IOP Conference Series: Earth and Environmental Science

Research on the Features of Chlorophyll-a Derived from RapidEye and EOS/MODIS Data in Chaohu Lake

To cite this article: X Wen *et al* 2014 *IOP Conf. Ser.: Earth Environ. Sci.* **17** 012111

IOP Conf. Series: Earth and Environmental Science **17** (2014) 012111 doi:10.1088/1755-1315/17/1/012111

Research on the Features of Chlorophyll-a Derived from RapidEye and EOS/MODIS Data in Chaohu Lake

X Wen[1], Z Zhou[2], B Chen[1], Z Li[1] and X Tang[3]

[1] Changjiang River Water Resource Commission Changjiang River Scientific Research Institute, Wuhan, China

[2] Changjiang River Water Resource Commission Yangtze River Water Resources Protection Bureau, Water Environment Monitoring Center of Yangtze Valley, Wuhan, China

[3] Department of computer, Wuhan Ordnance N. C. O. Academy of PLA, Wuhan, China

E-mail: wxfei19@gmail.com

Abstract. Chaohu Lake is one of the largest freshwater lakes in China, however, with the rapid expansion of Hefei, the water environment of Chaohu Lake shows significantly deterioration. In this paper, RapidEye and MODIS imagery were used to monitor the chlorophyll alpha (Chla) distribution in Chaohu Lake. After analyzing the correlation between in-situ measured Chla concentrations and each channel of RapidEye and MODIS imagery, the optimal band combination for the establishment of Chla concentration was determined. For RapidEye imagery, the red edge channel and near infrared channel are relatively more sensitive than other channels. The inversion model using the feature of (B5+B4)/(B2+B1) worked the best with the square value of correlation coefficient reaching up to 0.745. A similar procedure was applied to MODIS imagery. The experiments show that RapidEye with its red edge channel is an effective data source for water environment monitoring, it could provide high spatial resolution of Chla distribution thematic map, MODIS with its higher temporal resolution is also an effective data source in dynamically monitoring water environment. The Chla concentration in the western half of Chao Lake is higher than that in the eastern half.

1. Background

Chaohu Lake is the largest freshwater lake in the Anhui Province, and is also the fifth largest freshwater lake in China. Situated in the depression between the Yangtze River and the Huaihe River in the middle of Anhui Province, Chaohu Lake (31°25′28″-31°43′28″ N and 117°16′54″-117°51′46″ E) is one of the large shallow lakes of the middle and lower reaches of the Yangtze River, covering 760 square kilometers with an average depth of 2.5 m. Surrounded by the cities such as Hefei City, Chaohu City and Liu'an City, Chaohu Lake assumes the responsibility of water supply, irrigation, fishery, transportation, and it is also the carrier for shipping and tourism in Anhui [1].

Several rivers including Nanfei River, Hangbu River, Fengle River, Baishishan River, flow into Chaohu Lake, and flow into Yangtze River by passing through Yuxi River in the east of Chaohu Lake. Since the mid-20th century, with the rapid development of industrialization and urbanization in the

[1] Corresponding author: Xiongfei Wen, Tel.: +86-27-82926550; fax: +86-27-82820076

IOP Conf. Series: Earth and Environmental Science **17** (2014) 012111 doi:10.1088/1755-1315/17/1/012111

Chaohu Lake basin, especially the rapid expansion of Hefei City, the water environment of Chaohu Lake shows significantly deterioration, and a series of eco-environmental problems, such as the blue-green algal bloom pollution and eutrophication have gradually become more and more serious that cannot be ignored [2].

Remote sensing technique, with its synoptic view, repetitive coverage, cost effectiveness and availability, is an effective approach to dynamically monitor the lake's water environment [3-5]. In this paper, two kinds of satellite imagery were collected to analyze the Chla concentration distribution in Chaohu Lake.

