A Study on the Quantitative Remote Sensing Model for the Suspended Sediment Concentration in Coastal Waters with ASTER Data

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Abstract- **Suspended sediment concentration (SSC) is one of the most important water quality parameters. After corrected by 6S atmospheric model, the spectral profiles of water reflectivity of ASTER data are analyzed. There is greater difference in spectral visible and near-infrared bands than that in spectral short wave infrared bands. The higher SSC is, the larger R_R/R_G is, in which R_G and R_R are the reflectivity of green band (channel 1) and red band (channel 2). So SSC may be expressed as the function of R_R/R_G: SSC = f(R_R/R_G). The quantitative remote sensing model for estimating SSC in coastal waters is founded. The model is well applied in coastal waters of the Yellow River Delta in China.**

Key Words- **ASTER data, suspended sediment concentration, quantitative remote sensing analysis**

Ⅰ. INTRODUCTION

The ASTER system, flying on Terra (EOS-AM1) polar orbiting spacecraft with other four sensors, has three spectral visible and near-infrared (VNIR) bands of 15-m resolution, six spectral short wave infrared bands of 30-m resolution and five spectral thermal infrared bands of 90-m resolution. Its relative high spatial resolution and wide spectral range not only provide new data source for resource and environment application on land, but also can be used for water environment research in coastal waters and inland water.

Suspended sediment concentration (SSC) is one of the most important water quality parameters. In the early 70's in 20^{th} century, Reference[1] established a linear statistical model for estimating SSC in Delawane Bay with MSS data. After that, many researchers developed various models to simulating the relationship between SSC and remote sensing data, especially using NOAA AVHRR data and TM data[2-7]. In recent years, algorithms for the calculation of suspended sediment with SeaWiFS data were researched[8-10]. But in coastal waters, there is still no uniform remote sensing model for estimating SSC. Many algorithms were concentrated in the quantitative relationship between SSC and water reflectivity of one or more bands of remote sensing data. For coastal waters research, the 1.1 km resolution of AVHRR and SeaWiFS data may be too coarse, while TM and ASTER data is more preponderant in spatial resolution.

In this paper, based on the spectral profiles of water reflectivity corrected by 6S atmospheric model of ASTER data, a quantitative remote sensing model for estimating SSC with multi-bands of ASTER data in coastal waters is founded and is applied in coastal waters of the Yellow River Delta in China.

This paper is organized as follows. In section Ⅱ, a brief introduction of the water characters on ASTER image in the study area is given. Algorithm for estimating SSC with ASTER data is presented in section Ⅲ, which includes atmospheric correction of ASTER data, foundation of quantitative remote sensing model and the estimation of SSC distribution. Section Ⅳ is the conclusion.

Ⅱ. WATER CHARACTERS ON ASTER IMAGE

The ASTER data used in this paper acquired on 25^{th} August 2001, covering Yellow River Delta in China(Fig. 1). It seems much difference on ASTER image with different quality water, from which qualitative distribution of SSC may be directly extracted from remote sensing data. In Figure 1, points named "PROFILE#1.1" to " PROFILE#1.4" are on behalf of different SSC water. SSC increased from point "PROFILE#1.1"to " PROFILE#1.4".

Figure 1. Water characters on study area's ASTER321 image

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Ⅲ. ALGORITHM

Pre-process like atmospheric correction and water extraction on remote sensing data should be done first. Then reflectivity spectral profile is analyzed and quantitative remote sensing model for estimating SSC is founded. Figure 2 is the processing flow chart.

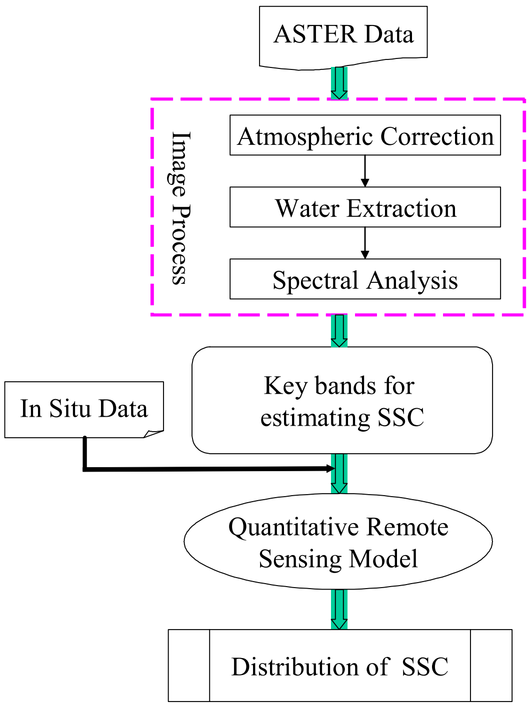


Figure2. Scheme of quantitative remote sensing model for estimating suspended sediment concentration

