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# Suspended Particle Size Retrieval Based on Geostationary Ocean Color Imager (GOCI) in the Bohai Sea

**Dejuan Jiang**[‡], **Hua Zhang**[‡*], **Tao Zou**[‡], **Yanfang Li**[‡], **Cheng Tang**[‡], **and Ruize Li**[#]

[‡] Key Laboratory of Coastal Environmental Processes and
Ecological Remediation
Yantai Institute of Coastal Zone Research
Chinese Academy of Sciences
Yantai, Shandong 264003, P. R. China

[#] Geographical Science and Planning School
Ludong University
Yantai, Shandong 264025, P. R. China

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## ABSTRACT

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The suspended particle size has an important effect on the settling velocity of particles, the penetration of sunlight into the sea and the transmission of sound. It is of importance to investigate the spatio-temporal distribution of suspended particle size. In this paper, a new empirical model was developed based on Geostationary Ocean Color Imager (GOCI) data for retrieving the median suspended particle size (d50), and then, the spatio-temporal variation in GOCI-retrieved d50 was analyzed over the Bohai Sea. The results showed that the new model gained the satisfactory retrieval results in the Bohai Sea. Spatially, median particle size in the Bohai Sea showed an obvious onshore-offshore gradient, which was smaller in the coastal waters, especially in the Laizhou Bay, the Bohai Bay, and the Liaodong Bay while larger at the Bohai strait and the northwest part of central Bohai Sea. Hourly variations of d50 data depicted the short-term dynamics of suspended sediments. The daily-averaged d50 had a similar pattern of spatial distribution and numerical values to the hourly data but with a distinct temporal variation. In addition, the findings of this study suggested the possible effects of tide, wind, turbulence and riverine input on the median particle size distribution.

**ADDITIONAL INDEX WORDS:** *Suspended particle size, GOCI, spatial distribution, temporal variation, Bohai Sea.*

## INTRODUCTION

Suspended sediments play an important role in physical, chemical and biological processes of the ocean (van der Lee *et al.*, 2009). For example, the suspended particle size has a big impact on the settling velocity of particles (Kostadinov *et al.*, 2009; Manning *et al.*, 2013; Markussen and Andersen, 2013), the transmission of sound (Bowers *et al.*, 2007; Rouhnia *et al.*, 2014), the penetration of sunlight into the sea and subsequent primary productivity (Astoreca *et al.*, 2012; Bowers *et al.*, 2009). Suspended particles absorb polluting matters such as heavy metals, persistent organic pollutants and radioactive materials which will therefore be transported and deposited in the sediments and further cause environmental and engineering problems (van der Lee *et al.*, 2009). Therefore, studies on the suspended particle size distribution (PSD) and the dynamics of suspended particles are of importance (Bowers *et al.*, 2007; Qing *et al.*, 2014; van der Lee *et al.*, 2009).

In turn, PSD is affected by tide cycle (Braithwaite *et al.*, 2012; Markussen and Andersen, 2014), turbulence (Braithwaite *et al.*, 2012; Renosh *et al.*, 2014), salinity gradient (Mari *et al.*, 2012; Ren *et al.*, 2014). In estuaries and coastal waters, PSD is also controlled by riverine input and human activities (Ahn *et al.*, 2012; Kolker *et al.*, 2014; Ren *et al.*, 2014; Smith *et al.*, 2011). For example, some previous studies have investigated the important role of turbulence in flocculation and floc break up (Markussen and Andersen, 2014; Renosh *et al.*, 2014). Braithwaite *et al.* (2012) found that the median particle size changed in a regular way by a factor of 3 or more over each tidal cycle and has a positive correlation with the Kolmogorov microscale (the size of the smallest turbulent eddies).

To determine particle size, different methods have been developed and most of them are made under laboratory conditions such as sieving, sedimentation, electrozone sensing (Coulter Counter) (Filippa *et al.*, 2011; Rawle, 2010). These methods are reasonably accurate in determining unconsolidated particle size distribution, but they disrupt particle aggregates that might be present in situ, especially in the coastal waters (Gartner *et al.*, 2001). Direct, undisturbed and in situ measurements of particle size in the sea can be made with floc cameras (Graham *et al.*, 2012; Manning *et al.*, 2013; Mikkelsen *et al.*, 2005) and laser diffraction instruments (such as Laser *In Situ* Scattering and Transmissometry, LISST) (Astoreca *et al.*, 2012; Braithwaite *et al.*, 2012; Filippa *et al.*, 2011; Renosh *et al.*, 2014). However, as with experimental observation or in situ measurement, the volume of water sampled and the length of the observing period are relatively short (Bowers *et al.*, 2007). The monitoring and retrieval

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[*] Corresponding author: hzhang@yic.ac.cn

of particle size based on remote sensing data is therefore required to provide the necessary spatio-temporal coverage (Bowers *et al.*, 2007; Kostadinov *et al.*, 2009; Qing *et al.*, 2014).

