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Application of MODIS data in monitoring suspended sediment of Taihu Lake, China*

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Abstract Application of MODIS in ocean color is mainly based on bands 8–16 with the spatial resolution of 1 000 m. This spatial resolution, however, can not meet the application demand of inland waters where the areas are relatively small. With the assumption of the black water at shortwave infrared (SWIR) wavelengths (>1 000 nm), we first propose an atmospheric correction method for bands 1 and 2 with their spatial resolution of 250 m, and we then establish a quantitative retrieval model for suspended sediment concentration retrieval using the *in-situ* data collected in Taihu Lake. We also use MODIS data to retrieve the suspended sediment concentration of Taihu Lake with the retrieval model. The comparison between the retrieved and measured suspended sediment concentrations confirms that our algorithm can provide reliable data for monitoring the suspended sediment in Taihu Lake.

Keyword: Suspended sediment concentration; MODIS; atmospheric correction; Taihu Lake

1 INTRODUCTION

The process of traditional methods for water quality monitoring mainly includes the collection and laboratory analyses of water samples. Then, the water quality is evaluated based on the results of laboratory analyses. These methods are more precise, but they are carried out on the limited water samples thus may not reflect the overall transformation of the water quality. Particularly, the traditional methods can not perform and realize the real-time monitoring. Remote sensing can observe over a large area at the same time. Water quality monitoring by remote sensing can reflect the variation of water quality on different time and space scales and is able to detect the pollution sources and pollutant movement. Therefore, using remote sensing to monitor water quality has attracted considerable attention and the approach has become a research hotspot in the field of oceanography.

Many studies have been done using remotely sensed data for water quality monitoring. Tassan (1993) established a three-component model and used this model to retrieve suspended sediment concentration (SSC) from TM data. Moore et al. (1999) developed an algorithm and used the marine reflectance ratios between the different bands to retrieve SSC. The ratios include the one between the different visible bands and the one between the different near-infrared (NIR) bands. These studies demonstrated that in the areas with low SSC, results retrieved from the two ratio algorithms described above can agree well with each other, but in the areas with high SSC, the NIR ratio algorithm works better than the other one does. Application of their algorithms to MERIS demonstrated that it is possible to retrieve SSC within ±50% error. Taking the reflectance ratios between the near-infrared and visible bands into consideration, Doxaran et al. (2003) showed that these ratios had high correlation with SSC. Doxaran et al. (2002) also found an empirical relationship between the SSC and remote sensing reflectance ratio which is between NIR and visible bands of SPOT-HRV. They then used this relationship to retrieve SSC in the Gironde estuary in France from SPOT-HRV data with precision better

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than ±35%. Miller and McKee (2004) used MODIS Terra 250 m imagery to map the distribution of suspended sediment in the northern Gulf of Mexico and found a linear relationship between SSC and water reflectance of MODIS Terra band 1. Their study demonstrated that the MODIS Terra could provide data well suited for monitoring the dynamic change of SSC in coastal waters. Chen et al. (2007) established an empirical relationship between the turbidity and the remote sensing reflectance of MODIS band at 645 nm and applied this relationship to retrieve the turbidity of Tampa Bay. Using SeaWiFS data, Deng et al. (2003) studied the three-dimensional distribution of suspended sediment in Changjiang (Yangtze) estuary and Hangzhou Bay, but their algorithm only applied to the water with SSC between 10 and 100 mg/L. Warrick et al. (2004) used SeaWiFS data to retrieve SSC in the Santa Barbara Channel. Han et al. (2006) retrieved SSC of Changjiang River estuary using CMODIS data. Yuan et al. (2001) analyzed the correlation between the SSC of DianChi and TM data. They then established a model to retrieve SSC of DianChi using TM data. Wang et al. (2007) used principal component analysis method to retrieve SSC of Taihu Lake using MODIS data. Other studies for SSC retrieval using remote sensing approach have been done worldwide (Hellweger et al., 2004; Wang, 2004; Li, 1986; Yin et al., 2005; Ma et al., 2005; Lv et al., 2005).

