Chlorophyll-a retrieval of coastal waters based on in situ hyperspectral data

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ABSTRACT

The chlorophyll-a concentration is a major water quality parameter for coastal remote sensing. The water quality parameters of the Sishili Bay in Yantai's coastal region were obtained at the same time when the hyperspectral remote sensing data were in situ measured. According to the principle of the three-band model, the hyperspectral remote sensing data in situ measurements were averaged to the same band range of Medium Resolution Imaging Spectrometer (MERIS) (660 ~ 670nm, 703 ~ 713nm and 750 ~ 758nm) and Moderate Resolution Imaging Spectroradiometer (MODIS) (662 ~ 672nm and 743 ~ 753nm). The obtained results show that there was a good linear relationship between the chlorophyll-a concentration and simulated $[(B_7^{-1}-B_9^{-1})\times B_{10}]$ of MERIS and $[B_{13}^{-1}\times B_{15}]$ of MODIS. The determination coefficients were 0.714 and 0.753 for the simulated MERIS and MODIS, with the root mean squared errors (RMSE) of $1.48\mu g\cdot L^{-1}$ and $1.38\mu g\cdot L^{-1}$, respectively. The result demonstrated that the three-band model could be applied to retrieve chlorophyll-a concentration in Yantai's coastal region even if the chlorophyll-a concentration was lower than $10\mu g\cdot L^{-1}$. However, MODIS and MERIS data still needs to examine mapping chlorophyll-a concentration of Yantai's coastal waters.

Keywords: coastal waters, chlorophyll-a, hyperspectral data, three-band model

1. INTRODUCTION

In case 2 waters, the chlorophyll-a (Chl-a) concentration is one of the main water quality (WQ) parameters that could be retrieved from the reflectance of remote sensing (Rrs). The retrieval of Chl-a is based on the relationship between the Rrs and the inherent optical properties (IOP): total coefficients of absorption and backscattering [1]. The reflectance of remote sensing varies depending on the total absorption coefficient and total backscattering coefficient:

$$Rrs = \frac{f}{Q} \times \frac{b_b}{a_{water} + a_{CDOM} + a_{tripton} + a_{Chla} + b_b} \tag{1}$$

$$b_b = b_{b-water} + b_{b-CDOM} + b_{b-tripton} + b_{b-Chla} \tag{2}$$

where Rrs is the reflectance of remote sensing; f and Q are the parameters that vary depending on the light field[2]; b_b is the total backscattering coefficient; a_{water}, a_{CDOM}, $a_{tripton}$ and a_{Chla} are the absorption coefficients of water, CDOM (colored dissolved organic matter), tripton and Chl-a, respectively; $b_{b-water}$, b_{b-CDOM}, $b_{b-tripton}$ and b_{b-Chla} are the backscattering coefficients of water, CDOM, tripton, and Chl-a, respectively.

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Since the backscattering coefficients of CODM and Chl-a are very low, it could be ignored when counting Rrs[2]. Thus the b_b can be described as follows:

$$b_b \approx b_{b-water} + b_{b-tripton} \tag{3}$$

There exists a positive correlation between the Chl-a concentration and the absorption coefficient (a_{Chla}).Thus a_{Chla} should be isolated from other bio-optical parameters if one wants to retrieve Chl-a concentration.

Chl-a concentration is commonly retrieved by using blue-green ratio in open ocean waters. And this method is efficient and has relative high retrospective precision in open ocean waters. But the method is confined when it is used to retrieve Chl-a of coastal or inland waters[3]. These algorithms that derived case 1 waters are not applicable to case II waters, especially for turbid and productive waters, because of abundant variable CDOM and tripton[4, 5]. It is quite difficult to retrieve Chl-a of coastal or estuary waters because of the overlap of absorption and backscattering caused by CDOM and tripton. In many coastal or estuary waters, the absorption of CDOM and the backscattering of tripton dominates the water column optics and influence Chl-a concentration retrieval. To retrieve Chl-a concentration of coastal or estuary waters, many algorithms have been put forward[6-10], such as fluorescence algorithms, the ratio of Rrs (Rrs_{705}/Rrs_{670} or Rrs_{725}/Rrs_{675}), and the derivative spectrum algorithms. All these algorithms are based on the assumption that the absorption and fluorescence quantum yield of Chl-a are constants[11, 12]. But these parameters are variable as the environmental conditions change, such as illumination conditions, nutritional status, and temperature [13]. Furthermore, these empirical algorithms only could be used in some special areas. So the Chl-a concentration cannot be retrieved accurately when using these empirical algorithms to retrieve Chl-a concentration of coastal waters. Some researchers use analytical model for the Chl-a retrieval. But analytical algorithms need special bio-optical parameters that could hardly be obtained for us[14]. In addition, the retrospective precision of these analytical algorithms is lower than that of other models. So the semi-analytical algorithms are mostly been used to retrieve WQ parameters in water color remote sensing.

