THE MODELING FOR DYNAMIC ALGAE BLOOMS PREDICTION BASED ON REMOTE SENSING

WEI Qingyu [**a], JIANG Nan[b], LU Heng[c], HU Bin[b]

[a]School of Geographic and Oceanographic Sciences, Nanjing University, Nanjing 210093, China - weiqingyu@nju.org.cn
[b]Nanjing Institute of Geography and Limnology, Chinese Academy of Sciences, Nanjing 210008, China
[c]College of Geographic Information Science, Nanjing Normal University, Nanjing 210097, China

KEY WORDS: Algae Blooms; Forecast and Early Warning; Remote Sensing

ABSTRACT:

As the algae blooms in the Taihu Lake of our country are more and more frequent and have become to be a big threat to ecosystem environment, aquatic breeding industry and human health. In this paper, by summarizing current research conditions on the algae blooms forecast, with MODIS data and ground collecting data in the Taihu Lake in China, the authors use a new concept to construct the algae blooms prediction model. This concept considers the optical characteristics of the four periods of algae blooms and also the affects of meteorology and hydrology environment. This model is in hope of to forecast and early warning in the future.

1. INTRODUCTION

Cyanobacteria and Lake Eutrophication in China is the current outbreak of the most important environmental problems, and the lake eutrophication control is one of the world's focuses of attention.

Taihu is located at the common boundary of province Jiangsu and Zhejiang. The mean depth of the Taihu Lake is 1.89m; the whole area is about 2338km^2, which is the third biggest lake in China and one of the most active areas in China (Pu, 1998). At the same time the Taihu Lake is an economy developed region. The landscape surrounding the lake is beautiful and the Taihu Lake is a famous scenic resort, because of the dainty scenery and brilliant culture landscape, attracts thousands of Chinese and foreign countries tourists annually. With the reform and opening up and rapid economic development, a large number of point sources, sources of pollutant have been discharged to the Taihu Lake. The Taihu Lake eutrophication is the underlying reason which causes the Taihu ecological crisis. Cyanobacteria erupt almost every year. Especially in May 2007 the Taihu Lake cyanobacteria bursts out sharply in a short time because of continuous high temperature heat. Deterioration of water quality spreads rapidly in the Wuxi City, including the East Wuxi City Waterworks, accounting for the remaining 70 percent of the city's water quality have been Waterworks pollution. The lives of 2 million population drinking water smell unbearable. Cyanobacteria outbreak of that year seriously undermined the balance of lake ecosystems, fisheries resources and aquaculture industry. In addition, much study shows that, the Taihu Lake, the main water cyanobacteria Microcystis population, the algae toxin can damage human liver and a tumour promoter effect, a serious threat to people's health.

2. DATA PREPARATION

The use of remote sensing technology to monitor the water, cyanobacteria have an unparalleled advantage in other ways, which not only can provide the distribution of water of the entire lake or the region as a whole, quickly and in a timely manner, but also can setup up a continuous monitoring system on the concentration of cyanobacteria, achieving Blue Algae Bloom early (Chang, 2004). At the same time, with the help high temporal resolution remote sensing satellite images on cyanobacteria, the drift of water, assessment the losses caused by cyanobacteria, and the formation mechanism of microcystin generated by the water, the biogeochemical impact are of great significance. Meanwhile it can provide a scientific basis for the control of cyanobacteria. The remote sensing technology had provided effective and low-cost means of monitoring synoptic water quality over inland waters (Krawczyk, 2003; Kutser, 2006).

This paper is based on MODIS remote sensing data sources. MODIS sensors are both equipped on the Terra and Aqua satellite, which have advantages such as doubling a day re-imaging cycle, a large scope of coverage, low cost etc. They also have the advantages of easy handling for natural disasters remote sensing monitoring. They are visible to the thermal infrared spectra of the 36 channels, with a spatial resolution of 250 m ~ 1000m. MODIS data plays an increasingly important role in the remote monitoring of inland lakes(Bowers, 2001; Nezlin, 1999). Our prediction model is focused on the study of monitoring the tropic state of water bodies in the Taihu Lake, which bases on the MODIS images. MODIS is a cross-track scanning radiometer with 36 spectral bands: 29 with 1-km (at nadir) pixel dimensions, five with 500-m pixels, and two with 250-m pixels. As a data source for algae blooms monitoring, it estimates chlorophyll-a concentration with normalization based on the data set from in situ.

