

# MODELING ON THE ESTUARINE TURBIDITY MAXIMUM OF YANGTZE ESTUARY BEFORE AND AFTER THE REGULATION WORKS USING Z-MODEL

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Existence of the estuarine turbidity maximum (ETM) zone is ubiquitous in partially mixed estuaries. It is characterized by high suspended sediment concentration. The position of the TM usually corresponds to the head of the salt intrusion. In the Yangtze Estuary, the ETM zone is extremely large in spatial scale, spreading over the entire mouth zone downstream the South Branch and inside the 10 m isobaths. The ETM is also accompanied by a broad shallow area (basically around 6 m) in the mouth zone, namely the mouth bars. The presence of the mouth bars hampers the navigation significantly. Thus extensive engineering works are implemented to achieve deeper water depth with the help of dredging activities in the North Passage in the Yangtze Estuary. However after the completion of the engineering works, high siltation appears in the middle segment of the North Passage. The hypothesis is that the location of high siltation (expressed in the morphology) falls in the range of ETM zone modified by the completion of the engineering works. The formation and development of ETM and consequent morphodynamic development is focused on. A three-dimensional z-layer model Delft3D is employed. This study clearly shows that salinity gradients can be better simulated using the z-layer model, where the stratification at the upper limits of the salt wedge is better resolved. Afterwards, the consequent morphological changes are qualitatively demonstrated. The study shows the capability of this z-layer model to exploit the mechanism of generation and development of ETM, thus to explain the complex phenomenon of the high siltation in the North Passage of Yangtze estuary

*Keywords: Turbidity maximum; fine sediment; salt intrusion; salinity gradients, Delft3D; 3D z-layer model; Yangtze Estuary.*

## 1 BACKGROUND

### 1.1 Estuarine Turbidity Maximum In Yangtze Estuary

Yangtze Estuary is located at the north of Shanghai, China, which of the longitudinal length is about 160 kilometres. The width at the entrance is about 90 km. Yangtze Estuary is a delta characterized by ample flow and sediment and obvious tidal influence, which create a basic regime of the estuary characterized as three-stage bifurcation, four-river mouth split, shoal developed, available navigation channel alternated, sandbar and submerged delta stretching.

Existence of the estuarine turbidity maximum (ETM) zone is ubiquitous in partially mixed estuaries. It is characterized by high suspended sediment concentration. The position of the TM usually corresponds to the head of the salt intrusion. The widely accepted mechanisms of the formation of turbidity maximum are density stratification effect which induces gravity circulation and then sediment trapping. With respect to sediment, it is the fine sediment property that matters. In the Yangtze Estuary, the ETM zone is extremely large in spatial scale, spreading over the entire mouth zone downstream the South Branch and inside the 10 m isobaths, see Fig. 1. The ETM is also accompanied by a broad shallow area (basically around 6 m) in the mouth zone, namely the mouth bars (Pan, 1999; Shen, 2001). The presence of the mouth bars hampers the navigation significantly.

After more than 40 years study, North Passage was selected as the deep-draft navigation channel and the regulation works was started in 1998. The channel depth will be dredged phasing from 7.0m (under Theoretical Lowest Water Level) to 8.5m, 10m and 12.5m. Thus extensive engineering works, consisting two long training dikes and 19 groins, are implemented to achieve deeper water depth with the help of dredging activities in the North Passage of the Yangtze Estuary.

After Yangtze Estuary deep water channel project in 1998, mouth bar terrain disappear, however turbidity maximum zone also persists. At the same time, after the completion of the engineering works, high siltation appears in the middle segment of the North Passage. To fulfill the needs of navigation, the maintenance dredging amount is unexpectedly large which is inefficient economically.

The aim of this study is to explore the causes of high siltation in the North Passage. The hypothesis is that the location of high siltation (expressed in the morphology) falls in the range of ETM zone modified by the completion of the engineering works. The formation and development of ETM and consequent morphodynamic development is focused on. Studies through field data analysis before and

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after the Project reveal the evolution models of North Passage on the Yangtze Estuary, as well as the impact to the deep water channel siltation.