A. Atmospheric Correction for ASTER data

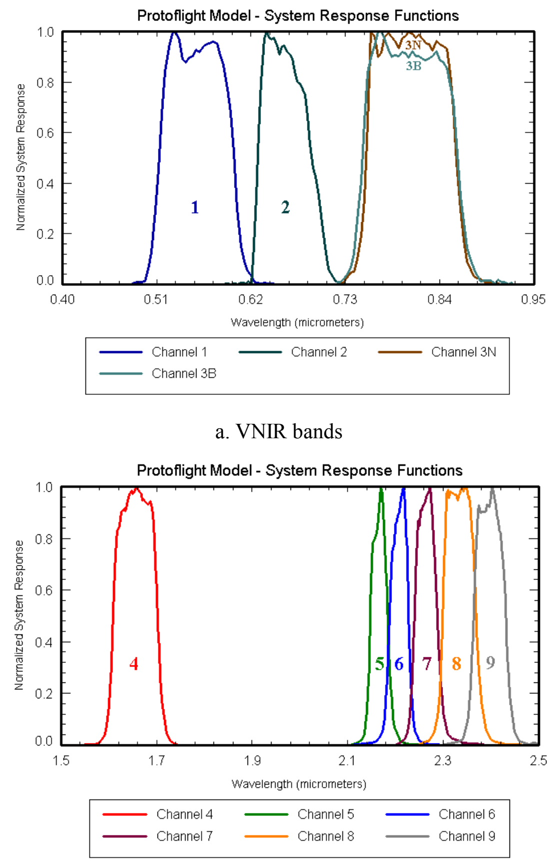
Because of low reflectivity, it is important to eliminate atmospheric influence for water environmental remote sensing analysis. There are two main methods to eliminate atmospheric influence: one is relative radiation correction, the other is absolute correction using atmospheric correction model. Absolute atmospheric correction is necessary in order to make the result comparability for different time and different sensors.

In this paper, 6S（Second Simulation of Satellite Signal in the Solar Spectrum）model was chosen for atmospheric calibration. 6S code is used to correct atmospheric affection between 0.25-4.0μm, in which important atmospheric process like absorption of vapour, CO_2, O_2, O_3 and scattering of molecules and aerosol [11]. The main aim of 6S code is to calibrate atmospheric affection in short wave, so it's superior to other atmospheric calibration models like LOWTRAN when processing atmospheric scattering[12].

At present, 6S code hasn't bands setting for ASTER data. Except Landsat ETM+ data, the data input is reflectivity or radiation, not the pixel value. For more practical and more universal purpose, some complementarities have been done in the code.

1) For usual-used image data (like TM, SPOT), codes for pixel value input and transformation from pixel value to radiation value have been added in the 6S model;

2) The System Response Functions (Figure 3) of ASTER data in three spectral visible and near-infrared (VNIR) bands and six spectral short wave infrared bands are interpolated in 0.0025 μ m intervals and added to the model, and the corresponding content in the model is modified and completed.



a. VNIR bands

b. short wave infrared bands

Figure 3. Response functions of ASTER data

B. Foundation of Quantitative Remote Sensing Model

Because of the high suspended sediments in coastal waters, the back-scattering is strong. So there is good reflection in remote sensing images with different SSC. Back-scattering of water is determined by water molecule, suspended sediments and alga. Yellow substance is dissolvable and no scattering ability, but it has strong absorption in short wave, which may reduce the spectral albedo. So only under low absorption of both water and yellow substance, the real value of SSC may be estimated. Water has strong absorption in near-infrared wave. Yellow substance has strong absorption in short wave, while for wavelength shorter than 0.6 μ m, its absorption is near zero[13]. So the most suitable wavelength for remote sensing SSC is from 0.6 to 0.8 μ m, which is correspond with channel 1 to channel 3 of ASTER data, channel 2 to channel 4 of TM data and channel 1 of NOAA/AVHRR data. With the increase of SSC, the maximum value of spectral reflectivity moves to red band (longer wavelength)[14].

After corrected by 6S model, spectral profiles of water reflectivity with different SSC are shown in Figure 4, in which "relative clean water", "low SSC", "middle SSC" and "high SSC" correspond to points "PROFILE#1.1", "PROFILE#1.2", "PROFILE#1.3" and "PROFILE#1.4" in Figure 1.

