Geoscience and Remote Sensing (2021) Vol. 4: 54-61
Clausius Scientific Press, Canada

DOI: 10.23977/geors.2021.040106
ISSN 2523-2592

Study on Dynamic Model of Marine Ecosystem Based on Chlorophyll Concentration Distribution

XiangGuang Zhang[a], YongSheng Xu[b,*]

Institute of Oceanology, Chinese Academy of Sciences, Qingdao, Shandong 266071, China

[a] zxg@qdio.ac.cn, [b] yongsheng.xu@qdio.ac.cn

**corresponding author*

Keywords: Chlorophyll concentration, Marine ecosystem, Dynamic model

Abstract: Marine ecosystem has two important basic characteristics, namely, nonlinearity and hierarchy. Non-linearity leads to high correlation between ecological parameters in marine ecosystem dynamics model, which leads to large errors in simulation results. This paper describes the monitoring and prediction technology of chlorophyll a concentration based on MODIS image data, and based on this, interprets and analyzes MODIS image data, and establishes a water ecological dynamic model. Firstly, MODIS image data are interpreted and analyzed, and the initial data are processed by projection transformation and region of interest clipping, and then atmospheric correction is performed. At the same time, the remote sensing inversion model of chlorophyll a concentration of marine algae is established by using BP neural network technology combined with optical and radar remote sensing. The research results show that the method described in this paper can overcome the disadvantage of low resolution of MODIS image data and provide fast and real-time monitoring results.

1. Introduction

Marine ecosystem refers to a unified whole formed by the interaction of living and abiotic components in a certain sea area through material circulation and energy flow. Its main function is the material circulation, energy information flow and its feedback regulation mechanism to maintain its balance [1]. Therefore, it is the common goal of marine ecological research work to improve the ability to predict the response of marine ecosystem to global changes by strengthening the understanding of the structure and function of marine ecosystem [2]. In order to protect the marine environment on which human beings depend and promote the sustainable development of human beings and the ocean, it is urgent for people to understand the marine ecosystem from a scientific point of view and study its changes and causes.

Algae are the producers in the ocean and the basis of the marine food chain. Chlorophyll A is the main photosynthetic pigment in algae cells. Chlorophyll A concentration and its dynamic changes reflect the abundance, biomass and its changing rule of algae in water. It is an objective biological index reflecting the nutritional status of marine water, and it is also the most important index in the evaluation of marine eutrophication status [3-4]. The chlorophyll-a concentration of algae is obtained by retrieving the model established in the study area from multi-source remote sensing data, which is of great significance for studying the algae distribution in the whole sea area and the primary productivity in the marine ecosystem, and has become an effective method for red tide monitoring [5-7]. In this paper, the algae in the Yellow Sea coastal waters are taken as the research object, the chlorophyll a concentration of marine algae is analyzed by using multi-source remote sensing images, and the remote sensing inversion method of chlorophyll a concentration of marine algae is studied by using BP neural network technology.

2. Introduction and Establishment of Marine Ecosystem Dynamics Model

Marine ecological dynamics model can describe the actual changes of ecosystem state variables under the influence of physical, chemical and biological factors, and it quantitatively describes the interaction mechanism of each process by means of computer simulation. Ecological models are various and vary in complexity. In this paper, we try to use the relatively simple ecological model which can represent the most important ecological mechanism to carry out the accompanying assimilation experiment, and realize the temporal and spatial changes of the parameters in the model. The model grasps the main food chain of the ecosystem, abstracts the main attributes, and uses as few variables and equations as possible to describe the ecosystem comprehensively.

Therefore, we have established a $NPZD$ model based on nitrogen cycle, that is, all nutrients and phytoplankton are expressed by their total concentration and total biomass P and N, and all kinds of zooplankton and debris are expressed by their total biomass Z and D. The four state variables $NPZD$ in the model can be uniformly expressed as:

$$\frac{\partial C_i}{\partial t} = Phy(C_i) + Bio(C_i) + S \qquad (1)$$

Among them, C --state variable(C_1-phytoplankton P, C_2-Zooplankton Z, C_3-nutritive salt N, C_4-clastic D).