### 1.2 The Improvement Project of the Deep-Draft Channel of the Yangtze Estuary

With the rapid development of China's economy and society, the demand for cargo transport increases dramatically. It is necessary to have a deep navigation channel in Yangtze Estuary to meet the demand of large-sized ships to come into and out of Shanghai harbor and the Yangtze River Valley. After more than 40 years study, North Passage was selected as the deep-draft navigation channel and the regulation works was started in 1998. The channel depth will be dredged phasing from 7.0m (under Theoretical Lowest Water Level) to 8.5m, 10m and 12.5m.

The Improvement Project was selected to locate in South Channel and North Passage, where there were the best river pattern and construction conditions. The project, combining regulating structures with channel dredging, constructs the diversion gap control works at the bifurcation area of North Passage and South Passage, two 50km long training dikes and 19 groins alongside the passage. The total length of the structures reaches 141.484km. The navigation channel would be dredged and maintained to the depths of 12.5m under theoretical lowest tide level with the bottom 350-400m wide. Thus the third/fourth generation container ships will be able to enter Yangtze Estuary under all weather conditions, while fifth generation container vessels and 100,000-ton bulk carriers can use a tidal window.

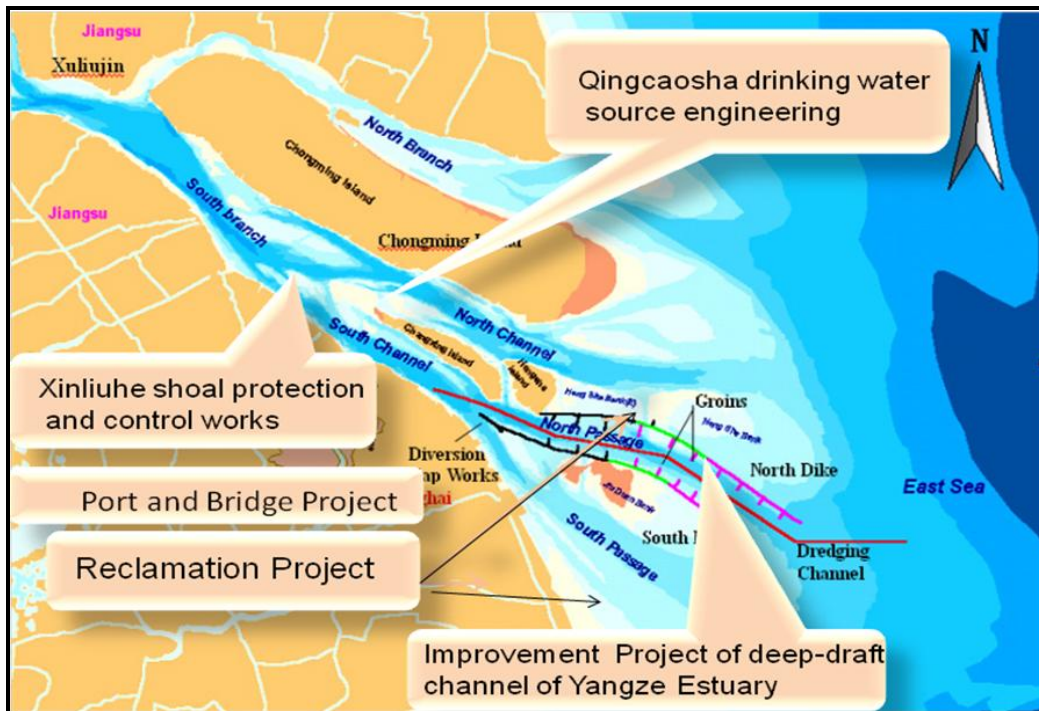


Fig.1 General Plan of Yangtze Estuary

The regulation works of North Passage, combining regulating structures with channel dredging works, based on channel dredging as the guideline for the design, is set to construct training dikes and groins along with the side of passage, so as to give full play to the functions of water diversion, sand retention and siltation reduction by improving the flow field conditions of North Passage.

