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Impact of Aerosol Type on Atmospheric Correction of Case II Waters

Junjie Shen¹, Jie Jiang^{1,2}, Yixi Du¹ and Yangyang Liu¹

¹ School of Geographic and Biological Information,
Nanjing University of Posts and Telecommunications, Nanjing 210023, PR China

² Smart Health Big Data Analysis and Location Services Engineering Lab
of Jiangsu Province, Nanjing 210023, PR China
jiangj@njupt.edu.cn

Abstract. The impact of aerosol is a key issue on atmospheric correction in remote sensing. The aim of this work is to evaluate the radiative impact of the aerosol type on the results of the atmospheric correction in Lake Taihu, a typical case-2 water. The atmospheric correction of MERIS images were carried out using the 6S atmospheric radiation transfer model. The water reflectances obtained by different aerosol types were compared with the measured spectral data. The correction results of the Continental and Maritime model are similar, and more reliable than the results of urban model. Continental aerosol model achieved good results in bands from 3 to 9, but in other bands, the results of maritime aerosol model are better than the continental results. Therefore, Selection of an accurate aerosol model is the primary task of atmospheric correction.

1. Introduction

Remote sensing, with the ability of covering large spatial areas at frequent intervals, has become a powerful and efficient tool to monitor water quality in inland waters. In most water areas, more than 90% of sensor-measured signals come from atmosphere in the visible wavelengths, only 10% of signals originate from water body [1]. Therefore, it is necessary to remove the atmospheric effects from the top of atmosphere (TOA) reflectance before applying the satellite data to quantitative estimation of the water quality parameters.

The standard atmospheric correction method over case-1 waters is widely used by exploiting the fact that the water-leaving reflectance at near infrared (NIR) wavelengths can be neglected in this type of clear water [2]. However, in most inland and coastal waters, the assumption of zero water-leaving reflectance at NIR wavelengths becomes invalid because of the high backscattering of algae and minerals [3,4]. Various algorithms have been developed to enhance the accuracy of atmospheric correction in inland turbid case-2 water. Hu et al. assumed that the type of aerosol does not vary much over relatively small spatial scales [5]. So the aerosol parameters obtained from the clean water pixel using the standard NIR algorithm, can be transferred to the turbid area by using the nearest neighbor method. Ruddick et al. developed an NIR spectral relationship to improve the retrievals of water-leaving reflectance and obtained satisfied results [6]. In this study the assumptions of zero water-leaving radiance were replaced by the assumptions of spatial homogeneity of the 765: 865 nm ratios for aerosol reflectance and for water-leaving reflectance. These two ratios were imposed as calibration



parameters after inspection of the Rayleigh-corrected reflectance scatterplot. Wang et al. replaced the near-infrared bands by short-wave infrared bands of MODIS data, regarding the water leaving reflectance in these bands as negligible because of its strong absorption, and obtained a better correction effect [7]. In a word, accurate estimation of aerosol parameters plays critical role in atmospheric correction, no matter in case-1 or case-2 water.

In this paper, the atmospheric correction of MERIS images are carried out using the Second Simulation of a Satellite Signal in the Solar spectrum (6S) atmospheric radiation transfer model in Lake Taihu, a typical case-2 water. The water reflectances obtained by different aerosol types are compared with the measured spectral data. The aim of this work is to evaluate the radiative impact of the aerosol type on the results of the atmospheric correction.

2. Study area and Data

2.1. Overview of study area

Lake Taihu is located in the Yangtze River Delta, which is one of the five largest freshwater lakes in China, with an area of 2338 km² and the average depth of 1.9 m. Lake Taihu (between 30.5–31.6 N and 119.5–120.9 E) is a typical large inland shallow lake. The water of Lake Taihu is consistently extremely turbid and is terrestrial input and sediment suspension. The optical properties of this lake are particularly complex and dominated jointly by chlorophyll, suspended matter, and yellow matter.