Bowers *et al.* (2007) developed a model to estimate the averaged size of particles suspended near the sea surface using Sea-viewing Wide Field-of-view Sensor (SeaWiFS) images, which can be applied to the mainly mineral, flocculated particles commonly found in tidally mixed shelf seas and estuaries. van der Lee *et al.* (2009) done some improvements to Bowers *et al.* model and applied it to Moderate Resolution Imaging Spectroradiometer (MODIS) data. Kostadinov *et al.* (2009) developed a novel bio-optical algorithm to retrieve the parameters of a power law particle size spectrum from monthly SeaWiFS imagery and estimated PSD at global scales. Qing *et al.* (2014) constructed a simple band ratio empirical model using the MERIS (MEdium Resolution Imaging Spectrometer) data and MODIS data to estimate the median size of inorganic suspended particles in the Bohai Sea.

However, the satellite data such as SeaWiFS, MODIS and MERIS images have a coarse resolution in terms of space and time. Limited by cloud coverage, good images is too few to reveal the dynamics of suspended particle and its size distribution. Fortunately, GOCI (Geostationary Ocean Color Imager) data has been launched in June, 2010 with a high spatial resolution of 500 m and having eight images every day, which can be used to observe the short-term changes in coastal zones and oceans and consider regional characteristics (Ryu *et al.*, 2012). In this study, we introduced a new model to retrieve the suspended particle size using the GOCI data based on the models of van der Lee *et al.* and Qing *et al.*, and investigated the spatio-temporal distribution of suspended particle size in the Bohai Sea.

## MATERIALS AND METHODS

### Study site

Bohai Sea (Figure 1), in the north China, is a semi-enclosed inner shelf sea, connecting to the Yellow Sea through the Bohai Strait (Bi *et al.*, 2011). It is a shallow sea with a mean depth of 18 m and the maximum depth is about 70 m at the Bohai Strait (Wang *et al.*, 2014). It has a total area of 77 000 km$^2$, consisting of three shallow bays of the Laizhou Bay, the Bohai Bay and the Liaodong Bay. There are more than 17 rivers delivering freshwater and sediment to the Bohai Sea, which four large to median-sized rivers are the Yellow River, the Haihe River, the Luanhe River and the Liaohe River (Figure 1), and the Yellow River has the highest water discharge and sediment load to the sea (Bi *et al.*, 2011; Ruddick *et al.*, 2012). The area surrounding the Bohai has a population of 260 million people and is the most economically developed region in North China, which is polluted due to the rapid industrialization and urbanization of the surrounding area in the past 30 years (Hu *et al.*, 2009).

River discharge, resuspension, human activities and exchange with water masses of the Yellow Sea are the factors influencing the spatio-temporal pattern of suspended particle matters in the Bohai Sea (Cui *et al.*, 2010; Qing *et al.*, 2014). The constituents of suspended particle matters in the estuarine and coastal waters are mainly inorganic small particles from the land, and then biogenic particles such as organic debris, skeletons, organic films in the central Bohai Sea and the Bohai Strait (Jiang *et al.*, 2000; Qin *et al.*, 1982; Qing, 2011; Yang *et al.*, 1989). In the seabed of the Bohai Sea, the surface sediments are generally fine, consisting of soft clay mud, fine silt mud, coarse silt and fine sand (Jiang *et al.*, 2000). In the Yellow River (Huanghe) estuary adjacent waters and the Bohai Bay, clayey silt is the main composition of the sediments and most of particles are smaller than 0.01 mm in size (Qin *et al.*, 1985). On the southern and southeastern Laizhou Bay, fine-grained sediments appear to be limited to patches, and sandy and silty sediments occur occasionally (Qiao *et al.*, 2010). In the Liaodong Bay, the sediments are mainly composed by silt and fine sand while find sand in the central Bohai Sea (Jiang *et al.*, 2000; Yu, 2011).