The regulating structures include two training dikes, one split point control works between North Passage and South Passage, and 19 groins along the two dikes.

The diversion gap control works are constructed to stabilize South Jianya Shoal and keep it from eroding to maintain the river regime of North Passage and South Passage, retain flow and sediment distribution rate between North Passage and South Passage.

South and North training dikes are constructed to further shape river behavior of North Passage and provide support for the groins to form the regulating lines, stop the influence of sediment stirred up by wind wave on the shoals beside the channel, block ebbing current diverted from Jiangya gully to North Passage, and prevent sediment of North Channel from discharging to North Passage through Hengsha East Shoal Gully.

The Groins are constructed to form reasonable regulating lines of the channel and maintain flow field benefit the shaping and maintenance of the deep navigation channel.

The Improvement Project was carried out under the principle of “planning at very beginning, phased construction for phased benefits”, and the Project was done in three phases. In March of 2000, the first phase project completed the 8.5-meter-deep waterway before schedule, and was accepted by the National Completion Acceptance Meeting in 2002. Phase II Project started in April of 2002, and achieved the period target of 9-meter-depth in May of 2004. On March 2005, the 10-meter-deep waterway was completed. Phase III Project started in April of 2009, and a channel depth of 12.5m was achieved in 2010.

With the help of regulating structures and improvement of dredging techniques, the navigation channel was maintained with acceptable dredged volume. The guarantee rate of navigation was up to 100% since the water depth of 12.5 meter was achieved from Mar. 2010.

## **2 THE CHANGE OF ESTUARINE TURBIDITY MAXIMUM IN YANGTZE ESTUARY BEFORE AND AFTER THE REGULATION WORKS**

Analyses of the riverbed change after the construction of the first and second phase regulation works show that the regulation principle presented compared with nature morphology change in the Yangtze Estuary.

The general effects of the regulation works in North Passage can be shown as Fig. 2 and Fig. 3.

The construction of split point control work between the North Passage and South Passage stabilized the central shoal and stopped the continuous erosion and recession of the shoal ridge, which provides a favorable boundary for the distribution of runoff and sediment transport.

The two training dikes give a stable boundary for North Passage, which block the water and sediment interchange between shoal and channel and give a effective barrier for sediment transport from shoal to channel during typhoon season or winter storm.

Before the project, ebb channel is located at south and flood channel is closed to north, between the ebb and flood channel, mouth bar (sill) formed due to the complex morph-dynamic conditions and sediment flocculation in the maximum turbidity area (same area with mouth bar). After the project, which formed the regulating line along the groins heads and adjusted the flow fields, deepened the mouth bar area and merged the ebb with flood channel, a faintly-curved channel was obtained in the North Passage.

In the groin fields, sedimentation happened due to the velocity decreasing in these areas. The channel transferred from a wide-shallow river pattern to a narrow-deep pattern, which is favorable for channel maintenance.

At the entrance of North Passage, sedimentation happened and the cross-section area decreased due to the fact that runoff distribution from the South Channel declined caused by the river friction increasing in North Passage. And near the split point, south training dike blocked the gully used to discharge some runoff from North Passage to South Passage, which was also reduced the hydrodynamic condition near the entrance. But in this area, the water depth is still enough to maintain the development and equilibrium of North Passage.

In the middle bend area, there was a gully connected North Passage with North Channel. After the construction of north training dike, it blocked the water and sediment interchange between the two channels, thus in this area, velocity decreased and sedimentation happened.

The lower reach of the North Passage, after the project, the flow field changed from rotating tidal current to alternating tidal current, and the hydrodynamics increased, thus erosion happened.

Out of the North Passage, some sedimentation happened. With the morphological adjustment inside the North Passage, some sediment was eroded and transported outside of the regulating structure. Out of the regulating structures, the channel was getting wide and velocity decreasing, which can cause sedimentation. In this area, it is relatively deep and the strong rotating velocity field will help to take away the sediment.