[*] Cooperative Project with the State Bureau of Surveying and Mapping: The Projection of New Socialist Villages - Algae Blooms' Dynamic Prediction Model for Taihu Lake; Supported by open fund: JK20050303 Geo-Information Science Key Laboratory of Jiangsu Province

[**] weiqingyu@nju.org.cn; phone 86 25 86882079; No.22 Hankou Road, Nanjing 210093, P.R. China

2.1 Geometric Correcting

The Geometric correcting uses the projection Geographic Lat/Lon, reference point for WGS-84. The correcting is based on the inherent Lat/Lon information of MODIS 1B data and accessed by ENVI procession automatically to correct geometry.

2.2 Radiometric Calibration

The value of radiation on sensor can be calculated with radiometric calibration of the image data in the metadata recorded of each bands, corrected incremental coefficient and corrected offset can be written as

$$R = Scales * (DN - Offsets) \quad (1)$$

where scales = reflectivity zoom factor

DN = the storage value of MODIS 1B data

Offsets = reflectivity zoom intercept

R = reflection rate

2.3 Atmospheric Correcting

This study used image-based approach to correct the atmosphere; the specific method is to remove the minimum histogram law. The basic idea is that an image can always be found by one or certain kinds of features, whose radiance or reflectivity is close to zero. Then the corresponding location of the pixel brightness values in the image should be the same. Measured and indicated that these positions on the pixel brightness are not zero. This value should be on the atmosphere led to the scattering of radiation value. Assumption atmospheric radiation-caused by the reflection rate of value is added by Δr, which in image in the limited area is a constant, the size of its value only with the band on, and that each band similar to the reflection rate is the minimum value $r_{\min}$ as Δr. In this way, the image of each pixel of the reflectivity is less than the value $r_{\min}$ of this band; the atmospheric effects can be removed roughly.

3. CYANOBACTERIA WATER REMOTE SENSING, MONITORING AND EARLY-WARNING DYNAMIC MODEL

3.1. Based on Spectral Characteristics of the Monitoring Model

Microcystin (Microcystis) is belongs to Cyanophyta colored balls algae Head, of energy self-support type of plankton growth in the water microcystin cells and a monomer form of cystic unshaped groups, often from several groups dozens, or even hundreds of thousands of single cells. In order to validate its applicability in the near-infrared wavelengths to Case II waters, laboratory research found simply parameterized equations employing microcystin spectrum at 550 nm and 710nm. And there are two very obvious reflection peaks in the 440 nm and 670 nm and has a very obvious absorption peaks. For microcystins in particular, there is an absorption peak near 620 nm. In the bile of the green algae, the absorption peak is unique for microcystin (Dekker, 1993; Jupp, 1994). It was showed that both equations gave out comparative good performance with coefficient determination (R2) larger than 0.85 and root mean squared error (RMSE) is much lower than data span of the training and test data. Microcystis unique spectral characteristics make remote monitoring of microcystin concentration possible. Based on the transfer of radiation in waters, the bio-optical model could integrate well apparent optical properties (AOPs) with inherent optical properties (IOPs). However, further investigation is needed to upgrade the bio-optical dataset and to refine the model for the universal applications. Figure 1 shows the framework of the model of Dynamic Prediction Model of Algae Blooms.

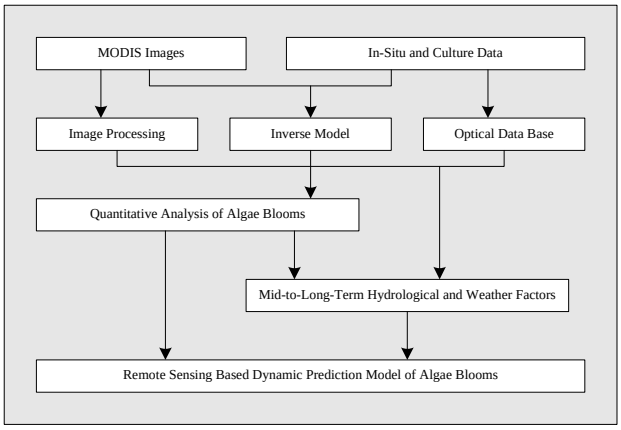


Figure 1. Framework of the model of dynamic prediction model of algae blooms

3.1.1 Field Observation Experiment

Eutrophic lakes in the middle and lower reaches of the Yangtze River microcystin growth and formation water, for the four major periods: dormancy, recovery, biomass increase, and the accumulation of floating. According to the different period and four satellite transit time of cyanobacteria, we can emplace fixed-point in the Taihu Lake excluding the East Taihu Lake (Wuli Lake, Meiliang Bay, the lake district, etc.) and make full use of the ASD Object Spectrometer spectral characteristics of water and underwater Trios Hyperspectral Radiometer spectral characteristics. Meanwhile we can also use AC-S and BB9 to measure the absorption coefficients of water and the backscattering coefficients. And surface water sampling, sample record time, weather conditions, wave height, water temperature, wind speed and wind direction can be collected at the same time.