MODIS on the satellites of both the Aqua and Terra has 36 bands and three spatial resolutions including 250 m, 500 m and 1 000 m. MODIS data has a near daily coverage and is free for public, making it applicable to dynamic monitoring on large scale. At present, the software used in ocean color atmospheric correction for MODIS is SeaDAS, which uses bands 8–16 with spatial resolution of 1 000 m. The low spatial resolution can not meet the application demand of inland waters with small area. MODIS has two bands whose spatial resolution is 250 m and these two bands have sufficient sensitivity to monitor the changes in color for inland waters (Hu et al., 2004). Several studies have demonstrated that these two bands have potential to monitor the water quality of inland waters (Hu et al., 2004; Miller et al., 2004). As a result, we focus our study on monitoring suspended sediment of inland waters using MODIS data. For the 1 000 m and 250 m spatial resolution data of MODIS-Terra, they are not well calibrated and contain more noise compared with the MODIS-Aqua data (Hu et al., 2004). Then, our study is focused on using MODIS-Aqua data, but the approach developed in this study can be applied to MODIS-Terra data as well.

Taihu Lake is located in the Changjiang delta and is the third largest freshwater lake in China with an area of about 2 338 km^2. Taihu Lake is a multifunctional supplier for drinking water, irrigation, shipment, tour, aquiculture and industry and plays an important part in people's daily life and industrial production in the region. With the rapid economic development in Taihu Lake valley, the environmental contamination is becoming a serious problem, especially the water pollution and eutrophication. The bad water quality has serious negative influence on the sustainable development of the nature, society and economy in Taihu Lake valley. Thus, it is important to study and assess the water quality of Taihu Lake.

The purpose of this study is to develop an approach for application of MODIS 250 m data for monitoring SSC of Taihu Lake. We first put forward an atmospheric correction method that can meet the application demand of inland waters. We call it atmospheric correction algorithm for high spatial resolution bands of MODIS. Then, we establish a SSC quantitative retrieval model using the in-situ data. Finally, using MODIS data, we retrieve the SSC in Taihu Lake.

2 DATA AND METHODS

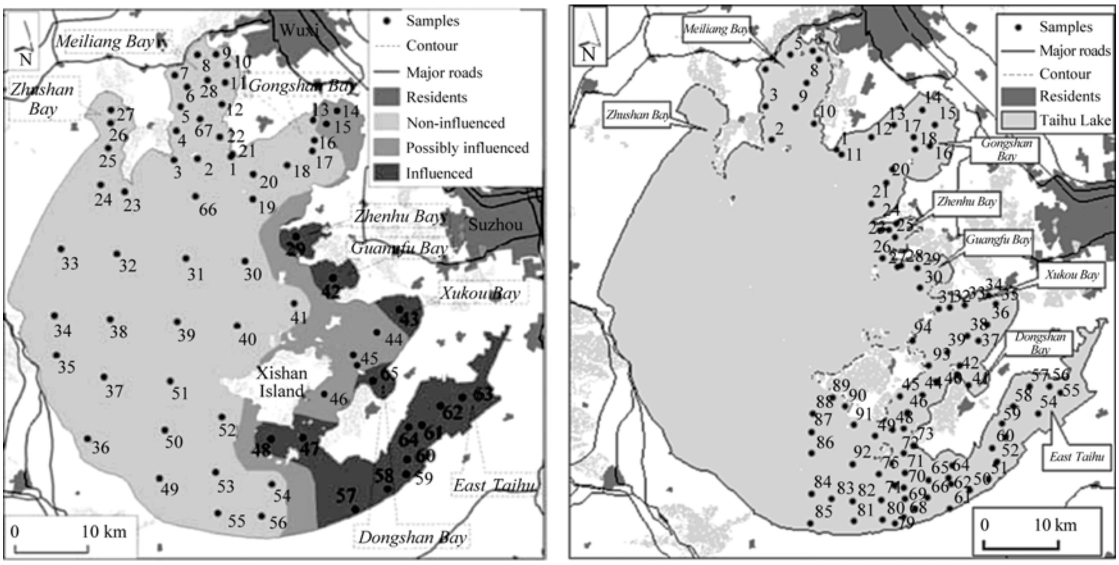
2.1 IN-SITU DATA

Two cruises (2004 autumn cruise and 2007 summer cruise) were carried out during Oct. 10–29, 2004 and June 10–18, 2007 to Taihu Lake. The water spectra and concentrations of the three components (Ma et al., 2006) were measured. There were 67 cast stations for the autumn cruise. We measured the water spectra for 66 cast stations. Spectra data of station No. 48 was not measured due to the weather. There were 94 cast stations for the summer cruise. Among these 94 cast stations, both water spectra and concentrations of the three components were measured for 75 stations. For the other 19 stations, only concentrations of the three components were measured. The cast stations for the autumn and summer cruises are shown in Fig.1. Measurement of the parameters is detailed in Ma et al. (2006). The Remote Sensing Reflectance (R_{rs}) spectra measured during the autumn cruise are shown in Fig.2.

