Characteristics of tidal waves in the eastern Jiangsu coast and Changjiang Estuary

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KEYWORD: tide type; semidiurnal constituents; diurnal constituents; amphidromic point

ABSTRACT: With the coastal development of Jiangsu Province raising to the national strategy, the research on hydrodynamic environments in Jiangsu coast and the Changjiang Estuary has been a focus. Through studying and analyzing on characteristics of tidal waves, it found that the dominant tidal type in Jiangsu coast and the Changjiang Estuary is semidiurnal tide, with local regular and irregular diurnal tide in the northeastern region of the abandoned Yellow River Estuary. Meanwhile, the semidiurnal constituents (M_2) and diurnal constituents (K_1) in Jiangsu coast both have their corresponding amphidromic points with different positions and cotidal charts. In addition, by comparing the positions of the amphidromic points with former researches, it shows that the positions of the semidiurnal and diurnal constituents have the trend of moving northeastward of Jiangsu coast.

INTRODUCTION

The Jiangsu coast connects directly with the Changjiang Estuary in Qidong. They locate at the west part of the Yellow Sea and East China Sea, and constitute the entire Changjiang delta that being famous for its abundant tidal flat resource and the specially submerged radial sand ridges (figure.1).

However, due to poor land resource, the society and economy of the Jiangsu coastal cities were in long-term slow development patterns in past decades. Until early 21th century, with the exploitation of Jiangsu coast rising to the national strategy, the utilization and exploitation of tidal flat and navigation channel resources are more and more concerned. The Jiangsu Province government even thereby put forward a medium term and long term planning for large scale reclamation of tidal flat along the Jiangsu coast, which have became a great stimulation for development of coastal cities in latest decade (Xiong, 2005).

Nevertheless, under combined functions of tidal waves from the Yellow Sea and the East China Sea, tidal waves in the eastern coast of Jiangsu and Changjiang Estuary show distinguished mobile tidal wave features, which are well known for radial tidal current and gigantic tidal range. Consequently, the under water topography around the Jiangsu coast and the Changjiang Estuary are so complex and difficult to reveal their historical and modern evolution patterns, which may greatly decrease difficulties on exploitation of tidal flat.

According to geomorphology measurements and relative studies in past decades, it shows that there are about 13.3 hectare submerged sand ridges and large amount of tidal creeks and channels, which crisscross together(Zhang, 2003; Hou, 2006; Ren, 1986) with the center at Qianggang. Complicated topography further induces fragile ecology environment that is easily damaged by coastal disasters as typhoons, storm surges and huge waves.

At present, it is therefore greatly necessary to reveal tidal waves characteristics in the eastern Jiangsu coast and the Changjiang Estuary, which can greatly contribute to exploitation and utilization of the Jiangsu coast.

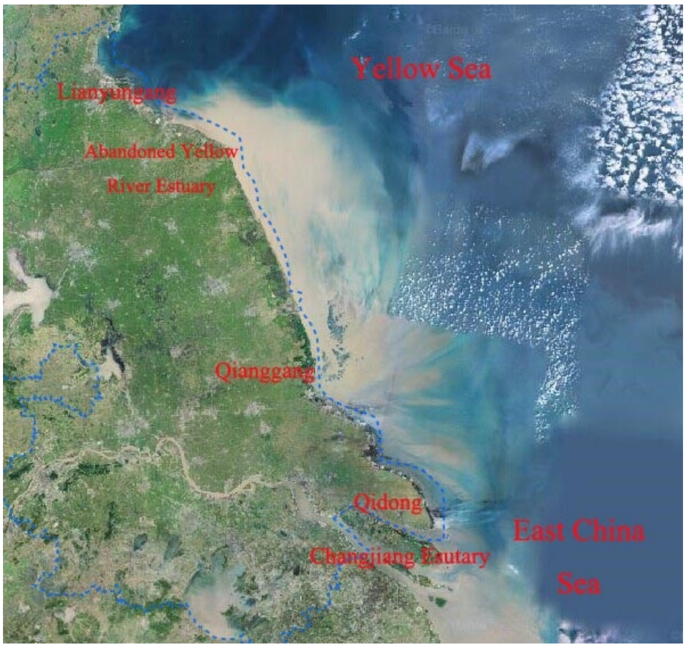


Figure.1 Jiangsu coast and numerical model domain

TidAL wave simulations

Shallow water equations

Tidal waves were simulated by the MIKE21 model. The relevant two dimensional shallow water equations are given as,

