

## GIS based Visual Expression of Marine Numerical Simulation- Flow Field and Silt Sediment as Example

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### Abstract

*Numerical simulation has been widely applied in ocean engineering owing to its low cost, short cycle and wide application range. However, post-processing software of numerical simulation doesn't support production specification of marine engineering and other industries, and integration production is not flexible. According to particularity of numerical simulation and user requirements, this paper took GIS as the solution to achieve dynamic visualization of numerical simulation and one-click generation of business products. Firstly, based on its characteristics, convert marine numerical simulation data into vector field represented by arrows or scalar field represented by grid. Secondly, GIS based spatial display and analysis technology is used to realize the visualization expression of marine numerical simulation data. In order to improve the effect of display and expression, we achieve rendering through symbol and color stretching mapping. Finally, we output numerical thematic map through custom map range and great map decoration function.*

**Keywords:** *GIS, numerical simulation, visualization, cartography export*

### 1. Introduction

Ocean engineering is comprehensive science and technology for the development and utilization of marine. The traditional research methods of Marine engineering include the research on the model of pure mathematics and physics method, hydraulic model experiments and the field test. After entering in twenty-first century, numerical simulation has been widely applied in ocean engineering owing to its low cost, speediness, short cycle, not subject to time and space constraints of model site and the model can be used for a long time and is easy to modify after construction.

With the development of the industry normalization and standardization, the post processing of numerical simulation that is analysis of numerical simulation data and generation of various graphics has become more and more strict [1]. However, the existing numerical simulation post-processing software still not perfect in the professional cartography, for example, Matlab can get calculation result quickly and with high development efficiency, but for huge data the computing ability is low and execution efficiency is shortage. It is not software of product making and cannot support the industry standard [2]. Surfer has powerful function of results display, but it displays more like a sketch map and it has not adequate solution about geographical

spatial information. In addition, Surfer does not support the production norms of marine engineering industry, and its map decoration function is not flexible, so it is difficult to produce the standard industry thematic map.

GIS can solve the expression in space characteristic of ocean numerical simulation data greatly due to its powerful ability of spatial data organization, ability of spatial analysis and expression, precisely coordinate and projection system. Meanwhile, GIS originated from cartography. Its technology system provides a powerful support for automatic cartography, so this paper chooses GIS as a solution to solve the above problems [4, 5].

However, from the beginning of GIS, it is to meet the demand of surveying and mapping, geographic and other industries. GIS mainly analyze static data of land that changes slowly. Numerical simulation data is dynamic data of ocean that always changing. So GIS itself has no direct support for the results of numerical simulation data. This paper solves the problem mainly have three aspects: First, convert simulation data format under GIS circumstances; then, express simulation result according to display custom under GIS environment; finally, realize the integration of standard drawing based on the advantage of GIS drawing.

## 2. Research Contents

This paper uses the GIS environment of ArcGIS10, achieves marine numerical simulation results GIS expression based on ArcGIS Engine10 and C # language.

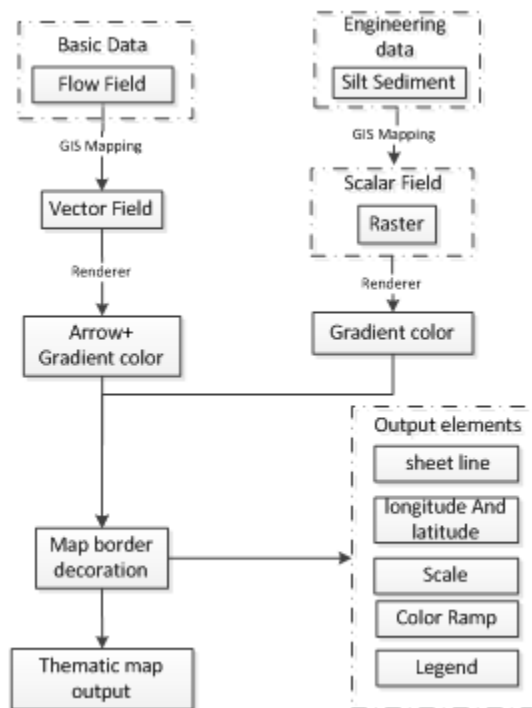


Figure 1. Flow Diagram

According to data processing, the paper mainly includes three aspects as follows: realize analysis and format conversion of numerical simulation data; express result data in the form of GIS; produce thematic map that meet with industry demand and batch output it by one-click based on GIS. The basic process is shown in Figure 1:

- (1) Simulation data format conversion

The experimental data of ocean simulation is the plain text stored in the TXT file. To carry on the analysis, it is necessary to understand its storage format in text file and extract the parameters information that the article needed. And then convert it to the vector field or scalar field file under GIS environment. As for flow field data, it is necessary to obtain X, Y coordinate of the flow field point, U, V components, etc. and to store it in point layer with IPoint format under the environment of GIS; velocity and direction of flow is expressed as layer's attribute fields. The converted GIS data with spatial information are stored as layer. And it makes spatial information and non-spatial information associated. And it is managed by spatial database.

#### (2) Analysis of data visualization

Numerical simulation data was converted to two categories: vector and raster. The following we will analyze problems about numerical simulation data that need to be solved. For flow field, GIS combine color coding with icon method in traditional flow visualization methods, mainly to solve the arrow symbol making, length and angle assignment, color rendering, etc. Meanwhile, in order to improve the efficiency and enhance the display effect the paper also carry out sparse processing to huge flow field data based on the row and column number in Figure 2. For scouring and silting data, GIS use color stretch mapping to achieve render, mainly solves the creation of color ramp and render with multiple color ramp.

In addition, GIS can overlay display the vector flow field data and raster silt sediment data based on the spatial location of objects. For long time series current data, GIS not only can express their movement tendency of time sequence directly, but also can generate curve of changing process in the time dimension which including single point of water level, flow velocity and direction, etc.

#### (3)The decoration and output of thematic map

According to the industry standards, this paper makes drawing templates and realizes standard label of map decoration elements such as the map border, graticules, legends, and so on. Otherwise, this paper conducts process adjustment and module packaging and achieves one-click processing, so the system can automatically generates thematic maps without manual interaction as long as the user has specified the output range. The key point of the system is to obtain map extent by the mouse pulling box, label graticules adaptively, achieve conversion of plane coordinate and latitude and longitude.

### **3. Organization and Management of Marine Numerical Simulation Data**

To conduct visualization expression of marine numerical simulation data, the first is to compose specific interpretation program to transform format of numerical simulation data. Use the advantage of GIS on spatial data management, to convert marine numerical simulation data into vector field, scalar field and other GIS supported visualization forms to be organized.

#### **3.1 Flow Data Conversion**

The numerical simulation data of flow include X, Y, U, V four parameters. As shown in Figure 2(a), A1 represents X, Y coordinate values, B1 (U, V) represents velocity components on the direction of X, Y coordinate. In the analysis of flow numerical simulation data, flow vector files are created taking hour as the unit. Then reading the TXT data and storing parameters in the "List" generic array. Analyze U, V variable in generic array to gain angle, velocity and coordinate info of flow data, which will be stored in the created vector file; coordinate, velocity and angle are expressed as a property field of layer. The analytical results shown in Figure 2 (b), A2 in the GIS format file corresponding to A1 in Figure 2(a), velocity and direction in B2 obtained by

analytic of U, V component in B1. Due to large amount of flow data, the visual effect is relatively poor, so sparse operation is carried out based on row and column number. C is row and column info calculated from X, Y coordinate and distance between points.

A1		B1	
x <sub>i</sub>	y <sub>i</sub>	U <sub>i</sub>	V <sub>i</sub>
724342.375000	3904931.250000	-0.355219	-0.129263
724367.562500	3904932.000000	-0.356056	-0.130945
724392.750000	3904932.500000	-0.357895	-0.128038
724417.937500	3904933.000000	-0.359610	-0.128078
724443.125000	3904933.500000	-0.360753	-0.126920
724468.375000	3904934.000000	-0.361501	-0.126120

A2		B2		C			
OID	shape	x	y	Length	ORIENT	i	j
1	Point	714651.003534	3881469.624759	.204382	284.86713	11	1
2	Point	714676.197415	3881470.180023	.204889	284.412192	12	1
3	Point	714701.391296	3881470.735287	.207338	284.297363	13	1
4	Point	714726.585176	3881471.290551	.210876	284.772342	14	1
5	Point	714751.779057	3881471.845815	.213813	284.916538	15	1
6	Point	714776.972938	3881472.401079	.216769	285.080464	16	1

Figure 2(a) Numerical simulation file format

Figure 2(b) GIS file format

Figure 2. Flow Data Format Conversion

### 3.2 Silt Sediment Data Conversion

At present, ocean phenomenon generally showed by the form of field. And two data structures GRID and TIN can used as scalar field in GIS. Silt sediment numerical simulation data is stored in the form of discrete points, which is similar with flow data format, form like (X, Y, C), where C is the scouring and silting thickness value. As silt sediment is long time series data, it needs to be studied in unit of time. For project area's erosion deposition variation diagram, array form is assigned to corresponding grid center point vector layer in computational domain, and raster conversion is also necessary.