2.2 ATMOSPHERIC CORRECTION

The total radiance L_t, at a wavelength λ, received by sensor is given as (Robinson, 2004):

$$L_t(\lambda)=L_r(\lambda)+L_a(\lambda)+tL_f(\lambda)+TL_g(\lambda)+tL_w(\lambda) \quad (1)$$



a b

Fig.1 Cast stations of Taihu Lake cruises

a. 2004 autumn cruise; b. 2007 summer cruise

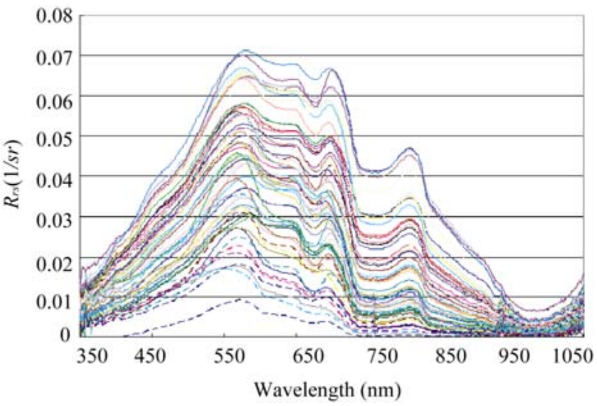


Fig.2 R_{rs} spectra measured in 2004 autumn cruise

The term of the parameters in Eq.1 is detailed in Gordon et al. (1994a). The purpose of atmospheric correction is to remove the atmospheric and ocean surface effects from Eq.1 and to get the L_w term which has the water information.

On the equation, we put forward an atmospheric correction algorithm for Taihu Lake that is relatively turbid and small. This algorithm uses SWIR wavelengths to realize the correction of MODIS bands 1, 2 whose spatial resolution is 250 m. The bands used in this study are listed in Table 1. The algorithm is detailed as following: For productive waters (e.g., pigment concentration > ~2 mg/L (Ma et al., 2007)) and inland waters with high sediment concentration, the NIR L_w can be significant (Siegel et al., 2000; Ruddick et al., 2000; Wang et al., 2005). Many studies have been conducted for the purpose of eliminating the effect of NIR L_w (Hu et al., 2000; Lavender et al., 2005; Ruddick et al., 2000). However, all these studies had limitations because of the complexity of inland waters. For the SWIR wavelengths, the fresh water has significant larger absorption ability than that for the NIR wavelengths and the absorption increases rapidly with the increase of wavelengths (Haleet et al., 1973). Then, with the assumption of black water at the SWIR wavelengths, we realize the atmospheric correction of MODIS bands 1 and 2.

Table 1 MODIS bands used in this study

Band	1	2	5	6	7
Bandwidth/nm	620-670	841-876	1230-1250	1628-1652	2105-2155
Center-wavelength/nm	645	859	1240	1640	2130

2.2.1 L_r

L_r of bands 8–16 can be calculated precisely from exact Rayleigh Look Up Table (Gordon et al., 1988; Wang, 2005). We then can get L_r of bands 1, 2 from that of bands 13, 16 (1 and 13, 2 and 16 are respectively the nearest bands):

$$L_r(\lambda_i)/L_r(\lambda_j) = L_{rs}(\lambda_i)/L_{rs}(\lambda_j) = \tau_r(\lambda_i) F'_0(\lambda_i)/(\tau_r(\lambda_j)F'_0(\lambda_j)) \quad i=1, 2 \quad j=13, 16 \quad (2)$$

where L_{rs} is the single-scattering term of L_r, τ_r is the optical thickness of air molecule, and F'_0 is the instantaneous extraterrestrial F_0 reduced by two strips through the ozone layer, then:

$$F'_0 = F_0 \exp[-\tau_{oz}(1/\cos\theta_v + 1/\cos\theta_s)] \quad (3)$$

where θ_v, θ_s, τ_{oz} are the satellite zenith angle, the solar zenith angle and ozone optical thickness, respectively, The L_r of SWIR bands comprises such a small part in the total radiance and it can be calculated by single-scattering algorithm (Gordon et al., 1989).