$$\frac{\partial h}{\partial t}+\frac{\partial h\bar{u}}{\partial x}+\frac{\partial h\bar{v}}{\partial y}=0 \tag{1}$$

$$\begin{aligned}&\frac{\partial h\bar{u}}{\partial t}+\frac{\partial h\bar{u}^2}{\partial x}+\frac{\partial h\bar{u}\bar{v}}{\partial y}=\\&f\bar{v}h-gh\frac{\partial h}{\partial x}+\frac{t_{sx}}{r_0}-\frac{t_{bx}}{r_0}+\frac{\partial}{\partial x}\left(hT_{xx}\right)+\frac{\partial}{\partial y}\left(hT_{xy}\right)\end{aligned} \tag{2}$$

$$\begin{aligned}&\frac{\partial h\bar{v}}{\partial t}+\frac{\partial h\bar{v}^2}{\partial y}+\frac{\partial h\bar{u}\bar{v}}{\partial x}=\\&f\bar{v}h-gh\frac{\partial h}{\partial y}+\frac{t_{sy}}{r_0}-\frac{t_{by}}{r_0}+\frac{\partial}{\partial x}\left(hT_{xy}\right)+\frac{\partial}{\partial y}\left(hT_{yy}\right)\end{aligned} \tag{3}$$

Where the t is time; h is water level; h is water depth; $\bar{u}$ and $\bar{v}$ are velocities in x and y direction respectively; t_{sx} and t_{sy} are respectively shear stress at water surface in x and y direction; t_{bx} and t_{by} are respectively shear stress at water column bottom layer in x and y direction; f is the Coriolis coefficient; T_{xx}, T_{xy}, T_{yx} and T_{yy} are horizontal viscosity terms respectively.

The finite volume method is used to discrete and solve the shallow water equations, considering moving boundary impacts in numerical simulation of tidal flat submersion process.

Model domain and verification

The model domain covered the Jiangsu coast and Changjiang Estuary with 30°54′N-35°36′N in north-south direction and 119°13′E-123°19′E in east-west direction (figure.1).

Hydrodynamic data in Dec. 2006 covering tide level series and tide current series were compiled and utilized to verify the hydrodynamics numerical model. Figure.2 gives out a part of verification results.

As figure.2 shown, the simulated values and measured results are consistent well, which declare the accuracy of the numerical model in tidal waves simulation.