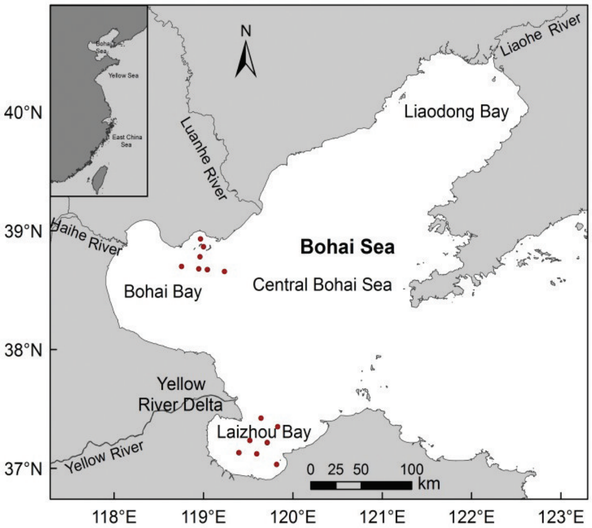

Figure 1. Location of the Bohai Sea and in situ measurements (red circles)

### Field survey

Two cruises over the Bohai Sea were conducted in 2014, respectively in spring (19/04-05/05) and summer (11/08-05/09). At each sampling station, the suspended particle size distribution was measured using the LISST-100X instrument. The LISST uses the diffraction of a laser by particles to perform a non-intrusive measurement of the volume concentration of suspended particles (Ouillon *et al.*, 2010), having diameters ranging from 2.5 to 500 μm in 32 size classes in logarithmic scale (Hill *et al.*, 2013; Renosh *et al.*, 2014). It is a widely used instrument for in situ measurements of the size distribution of suspended matters in estuarine and marine waters (Agrawal and Pottsmith, 2000; Hill *et al.*, 2013; Markussen and Andersen, 2013; Renosh *et al.*, 2014).

### GOCI data

GOCI is the world's first geostationary ocean color satellite and has been developed by Korea Aerospace Research Institute (KARI) and EADS Astrium according to the user requirements assigned by Korea Ocean Research & Development Institute (KORDI) (Ryu *et al.*, 2011). GOCI has six visible bands with band centers of 412 nm, 443 nm, 490 nm, 555 nm, 660 nm and

680 nm, and two near-infrared bands with band centers of 745 nm and 865 nm. It covers the 2 500 km×2 500 km square around Korean peninsula centered at 36°N and 130°E with about 500 m of ground sampling distance (GSD) and it can acquire the data eight times a day during the daytime (from 00 AM to 07 AM UTC). This spatio-temporal resolution of the GOCI is very efficient to real-time monitor the short-term changes in the Northeast Asian waters surrounding the Korean peninsular, such as the diffusion and movement of suspended particulate matters, dissolved organic matters and the other polluted materials, the formation and decay of red tides, and ocean disasters (He *et al.*, 2013; Ruddick *et al.*, 2012; Ryu *et al.*, 2012).

In this study, GOCI Level 1B products, the top of atmosphere radiance, were obtained from the Korea Ocean Satellite Center (KOSC) for the period of 19th April to 5th May and 11th August to 5th September of 2014. The full region was cropped to the Bohai Sea and then atmospherically corrected using the GOCI Data Processing Software (GDPS), version 1. 2. 0 (dated 20130308), to give level 2 (L2) data for the remote sensing reflectance, $R_{rs}$, defined as the water-leaving radiance divided by the above-water downwelling irradiance for the further retrieval of PSD. No-cloud GOCI $R_{rs}$ was selected and the time difference between GOCI overpass and in situ measurement was less than 6 h. Totally 17 groups of matched GOCI $R_{rs}$ were extracted on spring (19/04-05/05) and summer (11/08-05/09), 2014 (Figure 1).

## Tide and wind data

The tide data at Laizhou Port tidal station in the Bohai Sea was gained from the Tide Table Book of 2014, which was edited by the National Marine Data and Information Service, China. Daily wind data on May 5, August 12 and September 4, 2014 was retrieved by ASCAT (Advanced SCATterometer) images with the spatial resolution of 0. 25°×0. 25°.

## Retrieval model

The models developed by Bower *et al.* (2007), van der Lee *et al.* (2009) and Qing *et al.* (2014), respectively, and GOCI data were used to estimate the median particle size (d50) over the Bohai Sea. But the retrieved results were not satisfactory. One possible reason was that remote sensing data and bands used for d50 estimation were different and another was probably the difference in the study area or in situ measurement method for the use of model development and validation (Table 1). However, we also found that d50 closely related to the remote sensing reflectance ($R_{rs}$). Therefore, we established a new model (Table 1) based on the relationship between measured d50 data and the remote sensing reflectance ($R_{rs}$) derived from GOCI data.