In summary, the regulation works in North Passage is successful. The principle of regulating works combining with channel dredging can be adopted for the regulation works in North Channel.

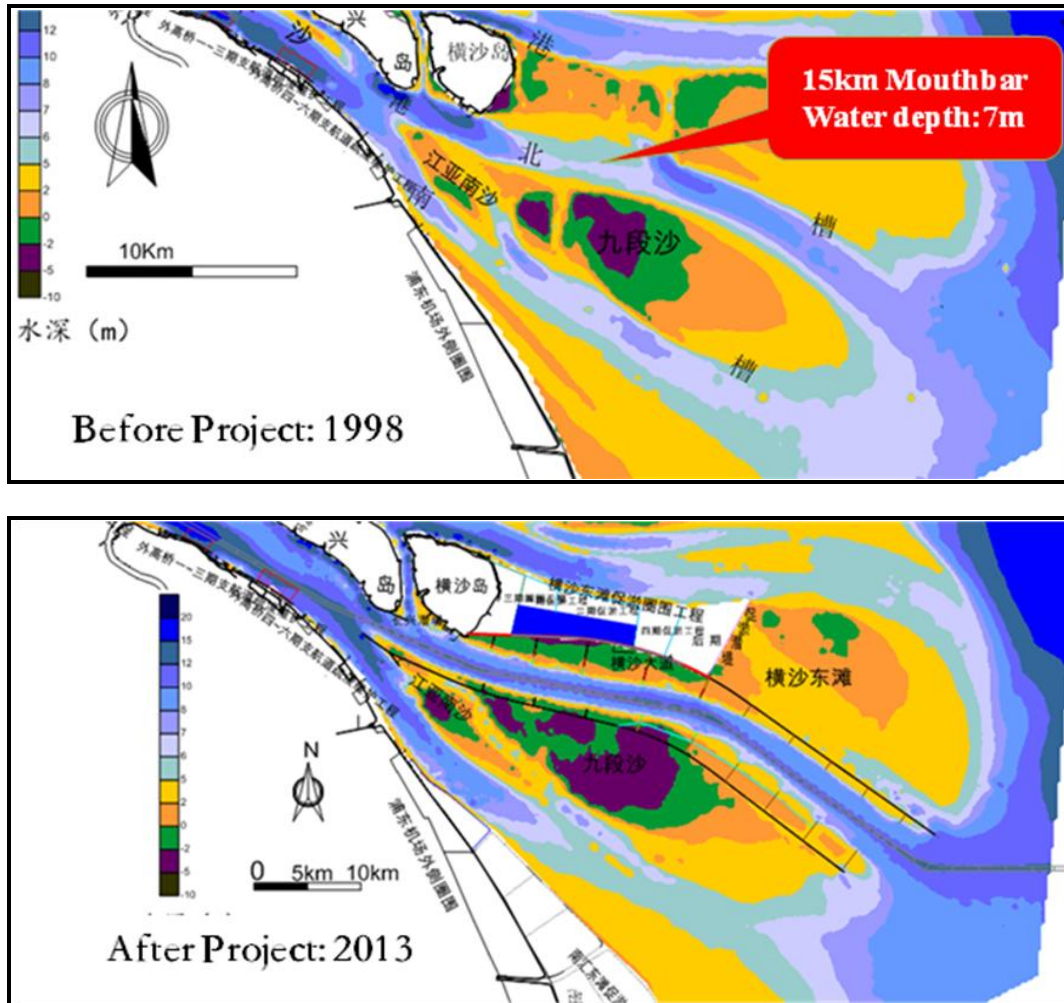


Fig. 2 Bathymetry change between 1997 and 2010

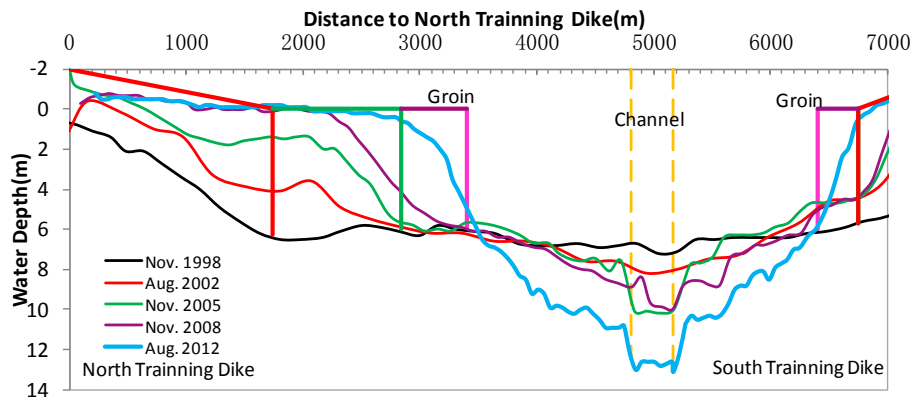


Fig. 3 Bathymetry changes after the North Passage regulation works (Cross Section in the Middle of North Passage)

After Yangtze Estuary deep water channel project in 1998, mouth bar terrain disappear, however turbidity maximum zone still persists. Siltation distribution related to the ETM in the North Passage of YE, see Fig. 4.