Phy --Changes of state variables caused by physical mechanisms such as convection and diffusion;

Bio --Changes of state variables caused by biological mechanisms such as growth, death and predation;

S --Source and sink terms, due to the research needs of this paper, do not consider the source and sink terms in the model for the time being.

The schematic diagram of the model is shown in Figure 1:

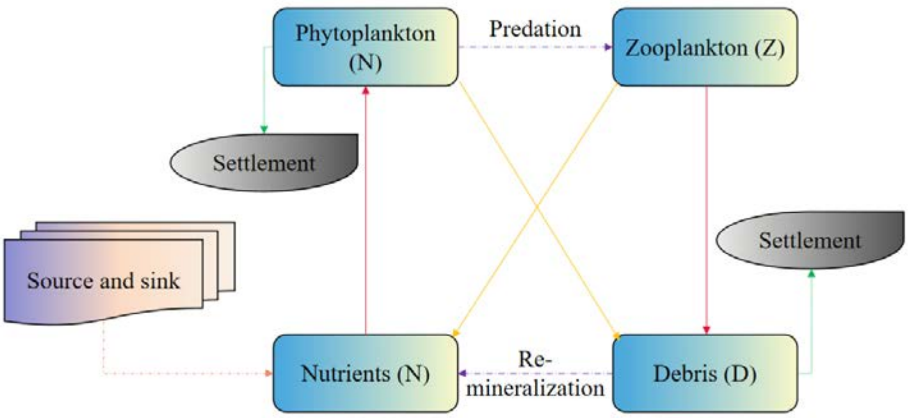

Fig.1 Schematic Diagram of $NPZD$ Model Operation Mechanism

Nutrients (N) are very important, which often drive biochemical processes and control the growth of phytoplankton, and come from the remineralization of debris (D). Green phytoplankton (P) is the most basic producer in the ocean, which absorbs nutrients and carbon dioxide for photosynthesis, and its productivity directly or indirectly affects the productivity of other organisms in the waters. Zooplankton (Z) is a consumer in the ocean, preying on phytoplankton and releasing nutrients; Dead phytoplankton and zooplankton form debris together.

3. Study on Chlorophyll Inversion Model

3.1 Acquisition of Chlorophyll a Concentration

(1)Basic data processing

The MODIS image data used in this study is 1B data set, which is obtained from MODIS receiving center of a university. Before the calculation, a series of data processing were carried out in ERDAS 8.6 software, including projection conversion and image clipping, and the processed data were converted into. *asc file for output.

(2)Atmospheric correction of MODIS data

In the process of obtaining information, remote sensors are inevitably affected by the absorption and scattering of atmospheric components such as atmospheric molecules, aerosols and cloud particles, so the measured values of remote sensors are different from the actual spectral radiance of ground objects. The remote sensing quantitative inversion of surface parameters must first correct the uncertain information of target radiation [8]. In this paper, the atmospheric correction method of 6s (second simulation of the satellite signal in the solar spectrum) model is used to calculate the real spectral reflectance of the target.

When using 6S software for atmospheric correction, the input parameters are: solar zenith angle, satellite zenith angle, solar azimuth and satellite azimuth. These parameters can be obtained from MODIS image header files; Atmospheric composition parameters, including water vapor, dust particle size and other parameters: this time, due to the lack of atmospheric measured data, the standard atmospheric model provided by 6S-mid-latitude summer is selected as the substitute; Aerosol component parameters, including moisture concentration and the percentage of smoke and dust in the air; Atmospheric path length of aerosol; Observe the altitude and sensor height of the target; Spectral conditions.