The retrieved results of median particle size over the Bohai Sea were assessed using 5 performance indicators, including the correlation coefficient (*CC*), the mean error (*ME*), the mean absolute error (*MAE*), the relative bias (*BIAS*), the root mean square error (*RMSE*) (Jiang *et al.*, 2012). *CC* was used to assess the agreement between the retrieved and measured d50. *ME* was used to scale the average difference between the retrieved and measured d50, whereas *MAE* was used to represent the average magnitude of the error. *BIAS* described the systematic bias of the retrieved d50. *RMSE*, which gave a greater weight to the larger errors relative to *MAE*, was used to measure the average error magnitude. The formulas were listed as follows:

$$CC = \frac{\sum_{i=1}^{n}(G_i - \bar{G})(S_i - \bar{S})}{\sqrt{\sum_{i=1}^{n}(G_i - \bar{G})^2} \times \sqrt{\sum_{i=1}^{n}(S_i - \bar{S})^2}} \tag{1}$$

$$ME = \frac{1}{n}\sum_{i=1}^{n}(S_i - G_i) \tag{2}$$

$$MAE = \frac{1}{n}\sum_{i=1}^{n}|S_i - G_i| \tag{3}$$

Table 1. *d50 quantitative retrieval models*

| Authors | Model | Data/bands | *In situ* measurement method | Study area | Indicators |
|---|---|---|---|---|---|
| Bower *et al.* (2007) | $d50 = A/b^*$, $b^* = R(a_w + a_m{}^* MSS + a_x)/(f\gamma MSS)$, $R = 1.84nLW/F_0 = 1.84\pi R_{rs}$, $MSS = 0.2 + 20.8\ R_{rs}(665)/R_{rs}(555)$, $A = 27$, $a_w = 0.43$, $a_m{}^* = 0.021$, $a_x = 0$, $f = 0.44$, $\gamma = 0.019$ | SeaWiFS/665nm | LISST-100B | Irish Sea | $R^2 = 0.79^{\#}$ |
| van der Lee *et al.* (2009) | $d50 = A/b^*$, $b^* = 2.32(R_{rs}(665) + R_{rs}(555))$, $A = 27$ | MODIS/555nm, 665nm | LISST-100B | Irish Sea | $R^2 = 0.75^{+}$ |
| Qing *et al.* (2014) | $\lg(d50) = aR_{rs}(560)/R_{rs}(665) + b$, $a = 0.137$, $b = 0.667$ | MERIS/560nm, 665nm | Malvern Mastersizer 2000 | Bohai Sea | $R^2 = 0.49$, $e = 27.0\%$, $RMSD = 4.31\mu m$ |
| Ours | $\lg(d50) = a(R_{rs}(555) + R_{rs}(660)) + b$, $a = -9.201$, $b = 1.6817$ | GOCI/555nm, 660nm | LISST-100X | Bohai Sea | $R^2 = 0.51$, $CC = 0.72$, $BIAS = -3.24\%$, $RMSE = 8.09\mu m$ |

Note: $^{\#}$ indicated that $R^2$ was the coefficient of determination between the observed and algorithm $b^*$, not $d50$; $^{+}$ indicated that $R^2$ was the coefficient of determination between $b^*$ and the sum of $R_{rs}(665)$ and $R_{rs}(555)$, $e$ was the average percent difference, and *RMSD* was the root mean squared deviation.

$$BIAS = \frac{\sum_{i=1}^{n}(S_i - G_i)}{\sum_{i=1}^{n} G_i} \times 100\% \quad (4)$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(S_i - G_i)^2} \quad (5)$$

where $n$ was the total amount of in situ data or remote sensing data; $G_i$ and $S_i$ were the $i$th values of the measured and retrieved values, respectively; $\bar{G}$ and $\bar{S}$ were the mean values of measured and retrieved values, respectively.

## RESULTS AND DISCUSSION

### Evaluation of retrieval model

The relationship between lg(d50) and $R_{rs}(555)$, $R_{rs}(660)$, $(R_{rs}(660)+R_{rs}(555))$, $R_{rs}(555)/R_{rs}(660)$, $R_{rs}(660)/R_{rs}(555)$, respectively, was analyzed, and lg(d50) was found to have a goodness fit with $R_{rs}(555)$, $R_{rs}(660)$ or $(R_{rs}(660)+R_{rs}(555))$ but had a weak correlation with $R_{rs}(555)/R_{rs}(660)$ or $R_{rs}(660)/R_{rs}(555)$. In contrast, lg(d50) more strongly correlated with the sum of $R_{rs}(660)$ and $R_{rs}(555)$ than $R_{rs}(555)$ or $R_{rs}(660)$ (Figure 2a–c). Moreover, the established model based on the relationship between lg(d50) and the sum of $R_{rs}(660)$ and $R_{rs}(555)$ had better retrieved results (Table 2, Figure 2d), and 5 indicators of *CC*, *ME*, *MAE*, *BIAS*, and *RMSE* were 0.72, −1.00 μm, 6.41 μm, −3.24% and 8.09 μm, respectively. Also, we observed that this model underestimated the median particle size (Figure 2d, Table 2), possibly due to some uncertainty from the LISST field measurement, the remote sensing monitoring, the retrieval model itself, or their combination. In general, the retrieved results were satisfactory for the study area, and thus, this model was selected to analyze the spatio-temporal distribution of median suspended particle size over the Bohai Sea.

