Spatio-temporal Analysis of suspended sediment Concentration in the Yongjiang Estuary Based on GOCI

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Spatio-temporal Analysis of suspended sediment Concentration in the Yongjiang Estuary Based on GOCI

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Abstract. The concentration and spatio-temporal variation of suspended sediment concentration in the estuary area are of great significance to the nearshore engineering, port construction and coastal evolution. Based on multi-period GOCI images and corresponding measured suspended sediment concentration (SSC) data, three inversion models (the linear regression model, the power exponent model and the neural network model) were established after rapid atmospheric correction. The results show that the absolute error of the three models is 0.20, 0.16 and 0.10 kg/m$^3$ respectively, and the relative errors are 38%, 23% and 18% respectively. The accuracy of the neural network (8-17-17-1) is the best. The SSC distribution diagrams in an ebb and flow cycle are obtained using this ANN model. The results show that with Yongjiang estuary for segmentation, the high concentration area is located in the north and the lower is in the south around Jintang Island deeper water area. When the tide rises, the water flow disturbs a large amount of sediment, and then the sediment concentration increases and high area high concentrations water body moves along the SE-NW. When the tide falls, flow rate decreases and the sediment concentration decreases. However, with the falling tide, the concentration of suspended sediment in the northern sea areas gradually increases, and is higher than 1 kg/m$^3$, and gradually moves along the NW-SE until to the estuary.

1. Introduction

The offshore area outside Yongjiang estuary belongs to typical class II water. It has characteristics of strong tidal flow and high suspended sediment concentration (SSC) under joint influence of Yangtze estuary southward water, Qiantang river runoff and tidal wave of the East China Sea [1]. It is very important for study on sediment change of surrounding waters, to-be-constructed gate and other coastal projects to master the spatial change and migration state of SSC in the waters. However, traditional sampling methods only can be used for obtaining discrete data on spatial-temporal distribution. It is difficult to recognize the spatial-temporal distribution of SSC in large-area sea areas continuously, synchronously and accurately. Satellite remote sensing, especially geostationary orbit satellite, has advantages of short cycle, high spatial resolution and wide coverage, and a large number of reliable data are provided for suspended sediment dynamic monitoring [2]. At present, scholars at home and abroad apply polar orbit satellite images for a lot of studies on coastal estuary suspended sediment inversion, such as MODIS, AVHRR, TM/ETM, MSS, HI, MERIS, etc. [3,4,5,6,7]. Remote sensing inversion of SSC lies in establishing a quantitative model between remote sensing information and measured data of SSC. Current inversion models mainly include experience model, Gordon model, negative exponential...
model, logarithm model, power exponent model, etc. [8]. In addition, the neural network, principal component analysis and other models are also applied in the suspended sediment inversion [9]. Richard used SPOT and TM data for scene spectrum test, synchronous or quasi synchronous sampling in different sea areas. A variety of suspended sediment remote sensing inversion models based on mathematical statistical analysis are established [11]. Zhang, etc. used MODIS images and measured data for statistical correlation analysis, and total suspended matter concentration of Yellow and East China Seas were inverted [4]. He Xianqiang, Liu Meng, Xie Dongfeng, etc. established suspended sediment inversion models respectively for studying sediment evolution and suspended sediment transportation rule in Hangzhou Bay [1,12,13]. However, remote sensing spectral information is affected by sediment color, type, particle size and mineral composition. The complex optical properties of suspended sediment provide remote sensing inversion with strong regional and temporal features [14]. Therefore, measured data should be combined to establish an optimal model of suspended sediment inversion in line with regional characteristics in view of the sea areas outside Yongjiang estuary.