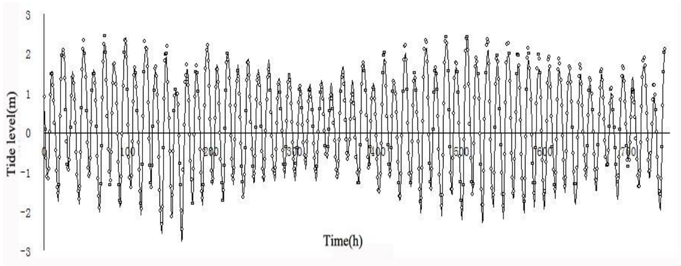


Figure.2a Verification of tide level series at Dafeng station

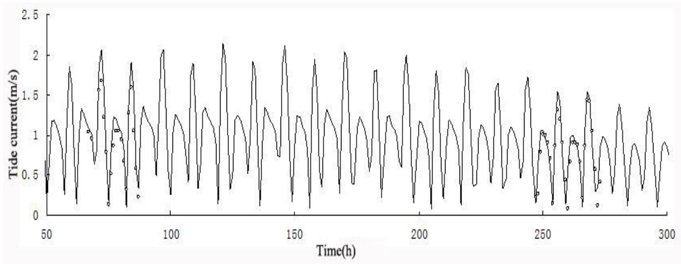


Figure.2b Verification of tide current series at Xiyang channel

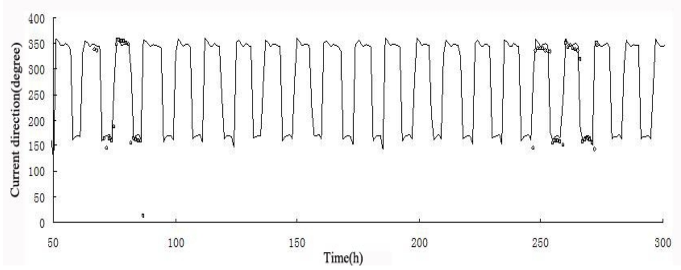


Figure.2c Verification of tide current direction series at Xiyang channel

characteristics of tidal constituent

Tide types

Tide type is commonly determined by amplitude ratio of semidiurnal constituent and diurnal constituent, which is always defined as,

$$A = (H_{K1} + H_{O1}) / H_{M2} \tag{4}$$

Where the A is usually named tide type number, determining the tide type of water area; H_{K1}, H_{O1}, H_{M2} are respectively the amplitude of K_1, O_1, M_2 tide constituent.

While the A is equal to or less than 0.5, the relevant tide type belongs to semidiurnal tide, and A is bigger than 4.0, the tide type belongs to diurnal tide, then others belongs to compound tide.

According to the simulation results, the tide type number (A) are calculated, and then the tide type distribution in the eastern Jiangsu coast and the Changjiang Esutary is shown in figure.3.

As figure.3 shown, tide type of eastern Jiangsu coast is relatively simple. Major part of sea area belongs to semidiurnal tide, and there is only a limited range of diurnal tide lying in the east of Lianyungang, which is surrounded by compound tide area. Similarly, tide type in the east of the Changjiang Estuary is also unitary and dominated by semidiurnal tide, which is actually dominated by progress tidal waves from the East China Sea, being the same with the southern Jiangsu coast.

Semidiurnal and diurnal constituents

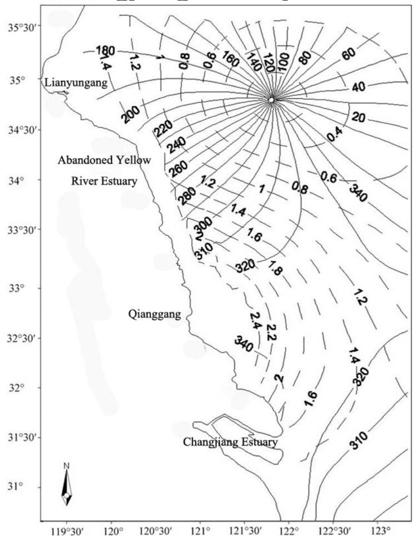
To reveal the tidal components, figure.3 gives out cotidal chart of semidiurnal constituent (M_2) and diurnal constituent (K_1).

As figure.4 shown, the semidiurnal constituent of M_2 in the eastern Jiangsu coast is a distinguished rotated tide system, with the amphidromic point (34°45′N, 121°50′E) in the east of the abandoned Yellow River Estuary. Nevertheless, it presents obviously progressive tidal wave characteristics in the southeast of the radial sand ridges and east of the Changjiang Estuary. The rotated tidal wave from the south Yellow Sea and the progressive tidal wave from the East China Sea converge in front of the Qianggang, locates at the center of the Jiangsu coast. They form the modern distribution patterns of M_2 constituent in Jiangsu coast and Changjiang Estuary.