After inputting the above parameters, 6S software will calculate various atmospheric parameters, and at the same time give the atmospheric correction coefficient x_a, x_b, x_c, and the atmospheric corrected reflectance ACR (atmospheric corrected reflectance) can be obtained by the following formula:

$$Y = x_a * (L_i) - x_b \quad (2)$$

$$ACR = \frac{Y}{1 + x_c * Y} \quad (3)$$

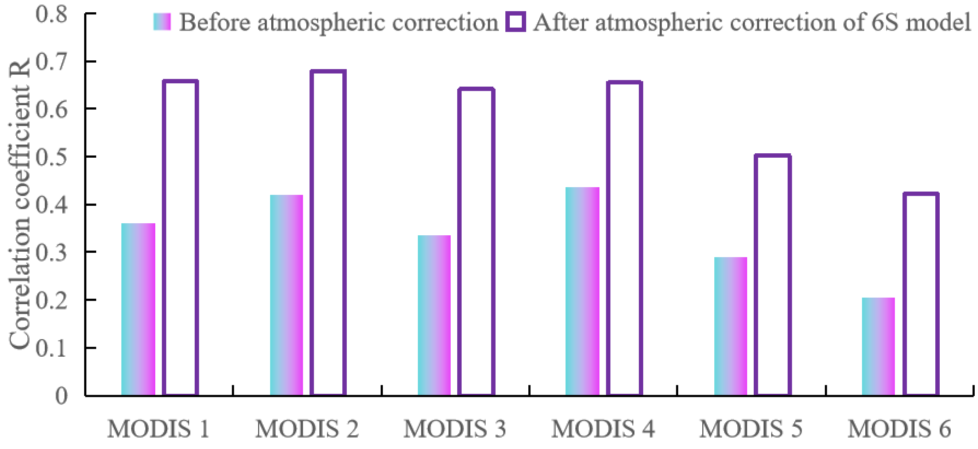

Fig.2 Correlation Coefficient between Chlorophyll a Concentration and Modis Data Before and after Atmospheric Correction

Fig. 2 is the correlation coefficient between chlorophyll concentration and each band of MODIS data before and after atmospheric correction. It can be seen from fig. 2 that the correlation between each band of MODIS image and chlorophyll has been significantly improved after atmospheric correction by 6S model, and the effect of atmospheric correction is obvious.

(3)Calculation of chlorophyll a concentration

In this study, chlorophyll a concentration was retrieved by empirical algorithm, and the formula proposed by O'Reilly (1998) was selected:

$$R_{\max} = \log_{10}\left(\frac{R_{rs}443}{R_{rs}555} > \frac{R_{rs}490}{R_{rs}555} > \frac{R_{rs}510}{R_{rs}555}\right) \quad (4)$$

$$Chl - a = 10^{\left(0.336 - 3.067R_{\max} + 1.930R_{\max}^2 + 0.649R_{\max}^3 - 1.532R_{\max}^4\right)} \quad (5)$$

Where $R_{\max}$ is the maximum value of the band ratio; $R_{rs}(\lambda)$ is remote sensing reflectivity; $Chl - a$ is chlorophyll a concentration.

3.2 Independent Grid Thought in the Process of Ecological Parameter Inversion

When the adjoint assimilation method is used to optimize the ecological parameters in Haixiang ecosystem dynamics model, the observed data are generally less than the number of ecological parameters to be optimized. For this model, only the data of nutrients and surface phytoplankton (chlorophyll a) are available, which will cause the ill-posed inverse problem of mathematics and physics. In this paper, the “independent point” scheme is adopted, which has been successfully applied widely in marine numerical models. The main idea of this scheme is to select some grid points as the “independent points” to be optimized in the simulation area, and only optimize the parameter values at the “independent points”, while the parameter values at other grid points are interpolated from the parameter values at the independent points. The advantage of this method is that the number of variables of ecological parameters to be optimized is reduced, and the fitness of inverse problems in mathematics and physics is improved to a certain extent.