### Spatio-temporal variation in median particle size

The spatial distribution and hourly variations in the median suspended particle size over the Bohai Sea were shown in Figure 3, taking September 4, 2014 as an example.

A strong onshore-offshore gradient of depth-averaged d50 was observed over the Bohai Sea, which appeared to be opposite to the spatial distribution of total suspended sediment (TSS) concentration (Ruddick *et al.*, 2012). In general, d50 ranged from about 10 μm to 30μm in the coastal waters and around 40 μm in the offshore and deeper waters. Particles were smallest in the Bohai Bay, the Laizhou Bay, the Liaodong Bay with high turbidity and high TSS concentration, suggesting a potential effect of riverine transport and salinity gradient on the spatial distribution of d50

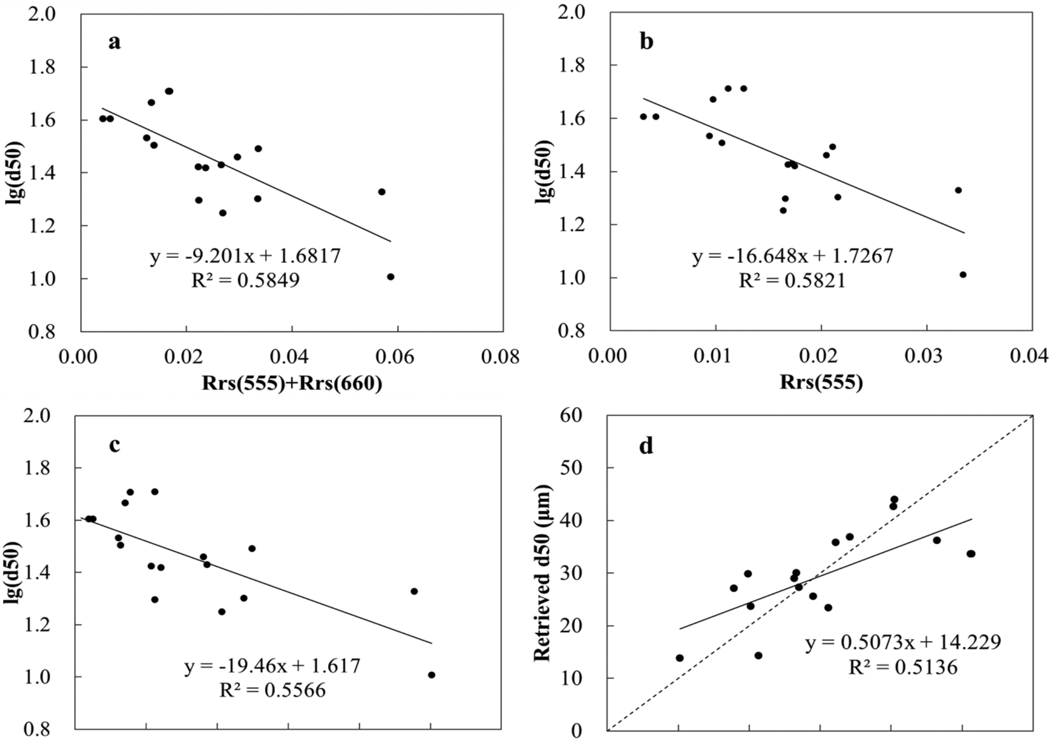

Figure 2. The retrieval model (a, b, c) and the comparison between measured and selected model-retrieved d50 (d) ($p$=0.01 for Figures a–d; the number of samples was 17)

Table 2. *Indicators of 5 retrieval models*

| Variables | Model | *CC* | *ME* (μm) | *MAE* (μm) | *BIAS* (%) | *RMSE* (μm/%) |
|---|---|---|---|---|---|---|
| $R_{rs}(555)+R_{rs}(660)$ | $\lg(d50)=a(R_{rs}(555)+R_{rs}(660))+b$,<br>$a=-9.201, b=1.6817$ | 0.72 | -1.00 | 6.41 | -3.24 | 8.09/26.16 |
| $R_{rs}(555)$ | $\lg(d50)=aR_{rs}(555)+b$,<br>$a=-16.648, b=1.7267$ | 0.71 | -0.95 | 6.51 | -3.08 | 8.17/26.43 |
| $R_{rs}(660)$ | $\lg(d50)=aR_{rs}(660)+b$,<br>$a=-19.46, b=1.617$ | 0.69 | -1.11 | 6.45 | -3.58 | 8.38/27.13 |
| Rrs(555)/Rrs(660) | $\lg(d50)=a(R_{rs}(555)/R_{rs}(660))+b$,<br>$a=0.1377, b=1.112$ | 0.52 | -1.46 | 7.32 | -4.74 | 9.97/32.24 |
| Rrs(660)/Rrs(555) | $\lg(d50)=a(R_{rs}(660)/R_{rs}(555))+b$,<br>$a=-0.7576, b=1.7936$ | 0.56 | -1.32 | 7.32 | -4.27 | 9.66/31.27 |