3.1.2 Laboratory Experiments

In the laboratory analysis of water samples surface concentrations of chlorophyll a, suspended solids, such as yellow substance concentration, using spectrophotometer, and use QFT technology (Quantitative Filter Technique) of the absorption coefficient (a). At the same time slot through the indoor simulation experiments were measured using different BB9 cyanobacteria chlorophyll a growth period after the backscattering coefficient (b_b), and the use of cyanobacteria QFT technology absorption coefficient of chlorophyll a (a).

According to the model of water body radioactive transfer (Mobley, 1994), water surface and the ratio of the radiation absorption and backscattering coefficient after the relationship between can use the following mathematical relationship between the expressions:

$$R(0^-,\lambda)=\frac{E_u(0^-,\lambda)}{E_d(0^-,\lambda)}=f\frac{b_b(\lambda)}{a(\lambda)+b_b(\lambda)} \quad (2)$$

where: λ = wavelength

$R(0^-,\lambda)$ = wavelength radiation reflectivity

$a(\lambda)$ = wavelength absorption

$b_b(\lambda)$ = wavelength back-scattering

f = variable parameters

The totally absorption $a(\lambda)$ can be expressed by the product of composition strength and absorption unit; back-scattering $b_b(\lambda)$ also be expressed by the product of after-scattering unit coefficient and composition strength (Morel, 1977)(To simplify, all the wavelength parameter λ are omitted):

$$b_b=b_{bw}+b_{bp}{}^*C_P+b_{bm}{}^*C_m+b_{bt}{}^*C_t \quad (3)$$

$$a=a_w+a_P^*C_p+a_m^*C_m+a_t^*C_t+a_g^*C_g \quad (4)$$

Where $a=a_w+a_P^*C_p+a_m^*C_m+a_t^*C_t+a_g^*C_g$

b_{bw} = after-scattering coefficient of water

b_{bp}^* = after-scattering unit coefficient of chlorophyll-a other water algae

b_{bm}^* = after-scattering unit coefficient of chlorophyll-a microcystin

b_{bt}^* = after-scattering unit coefficient of inorganic particles

a_w = absorption unit of water

a_P^* = absorption unit of other algae in water

a_m^* = absorption unit of Microcystin

a_t^* = absorption unit of inorganic particles

a_g^* = absorption unit of colored dissolved organic matter

C_P, C_m, C_t, C_g = strength of chlorophyll-a other algae, chlorophyll-a microcystin, inorganic particles and the concentration of colored dissolved organic matter.

This established the undersea radiation reflectivity of the group and the correlation between the mathematical expressions (Werdella, 2005). Therefore, in the four substances known characteristics of the scattering and absorption properties under the conditions can be simulated in accordance with its concentration of different components of the ground water or the atmosphere top reflectance spectroscopy (TOA, Top Of Atmosphere) reflectance spectroscopy Instead, it will have know at different wavelengths on the ground reflectance rate, or the top of the reflectivity of the atmosphere, through the establishment of linear equations can be obtained corresponding concentration, thereby monitoring microcystin concentrations of chlorophyll a realization of cyanobacteria, the remote monitoring of the outbreak.

3.2. Based on weather conditions forecast model

Temperature and light on the growth of algae plays a leading role, and the wind direction and wind speed is a direct impact on the spread of algae in water, which makes weather conditions from the perspective of the cyanobacteria, warning possible.