The specific process is as follows [9]:

The parameter values of evenly selected grid points in the calculation area are recorded as $P_{ii,jj}$ (ii, jj represents the grid index of independent points), and the parameter values of other grid points are recorded as $P_{i,j}$ (i, j represents the grid index of calculated grid points). The relationship between them is [10]:

$$P_{i,j} = \sum_{ii,jj} \phi_{i,j,ii,jj} \cdot P_{ii,jj} \quad (6)$$

In which $\phi_{i,j,ii,jj}$ is the weight coefficient $\frac{w_{i,j,ii,jj}}{\sum_{ii,jj} w_{i,j,ii,jj}}$ and $w_{i,j,ii,jj}$ is the interpolation coefficient in cressman form:

$$w_{i,j,ii,jj} = \begin{cases} \frac{R^2 - r^2_{i,j,ii,jj}}{R^2 + r^2_{i,j,ii,jj}}, & r \le R \\ 0, \quad r > R \end{cases} \quad (7)$$

r is the distance between the independent point and the grid point to be calculated, and R is called the influence radius. Through mathematical deduction, it can be obtained that the gradient of the cost function J at the independent point (ii, jj) with respect to the ecological parameters is:

$$\frac{\partial J}{\partial P_{ii,jj}} = \sum_{i.j} \phi_{i.j,ii,jj} \cdot \frac{\partial J}{\partial P_{i,j}} \quad (8)$$

After finding the gradient of the cost function J with respect to the ecological parameter $P_{ii,jj}$ at the independent point, the parameter value at the independent point can be adjusted by using the relevant optimization algorithm, and then the correction relationship of the ecological parameter at the independent point can be obtained:

$$K\left(P_{ii,jj} - \overline{P_{ii,jj}}\right) + \sum_{i,j} \phi_{i,j,ii,jj} \cdot \frac{\partial J}{\partial P_{i,j}} = 0 \quad (9)$$

$\overline{P_{ii,jj}}$ is the prior ecological parameter value, K is the undetermined coefficient, and the value depends on the optimization algorithm. As for the selection of specific independent grid points and influence radius, an independent point is set for every five grid points in the longitude and latitude direction, and the influence radius is set to 8°.

3.3 Determination of Bp Neural Network Structure

According to the previous analysis of MODIS images and radar images obtained in the study area, the backscattering coefficients from MODIS characteristic bands MODIS1, MODIS2, MODIS3, MODIS4 and HH, VV polarization modes are highly correlated with the algae chlorophyll a concentration in the study area, so it is selected as the input neuron of BP neural network structure, and the algae chlorophyll a concentration value is selected as the output neuron of the network structure.

The above selected six sensitive factors (MODIS1, MODIS2, MODIS3, MODIS4, VV and HH) are divided into different combinations. In order to highlight the advantages of the combination of optical remote sensing and radar remote sensing, the input parameters are divided into optical parameters, radar parameters, the combination of optical parameters and radar parameters. Table 1 lists these combinations. Taking them as the inputs of BP neural network respectively, and then comparing the accuracy of the inverted algae chlorophyll a concentration values, the best combination of input parameters is found out.

Table 1 Combination of Input Parameters

Number of nodes	Input	Output
2	VV, HH	Chlorophyll a concentration in algae
4	MODIS1, MODIS2, MODIS3, MODIS4	Chlorophyll a concentration in algae
6	MODIS1, MODIS2, MODIS3, MODIS4, VV, HH	Chlorophyll a concentration in algae

To sum up, the BP neural network model finally determined in this study is: MODIS1, MODIS2, MODIS3, MODIS4, HH and VV are the input parameters of the network model, there are 6 hidden layer nodes, and the algae chlorophyll a concentration value is the output parameter (Figure 3).