2.2.2 L_a

For the calculation of L_g, we first calculate sun glint coefficient based on Cox et al. (1954). The influence of sun glint can be neglected if the coefficient is smaller than the threshold (0.0001 in our algorithm). Otherwise, L_g can not be neglected and it can be calculated based on Wang et al. (2001). L_f is calculated based on Gordon et al. (1994b).

We get $L_a(\lambda)$ (λ=1 240 nm, 2 130 nm. The reason for choosing 1 240 nm and 2 130 nm is detailed in Wang (2007)) from Eq. 1 with the assumption that L_w (1240) and L_w (2130) can be neglected. From Wang et al. (1994):

$$L_a(\lambda_i)F'_0(\lambda_j)/ L_a(\lambda_j)F'_0(\lambda_i) = \varepsilon(\lambda_i, \lambda_j) = \exp[c(\lambda_j - \lambda_i)] \quad (4)$$

we can get parameter c which is related to the aerosol type. Then, L_a of bands 1, 2 can be calculated from:

$$L_a(\lambda_i) = L_a(\lambda_5)\, F'_0(\lambda_i) \exp[c(\lambda_5 - \lambda_i)]/ F'_0(\lambda_5) \; i=1,2 \quad (5)$$

We choose L_a (λ_5) as the basis for aerosol extrapolation because that the L_a can usually be more accurately extrapolated for shorter wavelength distance than for the longer one (Wang, 2007). So far, the L_a of bands 1, 2 is obtained and we then have L_w from Eq.1:

$$L_w(\lambda_i) = (L_t(\lambda_i) - L_r(\lambda_i) - L_a(\lambda_i) - tL_f(\lambda_i) - TL_g(\lambda_i))/t \quad i=1,2 \quad (6)$$

2.3 SSC RETRIEVAL MODEL

The reflectance of wavelength domain 700–900 nm is more sensitive to the change of SSC (Mahtaba et al., 1998) and thus it is the best choice for SSC retrieval. We use band 2 to retrieve SSC in Taihu Lake. The model for SSC retrieval is based on the R_{rs} of band 2. Then, we can translate L_w into R_{rs}:

$$R_{rs} = L_w/ (t_s \cos\theta_s F'_0) \quad (7)$$

t_s is the diffuse transmittance from the sun to water.

Before establishment of the retrieval model, we have to translate the in-situ hyperspectral R_{rs} into R_{rs} (λ_2), with λ_2 the center-wavelength of band 2, by means of band-equivalent calculation (Gordon, 1995):

$$R_{rs}(\lambda_2) = \int s(\lambda)\, R_{rs}(\lambda)\, d_\lambda / \int s(\lambda)\, d_\lambda \quad (8)$$

$S(\lambda)$ is spectral response.

Using the R_{rs} and SSC measured during 2004 autumn cruise, we then establish a SSC quantitative retrieval model by means of least-square fitting method:

$$\log_{10}(\text{SSC}) = 0.3568 \ln (R_{rs}(\lambda_2)) + 3.3431 \quad (9)$$

SSC is in mg/L. The correlative coefficient is 90%. We use data collected from the 56 stations to establish the model. There are 66 stations for the autumn cruise. Data for the other 10 stations measured on Oct. 21, 2004 is used for validation. The comparison between the model estimated and measured SSC is shown in Fig.3. The average relative error is about 20.5%.

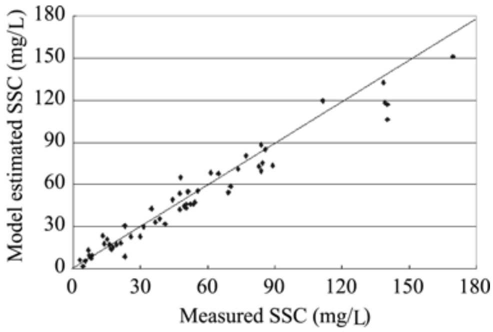


Fig.3 Comparison between model estimated and measured SSC

3 RESULTS

There is only one MODIS-Aqua image can be used for the time of 2004 autumn cruise. However, for the time of 2007 summer cruise, there is no image can be used. Then, we use one image acquired for the time that is closest to the 2007 summer cruise time. We use these two MODIS-Aqua images (Fig.4) to assess the precision of our algorithm.