Recently, Dall'Olmo et al[15] proposed a semi-analytical retrieval model of Chl-a, three-band model. The three-band model was originally used to estimate the pigments in terrestrial vegetation [16, 17]. Afterwards, the model is used to evaluate Chl-a concentration in turbid waters and then applied to the satellite data to retrieve Chl-a concentration[11, 12, 18]. The three-band model is described as follows (in equation 4):

$$C_{Chla} \propto \left[\frac{1}{R(\lambda_1)} - \frac{1}{R(\lambda_2)} \right] \times R(\lambda_3) \tag{4}$$

Where C_{Chla} is the concentration of Chl-a; $R(\lambda_1)$, $R(\lambda_2)$ and $R(\lambda_3)$ are the reflectance of remote sensing at λ_1, λ_2, λ_3 wavelength, respectively. The purpose of this study is to examine the three-band model and its special case: two-band model for the retrieval of Chl-a in Yantai's coastal waters from in situ hyperspectral measurements.

2. METHODOLOGY

1.1 Data processing

The study area in the Sishili Bay is located in the south of North Yellow Sea, along the Yantai coastal line (Figure1). It is a seaculture area where lots of feeding bait is put into it so as to improve fishery production every year. For this reason, red tide frequently occurs especially in the summer and this could rapidly lead to the decline of fishery production. Thus, monitoring the status of water is an urgent task for guideline on fishery production.

USB4000 spectrometer is used to measure the reflectance of coastal water in the study area. Its optical sensor could operate between 345nm and 1046nm, with 0.2nm spectral resolution in red spectral region. The spectral data were resampled with 1nm spectral resolution. The WQ parameters were obtained by YSI instrument. The Chl-a concentration used to build the retrieval model was the integration of upper 25cm. All the data were collected from the same cruise on 4th November 2008.

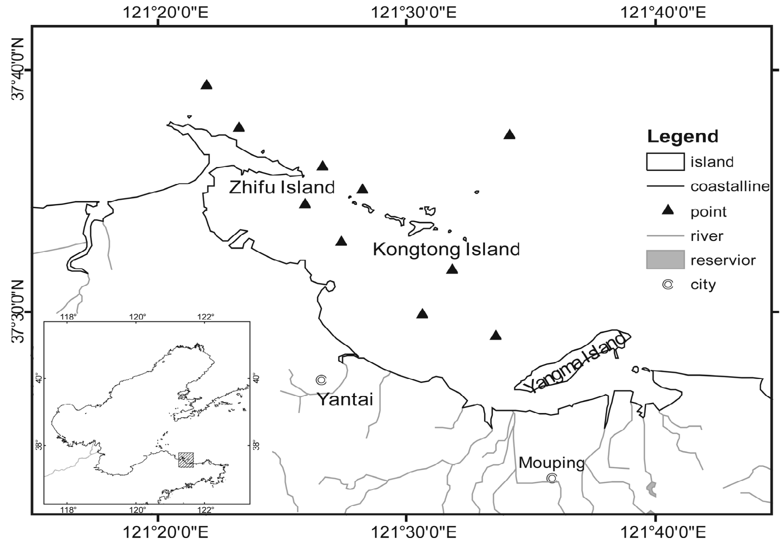

Fig.1. Sampling stations.