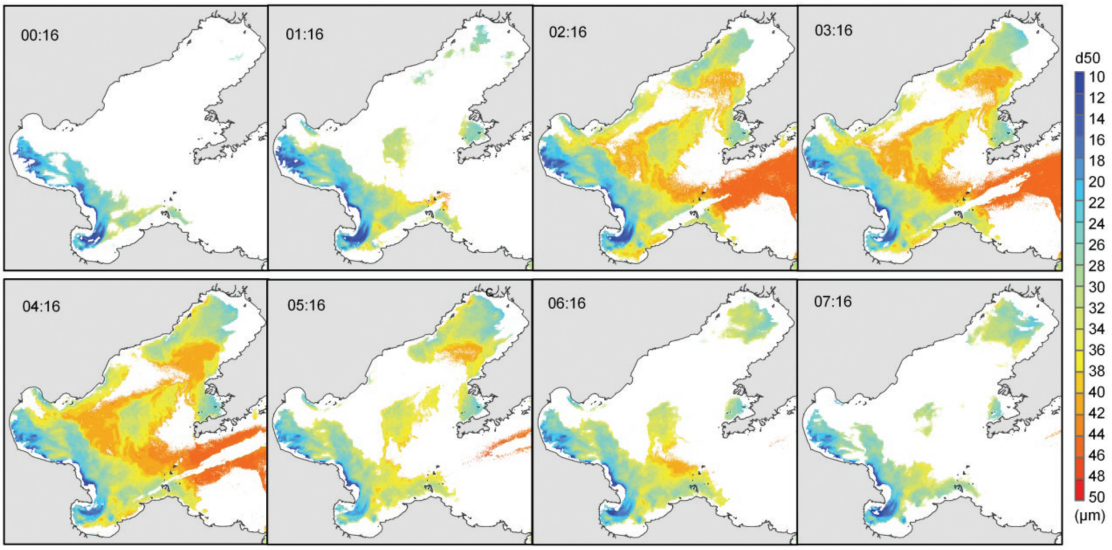

Figure 3. GOCI-retrieved d50 data for September 4, 2014 from 00:16 to 07:16 UTC, every hour (Clouds and invalid data were shown in white; Land was shown in grey)

(Mari *et al*., 2012). There are several great rivers flowing into the Bohai Sea, such as the Yellow River into the Laizhou Bay, the Haihe River into the Bohai Bay, the Liaohe River into the Liaodong Bay (Figure 1). Therefore, large number of inorganic suspended particles was transported from rivers into the sea and resulted in small particles appearing near the coast. Also, the tide-generated turbulence along the coasts brought fine-grained sediments into resuspension or broke up aggregates into small-sized particles (Bowers *et al*., 2007; Markussen and Andersen, 2014). However, it should be noted that d50 was relatively large on the southern and southeastern Laizhou Bay (Figure 3), possibly because the sediments of find sand and silt fractions were carried into resuspension by the tide currents and wave action. In contrast, d50 was larger in the offshore waters, and the largest at the Bohai Strait and the northwest part of central Bohai Sea. Low turbulence and low TSS concentration appeared in these waters and suspended particles collision may be easy to cause flocculation or aggregation. Moreover, the large particle size in the offshore waters was also attributed by the composition of biogenic particles.

Compared with earlier studies, the median particle size in our study had a similar spatial pattern to the MODIS-retrieved results by Qing *et al*. (2014). Numerical values were in accordance with those (the Yellow River estuary) by Zhou *et al*. (2007), but higher than those by Qing *et al*. (2014), mostly because of a difference in the *in-situ* measurement method used for the model development. For the studies of Zhou *et al*. (2007) and ours, the observed data of particle size were gained through LISST-100X measurement. LISST deemed flocs or aggregates as an entity (a single particle) (Bowers *et al*., 2009). But in the study of Qing *et al*. (2014), the particle size was measured through laboratory analysis, which water samples were filtered and processed by $H_2O_2$ and HCL and aggregates were be disrupted. In this case, organic particles were neglected and the particle size was much smaller than those determined by the LISST instrument.