First, we use our atmospheric correction algorithm to process the selected two MODIS-Aqua images. The atmospheric correction results are shown in Fig.5. In order to assess the precision of our atmospheric correction algorithm, we compare the atmospheric correction result obtained by processing MODIS-Aqua image acquired on Oct. 21, 2004 with *in-situ* data measured on the same day (Table 2).

Table 2 Comparison between retrieved R_{rs} (λ_2) and *in situ* data of the 10 stations on Oct. 21, 2004

Retrieved $R_{rs}(\lambda_2)$	Measured $R_{rs}(\lambda_2)$	Relative error	RMS relative error
0.004 97	0.004 41	0.127	
0.006 50	0.005 83	0.116	
0.001 74	0.002 68	0.350	
0.003 17	0.003 84	0.176	
0.004 23	0.007 89	0.464	
0.002 50	0.005 39	0.536	
0.007 87	0.005 98	0.317	
0.004 10	0.004 23	0.030	
0.006 61	0.010 84	0.390	
0.015 33	0.009 94	0.543	0.184

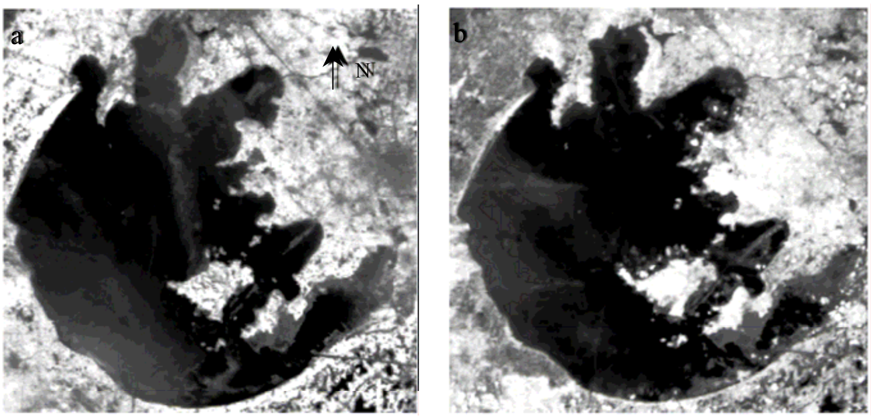


Fig.4 MODIS-Aqua band 2 radiance image of the Taihu Lake (30°55′– 31°33′ N, 119°52′– 120°37′ E) acquired on (a) Oct. 21, 2004. (b) June 8, 2007

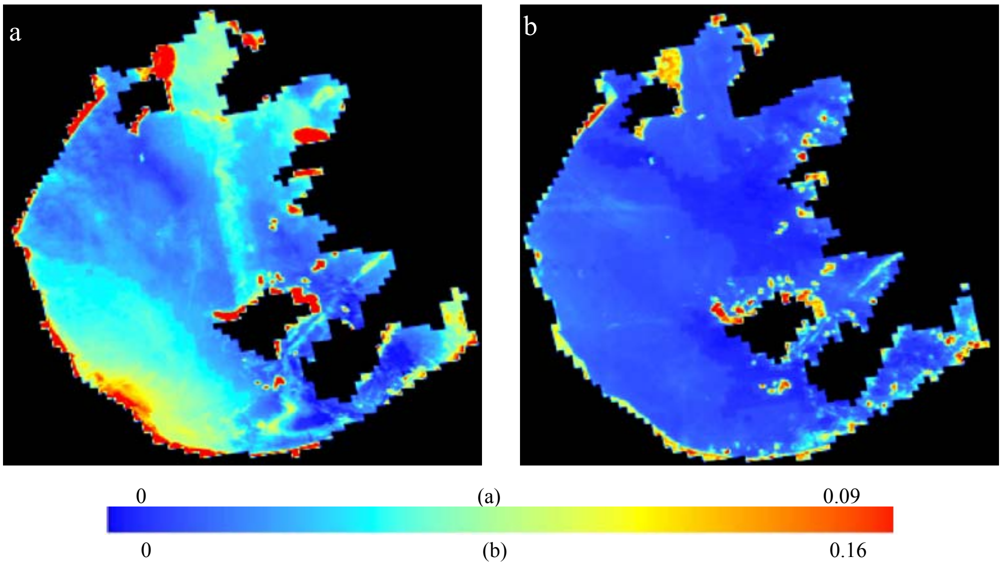


Fig.5 R_{rs} (λ_2) retrieved from MODIS-Aqua images acquired on (a) Oct. 21, 2004. (b) June. 8, 2007