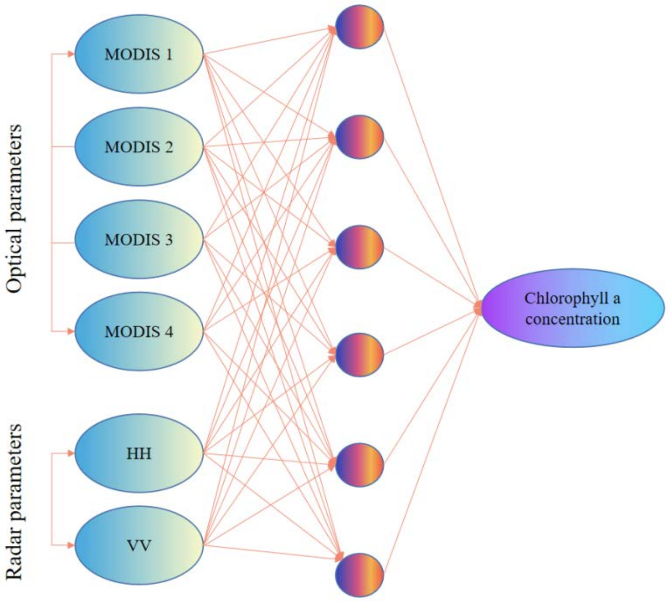

Fig.3 Structure Diagram of Bp Neural Network

4. Results and Discussion

4.1 Chlorophyll a Concentration Distribution Calculated by Ecological Dynamics Model

Fig. 4 is the distribution of chlorophyll a concentration calculated by ecological dynamics model. According to the figure, the concentration distribution of chlorophyll a in the coastal waters of the Yellow Sea on June 8, 2020 was from 1.5mg/L to 2.5mg/L, while that on June 15, 2020 was from 1.5mg/L to 2.8 mg/l.. Considering water temperature, wind field and other factors, the chlorophyll a concentration distribution calculated by the model is more accurate than that extracted from MODIS images.

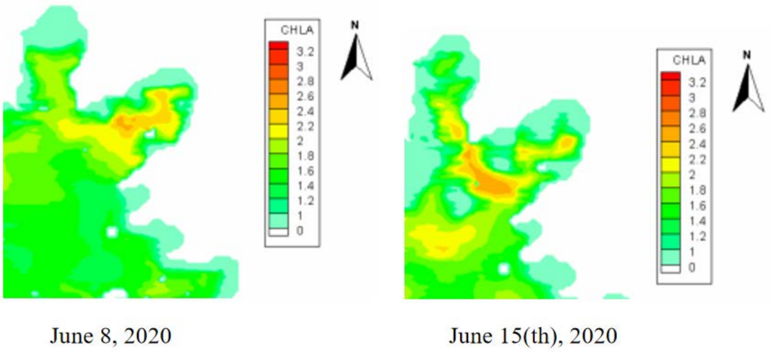

Fig.4 Distribution of Chlorophyll a Concentration Calculated by Ecological Dynamics Model

4.2 Prediction and Analysis of Bp Neural Network Model

After the model structure is determined by training and the ideal results are obtained, the network model is tested by 20 groups of test sample data, and the inversion results of algae chlorophyll a by BP neural network model are compared with the measured values, and the results are shown in Figure 5.

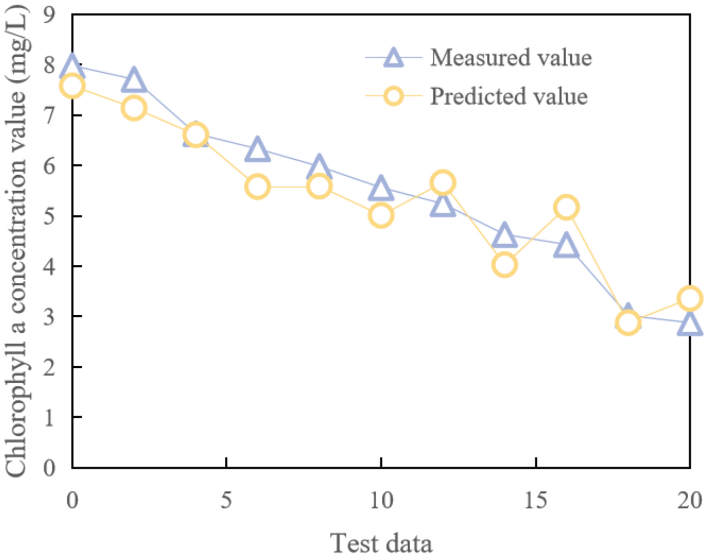

Fig.5 Comparison between Predicted Value and Measured Value of Bp Neural Network Model

Fig. 5 shows that the predicted value of chlorophyll a of algae by BP neural network model is close to the measured value of chlorophyll a of algae, which confirms the potential of BP neural network model in predicting chlorophyll a concentration.