In addition, though there are more polar orbit satellite images, the visit within a day is no more than twice. Images are more difficult to apply for studying suspended sediment spatial-temporal distribution in short time scales, such as one ebb and flow. In 2010, South Korea launched the first stationary orbit ocean color satellite with Geostationary Ocean Color Imager (GOCI). Compared with current polar orbit satellites, the temporal resolution is increased from two times to eight times a day. The spatial resolution is also increased to 500m. Therefore, the application of GOCI data has incomparable superiority. Choi established GOCI-based suspended sediment concentration inversion experience model aiming at offshore high suspended sediment sea areas [15], and it has been successfully applied to Gyeonggi gulf region. Those study show that GOCI image has an extreme advantage in the study of spatial and temporal change under the short time scales of the suspended sediment in the adjacent sea areas of the East China Sea and Korean peninsula [16, 17]. Therefore, taking Yongjiang estuary as the study area, GOCI remote sensing image and measured suspended sediment data are combined to construct a inversion model in line with regional characteristics and obtain the spatial-temporal distribution characteristics of the suspended sediment concentration field.

2. Research area and data

2.1. Overview of Yongjiang estuary

The sea area outside Yongjiang estuary has geographic position of 29°50’~30°15’N and 120°30’~122°10’E. The tidal range is generally around 4m. The ebb and flow diachronic difference is not great. The tide belongs to irregular semi-diurnal tide, and it is reciprocating flow basically. The maximum ebb flow velocity is 2.5m/s, and the maximum flood flow velocity is 2.3m/s. The concentration of suspended sediment is high, and the stratification phenomenon is obvious, the bottom maximum sediment concentration can reach 7kg/m$^3$. The substrate is mainly composed of clay silty sand. Due to the strong vertical sediment suspension effect of tidal current, the concentration of suspended sediment in waters shows strong periodicity with the daily variation of ebb and flow.
2.2. Measured data of suspended sediment

In the paper, measured surface suspended sediment concentration in June 2015 is collected. 10 measuring points (V1 - V10) are located in sea areas outside Yongjiang estuary (figure 1). The time includes spring tide phase on June 17 and 18, 2015 and neap tide on June 24 and 25, 2015.

2.3. Remote sensing data

South Korea new generation ocean color satellite data GOCI is adopted in the paper. The group sampling distance is 500m. The coverage area is 2500 x 2500km. The time resolution is 1 hour. Corresponding time is Beijing time 8:00 ~ 15:00. GOCI data of sunny weather and high quality in 14 images in one ebb and flow (June 6, 2015 and May 12, 2015) are collected. The space distribution characteristics of the suspended sediment field under ebb and flow short time scale are explored. All images undergo geometric precision correction (correction precision is less than one pixel), and the images will be used later.

3. Methodology

GOCI images and measured data of suspended sediment concentration are combined for establishing a remote sensing inversion model and feature analysis of suspended sediment outside Yongjiang estuary. Main technical roadmap is shown as follows.

Figure 2. Suspended sediment remote sensing monitoring flowchart

3.1. Rapid atmospheric correction

Rapid atmospheric correction is carried out on GOCI images. The result water-leaving radiance brightness value of atmospheric correction is used for model construction. Basic principle of rapid atmospheric correction: the information received by the satellite is the remote sensing information after ground reflection plus proximity pixel scattering and refraction.

In the study, quick atmospheric correction tool in ENVI software (Quick Atmospheric Correction: QUAC starts/Radiometric Correction/Atmospheric Correction Module/ Quick Atmospheric Correction (QUAC) in ENVI software Toolbox.) is utilized for completing multi-spectral rapid atmospheric correction. In the study, after undergoes rapid atmospheric correction, the spectrum curves of two kinds of objects (vegetation and water) are selected to compare with typical curves. The result shows that they have a good accordance.

3.2. Remote sensing inversion model of SSC

Firstly, the correlation of reflectivity and measured suspended sediment value at each band of GOCI is calculated. B7 wave band has the highest correlation with the measured SSC value. The correlation
In empirical model, an inversion formula is mainly constructed according to correlation. In the paper, B7 \((R_{745})\) wave band of two scenes and measured suspended sediment values (20 groups of data: 14 groups for fitting training and 6 groups for test evaluation) are adopted to establish a regression model. Quadratic polynomial is selected, and the inversion formula is shown as follows:

\[
SSC = -95.93 \times R_{745}^2 + 36.17 \times R_{745} - 2.067
\]

The remaining six groups of measured data are used for testing the accuracy of the inversion model: the mean square root error RSME is 0.2kg/m³, the average relative error is 38%, and the determination coefficient \(R^2\) is 0.804.