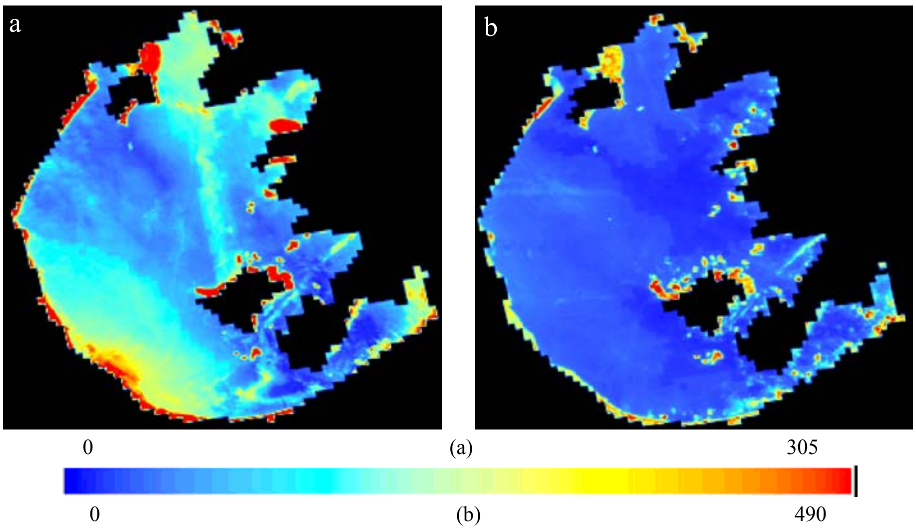


Fig.6 SSC retrieved from MODIS-Aqua images acquired on (a) Oct. 21, 2004. (b) June. 8, 2007

Second, using the atmospheric correction result, we retrieve SSC by means of our SSC quantitative retrieval model. The retrieved SSC is shown in Fig. 6. In order to assess the precision of our retrieval model, we compare the retrieved SSC with *in situ* data. The comparison is shown in Fig.7 and Table 3. As can be seen from Fig.7, almost all the retrieved SSC values are higher than the measured SSC values in the areas with relative low SSC. The reason is due to the effect of water bottom reflectance. Zhou (2007) and Ma et al. (2007) pointed out that the biggest water depth is 3 m and the average depth is 1.8 m in Taihu Lake. In the relatively clear areas, the atmospheric corrected L_w (858) contains the signal of water bottom reflectance and the SSC is overestimated.

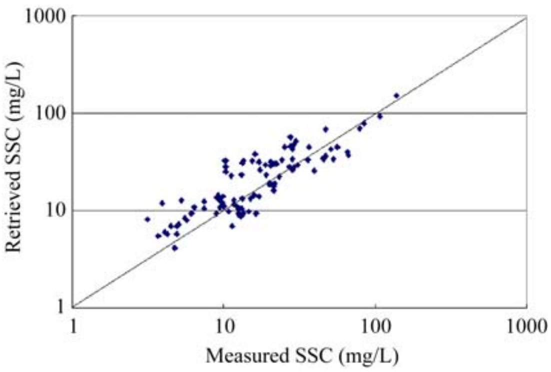


Fig.7 Comparison between retrieved and measured SSC. The retrieved SSC is from MODIS-Aqua image acquired on Jun. 8 2007

The measured SSC is from 2007 summer cruise. There are total 94 stations. The RMS relative error is about 48%

Table 3 Comparison between retrieved SSC and *in situ* data of the 10 stations on Oct. 21 2004

Retrieved SSC	Measured SSC	Relative error	RMS relative error
28.217	25.12	0.123	
35.178	24.08	0.461	
11.913	15.36	0.224	
19.501	22.48	0.133	
24.717	14.92	0.657	
16.045	26.60	0.397	
41.163	27.24	0.511	
24.091	18.12	0.330	
35.666	44.12	0.192	
71.188	41.40	0.720	0.212

4 DISCUSSIONS AND CONCLUSION

With the assumption of the black water at SWIR wavelengths, we first put forward an atmospheric correction algorithm for bands 1, 2. When we apply this algorithm to Taihu Lake, we get relatively good results. Then we establish a SSC quantitative retrieval model using the *in situ* data. Finally, using MODIS-Aqua data, we retrieve SSC by means of our atmospheric correction algorithm and SSC quantitative retrieval model. The retrieved SSC values agree well with measured ones, which confirms that our algorithm can provide reliable data for monitoring SSC in Taihu Lake.