1.2 The three-band model

The wavelengths in three-band model are selected according to the inherent optical properties (IOP) of Chl-a: the absorption and backscattering coefficients[11, 12]. According to the formulation 1, 2, 3, 4 and the principle of three-band model, the Rrs at λ_1 wavelength should be maximally sensitive to the absorption of Chl-a, and the first band is restricted within the range of 660~690nm. To reduce the impacts of CDOM and tripton, the Rrs at λ_2 wavelength should minimally sensitive to the absorption of Chl-a and in the meanwhile, the absorption and the backscattering coefficients of CDOM and tripton at λ_2 wavelength should be quite close to that of at λ_1 wavelength in order to guarantee the retrospective precision of Chl-a. The second band is confined to the range of 690~710nm. However, besides CDOM and tripton, the retrieval of Chl-a concentration is also affected by the backscattering of tripton. To account for the variability of backscattering, the third band is added to the three-band model. The absorption at λ_3 wavelength should be very close to the absorption of pure water and the third band is confined to the range of beyond 730nm. The two-band model is a special case of three-band model and could be applied to retrieve Chl-a concentration when the absorption of Chl-a at λ_1 wavelength is far more than that of CDOM and tripton at λ_1 wavelength[19].

Based on the reflectance curves of remote sensing (Figure 2) and the introduction of three-band model, the wavelength of 670nm, 690nm and 730nm were selected as λ_1, λ_2 and λ_3, respectively so as to build three-band model (Figure 3). The three-band model was built according to the selected bands. The determination coefficient was 0.247, and RMSE was $2.40\mu g \cdot L^{-1}$.

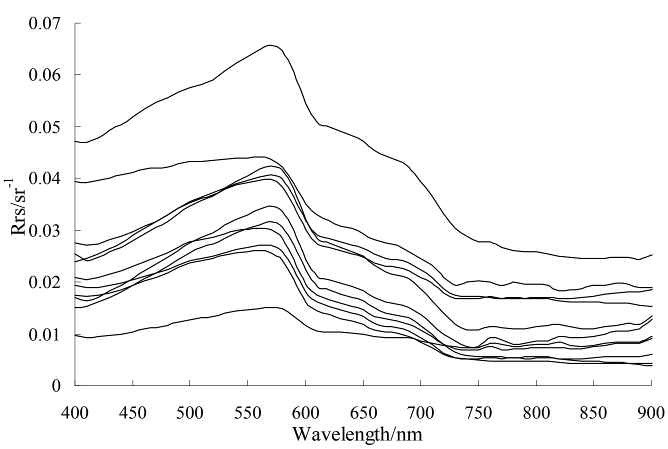

Fig. 2. Spectral reflectance curves of Sishili Bay.

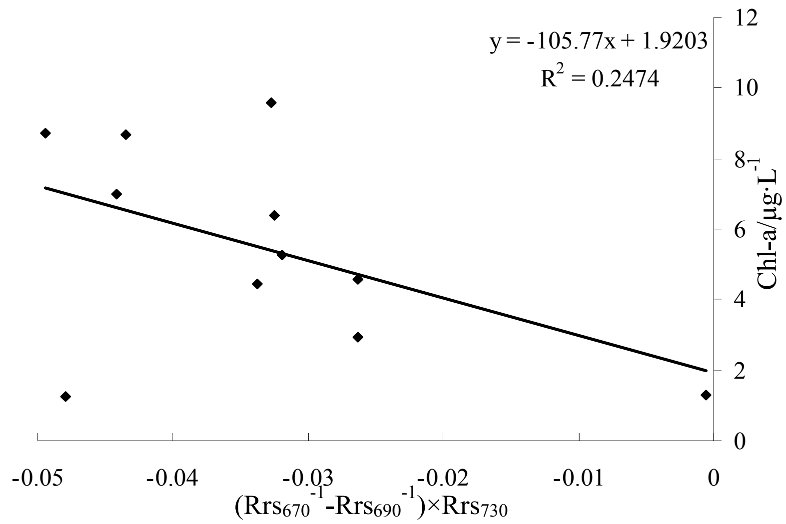

Fig. 3. Relationship between the Chl-a Concentration and $[(Rrs_{670}^{-1}-Rrs_{690}^{-1})\times Rrs_{730}]$.