2. Introduction of experiment data

The RapidEye constellation of five Earth observation satellites equipped with identical sensors and located in the same orbital plane stands apart from other has been in operation since February 2009. It provides of satellite-based geospatial information in their unique ability to acquire high-resolution, large-area image data on a daily basis. The RapidEye constellation collects an unprecedented 4 million square kilometers of data per day at 6.5 meter nominal ground resolution [6].

RapidEye's Multi-Spectral Imager (MSI) acquires imagery in five different spectral bands, and the presence of a red edge band is a unique feature that distinguishes RapidEye's satellites from most other multispectral satellites. The red edge band is located between the red band and the near-infrared (NIR) band without overlap. In the typical spectral response of green vegetation, the red edge band covers the portion of the spectrum where reflectance drastically increases from the red band towards the NIR band. Several studies suggested that the transition between the absorbance in red band and the reflection in the NIR band is able to provide additional information about vegetation, and is a useful instrument for water quality parameters extraction in productive inland water bodies with relatively higher phytoplankton content [7].

MODIS is the keystone instrument onboard a series of satellites commissioned as part of the National Aerospace and Space Administration (NASA) Earth Observation System (EOS). MODIS data provides the spectral information in 36 spectral bands ranging in wavelength from visible to thermal-infrared and at varying spatial resolutions, with the temporal resolution of 1–2 days, which is a valuable data resource in the application of meteorological and land/sea-surface feature inversion such as water environment dynamically monitoring [8]. The MODIS data used in this paper are provided by Goddard Space Flight Center of NASA.

The RapidEye imagery captured on Oct 17, 2012 and MODIS imagery captured on Oct 10/11/17, 2012 were collected in this paper.

3. Research Methods

3.1. Remote sensing imagery preprocessing

The preprocessing procedure of the remote sensing imagery includes radiometric calibration, geometric correction, etc.

The Rapideye and EOS/MODIS imagery were converted from digital numbers to exoatmospheric radiance by using the published post-launch gain, offset values and other parameters. The parameters include the mean solar exoatmospheric irradiance, solar zenith angle, etc. Then, in this section, the FLAASH atmospheric correction module was selected. According to the geographical position of Chaohu Lake and the capture time of the collected satellite imagery, the middle latitude winter atmospheric model and other key parameters were confirmed for FLAASH to convert the radiance file to reflectance.

In this paper, the digital topographic map covering Chaohu Lake was selected for image geometric correction. Firstly, digital topographic map was rectificated by using grid points of kilometers as the control points, then, taking the corrected digital topographic maps as base image, the road crossings point, bridges, or other distinctive feature of the permanent surface objects were selected as the control points to adjust geometric correction, and the error on the corrected imagery was about 1 pixel.

3.2. Water information extraction

The characteristic parameter of normalized differential water index (NDWI) is applied to water information extraction.

$$NDWI = (Green\text{-}NIR) / (Green\text{-}NIR) \quad (1)$$

Green and NIR is the reflectance of Green channel and Near Infrared channel respectively. The shoreline of Chaohu Lake includes both the artificial construction of cement road, exposed bedrock and the mucky soil covered with vegetation. The non-water information could be effectively suppressed by using NDWI parameter. The waters of Chaohu Lake could be extracted by using AOI tool with the support of NDWI parameter, the small islands in the lake area were masked in this section.

3.3. Chla information extraction

Existing research found that the spectral reflectance of Chaohu Lake showed the typical spectral characteristics of inland water. Phytoplankton-related spectral features are complicated, in the range of 400-500nm, the reflectance of algae is low for the high absorbance by algal pigments. Chlorophyll absorbance causes a reflectance minimum near 440 nm. In the range of 550-600 nm, for the smaller absorbance than blue and red spectral, the reflectance peaks at about 550 nm. The peak is affected by the amount of backscattering by cell walls. The reflectance minimum at 670 nm results from absorbance by Chla and the peaks in the range of 685-715 nm indicating the most significant spectral characteristic of algae water determined whether the water contains algae chlorophyll or not. These spectral-response features compose the foundation for the Chla concentration extraction.