## 4. Visualization of Marine Numerical Simulation Data

Marine numerical simulation data visualization is mainly reflected in the symbol, color stretching mapping, custom color, etc. The following is to study visualization expression about marine numerical simulation results, exemplified by flow and silt sediment data.

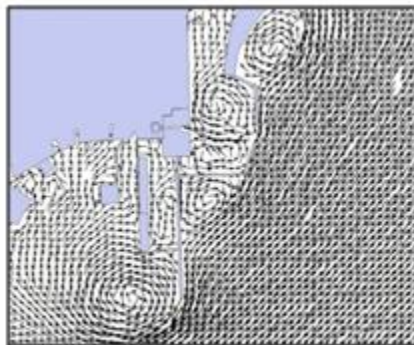


Figure 3(a) Raw Data

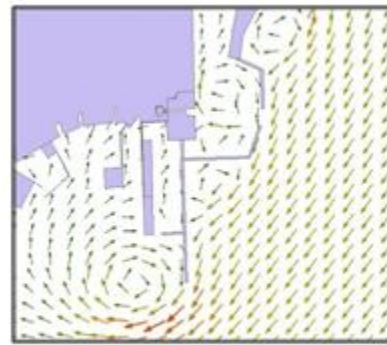


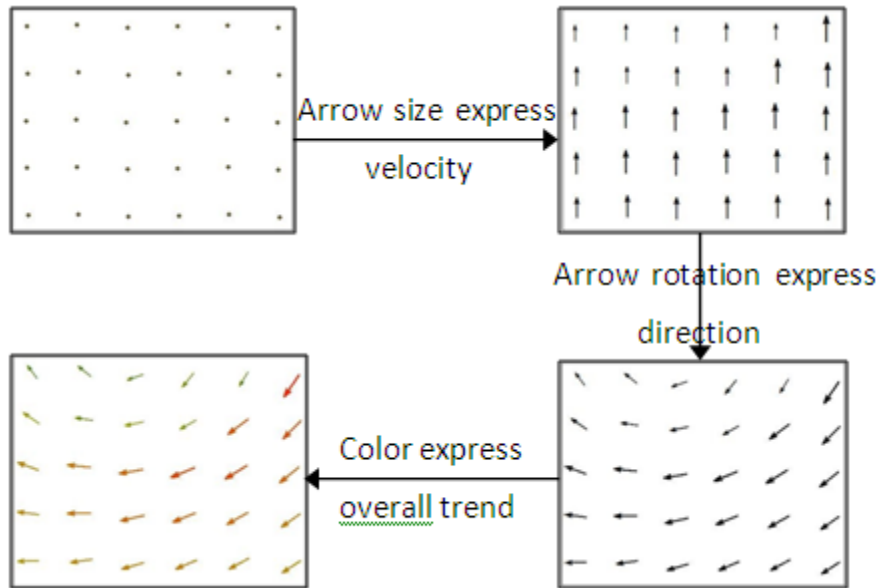
Figure 3 (b) Processed Data

Figure 3. Comparison of Flow Field Expression

### 4.1 Visualization of Flow Field Data

The flow field is a major dynamic change vector field in the ocean, which affects the project around suspended sediment and pollutants transport. Therefore, the correct expression of ocean flow field structure, is a breakthrough in research of marine engineering application, is the core content of the research in marine science. In order to consistent with the traditional expression form of ocean flow field, this paper made the

arrow symbol and rendered the direction and the velocity of the vector flow field with the arrow symbols. Figure 4 is the large amount flow field's expression effect drawing.