5. Conclusion

Marine ecosystem has two basic characteristics, namely, nonlinearity and hierarchy. Non-linearity is the main reason for the large error in the simulation results of marine ecosystem dynamics model, and the difficulty in determining the ecological parameters in the model makes it more difficult to simulate the marine ecosystem. Compared with other remote sensing data, MODIS image data is widely used in environmental monitoring because of its economy and rapid acquisition. However, because the inland water area is much smaller than the ocean, the medium resolution of MODIS images is limited. In this study, combining the processing of MODIS image data and the calculation of ecological dynamics model, the method of chlorophyll a concentration monitoring and prediction based on MODIS image data was expounded. Based on BP neural network, an inversion model is established to predict the chlorophyll a concentration of algae in the Yellow Sea coastal waters. On the whole, the BP neural network model is used to solve the problem of chlorophyll a inversion of algae in the near-shore second-class water body, and the inversion accuracy is improved.

References

[1] Yin J, Xu J, Xue Y, et al. Evaluating the impacts of El Nio events on a marine bay ecosystem based on selected ecological network indicators. Science of The Total Environment, vol. 763, no. 64, pp. 144205, 2021.

[2] Yang M, Wang J X. Marine High-tech Enterprise Ecosystem Based on Sustainable Development. Sustainable Computing: Informatics and Systems, vol. 28, no. 7, pp. 100399, 2020.
[3] Islam M S, Sun J, Liu H, et al. Environmental influence on transparent exopolymer particles and the associated carbon distribution across northern South China Sea. Journal of Oceanology and Limnology, vol. 39, no. 3, pp. 1430-1446, 2021.
[4] Andrade C, Alcantara E, Bernardo N, et al. An assessment of semi-analytical models based on the absorption coefficient in retrieving the chlorophyll- a concentration from a reservoir. Advances in Space Research, vol. 63, no. 7, pp. 2175-2188, 2019.
[5] Jang P G, Kang J H, Shin K. Study on the Distribution of Surface Chlorophyll-a and Subsurface Chlorophyll Maximum in the Southeastern Yellow Sea According to the Typhoon Paths and Water Masses. Ocean Science Journal, vol. 55, no. 3, pp. 1-20, 2020.
[6] Dorofeev V L, Sukhikh L I. Studying Long-Term Variations in Black-Sea Ecosystem Based on the Assimilation of Remote Sensing Data in a Numerical Model. Water Resources, vol. 46, no. 1, pp. 65-75, 2019.
[7] Wang T, F Chai, Xing X, et al. Influence of multi-scale dynamics on the vertical nitrate distribution around the Kuroshio Extension: An investigation based on BGC-Argo and satellite data. Progress In Oceanography, vol. 193, no. 9, pp. 102543, 2021.
[8] Grigoratou M, Monteiro F M, Ridgwell A, et al. Investigating the benefits and costs of spines and diet on planktonic foraminifera distribution with a trait-based ecosystem model. Marine Micropaleontology, vol. 166, no. 2, pp. 102004, 2021.
[9] Sun J, Xia J, Zhao X, et al. Effects of 1-aminobenzotriazole on the growth and physiological characteristics of Tamarix chinensis cuttings under salt stress. Forestry Research: English Version, vol. 32, no. 4, pp. 11, 2021.
[10] Thomas S, Pilditch C A, Thrush S F, et al. Does the Size Structure of Venerid Clam Populations Affect Ecosystem Functions on Intertidal Sandflats?. Estuaries and Coasts, vol. 44, no. 1, pp. 242-252, 2021.