For the RapidEye satellites imagery, since it has a unique Red Edge channel, several studies of productive inland water systems show that the reflected signal between 670 and 740 nm can give a better estimation distribution of Chla concentration[9-10]. Within this spectral range, Chla information is not affected by dissolved organic matter and other pigments. The reflectance in this range is a good indicator of Chla concentration. In this section, channel 4 and channel 5 of RapidEye satellite data were selected to establish Chla concentration inversion model for Chaohu Lake.

For the EOS/MODIS satellites imagery, the wavelengths for band 4, 2, 1 are 545-564nm, 630-690nm and 841-876nm respectively. The reflectance of Chla is smaller at band 4 and 2, while have a higher value in band 1. Band 4, 2, 1 of MODIS data were selected to establishing Chla concentration inversion model for Chaohu Lake.

The in-situ sampling Chla concentration data of Chaohu Lake was obtained combined by Water Environment Monitoring Center of Yangtze Valley and spatial information technology application institute of Changjiang River Scientific Research Institute during 10-11 October 2012. The distribution map of the in-situ sampling points for this paper is presented in Figure 1, the points No: 1-10 were sampled on 10 October 2012, and the points No: 11-20 were sampled on 11 October 2012.

3.3.1 Chlorophyll-alpha information extraction by using RapidEye imagery. The empirical model to retrieve the *Chla* concentration is one of the commonly used methods. After the remote sensing image preprocessing, the reflectance or radiance for each channel could be calculated, then these reflectance information for the corresponding sampling point will be extracted, for these different band combination, analyze the correlation between the in-situ chlorophyll alpha concentration , and to find the optimal band combination for the establishment of the chlorophyll alpha concentration inversion model.

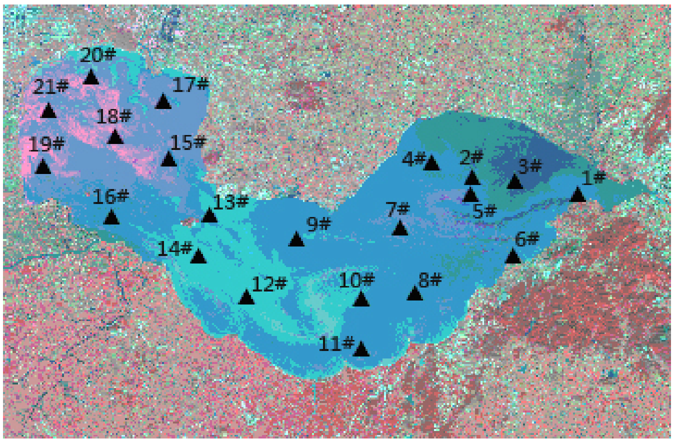


Figure 1. The distribution of the in-situ sampling point.

Analyzes the relationship between the reflectance of RapidEye imagery of each channel and Chla concentration, table 1 shows the correlation coefficient between in-situ measured chlorophyll alpha concentration and each channel of RapidEye imagery.

Table 1. The correlation coefficient between in-situ Chla concentration and each channel of RapidEye imagery.

correlation coefficient	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5
In-situ Chla concentration	0.094037	0.187542	0.002799	0.645981	0.689195

From table 1, it could be found the correlation coefficient of RapidEye imagery and the in-situ Chla concentration is greater at the Channels 4, 5 than other Channels. The table 2 gives a variety of combinations of RapidEye Channel 4 and 5 to retrieve the Chla concentration of Chaohu Lake This paper select the relatively better model to carry out the Chla concentration inversion. B 1, 2, 3, 4, 5 represent the Channel 1, 2, 3, 4, 5 of RapidEye imagery respectively.

Table 2. The band combination list of Chla concentration analysis.