**Figure 4. Flow Data Render Process**

(1) Vector expression of flow field based on arrow. Velocity and direction of flow are stores as layer attribute field after the numerical simulation data of flow are transformed into point layer in GIS environment. Using the arrow symbol to express flow field data, velocity indicated by the arrow length, direction indicated by the arrow angle of rotation, flow velocity and direction were obtained from layer attribute field. To realize it, whole flow field's velocity should be counted and classified in ArcGIS Engine; using IMarker Symbol interface to define symbol object for each classification, define arrow symbol size according to flow velocity; using IRotation Renderer interface to rotate arrow symbol, define arrow symbol angle according to flow direction. Finally, assign the symbol object to point objects through QI (Query Interface) method to realize the renderer of a segment point. Like this, we can do processing for all points.

To show the whole flow velocity variation more intuitively, all arrows are given color according to flow velocity. Flow elements are divided into several segments according to flow velocity, and then choose a start and end color to form a ribbon, finally define color object IAlgorithmicColorRamp, and establish mapping relation between the segment of flow velocity and ribbon colors in the basis of certain rules to render arrow symbols of each flow elements level into the corresponding color, as shown in Figure 4:

(2)Flow field uniform sparse. The ocean flow field is of large quantity data, when observed in large range and small scale there will be serious symbol cover and poor visual effect. So this paper do sparse processing to regional flow field data based on different levels of grid, call corresponding level grid to display flow field data respectively in different scale to simulate continuous change with the method of segment, stable control the current screen display number, maintain the distance between points at a relatively stable value, realize the dynamic, uniform flow field display. To realize it, the paper choose the smallest external square of flow field effective range as coverage of nested grid, and then divided it into several squares of equal size; generate multiple set of grid data according to different scale. Overlay point layer with the corresponding scale level grid data on sparse operation, and select the

point set by a center point principle. First, obtain the center point of grid cell; then iterate through all points in the grid to compare the distance between each point and grid center point in turn; finally, choose the closest point to center point as the retain display point. This can extract a sparse set of uniform points from flow field data.

#### 4.2 Visualization of Silt Sediment Thickness

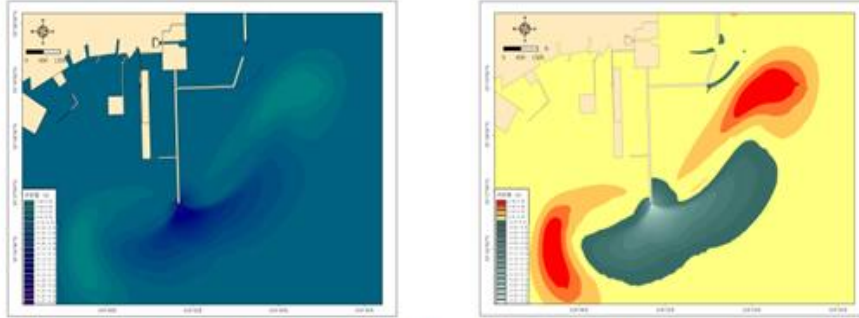


Figure 5 (a) Render with single ribbon      Figure 5 (b) Render with double ribbon

#### Figure 5. Annual Seabed Silt Sediment Trend Graph Around the Project

In the relative stable coast, under normal circumstances the seabed sediment is in the relative balance state. But when encounter with huge storm, storm and tide work together, the balance state was destroyed, the sediment is raised to become suspended sediment. After the wind stops, the turbulence intensity gradually weakened, the current carrying capacity is reduced, super saturation sediment deposition, sediment concentration decreases gradually until the seabed sediment formed again some kind of scouring and silting relative balance state, its corresponding seabed terrain from a relative equilibrium through erosion and sedimentation transition to another relative balance state, this is the dynamic process of " wave lift sand, tide transport sand". Figure5 is the simulation of the annual seabed silt sediment trend graph.

(1)Silt sediment thickness numerical simulation results are converted into raster data with spatial coordinate in GIS environment. That is array data which rank by grid row and column, with different grays and colors, can represent continuous surface. The paper adds color stretch mapping on raster sediment elements according to its pixel value, make it able to distinguish different elements. First, using IRasterStatistics interface to statistic maximum and minimum values of raster pixels and classify it. Then, usingIColorRamp interface to call color ramp that GIS its own has or using IAlgorithmicColorRamp to create your own color ramp. To establish color mapping relationship between color ramp and each classification, each silt sediment elements classification is rendered into the corresponding color. Figure6 is the interface of scalar field render.