Semi-analytical model (exponent model) realizes inversion of water composition by combining radiation transmission model, biological optical model and empirical equation. In the paper, B7 \((R_{745})\) and B3 \((R_{490})\) wave band specific values are adopted as parameters to construct a exponent model based on the power exponent model, and its basic expressions are shown as follows:

\[
SSC = 10^{a+b \times \frac{R_{745}}{R_{490}}}
\]

Wherein, a and b constants are determined by least-squares regression method. Wherein a is -1.512, and b is 0.6004. The remaining 6 groups of measured data are utilized for accuracy test on the inversion model. The mean square root error RSME is 0.16kg/m³, the mean relative error is 23%, and \(R^2\) is 0.823.

In addition, a BP neural network inversion model was also constructed by measured suspended sediment data and the reflectivity of 8 bands. The input layer belongs to a remote sensing reflectivity data set which is extracted according to GOCI data center wavelength, and there are a total of eight neurons. The output layer belongs to suspended sediment concentration data with one neuron. 14 groups of data are regarded as data in the learning phase. Six groups of data are used for testing the accuracy of the model. Finally, a double hidden layer structure (8-17-17-1) is obtained through the trial and error method. Implicit layer function: tansig; output layer function: Purelin; target accuracy: 0.0001; learning efficiency: 0.1; number of iterations: 100. The remaining six groups of measured data are utilized to test the accuracy of the inversion model: the mean square root error RSME is 0.1kg/m³, the average relative error is 18%, and \(R^2\) is 0.9. Figure 3 shows the result comparison of three models. BP model is the best one and useful for the next work.
4. Suspended sediment inversion results
The current distribution status of 14 scene suspended sediment fields on June 6, 2015 (6 flood scenes) and May 12 (8 ebb scenes) are simulated on the basis of BP neural network model in the above section. The field change characteristics within one ebb and flow cycle are analysed according to tide level changes. Four inversion charts of SSC under different tide conditions were obtained as shown in Figure 4.

Figure 4. SSC maps obtained by analyzing satellite images in the Yongjiang Estuary during four tidal phases, which include the flood tide (a), high tide (b), ebb tide (c), and low tide.

5. Discussion and conclusion
In the above figure, the spatial distribution of suspended sediment in the sea areas outside Yongjiang estuary is elaborated as follows: the SSC in the north of Yongjiang estuary is higher than that in the south. In addition, the high concentration area of suspended sediment is not across Yongjiang estuary, and cannot reach the deep-water area on the south. The overall distribution law is closely related to the topographic factors. The silty shallows are distributed in the north with frequent sediment transportation, and the concentration of suspended sediment is generally high. The water depth of sea areas between the south Jintang Island and the south coast is relatively large. The bedrock coast in this area has low sediment concentration which is relatively small compared with that on the north. However, it is necessary to further analyze the migration law of suspended sediment outside the Yongjiang estuary, thereby avoiding deposit under the sluice gate after construction.

In the paper, geostationary satellite GOCI is regarded as the data source. Quick atmospheric correction and neural network suspended sediment inversion model is adopted for obtaining suspended
sediment concentration fields in sea areas outside Yongjiang estuary. The Daily variation characteristics within one ebb and flood cycle is analyzed. Main conclusions are shown as follows:

1. Spatial distribution characteristics: the high concentration distribution of suspended sediment in the sea areas outside Yongjiang estuary is mainly located in the north shallows and low concentration area with larger water depth between the south bank and Jintang Island.

2. Daily variation characteristic: it is affected by tides prominently. The suspended sediment concentration field in sea areas outside Yongjiang estuary suffers from obvious daily variation. The suspended sediment concentration is high under low tide level as a whole, and it is relatively low at high tide level.

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