(B5+B4)/ (B2+B1)	x=(B5+B4)/ (B3+B2)	x=(B5+B4)/ (B3+B1)	x=(B4-B3)/ B4+B3)

Using the RapidEye imagery of Oct 17, 2012, the band combination listed in table 3 were experimented and validated, the band combination with higher correlation coefficient were selected to establish multi-spectral inversion model of Chaohu Lake Chla concentration. It could be found that the Chla concentration inversion model using (B5+B4)/(B2+B1), (B5+B4)/(B3+B2) and is relatively better than other models, and the inversion model using the feature of (B5+B4)/(B2+B1) works the best, the square value of correlation coefficient could reach up to 0.745.

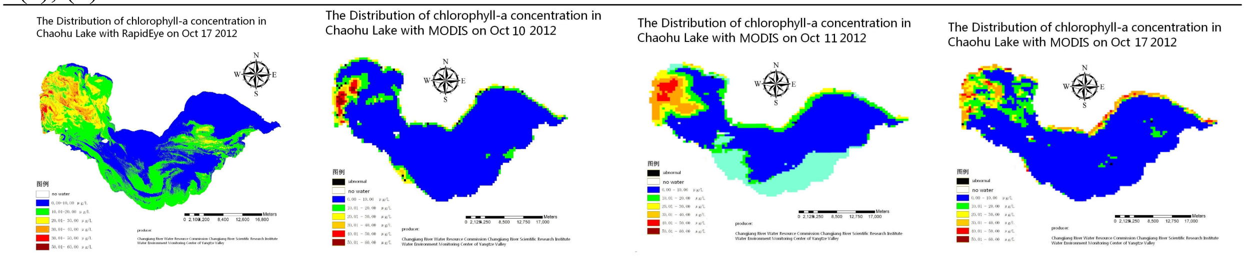
Applied the best model listed in Table 3, the Chla concentration distribution map of Chaohu Lake by using the RapidEye multi-spectral remote sensing imagery could be obtained with the support of ENVI and ARCGIS software, and the results is just shown in Figure 2(a).

It could be observed that the water environment in the west of Chao Lake is obviously more serious than that in the east. The inversion results show that during October 2012 the Chla concentration in Chaohu Lake is relatively higher, The Chla concentration with high-value areas are mainly located in the western half of Chao Lake, especially in the part of the coastal area along the west, Chla concentration could reach up to 60 mg/L, with the highest value of 200 mg/L, Chla concentration of the eastern half in Chaohu Lake is relatively lower, part of the region could reach up to 30 mg/L.

Table 3. The Chla concentration inversion model list for RapidEye imagery.

	Parameter	Inversion model	R^2
Inversion model	x= (B5+B4)/ (B2+B1)	$y = 14.033076\ x^2 + 1.707456\ x - 1.437236$	0.745
		$y = 27.887337\ x + 13.013124$	0.729
		$y = 1.219323e^{2.367348x}$	0.661
		$y = 23.269102\ \ln(x) + 14.989527$	0.667
	x=(B5+B4)/ (B3+B2)	$y = 3.515368\ x^2 + 20.505897\ x - 8.739155$	0.739
		$y = 27.196438\ x + 11.713075$	0.738
		$y = 1.414\ e^{2.261\ x}$	0.643
		$y = 23.701648\ \ln(x) + 15.905340$	0.707
	x=(B5+B4)/ (B3+B1)	$y = 1.454345\ x^2 + 17.081670\ x - 7.961408$	0.723
		$y = 20.50555\ x - 9.82154$	0.723
		$y = 1.672508\ e^{1.693839\ x}$	0.621
		$y = 21.840075\ \ln(x) + 11.347192$	0.690
	x=(B4-B3)/ B4+B3)	$y = 85.229741\ x^2 + 44.397210\ x + 8.516564$	0.689
		$y = 55.790784\ x + 8.988906$	0.662
		$y = 7.894982\ e^{4.724813\ x}$	0.598

3.3.2 Chlorophyll-alpha information extraction by using MODIS imagery. Considering the data synchronization between remote sensing imagery and in-situ sampling data, the MODIS imagery is also collected to extract the Chla concentration in Chaohu Lake. Using the similar procedure described in section 3.3.1, for channels 1-7 of MODIS imagery, the Infrared channel is relatively more sensitive than other channels. The inversion model using the feature of (B2-B1)/(B2+B1) works the best, with the square value of correlation coefficient reach up to 0.792. The Chla concentration thematic map of Chaohu Lake by using the MODIS imagery could be obtained, with the results shown in Figure 2(b), (c), (d).