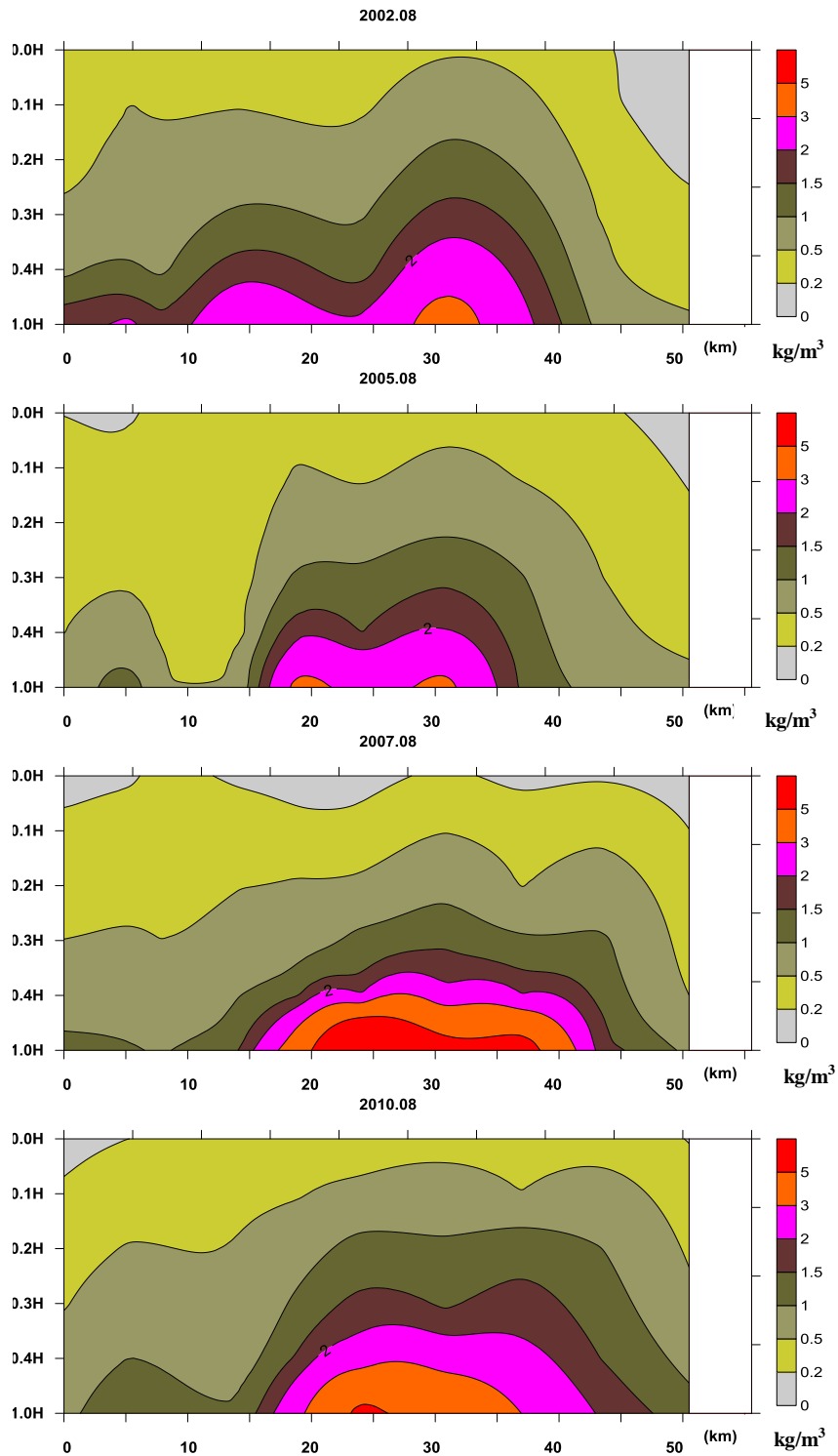


Fig.4 ETM change between 1997 and 2010

### 3 MODELLING SIMULATION OF ETM IN YANGTZE ESTUARY

A three-dimensional z-layer model Delft3D is employed. The model includes both tidal and subtidal processes which are crucial to generate and maintain the ETM, i.e., salinity gradients which caused stratification and density circulation in vertical, flocculation, sedimentation and (re-)suspension of mud/fine sediment, bathymetry caused tidal asymmetry. The magnitude and location of ETM are also controlled by the quantity and location of available sediment supply. The main goal of this work is to reproduce the turbidity maximum in the model and to study sensitivity of the turbidity maximum to different model parameters.