1.3 Validation of band range of MERIS and MODIS sensors

For future using remote sensor data to retrieve Chl-a concentration, we also validated the band range of MERIS and MODIS based on in situ hyperspectral data so as to determine whether three-band model of satellite image data was applicable for our research areas. According to the description of three-band model and band set of MERIS, the ranges of the three bands were selected and they were 660~670nm, 704~714nm, 750~758nm, respectively. The spectral data in situ measurements were averaged to these band ranges. The three-band model was built and the relationship between the averaged spectral data and Chl-a concentration is in Figure 4. The determination coefficient of three-band model is 0.714 and the RMSE is 1.48$\mu g \cdot L^{-1}$ when used to retrieve Chl-a concentration.

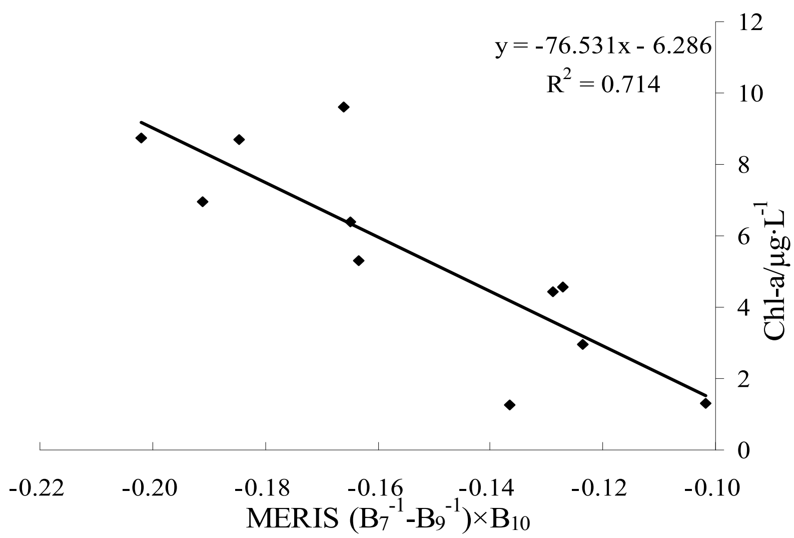

Fig. 4. Relationship between the Chl-a and MERIS $[(B_7^{-1}-B_9^{-1})\times B_{10}]$.

According to the band set of MODIS, the two bands are 660~670nm and 700~730nm, respectively. The two-band model for MODIS is described in Figure 5. The determination coefficient of two-band model is 0.753 and the RMSE is 1.38$\mu g \cdot L^{-1}$.

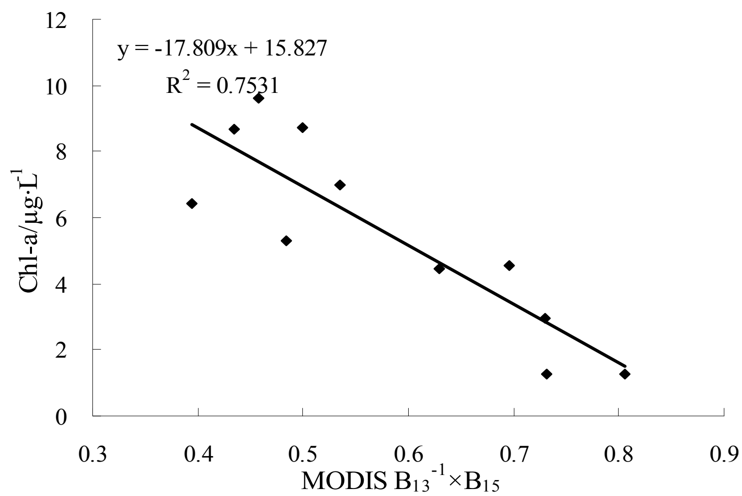

Fig. 5. Relationship between the Chl-a and MODIS [$B_{13}^{-1} \times B_{15}$].

