comparisons of discharge in base scenario and each SLR scenario in the North Branch and the South Branch are presented in Fig.8 (A-NB and B-SB indicate the cross-sections of the North Branch and the South Branch respectively, and positions of cross-sections shown in Fig.3). The ebb and flood discharges in the North Branch both increase substantially. However, flood discharge increases and ebb discharge decreases in the South Branch. Table 2 indicates the comparisons of flow split ratio in base and each SLR scenario in the North Branch and the South Branch. it can be seen that with SLR the ebb flow split ratio of the North Branch increases to 4.4%, 5.2% and 10.3% from 3.8% in 0.5m, 1m and 2m SLR scenarios respectively in the dry season, and the ebb flow split ratio of the South Branch decreases gradually. It can be concluded that the North Branch obtains more ebb flow, especially the ebb flow split ratio of the North Branch up to almost 10% in 2m SLR scenario, which is beneficial for development of the North Branch.

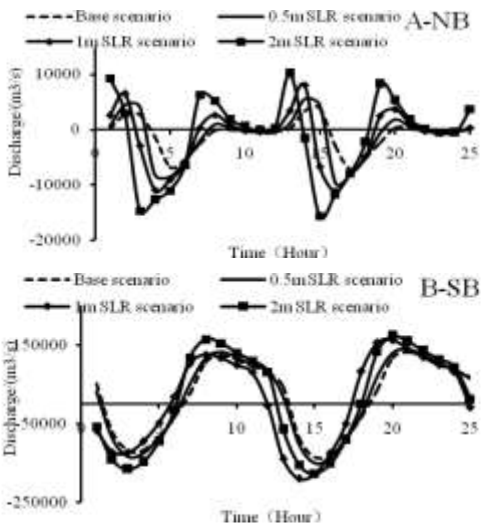


Fig.8 Comparisons of discharge in base scenario and each SLR scenario in the North Branch and the South Branch in the dry season (positive indicates ebb, and negative indicates flood)

Table 2 Comparisons of ebb flow split ratio in base scenario and each SLR scenario in the North Branch and the South Branch in the dry season

Scenario / Location	Base	0.5m	1m	2m
North Branch	3.8%	4.4%	5.2%	10.3%
South Branch	96.2%	95.6%	94.8%	89.7%

CHANGES OF SALINITY IN THE NORTH BRANCH DUE TO SLR

It's unequivocal that SLR will lead to the increases of salinity in estuaries without bifurcation. However, there is a contrary phenomenon for the North Branch which is the first branch of the three-bifurcation Changjiang River Estuary. Fig.9 indicates the time history of salinity at represented stations of the North Branch in base and SLR scenarios (positions of represented stations shown in Fig.3). The mean salinity of the estuaries is a product of two competing processes: freshwater flux from rivers that freshens the estuarine salinity and saline water from oceans during the flood period that raises the salinity of estuaries. Under the impact of SLR, salinity of the entire North Branch presents a deceasing trend. The time history of salinity at stations nb7 and nb17 hardly appear the cycle characteristics of tidal levels in base and each SLR scenario. The salinity decreases the most significantly at station nb3 with SLR influence, and the time history of salinity is affected by tidal periodicity. This phenomenon is due to that the increased runoff discharge and the flood flow of the South Branch flowing into the upper reach of the North Branch due to SLR. Table 3 shows the decreasing percentage of mean salinity in each SLR scenario compared with the base scenario at stations nb3, nb7, nb17 and nb29 in the North Branch. The mean salinity decreases in a range of 11.4-33.4%, 4.0-14.5%, 3.7%-13.1% and 3.4-15% at stations nb3, nb7, nb17 and nb29 respectively in 0.5-2m SLR scenarios. The decreasing extent in the upper reach is obvious greater than that in the middle and lower reaches.

Table 3 Decreasing percentage of mean salinity in each SLR scenario compared with the base scenario at stations nb3, nb7, nb17 and nb29 in the North Branch

SLR scenario / Station	0.5m	1m	2m
nb1	11.4%	21.5%	34.4%
nb7	4.0%	7.8%	14.5%
nb17	3.7%	7.4%	13.1%
nb29	3.4%	7.4%	15%

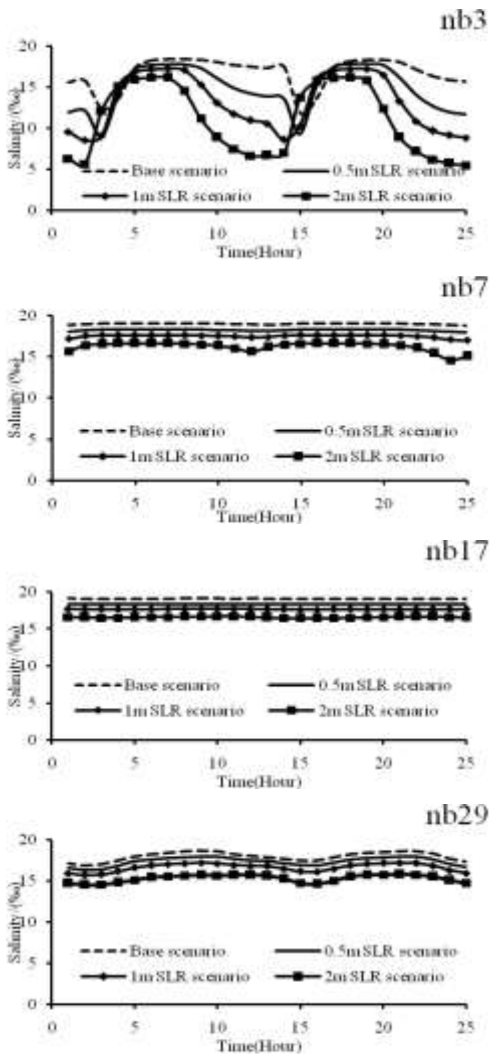


Fig.9 Time history of salinity at represented stations of the North Branch in base and SLR scenarios

CONCLUSIONS

A series of numerical studies were conducted to quantify the hydrodynamic and saline water intrusion processes in the North Branch. The model results demonstrate that SLR strengthens the flood flow in the upper reach of the North Branch and the South Branch with the tidal levels increasing by 19.4-85.5% and 21.6-87.5% respectively in 0.5-2 m SLR scenarios in the dry season. Amplifications of mean tidal level in the South Branch are greater than those in the North Branch due to SLR, and it would give rise to hammed water in the upper reach of the South Branch. Ebb flow split ratio of the North Branch increases from 3.8% to 10.3% in 2m SLR scenario. The ebb flow in the upper reach of the North Branch is strengthened while that in the upper reach of the South Branch is weakened with SLR. There is an evident decrease of salinity in the North Branch due to SLR, and the salinity in the upper reach of the North Branch is affected severely by the runoff and the flood tidal from the South Branch. The decreasing extent of salinity in the upper reach of the North Branch reaches to 34.4% in 2m SLR scenario, which is greater than that in the middle and lower reaches. In general, SLR enhances the ebb hydrodynamics and alleviates the saline water intrusion in the North Branch.

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