(a) (b) (c) (d)

Figure 2. The distribution of Chla concentration in Chaohu Lake: (a) with RapidEye on Oct 17, 2012, (b) with MODIS on Oct 10, 2012, (c) with MODIS on Oct 11, 2012, (d) with MODIS on Oct 17, 2012.

4. Conclusions and discussion

Compared the Figure 1(a) (b) (c) and (d), the Chla concentration distribution in the Chaohu Lake is quite similar. RapidEye imagery could be used to obtain the intimate view of Chla concentration distribution map for its red edge channel is very suitable in water monitoring with high spatial resolution. While the MODIS imagery could be applied to obtain the dynamical change of the Chla concentration distribution with its lower spatial resolution and higher temporal resolution. These two kinds of satellites could complement each other to monitoring the water environment of Chaohu Lake. RapidEye imagery is very suitable in water monitoring with high spatial resolution and MODIS imagery is suitable in dynamically monitoring water environment due to its high temporal resolution. Using the RapidEye and MODIS imagery, it is observed that the chlorophyll alpha concentration in the western half of Chao Lake is higher than that in the eastern half, and more attention should be paid to environmental protection with the development of economy.

Acknowledgments
This work was funded through a grant from the National Scientific Fund of China (No. 41201452, 41001281), the Basic Research Operating Expenses for the Central-level Non-profit Research Institutes of China (No. CKSF2012027/KJ, CKSF2012029/KJ, CKSF2011008/TB), the National Key Technology R&D Program of the Ministry of Science and Technology (No. 2013BAB05B01), and the Natural Science Foundation of Hubei Province, China (No. 2011CDB013) and the authors would like to thank two anonymous reviewers and Dr Peng Yi of Wuhan University for the good suggestions in finishing this paper.

References

[1] Xie P 2009 *Turn over the history of Chaohu Lake* (Beijing, Science Press)
[2] Yang G, Ma R and Zhang L 2010 Lake status, major problems and protection strategy in China *China J. of Lake Science*. **22** 799
[3] Jiang J, Huang Q and Sun Z 2006 Analysis of ecological environment of lake-wetland in Yangtze River basin *China Ecology and Environmnet.* **15** 424
[4] Lei S, Zhang X, Li R, Xu X and Fu Q 2011 Analysis the changes of annual for Poyang Lake wetland vegetation based on MODIS monitoring *Procedia Environmental Sciences(Part B).* **10** 1841-46
[5] Wang S 1989 The activity of human being in recent 40 years had influence over arid lake in China *China Arid Land Geography.* **12** 1-5
[6] RapidEye A G.http://www.rapideye.com/products/index.htm
[7] Horst W, Pablo R and Alexander M Write Paper :The RapidEye Red Edge Band.http://www.rapideye.com/upload/Red_Edge_White_Paper.pdf
[8] Platnick S, King M, Ackerman S 2003 The MODIS Cloud Products:Algorithms and Examples from Terra *IEEE Transactions on Geoscience and Remote Sensing*. **41** 459-73
[9] Ruddick K, Gons H and Rijkeboer M 2001 Optical remote sensing of chlorophyll a in case 2 waters by use of an adaptive two-band algorithm with optimal error properties *Applied Optics*,**40** 3575-85
[10] Schalles J, Gitelson A and Yakobi Y 2001 Estimation of chlorophyll-a from time series measurements of high spectral resolution data in an eutrophic lake *J. of Phycology* **34** 383-90.