Therefore, the average rainfall for observation, the daily average temperature, wind, and the establishment of equations:

$$D=f(r_{\min},\Delta d_r,t_{\max},\Delta d_t,w_{\max},\Delta d_w) \quad (5)$$

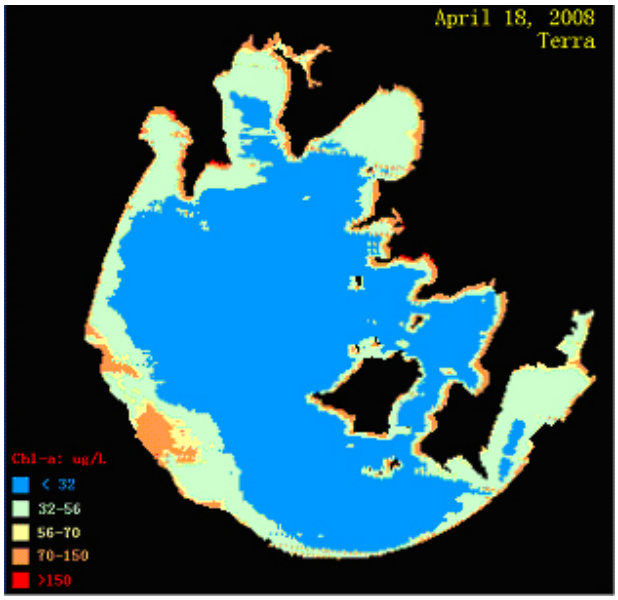
It can be concluded that when D continuous Δd_r days and rainfall is less than $r_{\min}$, and Δd_t days daily average temperature is higher than the historical average temperature of the month $t_{\max}$, and Δd_w consecutive days and the maximum wind speed is less than $w_{\max}$ of water, the possibility of grading.

April 18th, 2008, take the water quality to the situation as an example, which shown in Figure 2. MODIS/Terra shown on 11:25, April 18, the west coast of Lake Taihu, Wuli Lake, the water is obvious cyanobacteria outbreaks, chlorophyll-a level over 70ug/L; west coast and the Zhushan Bay, Meiliang Bay, Gonghu Bay has cyanobacterial greater scope to gather, chlorophyll-a level over 32ug/L, but do not form a water-hazard East Taihu Lake region has a higher content of chlorophyll, but the main area for quite water, float vegetation and algae in the water, very little .

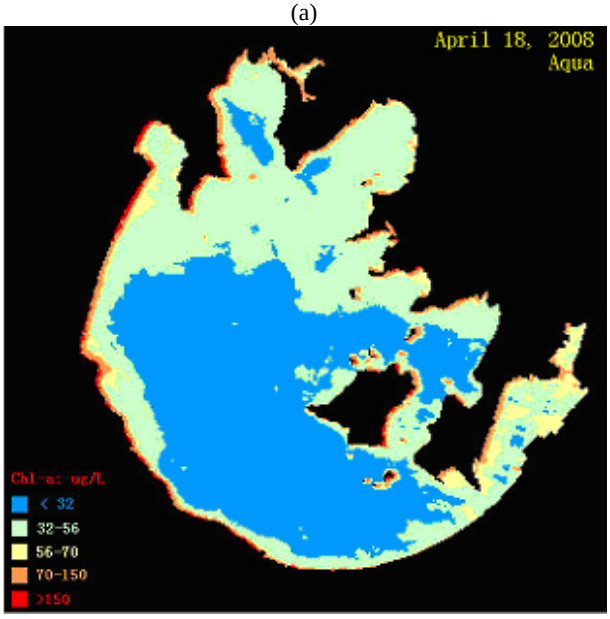
At 13:00 on April 18 of Aqua image, there are still significant Wuli Lake Taihu Lake water, cyanobacteria, chlorophyll-a level over 70ug/L; west coast and the Zhushan Bay, Meiliang Bay, Gonghu Bay, the eastern coastal areas have greater scope to cyanobacteria gathered, chlorophyll-a level over 32ug/L, but do not form a water-hazard East Taihu Lake region has a higher content of chlorophyll, but the main area for quite water, float vegetation and algae in the water, very little.

11:25 and 13:00 of the two remote sensing-film distribution in cyanobacteria are greater differences, mainly due to weather conditions affected; the temperature is 14-18℃, southeast wind 4-5 grade (about 6-10 m/s). The right temperature conditions

for the large number of breeding cyanobacteria, chlorophyll content of a rapid increase, but because of storms caused by fluctuations in the water roller, the cyanobacteria did not die on the Chung floating to the surface of Taihu Lake, caused no harm. As wind speed of 6-10 m/s wind affected the southeast, the southwest coast northward spreads of water-to disappear. Therefore, in a short period of 1.5 hours in cyanobacteria change very quickly. The large-scale presence of cyanobacteria in the lake for its chlorophyll a 32-56 ug/L, will not have a direct impact on the lives of production, but we must alert.