2.2. In situ data

The in situ reflectance spectra were measured by an ASD Field Spec spectroradiometer with 2 nm intervals from 350 nm to 1050 nm. The water spectra were measured according to the above-water method [5]. The radiance of the water surface, sky, and a 30% gray board was measured over the deck of an anchored ship. The synchronous GPS coordinates, wind speed, and direction were also recorded. Then, the remote sensing reflectance was extracted by using the following equation:

$$R_{rs} = \frac{(L_{sw} - rL_{sky}) \cdot \rho_p}{L_p \pi} \quad (1)$$

Where, R_{rs} , L_{sw} , L_{sky} , L_p and ρ_p represent the remote sensing reflectance, the total radiance, the sky diffuse scattering radiance, and the radiance and reflectance of the gray board, respectively. r is the gas-water interface reflectance ratio, which depends on solar position, observed geometry, wind speed, wind direction and surface roughness. The value of r is 0.025.

2.3. MERIS data and preprocessing

The full-resolution MERIS image covering Lake Taihu was acquired on October 20, 2004. The MERIS onboard ENVISAT satellite is mainly used to observe the color of marine and coastal ocean. The MERIS Level 1p data consists of the calibrated TOA radiances of the 15 bands [1]. The overlapping phenomenon of the MERIS data was removed using the smile correction processor provided by Beam software.

Thereafter, the corrected radiance was converted to reflectance in order to obtain the dimensionless value by using:

$$\rho = \pi L / F_0 \cos \theta_0 \quad (2)$$

Where ρ , L , F_0 , and θ_0 represent the TOA reflectance, the TOA radiance, the TOA irradiance, and the solar zenith angle, respectively.

3. Methods

3.1. Atmospheric correction based on 6S model

The 6S model is one of the most widely used radiative transfer model for atmospheric correction [8]. It enables accurate simulations of satellite and plane observation, accounting for elevated targets, use of anisotropic and lambertian surfaces and calculation of gaseous absorption.

The input parameters of 6S model include: geometrical conditions (the solar zenith angle, the view zenith angle, the solar and view azimuth angle), atmospheric model (includes air pressure, air temperature, water vapour and ozone density), aerosol model (type and concentration of aerosol), the altitude of target and sensor, the spectral conditions, etc.

Among them, aerosol model is a key factor affecting atmospheric correction. The International Association of Meteorological and Atmospheric Physics (IAMAP) define four basic aerosol components: water-soluble, dust-like, oceanic, and soot. Based on the mixture of 4 basic components, three tropospheric aerosols types models, Continental, Maritime, Urban were created in 6s model. The mixture of each aerosol type in 6S model is shown in table 1.

Table 1. Volume percentages of the four basic aerosols Particles of aerosol mode

	<i>Dust-like component</i>	<i>Water-soluble component</i>	<i>Oceanic component</i>	<i>Soot component</i>
Continental	0.70	0.29	-	0.01
Maritime	-	0.05	0.95	-
Urban	0.17	0.61	-	0.22

The methodology applied in this work is to analysis the accuracy of atmospheric correction caused by different aerosol type. The geometrical conditions are taken from the metadata of the image, Midlatitude Winter model is used as the description of the atmospheric conditions, Aerosol optical thickness (AOT) for 550 nm is 0.83 taken from AERONET. Atmospheric correction mode is selected, In this case, the ground is considered to be Lambertian, and the 6s model can retrieve the atmospherically corrected reflectance based on the atmospheric conditions and aerosol type.

3.2. Accuracy assessments

Two popular indices, namely, the Mean Relative Error (MRE) and the Root Mean Square Error (RMSE), were used to quantify the accuracy of atmospheric correction caused by different aerosol type. The two indices were defined as follows:

$$MRE = \frac{1}{N} \sum_{i=1}^N \frac{|x_{esti,i} - x_{mean,i}|}{x_{mean,i}} \times 100\% \quad (3)$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^N (x_{esti,i} - x_{mean,i})^2}{N}} \quad (4)$$

Where $x_{mean,i}$ is the variable that is known as the truth, which is observed from in situ measurements, and $x_{esti,i}$ represents the same variable of interest that is derived from 6s model. N is the number of observations.

4. Results and Discussion

The comparison between the atmospheric correction results caused by different aerosol type and the reference data from in situ radiometric measurements described in Table 2.