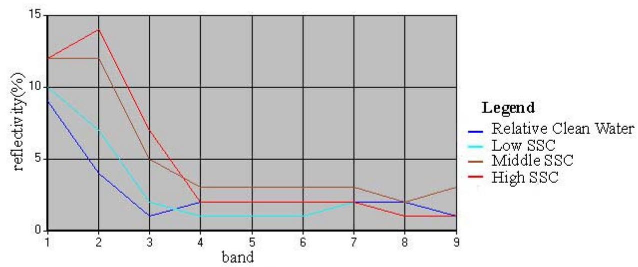


Figure 4. Spectral profile of different SSC water reflectivity

From Figure 4, there is greater difference in spectral visible and near-infrared bands (B1 to B3) than that in spectral short wave infrared bands (B4 to B9). The higher SSC is, the larger R_R/R_G is, in which R_G and R_R are the reflectivity of channel 1(green band) and channel 2(red band). So SSC may be expressed as the function of R_R/R_G:

$$SSC = f(R_R/R_G) \quad (1)$$

We defined WSI= R_R/R_G. If there are in situ measurement data of reflectivity and SSC, the function between SSC and WSI will be established. In our work, it's impossible to get the in situ measurement data. Because our study region lies in coastal waters of Yellow River Delta, experiment data from reference [14] in Yellow River Delta were adopted, where the SSC was divided into 8 ranks from 43.3mg/l to 2324.8mg/l (Table 1).

Using the data listed in Table 1, an optimal curve (Figure 5) was gotten under the regressive analysis between WSI and SSC. It is an exponential function, in which the correlative coefficient is 0.9739:

$$SSC = 1.6821\exp(5.1038 \cdot WSI) \quad (2)$$

Using Equation (2), SSC is calculated and the distribution of SSC in coastal waters is gotten.

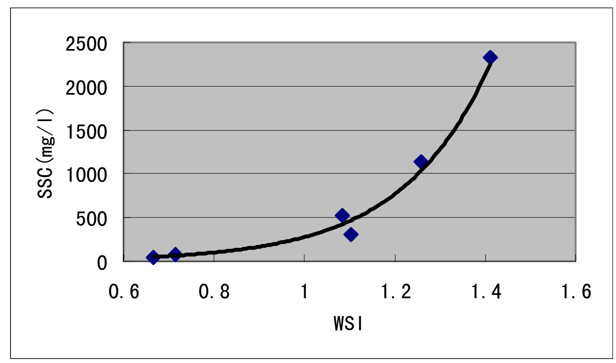


Figure 5. The relationship between SSC and WSI in coastal waters near Yellow River Delta

TABLE I WATER REFLECTIVITY OF DIFFERENT SUSPENDED SEDIMENT CONCENTRATION

SSC (mg/l)		43.3	81.0	308.6	522.6	1140.4	2324.8
Reflectivity	R_G	2.25	3.50	9.25	12.00	12.40	15.60
(%)	R_R	1.50	2.50	10.20	13.00	15.60	22.00
WSI = R_R/R_G		0.6667	0.7143	1.1027	1.0833	1.2581	1.4103

C. ESTIMATION OF SSC DISTRIBUTION

Using the quantitative remote sensing model established above, the distribution of SSC in coastal waters is calculated. The detail process is as follow.

1) Atmospheric Calibration

Atmospheric calibration was done for 3 spectral visible and near-infrared bands and 6 spectral short wave infrared bands using 6S code modified as above.

2) Water Extraction

The reflectivity of water is lower than that of land in short wave infrared bands. If threshold value of channel 4 is chosen suitably, the water region will be extract well. In this paper, if R4<0.06, there may be the water region, in which R4 is the reflectivity of channel 4.

3) Calculation of SSC

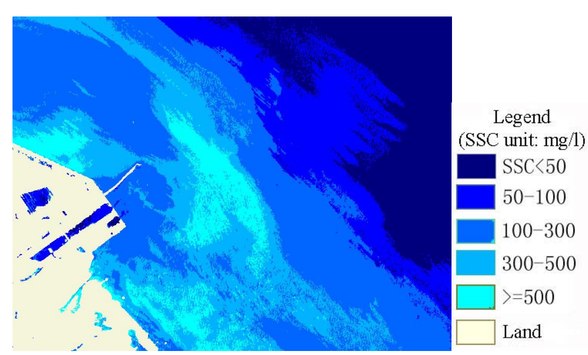


Figure 6. SSC distribution from ASTER data

Using Equation (2), the distribution of SSC is calculated (Figure 6). The distribution reflects the SSC well and is reasonable, which is consonant with the image in Figure 1.

Ⅳ. CONCLUSION

After analyzing the spectral profiles of water reflectivity corrected by 6S atmospheric model of ASTER data, a quantitative remote sensing model for estimating SSC with WSI in coastal waters is founded, where WSI= R_R/R_G. The model is well applied in coastal waters of the Yellow River Delta in China.

The model may be used by other sensors' data having similar Visible and Near-Infrared bands with ASTER bands.

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