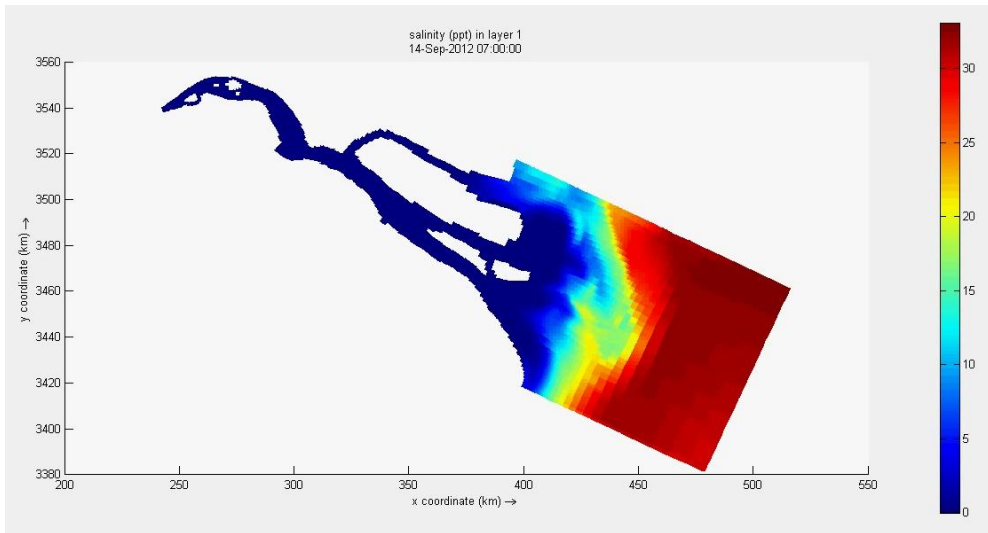


Fig.5 Local 3D model of Yangtze Estuary

The model results resembled the field measured data of current, water level, salinity with variation of the tidal wave force and river flow and dynamics of salt wedge with present land boundary conditions with hard structures. This study clearly shows that salinity gradients can be better simulated using the z-layer model (Fig. 6), where the stratification at the upper limits of the salt wedge is better resolved. Afterwards, the consequent morphological changes are qualitatively demonstrated. The magnitude and location of ETM are in the correct range, see Fig. 7.