(a)



(b)

Figure 2. The Chlorophyll a distribution of the Taihu Lake of April 18, 2008

The model of remote sensing algae blooms disaster was set up to give the amount of phytoplankton cells, the speed of cells increasing and region of algae blooms distribution from MODIS. Especially, modelling of hydrological, environmental processes and mid-to-long-term weather factors on a small and medium scale, as well as monitoring, managing and controlling require a large amount of data and information, different models and techniques, coupled with speed and accuracy, all of which can be incorporated into the model.

4. CONCLUSION

Firstly, the established model described in this paper is divided into three modules: the optical monitoring of algae biomass model based on the spectral characteristics, the perdition model based on the weather forecast elements, the modules matching model based on graphic images, which are complementary. Due to the characteristics and limitations of collected data, the first two models attract more attentions and the third one is used as a kind of supplemental method. With technological advances in remote sensing, image matching technology forecasting using water, there will be a wider world. Secondly, cyanobacteria fully consider the characteristics of their own changes, in accordance with cyanobacteria growth and the formation of water-four period (dormancy, recovery, biomass increase, floating and accumulation), rather than the usual sense of the spring, summer, autumn and winter 4 period, revealed a microcystin chlorophyll absorption and scattering properties change, the establishment of cyanobacteria growth and formation water, the different stages of chlorophyll a concentrations inversion model of optical monitoring algae, which is conducive to further improve the accuracy of inversion . However, when large swarms of algae, especially in view of the whole entire Taihu Lake average nitrogen and phosphorus content of up to 4.0 and 0.13 mg / L, algae has been a whole lake of the distribution of state, the bio-optical model, there are limitations. Finally, based on the elements of the forecast model in the study of algae in the water, is rare, so this is a highlight of this study. Biological and meteorological optical model of combining environmental factors, cyanobacteria prior to the outbreak of water-critical state of disaster warning levels, in theory than simply monitoring microcystin concentrations of chlorophyll a, outbreaks of water to achieve a more accurate early warning. Thus, the early take corresponding measures to reduce the outbreak cyanobacteria, and the impact of the loss is the firm founded.

Depending on the research above, a whole elementary algae blooms remote sensing monitoring system has been set up. The next step is to Taihu Lake cyanobacteria, remote sensing dynamic model of early-warning monitoring and verification, and further improved to stable input of the operation, for the people's production and life protection. And relevant system's software is putting into use in the routine operational monitoring work as well as that algae blooms satellite remote sensing monitoring report were issued with high precision.

REFERENCES

Bowers D. G., 2001. On the calibration and use of in situ ocean colour measurements for monitoring algal blooms. *International Journal of Remote Sensing*, 2-3, pp. 359-368.

Chang, K.W., 2004. Predicting algal bloom in the Techi reservoir using Landsat TM data. *International Journal of Remote Sensing*, 17, pp. 3411 -3422.

Dekker A.G., 1993. Detection of optical water quality parameters for eutrophic waters by high resoluteon remote sensing. Thesis, Vrije University,Amsterdam.

Jupp D. L. B., 1994. Detection, Identification and Mapping of Cyanobacteria - Using Remote Sensing to Measure the Optical Quality of Turbid Inland waters. *Aust. J. Mar. Freshwater Res.*, 45,pp. 801-828.

Krawczyk H., 2003. *Algae bloom detection in the Baltic Sea with MERIS data*. MERIS User Workshop, Frascati, Italy.

Kutser T., 2006. Monitoring cyanobacterial blooms by satellite remote sensing. *Estuarine,Coastal and Shelf Sciences*, 67, pp. 303-312.

Mobley C. D., 1994. *Light and Water: Radiative Transfer in Natural Waters*, Elsevier, New York.

Morel A. and L.Prieur. Analysis of variations in ocean colour. *Limnology and Oceanography*. 1977,22:709-722

Nezlin N.P., 1999. Patterns of Seasonal and Interannual Changes of Surface Chlorophyll Concentration in the Black Sea Revealed from the Remote Sensed Data. *Remote Sensing of Environment*, 69, pp. 43-55.

Pu P. and Yan J.,1998. Taihu Lake - A large shallow lake in the east China Plain. *Journal of Lake Science*, 10(Suppl.):1-18

Werdella P. J., 2005. An improved in-situ bio-optical data set for ocean color algorithm development and satellite data product validation. *Remote Sensing of Environment*, 1, pp. 122-140.

Zeichen M. M., 2004. Detection and monitoring of algal blooms using SeaWiFS imagery. *International Journal of Remote Sensing*, 7-8, pp. 1389- 1395.