On the other hand, our algorithm has some aspects that need to be further adjusted. First, for our algorithm, in relatively clear areas, the atmospheric corrected water leaving radiance contains the signal of water bottom reflectance and the SSC is then overestimated. The elimination of water bottom reflectance effect deserves further research. Second, we have the *in situ* data measured during the 2004 autumn and 2007 summer cruises at present. The validation of our algorithm only uses *in situ* data of 104 stations, 10 stations for the autumn cruise and 94 for the summer cruise. We need more *in situ* data which can cover larger dynamic range of the lake to validate our algorithm in future studies.

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References

Chen Z Q, Hu C M, Frank M K. 2007. Monitoring turbidity in Tampa Bay using MODIS/Aqua 250 m imagery. *Remote sensing of Environment*, **109**: 207-202.

Cox C, Munk W. 1954. Measurement of the roughness of the sea surface from photographs of the sun's glitter. *J. Opt. Soc. Am.*, **44**: 830-850.

Deng M, Li Y. 2003. Use of SeaWiFS imagery to detect three-dimensional distribution of suspended sediment. *International Journal of Remote Sensingm* **24**: 519-534.

Doxaran D, Froidefond J M, Lavender S J et al. 2002. Spectral signature of highly turbid water application with SPOT data to quantify suspended particulate matter concentration. *Remote sensing of Environment*, **81**: 149-161.

Doxaran D, Froidefond J M, Castaing P. 2003. Remote Sensing Reflectance of Turbid Sediment-Dominated Waters. Reduction of Sediment Type Variations and Changing Illumination Conditions Effects by Use of Reflectance Ratios. *Applied Optics*, **42**: 2 623-2 634.

Gordon H R, Brown J W, Robert H E. 1988. Exact Rayleigh scattering calculations for use with the Nimbus 7 Costal Zone Color Scanner. *Applied Optics*, **27**: 862-871.

Gordon H R, Castaono D J. 1989. Aerosol analysis with the Coastal Zone Color Scanner: A simple method for including multiple scattering effects. *Applied Optics*, **28**: 1 320-1 326.

Gordon H R, Wang M H. 1994a. Retrieval of water leaving radiance and aerosol optical thickness over the oceans with SeaWiFS: a preliminary algorithm. *Applied Optics*, **33**: 443-452.

Gordon H R, Wang M H. 1994b. Influence of oceanic whitecaps on atmospheric correction of ocean color sensors. *Applied Optics*, **33**: 7 754-7 763.

Gordon H R. 1995. Remote sensing of ocean color: a methodology for dealing with broad spectral bands and significant out-of-band response. *Applied Optics*, **34**: 8 363-8 374.

Hale G M, Querry M R. 1973. Optical constants of water in the 200-nm to 200-micrometer wavelength region. *Applied Optics*, **12**: 555-563.

Han Z, Jin Y Q, Yun C X. 2006. Suspended sediment concentrations in the Yangtze River estuary retrieved from the CMODIS data. *International Journal of Remote Sensing*, **27**: 4 329-4 336.

Hellweger F L, Schlosser P, Lall V. 2004. Use of Satellite imagery for water quality studies in NewYork harbor, Estuarine. *Coast and Shelf Science*, **61**: 437-448.

Hu C M, Carder K L, Frank E M. 2000. Atmospheric correction of SeaWiFS imagery over turbid coastal waters: a practical method. *Remote Sensing of Environment*, **74**: 195-206.

Hu C M, Chen Z Q, Clayton T D et al. 2004. Assessment of estuarine water-quality indicators using MODIS medium-resolution bands: Initial results from Tampa Bay, Florida. *Remote Sensing of Environment*, **93**: 423-441.

Lavender S J, Pinkerton M H, Moore G F. 2005. Modification to the atmospheric correction of SeaWiFS ocean color images over turbid waters. *Continental Shelf Research*, **25**: 539-555.