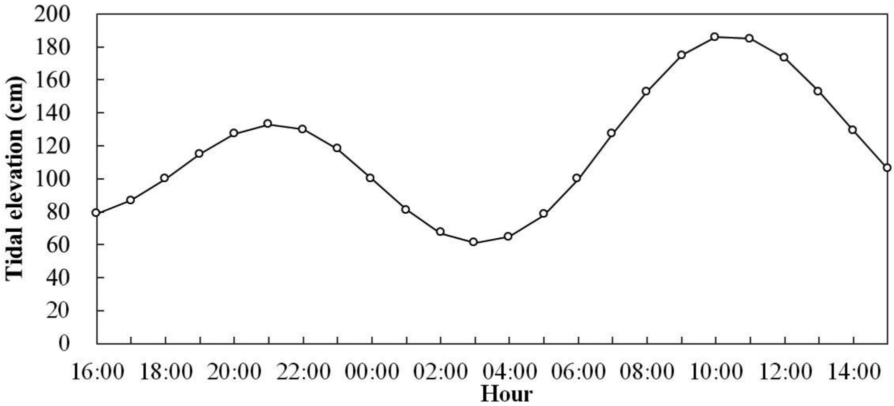

Figure 4. Tidal elevation observed at Laizhou Port tide stations from 16 : 00 UTC of September 3 to 15 : 00 UTC of September 4, 2014

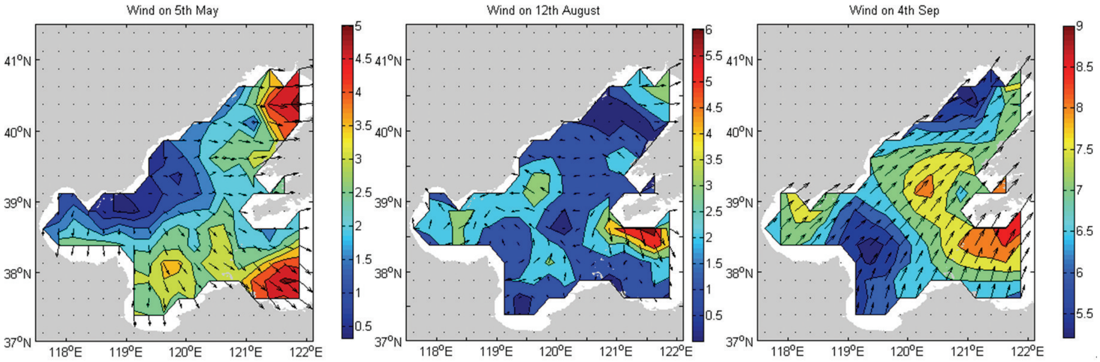

Figure 5. The daily wind speed (m/s) derived from ASCAT images on May 5, August 12 and September 4, 2014

Previous studies found that in the Bohai Sea, the semidiurnal tide played a significant role in the dynamics of the ocean environments and sediment dynamics (*e.g.*, Guo *et al.*, 1998; Son *et al.*, 2014). Hourly variations in GOCI-derived products could provide knowledge of short-term dynamics of suspended sediments over the coastal region which was influenced by tide. Seen from Figure 3, median particle size in the west part of Laizhou Bay increased from 01:16 to 05:16 and then decreased through 07:16 on September 4, corresponding to the tidal stage when the tidal elevation decreased and reached its least level at about 4:00 o'clock and then increased at Weifang Port tide station, located in the west part of Laizhou Bay (Figure 4, the peak or valley of tidal elevation at Weifang Port tide station lagged behind Laizhou Port tide station by about an half hour). Ebb flow started around 1 hour after the high tide, and the tidal currents would be at its maximum around 3-4 hours after the high tide (Lee *et al.*, 2013; Son *et al.*, 2014). Therefore, the ebb flow in the west part of Laizhou Bay might reach the maximum around 1:00 o'clock, corresponding to the least median particle size in the GOCI-retrieved d50 map (Figure 3). And then, it started to decrease and reached low slack tide at about 4:00 o'clock, corresponding to the increase in median particle size for this period. After slack tide, the tidal current turned into the flood flow from about 5 : 00 o'clock, corresponding to the decrease in the median particle size from 05 : 16 to 07 : 16. This finding implied that the median particle size might have a sensitive response to tidal dynamics, and particles aggregated at times of low turbulence and broke up during fast flows (Braithwaite *et al.*, 2012). Also, fast flows could lead to sediment (clayey silt) resuspension and then small particles suspended in the surface waters. Seen from Figure 5, the daily wind speed on September 4 in the west part of Laizhou Bay was 5.5 m/s, which also might have an influence on the short-term variation in d50. However, it, generally, seemed that the median particle size changed more with the tide variation.