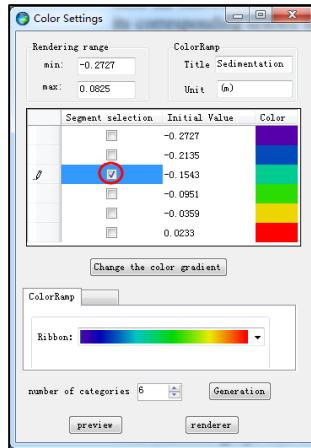


Figure 6. Interface of Scalarfield Render

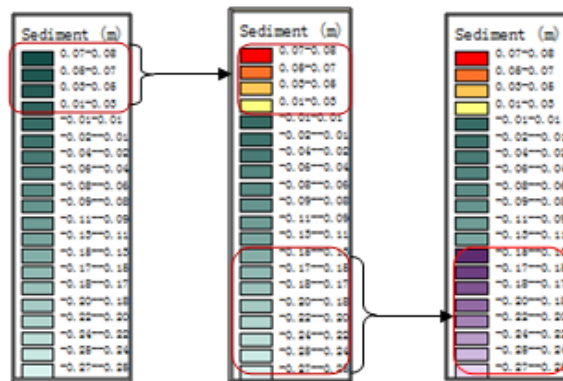


Figure7 (a) single Figure7 (b) double Figure7 (c) three

Figure 7. Color Ribbon

(2) The definition of scouring-silting change is a combination of erosion and deposition change, scouring and silting values change between -0.273 and 0.083 (unit: cm). When adding color mapping, single color ramp shall not enough to distinguish erosion area and deposition area, as shown in Figure 5(a) and Figure 7(a). So this paper realized the rendering method of multiple color ramps. As Figure 5(b) and Figure 7(b) shows, erosion area (value<0) and sedimentation area (value>0) using different color ramp mapping, which is more intuitively than the expression of Figure 5(a) and Figure 7(a). If more sophisticated distinguish is needed, the number of color ramp can be added relative to demand. As shown in Figure 7(c), the volume of scouring and siltation is divided into three segments :  $\{(-0.27) - (-0.15), (-0.15) - 0, 0-0.08\}$ . In order to highlight the most serious erosion area, the  $(-0.27) - (-0.15)$  segment color is changed. At the same time, this paper realized the color change of single segment to outburst sensitive segment. If there is one segment that doesn't want to be displayed, hide it. Click CheckBox in Figure 6 and change its color.

## 5. Output of Marine Numerical Simulation Thematic Map

After analysis and expression of ocean numerical simulation data, the thematic maps which compliance with project specifications and industry demand are need to be produced. Based on the GIS graphics rendering technology, this paper has customized

map output template and saved the related parameters information such as latitude and longitude interval, font size and scale format. When users obtain map extent by the mouse pulling box, the coordinate information of four corner point of output are calculated at the same time. Users add graticules to the drawing area by the way of draw line elements and customize scale, legend as required by the way of draw or combine elements. For some factors, such as scale and the position of north arrow, the users can interactively fine-tuning. The main work is shown as follows:

(1) Get the output map extent, draw border line and mask polygon

We can track rectangle by `INewEnvelopeFeedback` interface, and return coordinates of four corner point; then, connect the four corner points with line elements to generate border line; finally, draw the white mask polygon outside the selected mapping area that is generate four rectangles to cover base map.

(2) Adjustment and marking of graticules adaptively

The marking point and interval are the key point of adaptive drawing of graticules. For its beauty, the marking interval always rounding and should be adapted with the output map range, so this paper calculate proper longitude and latitude interval through the obtained map output range. For example, interval can take 1, 0.5, 0.125, *etc.*, but can't take 1.01, 0.49, 0.123, *etc.* Through marking interval and corner point coordinate of output range, the marking point can be calculated and rounded. First, find the first integer marking point on the left and upper line of the rectangle, and then find other integer marking point through the accumulation or decreasing. Annotation generally uses the format of degree, minute and second.

(3) The label transformation of plane coordinate and latitude and longitude

To meet the drawing demand of various thematic maps, this paper achieves the label conversion between the plane coordinate and latitude and longitude. At first, it must be guaranteed that the map has a specific projection. Then, we have to define points as `WKSPoint`, and realize the transformation of plane coordinate and longitude and latitude by the Inverse and Forward method of the `IProjectedCoordinateSystem` interface.