Li J. 1986. Remote sensing quantitative research about the suspended solids concentration. *Acta Scientiae Circumstantiae*, **6**: 166-173. (in Chinese)

Lv H, Li X G, Jiang N. 2005. Estimation of Suspended Solids Concentration in Lake Taihu Using Spectral Reflectance and Simulated MERIS. *Journal of Lake Sciences*, **17**: 104-109. (in Chinese)

Ma R H, Dai J F. 2005. Quantitative Estimation of Chlorophyll-a and Total Suspended Matter Concentration with Landsat ETM Based on Field Spectral Features of Lake Taihu. *Journal of Lake Sciences*, **17**: 97-103. (in Chinese)

Ma R H, Tang J W, Dai J F et al. 2006. Bio-optical model with optimal parameter suitable for Lake Taihu in water colour remote sensing. *International Journal of Remote Sensing*, **27**: 4 303-4 326.

Ma R H, Song Q J, Tang J W et al. 2007. A simple empirical model for remote sensing reflectance of Lake Taihu waters in autumn. *Journal of Lake Sciences*, **19**: 227-234. (in Chinese)

Mahtaba A L, Runquist D C, Han L H. 1998. Estimation of suspended sediment concentration in water using integrated surface reflectance. *Geoearto International*, **13**: 11-15.

Miller R L, McKee B A. 2004. Using MODIS Terra 250m imagery to map concentration of total suspended matter in coastal waters. *Remote sensing of Environment*, **93**: 259-266.

Moore G F, Aiken J, Lavender S J. 1999. The atmospheric correction of water colour and the quantitative retrieval of suspended particulate matter in Case 2 waters: application to MERIS. *International Journal of Remote Sensing*, **20**: 1 713-1 733.

Robinson I S. 2004. Measuring the Oceans from Space — The Principles and Methods of Satellite Oceanography. Praxis Publishing, Chichester, UK. p. 149-201.

Ruddick K G, Ovidio F, Rijkeboer M. 2000. Atmospheric correction of SeaWiFS imagery for turbid coastal and inland Waters. *Applied Optics*, **39**: 897-912.

Siegel D A, Wang M H, Maritorena S et al. 2000. Atmospheric correction of satellite ocean color imagery: the black pixel assumption. *Applied Optics*, **39**: 3 582-3 591.

Tassan S. 1993. An improved in-water algorithm for the determination of chlorophyll and suspended sediment concentration from Thematic Mapper data in coastal waters. *International Journal of Remote Sensing*, **14**: 1 221-1 229.

Wang M H, Gordon H R. 1994. A Simple Moderate Accurate Atmospheric Correction Algorithm for SeaWiFS. *Remote Sensing of Environment*, **50**: 231-239.

Wang M H, Bailey S W. 2001. Correction of Sun glint Contamination on the SeaWiFS Ocean and Atmosphere Products. *Applied Optics*, **40**: 4 790-4 798.

Wang M H. 2005. A refinement for the Rayleigh radiance computation with variation of the atmospheric pressure. *International Journal of Remote Sensing*, **26**: 5 651-5 663.

Wang M H, Shi W. 2005. Estimation of ocean contribution at the MODIS near-infrared wavelengths along the east coast of the U.S.: Two case studies. *Geophysical Research Letters*, **32**: L13606.

Wang M H. 2007. Remote sensing of the ocean contributions from ultraviolet to near-infrared using the shortwave infrared bands: simulations. *Applied Optics*, **46**: 1 535-1 547.

Wang Y H, Deng Z D, Ma R H. 2007. Suspended solids concentration estimation in Lake Taihu using field spectra and MODIS data. *Acta Scientiae Circumstantiae*, **27**: 509-515. (in Chinese)

Wang Y P. 2004. Water quality change in reservoirs of Shenzhen, China: detecting using landsat/TM Data. *The Science of Total Environment*, **328**: 195-206.

Warrick J A, Mertes L A K, Siegel D A et al. 2004. Estimating suspended sediment concentrations in turbid coastal waters of the Santa Barbara Channel with SeaWiFS. *International Journal of Remote Sensing*, **25**: 1 995-2 002.

Yin Q, Gong C L, Kuang D B et al. 2005. Method of satellite remote sensing of lake water quality and its applications. *Journal of Infrared and Millimeter Waves*, **24**: 198-202. (in Chinese)

Yuan G L, Zhu Y Y, He B et al. 2001. Remote sensing quality model of SS (suspended solid) in the dianchi lake water bodies. *Environmental Science and Technology*, **24**: 16-18. (in Chinese)

Zhou G. 2007. Research of simulation of water optical properties and remote sensing inversion of inland water quality parameter [Doctor Dissertation]. Institute of remote sensing applications Chinese academy of sciences, Beijing, China. p. 107-157. (in Chinese)