Figure 6 indicated the daily-averaged d50 maps on May 5, August 12 and September 4 of 2014, which were made respectively from their 8 instantaneous maps. Compared with any individual instantaneous map (Figure 3), taking September 4 for example, the daily average (Figure 6) was observed to have more valid pixels, which exhibited the advantage of GOCI data to maximally avoid the cloud disturbance and provide the good quality data for the analysis of ocean environment. Seen from Figure 3 and Figure 6, the spatial patterns and numerical values of the daily average on September 4 were generally similar to its instantaneous maps. However, a prominent difference in numerical values was found for 3 days of May 5, August 12 and September 4. Median particle

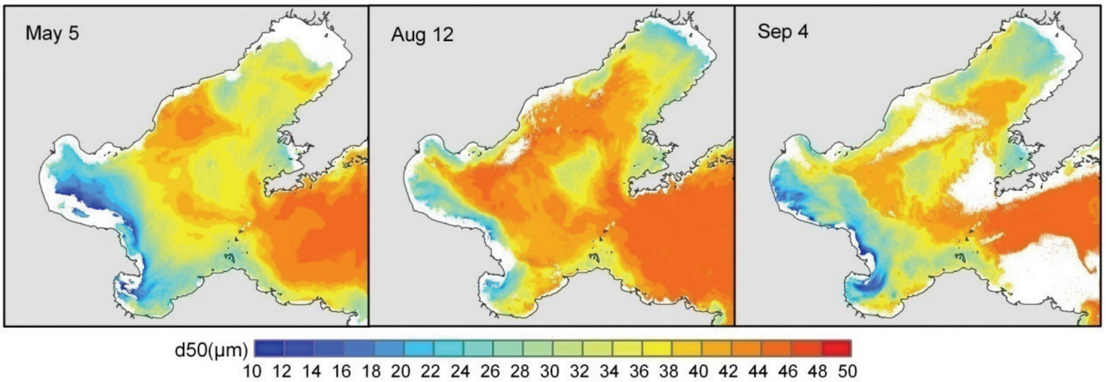

Figure 6. Daily average for GOCI-retrieved d50 data on May 5, August 12 and September 4 of 2014

size was larger on August 12 than that on May 5 and September 4. The wind speed was lower on August 12 than that on May 5 and September 4, although it was not high for these three days (Figure 5). Wind could increase turbulence and resuspension and in turn lead to higher suspended sediment concentration and lower particle size (Bi *et al.*, 2011; van der Lee *et al.*, 2009). In addition, the nutrient flux into the Bohai Sea was high in summer (Lin *et al.*, 2008; Wu *et al.*, 2013; Zhang *et al.*, 2012), which could increase the algae population and further accelerate the flocculation process over the Bohai Sea.

## CONCLUSIONS AND OUTLOOK

Based on the GOCI data and in-situ measurement data, a new empirical model was developed to retrieve the median suspended particle size (d50) and further, the spatial variation and temporal dynamics in d50 were investigated over the Bohai Sea. The results showed that the new model produced relatively good retrieved results and it could be used to estimate the median particle size over the Bohai Sea. Spatially, d50 indicated a distinct onshore-offshore gradient in the Bohai Sea, which ranged from about 10 μm to 30μm in the coastal waters and around 40 μm in the offshore and deeper waters. It was smallest in the high turbid waters such as the Bohai Bay, the Laizhou Bay, the Liaodong Bay, but largest at the Bohai strait and the northwest part of central Bohai Sea. Hourly variations in GOCI-retrieved d50 at 8 time intervals exhibited the short-term dynamics of suspended sediments, which were obvious at the west part of Laizhou Bay (taking September 4 for instance). A similar pattern of spatial distribution and numerical values was observed between the daily-averaged and the hourly d50 data but the daily value had a noticeable temporal variation. Additionally, this study also discussed the effects of tide, turbulence, wind, riverine input on the distribution of the median particle size over the study area.

In the future studies, the observed data of hourly wind data, salinity gradient, riverine input of discharge and sediment are necessarily combined with hydrological modeling to quantitatively explain their effects on the particle size distribution and sediment dynamics. Biological (such as red tides or algal blooms) effects on flocculation and floc breaking up would be expected to be investigated in the future. Long-term time series of GOCI data would be considered to analyze the seasonal and inter-annual variability in PSD. Also, it is importance of parting suspended particles into the organic and inorganic to know the dynamics of suspended particles and sediment-induced environmental effects. In addition, uncertainty lies in the LISST measurement, which in turn influences the accuracy of the retrieved results by the remote sensing data. Therefore, spectral measurements are suggested to be conducted to make up for this deficiency.

Overall, this study gave a good knowledge of the spatial distribution and temporal variation (short and long term) in the median suspended particle size over the Bohai Sea, which will be helpful for understanding sediment dynamics and their environmental effects.

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