(4) Automatic analysis and calculation function of the scale

The scale that ARCGIS provides does not conform to the requirements of the industry, so we ourselves need to make flexible scale. This paper determines the scale size through the output range automatically. For its beauty, scale length is determined as one-tenth of the output extent and scale length is rounded by the function of `Math.Round`. In addition, the display value of scale can be interactive and real-time adjusted, scale size will change with it.

## 6. Case Analysis

### 6.1 Induction of Project Area



**Figure 8. Geographical Location Map of Project**

At present, most berth of the Rizhao Port are overrunning except some special berth (cement, coal loading and crude oil berth). With the development of the hinterland economy and the growth of the port throughput, the cargo handling capacity will reach



3.2 tons and the contradiction of insufficient port capacity will popping out in 2015. Therefore, Rizhao Port Limited Company plans to build the #1 to #6 general berthson Southern District of Shijiu port in Rizhao Port. This project is located in the east of coke wharf engineering on western Shijiu Port in Rizhao. As shown in Figure 8:

## 6.2 Introduction of Engineering Data

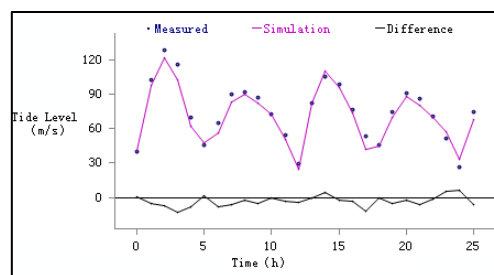
According to the engineering analysis, the construction of the project may change the hydrodynamic environment around engineering and the surrounding waters which result in silt sediment variation in the water surrounding the project. Meanwhile, riprap in construction will cause the suspended sediment spread and make seawater turbid. In order to study the impact of the project on the hydrodynamic environment, the numerical simulation for the movement of current field and diffusion of pollutant need to be calculated.

The current domestic software that most widely used in numerical simulation of complex coast mainly includes MIKE21, Delft3D and SMS etc. Marine numerical simulation data used in this paper is grid data with different cell size which generated by MIKE21, including flow field, suspended sediment and scouring and silting thickness data. Two-dimensional numerical model, MIKE21, has flexible grid and can freely control the mesh density. And it is applied to the hydrodynamic simulation of two-dimensional fluid of lakes, estuaries, coast, bay and other related simulation [6].

## 6.3 Test and Analysis on Simulation Results of Current Field

### (1) Test on simulation results of current field

After the current field numerical simulation on the water near Rizhao using plane two-dimensional numerical model MIKE21, the simulation result need to be tested. Figure9 is some tide station's 24-hours comparison chart of tide simulation value (blue), measured value (red) and the difference between the two (black). From the chart, we can figure out the water level changing trend with time of observation station and the correspondence degree of tidal numerical simulation results and the measured data to judge the credibility of the numerical simulation result. In addition, simulation value, measured value and the difference between the two of each station can also be analyzed.

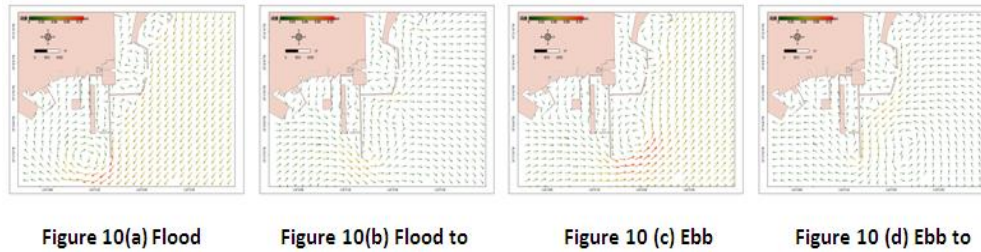


**Figure 9. Some Tide Station's 24-hours Comparison Chart of Tide Simulation Value and Measured Value**

In the traditional curve drawing, the color and pattern of title are not flexible. So this paper using TextBox to define the headline style which has realized the diversification and mobility on headline and output curve graph with screenshot function of GDI+.

### (2) Analysis on simulation results of current field

The current field numerical calculation is an important part to the study and evaluation of sea status current field and the calculation of current field distribution, and it is the foundation of marine environmental assessment. In view of the above flow field expression based on GIS, this paper generated business flow field thematic map.