The accuracies of the Continental and Maritime model are similar. The RMSE of Continental model is lowest, but its MRE is higher than the value of Maritime model. The errors of urban model are great compared with the above two types. The MRE of 172.98 indicates that the urban model is completely inappropriate in the Lake Taihu region. Because of its higher ratio of soot particles than the Continental and Maritime aerosols. Soot particle is a byproduct of burning fossil fuels, particularly coal with small size and strong absorption. So the Urban aerosol model used by the 6s model will enhance the value of absorption by atmosphere. That results in a larger error in the results of atmospheric correction.

Table 2. Accuracy evaluation of correction results for three aerosol models

	<i>Continental</i>		<i>Maritime</i>		<i>Urban</i>	
	<i>MRE</i>	<i>RMSE</i>	<i>MRE</i>	<i>RMSE</i>	<i>MRE</i>	<i>RMSE</i>
Band1	18.51	0.0040	12.85	0.0028	576.43	0.0933
Band2	16.03	0.0044	13.02	0.0039	376.93	0.0826
Band3	13.28	0.0051	19.00	0.0067	175.80	0.0530
Band4	12.64	0.0053	21.50	0.0083	144.78	0.0498
Band5	10.77	0.0058	23.74	0.0114	90.41	0.0405
Band6	9.03	0.0049	23.08	0.0104	73.95	0.0309
Band7	8.38	0.0043	22.81	0.0093	68.14	0.0252
Band8	9.08	0.0045	24.28	0.0095	63.57	0.0230
Band9	10.82	0.0047	26.95	0.0103	55.43	0.0198
Band10	25.97	0.0049	13.01	0.0032	123.26	0.0206
Band11	14.4	0.0034	32.81	0.0063	83.10	0.0139
Band12	24.89	0.0048	14.28	0.0036	113.33	0.0194
Band13	71.67	0.0070	19.31	0.0026	194.04	0.0179
Band14	89.76	0.0071	23.06	0.0024	230.15	0.0173
Band15	77.23	0.0054	28.38	0.0024	225.45	0.0148
Average	27.5	0.0050	21.21	0.0062	172.98	0.0348

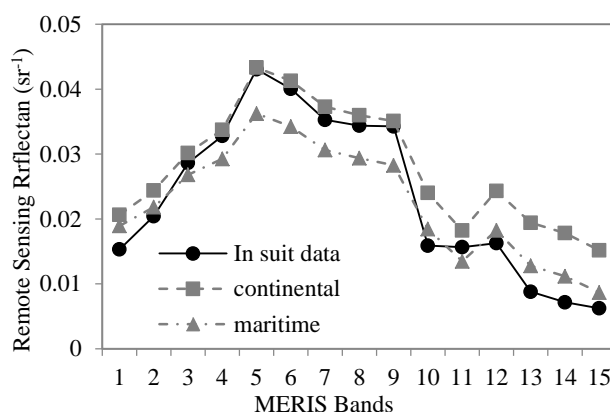
**Figure. 1.** Comparisons between atmospheric correction results and the in situ measurements.

Figure 1 shows the difference of water reflectance respectively retrieved by the in situ data and the correction results of continental and maritime aerosol models in each band. The water reflectance retrieved by continental models is higher than the value of maritime model in each band, this is due to the continental aerosol model containing 70% of the dust particles, its large size results in strong forward scattering and weak backward scattering. Since satellite sensor receives backscattered signals, So the continental aerosol model used by the 6s model will enhance the value of corrected surface reflectance.

Compared with the measured data, the correction results of continental aerosol model are very similar to the measured results in bands from 3 to 9, but in other bands, the results of maritime aerosol model are better than the continental results.

The area around Lake Taihu is one of the most populated regions with developed industry and agriculture. So there are many sources of aerosols include anthropogenic aerosols such as industrial pollutants and biomass burning aerosols, and natural aerosols such as dust and sea salt that be transported over long distances. It indicates the great complexity of aerosol particle type and optical characteristics at this location. Therefore, Selection of an accurate aerosol model is the primary task of atmospheric correction.

5. Conclusion

The present study tested several aerosol models used by 6s for the atmospheric correction of inland waters in Lake Taihu. The correction results of the Continental and Maritime model are similar, and more reliable than the results of urban model. Continental aerosol model achieved good results in bands from 3 to 9, but in other bands, the results of maritime aerosol model are better than the continental results.

6. Acknowledgments

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