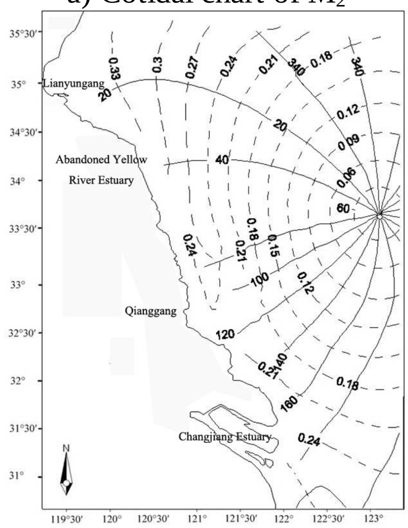
Meanwhile, the tidal ranges near the amphidromic point are smallest, but gradually increase with distance departing from the amphidromic point. The largest tidal ranges approaching the amplitude of 2.4m emerge near the Qianggang, where is the convergence area of the rotated tidal waves from the Yellow Sea and progressive tidal waves from the East China Sea. Moreover, the concurrent line and iso-amplitude line in font of the Qianggang are no longer perpendicular to each other, but present skew and even consistent. And the concurrent line further present concentric circle patterns with the centre at Qianggang, which may be induced by radial sand ridges in this area.

In addition, the distribution characteristics of diurnal constituent (K_1) presents similar features with the M_2 constituent, but with distinguished differences in the tide period and amphidromic point station. The tide period of K_1 constituent is about 2 times of M_2 constituent. And the amphidromic point station of K_1 constituent is relatively at the south-east of the M_2 amphidromic point. Meanwhile, there are no obvious distribution patterns for iso-amplitude line of K_1 in front of the Qianggang, differing from the distribution patterns of M_2, which indicates that the semidiurnal constituent would be more sensitive to underwater topography than diurnal constituent. Further, being consistent with patterns of semidiurnal constituent dominating the Jiangsu coast, the amplitude of K_1 constituent is distinctly smaller than that of M_2, with the largest amplitude (0.33m) outside Liangyungang sea area.

Similarly, due to distance apart from the amphidromic points being different, the cotidal chart of M_2 and K_1 is different in the east of the Changjiang Estuary.



a) Cotidal chart of M_2



b) Cotidal chart of K_1

Figure.4 Cotidal chart of tidal constituents. The solid lines represent the concurrent line with unit of '°' and the dashed lines represent the iso-amplitude line with unit of 'm'.

Amphidromic point stations

The amphidromic point is one of tidal wave characteristics, which is always formed by superposition of incident wave and reflected wave. Actually, its formation also impacted by combined function of land boundary feature, incident and reflected wave intensity, submerged topography, coriolis force and some other factors. In result, the amphidromic point would accordingly present obviously difference due to various external circumstances.

Table.1 gives out stations of amphidromic points of M_2 and K_1 constituents put forward by this paper, and also others stations of amphidromic points proposed by former scholars.

The table.1 indicates that the amphidromic points of semidiurnal and diurnal constituents are in continuously variation in latest 30 years, which may be influenced by various factors such as basic data, simulation techniques and so on. However, it can be further found that the stations of amphidromic points of M_2 are in similar longitudes but various latitudes, dissimilarly that the longitudes and latitudes of amphidromic points of K_1 are all in different.

Meanwhile, stations of amphidromic points varied in last decades, but there is a slight northward deviation in general. Through analysis, these evolutions may be induced by continuous adjustment of land feature and underwater topography in past decades, which are caused by continuous and large scale reclamations along the eastern Jiangsu coast. Moreover, as continuously strengthening of artificial activities in the coast nowadays, it also can be further proposed that the mordern evolution tendency of the amphidromic points would illustrates the feature trend of northward deviation.