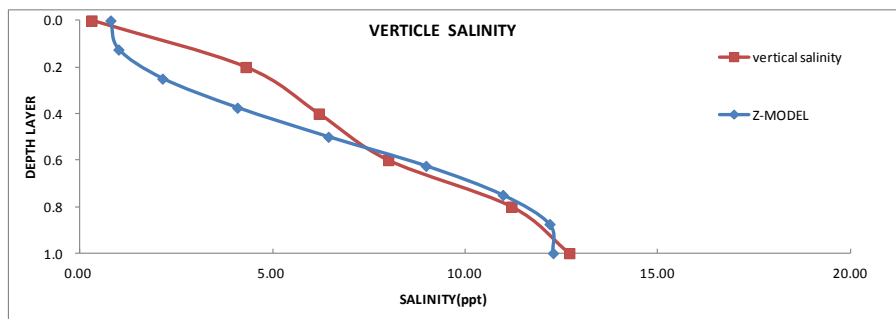
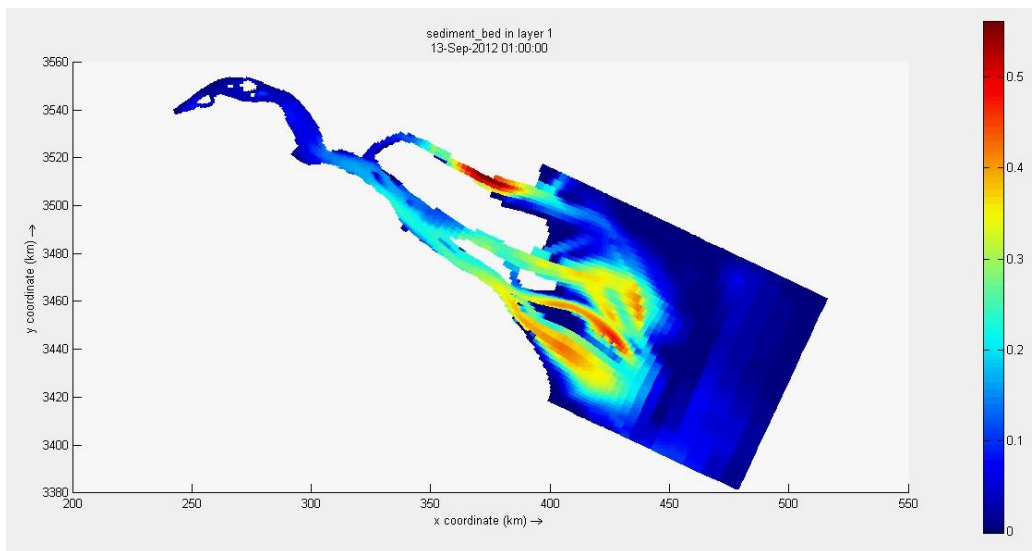


Fig.6 Vertical Salinity Simulation Using Z-model

The study shows the capability of this z-layer model to exploit the mechanism of generation and development of ETM, thus to explain the complex phenomenon of the high siltation in the North Passage of Yangtze estuary.



**Fig.7 ETM Simulation Using Z-moldel**

#### 4 CONCLUSION

The aim of study is trying to exploit the mechanism of generation and development of ETM using this z-layer model, thus to explain the complex phenomenon of the high siltation in the North Passage of Yangtze estuary.

This study clearly shows that salinity gradients can be better simulated using the z-layer model, where the stratification at the upper limits of the salt wedge is better resolved.

The location of ETM are in the correct range, but the magnitude of ETM is different with the natural process.

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