**Figure 10. Tidal Current Graph of Project Area**

Figure 10 (a) ~ 10 (d) is the flood, flood to ebb, ebb, ebb to flood four moment flow chart. Simulation sea area of flood moment mainly focuses on southwest direction, and ebb mainly focuses on northeast direction. From Figure 10, we can figure out the current field characteristics of the sea: the current field is regular semidiurnal tidal current characteristics; current field movement is reciprocating.

Since the complexity of the coast near Rizhao port, the engineering ocean area flow field is affected obviously and multiple circulations are formed in the offshore area. It can be seen from Figure 10: In flood moment, there is a clockwise vortex formed in the south side of the coke terminal, and clockwise vortex also exist on the eastern side of the West Breakwater; In flood to ebb moment, the clockwise vortex in the south side of Coke Terminal slightly southward migration, scroll position in the eastern side of the West Breakwater also slightly eastward migration, velocity becomes smaller; In ebb time, a counter-clockwise vortex is appeared on the eastern side of West Breakwater; In ebb to flood moment, there are two small vortices in the east sea area of the West Breakwater, the North one is clockwise rotation, the south one is counterclockwise.

#### 6.4 Analysis on the Simulation Results of Silt Sediment

Study the effect of ocean engineering on hydrodynamic and silt sediment not only has important theoretical value, but also has important practical significance. This article is to explore the impact of the southern district of # 1 to # 6 general berth of Shijiu port of Rizhao port on silt sediment.



**Figure 11(a) Before the Project      Figure 11(b) Change after the Project**

**Figure 11. Annual Seabed silt Sediment Trend Graph Around Project**

Figure 11(a) is a trend chart of simulation annual seabed silt sediment. From the figure we can see that the eastern side of Shijiu port west breakwater of Rizhao Port was affected by tide vortex and there is a deposition area B with about 6.5cm deposit thickness; and there is an erosion area A in east breakwater entrance area of Shijiu port, the maximum erosion thickness is about 4.3cm; and the southernmost region of Shijiu port West breakwater has a scouring region C, the maximum erosion thickness is about 26cm; and there is a deposition area D on the west side of erosion region affected by

tide vortex, the maximum sediment thickness is about 6.1 cm. The area near the project is a siltation balance district.

Figure 11(b) is the annual seabed silt sediment changes trend chart near the project after the completion of project, and the scouring and silting changes slightly compared to the previous situation. Because of the large number of the flow field vortex, scouring and silting trends caused by construction in the flow field vortex position has changed slightly. Erosion degree in the South of Shijiu port West Breakwater of Rizhao Port has weakened compared with the previous situation, and erosion degree in east breakwater entrance area of Shijiu port of Rizhao port has weakened than before. Meanwhile, deposition degree in southwest flow field vortex region has increased affected by the project, and the deposition degree in the southeast of West Breakwater has also increased than pre-engineering.

## 7. Summary

This paper achieves post processing of marine numerical simulation data based on GIS. First of all, using GIS as spatial data management platform to realize the numerical simulation data analysis and format conversion; Secondly, achieve the expression of result data by the way of GIS, including data symbolic and color mapping rendering; Finally, produce thematic map that conformed to industry demand based on GIS plat form and realize the one-click output of thematic map. By doing this we not only can improve the intuitive and vivid of the expression of numerical simulation data but also can generate all kinds of thematic map to meet the business needs of the application and provide technical support for the development of marine economy and decision of marine engineering.

## Acknowledgement

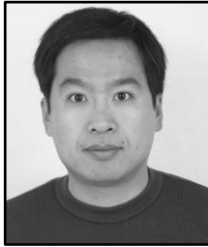
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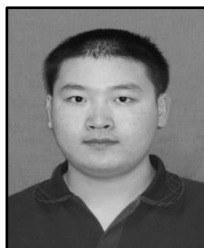
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**Bai Tao**, He received Master's degree in Physical Oceanography from Institute of Oceanography, Chinese Academy of Sciences. Now he works in numerical prediction room of North China Sea Marine Forecasting Center of Station Oceanic Administration. His current research interests include the research on dynamic estuarine process and silt sediment transport, the study on the influence of near shore marine engineering environment and the study on marine disaster prediction technology.



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