Table.1 Amphidromic points of M_2 and K_1

Tidal constituents	Scholars	Latitude longitude
M_2	Sheng(1980)	34°35′ N 121°12′ E
	Sheng(1984)	34°40′ N 122°30′ E
	Zhang(1996)	34°36′ N 121°24′ E
	Zhang (2005)	34°34′ N 121°26′ E
	Qu(2008)	34°35′ N 121°20′ E
	Zhuang(2009)	34°37′ N 121°08′ E
	This paper	34°45′ N 121°50′ E
K_1	Sheng(1980)	34°30′ N 122°10′ E
	Zhang(2005)	34°07′ N 121°53′ E
	Zhuang(2009)	34°00′ N 122°20′ E
	This paper	33°40′ N 123°05′ E

Conclusions

At present, there are important meanings to reveal the modern hydrodynamic environment around the Jiangsu coast and the Changjiang Esutary for exploitation and utilization of tidal flat in Jiangsu coast. Based on the field measurements and numerical simulation, the tidal constituent systems in Jiangsu coast and Changjiang Estuary are revealed and analyzed.

(1) The hydrodynamics around Jiangsu coast and the Changjiang Estuary is dominated by semidiurnal tide, with limited diurnal tide area in the east of Liangyungang.

(2) The cotidal chart of M_2 is dissimilar with that of K_1. Wherein the tide period of K_1 is 2 times of M_2, but the amplitude is contrary. The largest and smallest amplitude emerge respectively in front of Qianggang and around the amphidromic points.

(3) There are amphidromic point of M_2 and K_1 constituents in the eastern abandoned Yellow River Estuary, wherein the amphidromic point of K_1 constituent is in slight north-east-ward deviation from that of M_2. Due to coast line and underwater topography evolution induced by artificial activities, the modern amphidromic points of semidiurnal and diurnal constituents present slight north-east-ward deviation tendency.

Acknowledgements

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REFERENCES

[1] Fang G.H. 1986. Analysis and prediction of tide and tide current. *Beijin, China: Ocean Press.* (in Chinese)
[2] Hou, Q.Z., Xu, M., Lu, P.D. 2006. Channel-ridge system of southern Radiate Sand Ridges and stability of Xitaiyangsha. *Marine sciences* 30(6): 16-22. (in Chinese)
[3] Qu D.P. 2008. Princeton ocean model and the analysis of the numerical simulations of tide and tidal current in the Bohai Sea, Yellow Sea and East China Sea. *The first institute of oceanography, soa, Qingdao, China.* (in Chinese)
[4] Ren M.E. 1986. Coastal zone and tidal flat resources investigation in Jiangsu province. *Beijing, China: Ocean Press.* (in Chinese)
[5] Shen Y.J. 1980. Numerical computation of tides in the East China Sea. *Journal of Shangdong college of oceanology* 10(3): 26-35. (In Chinese)
[6] Shen Y.J., Ye A.L. 1984. Three-dimensional semidiurnal current field in the East China Sea. *Transactions of oceanology and limnology* (1): 1-10. (In Chinese)
[7] Wang Y.G., Yuan C.G., Huang H.M., Zhu H.M., Chen C. 2013. Research on sea-land demarcation and maximum theoretical tide level along Jiangsu coast. *Journal of waterway and harbor* 34(5):387-392. (In Chinese)
[8] Wu D.A, Yan Y.X., Ma L.Y., Tong C.F. 2008. Calculation and analysis of possible maximum tidal difference in Jiangsu radial sand ridges sea area. *Journal of Dalian Maritime University* 34(4):75-78. (In Chinese)
[9] Xiong W.Y., Wang J. 2005. The Sustainable utilization and integrated management of coastal zone in Jiangsu province. *East China Economic Management* 19(2):4-7. (In Chinese)
[10] Zhang D.S, Zhang J.L. 1996. M2 Tidal Wave in the Yellow Sea Radiate Shoal Region. *Journal of Hohai University* 24(5): 35-40. (In Chinese)
[11] Zhang W.S. 2005. Numerical modeling of tides wave in margin seas near China. *Hohai University, Nanjing, China.* (In Chinese)
[12] Zhang, R.S., Wang, Y.H., Wu, D.A., Shen, Y.G. 2003. Preliminary study on the developing mechanism of sandy island on the Radial Tidal Sands of Jiangsu coast. *Marine science bulletin* (4): 41-47. (In Chinese)