3. DISCUSSION

To validate the retrieval precision of three-band model, other algorithms were used to testify the validation. Dall'Olmo et al found the band ratio of Rrs_{725}/Rrs_{675} had relative good correlation with Chl-a concentration [4, 10, 20, 21]. In this study, the band ratio of Rrs_{725}/Rrs_{675} was used to retrieve Chl-a concentration. There is a good correlation between the ratio and Chl-a (Figure 6), and the determination coefficient is 0.725 and the RMSE is 1.45μg·L^{-1}. We also found a better correlation between the ratio of Rrs_{748}/Rrs_{667} and Chl-a concentration. The coefficient of determination is 0.843 and the RMSE is 1.10μg·L^{-1}.

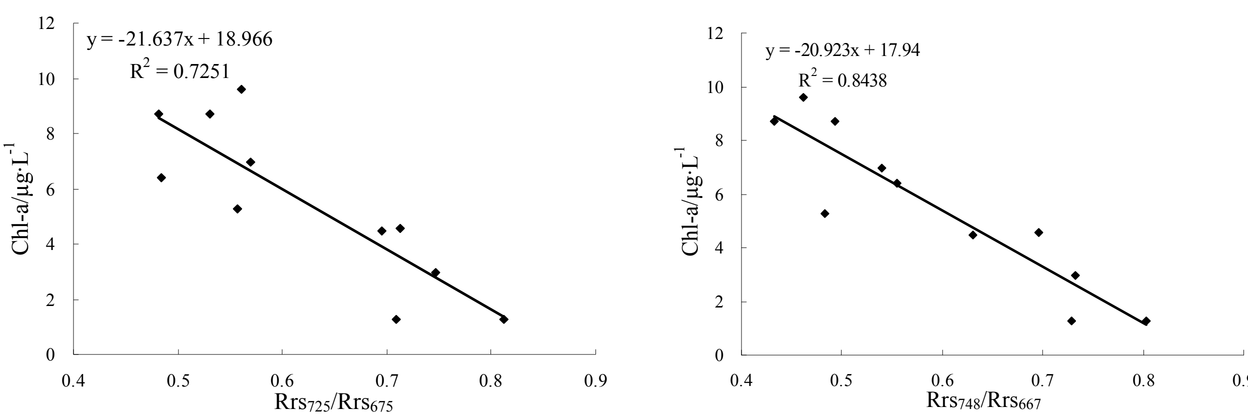

Fig. 6. Relationship between the Chl-a Concentration and the band ratio.

From the result of original three-band model that had been built according to the reflectance spectral curves, The determination coefficient was very low (R^2=0.247) and the RMSE was 2.40μg·L^{-1}. Since Chl-a concentration is below 10μg·L^{-1} in this case study, there is no apparent absorption and fluorescence peak at near 670nm band according to Figure 2. This is a main reason that led to lower retrospective precision of Chl-a concentration. It seems hard to retrieve Chl-a concentration by three-band model when Chl-a concentration is lower than 10μg·L^{-1} because it is impossible to find the exact absorption position and fluorescence peak position. But on consideration of the comprehensive Chl-a absorption and reflectance characteristics, if we could average the in situ spectral data, we could get better retrospective precision by using three-band model. The obtained results show that the determination coefficients are 0.714 and 0.753

for three-band model of MERIS and two-band model of MODIS, respectively. The RMSEs of three-band and two-band model were lower than $1.5\mu g \cdot L^{-1}$. The algorithms of three-band and two-band model could be used to retrieve Chl-a concentration even if the Chl-a concentration is low and the absorption and reflectance peak are not obvious. This still needs to be further investigation in the near future in the study area.

4. CONCLUSIONS

Using the three-band model, spectral data in situ measurements were averaged to the band range of MERIS and MODIS in this case study. The obtained results show that it is a good correlation between the processed spectral data and Chl-a concentration with the RMSE lower than $1.5\mu g \cdot L^{-1}$ when the algorithms of three-band and two-band model were used to retrieve Chl-a concentration. It is also possible to get a good precision even if the Chl-a concentration is lower than $10\mu g \cdot L^{-1}$. The case also indicates that the three-band model and the two-band model could be applied to retrieve Chl-a concentration in Yantai's coastal waters. In the near future, the three-band model is applicable in the study area using MERIS data and MODIS data to retrieve and map Chl-a concentration in coastal waters.

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