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HABs Monitor: A Tool for Detecting HABs in East China Sea

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Abstract

This paper designs and develops a tool for detecting HABS from ENVI+IDL+ArcEngine. With a friendly and artistic interface offered by third party control, this tool provides a function of HABs monitoring in East China Sea via Remote Sensing Images inversion. Through rows of buttons on the menu bar, this tool allows calculating spectrum reflectance, browsing field work data, interpolating in situ measurement data, retrieving water property parameters, and detecting HABs position by the threshold of chlorophyll-α and sea surface temperature. Data management module programmed in Structured Query Language (SQL) in our tool simplifies the data process and stores a large amount of information. This paper elaborates the original design, functional modules, and multi data sources that gives a general view toward this tool.

Key Word: *HABs monitor; ENVI+IDL; East China Sea;*

1. Introduction

The Harmful algal blooms (HABs) (also termed as red tides) have been detected to happen frequently in complex Case-2 Water, such as East China Sea (ESC) these years [1-2]. It was already reported that ESC has much more highly HABs occurrence rates than other three marginal seas along China mainland, during 2002 to 2008. And HABs are also considered to have caused tremendous damage in the coastal metropolis, Shanghai, especially in aquaculture industry in 2003 [2]. Many articles reported that A. tamarense blooms frequently happen in the East China Sea in the nearly decades [1, 4-6]. According to the statistics during 1986 to 1993, the ESC 30.5°N-32°N, 122.25°E-123.25°E became the most popular area for HABs, where the occurrence number reaches to about 91 times, and is called HABs hotspot in the Yangtze River Estuary and its adjacent sea. A large number of economic losses bring HABs an increasingly serious problem all around the world.

In order to mitigate the HABs' occurrence, which is very essential to detect, monitor and forecast, our tool uses current available remote sensing technology to trace their development and movement while traditional ship-based field sampling and analysis are very limited in both space and temporal frequency [7]. Nowadays, satellite ocean color sensors, such as moderate-resolution imaging spectroradiometer (MODIS), are thought to be an ideal instrument for estimating global phytoplankton biomass, especially in episodic blooms, because they provide relatively high frequency information in measuring bands from visible to near-infrared (NIR) spectral range. These bands and adequate spatial resolution make it possible to detect and trace HABs from space.

The advance in computer operation and information storage builds basis for high-capacity data process. Combined with daily satellite MODIS data exploring over the ESC, this can makes up a tool to monitor and survey the HABs occurrence. This article aims to design and realized a comprehensive tool, including three data source (Remote Sensing (RS) data, field work spectrum data, and ocean situ measurement data), data process models between them, HABs detection and monitoring report.

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2. General design of the tool

The tool for detecting HABs in ESC accomplished major functions simply through a button to realizing MODIS image preprocessing, water quality parameter inversion, HABs extraction and classification according to threshold analysis. By HABs water refinement result image and numerical report, the tool becomes an open-and-shut, user-friendly software.

The framework of the tool is three-layer architectures, which are Presentation Layer, Logic Layer and Data Layer (Figure 1). Presentation Layer characterizes in user interface design and mutual interaction. Logic Layer contains data processing flow, data models and output forms. Data Layer stores all of the input and output data, which obviously improves operating performance.

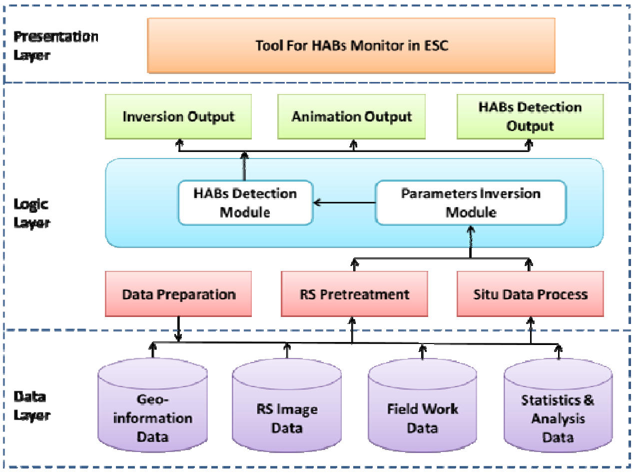

Figure 1. The framework of tool: the arrows dedicate the main process of the tool, which displays the general functions and operations.

Our tool displays ESC administrative division and coastline as its base map, supported from spatial geo-database information.

Image processing module carries on fundamental operations about radiometric calibration, geometric correction, bow correction and image clipping. Those data pretreatment makes ready for the following parameter inversions.

In situ measurement data processing module manipulates work field spectrum data, sea surface sand concentration (SSS) data, chlorophyll-α concentration (chl-α) data, sea surface turbidity (SSTU) data, sea surface temperature (SST) data. Spectrum measurement data ranges from 300 to 1000 nm at interval of every 3 nm, toward which this tool achieves average value, computes reflectance, gains normalization and selects characteristic band from inner-programmed algorithm. With regard to spatial distribution data such as SSS, chl-α, SSTU and SST, we reveals its change of gradient via various interpolation algorithms, such as Inverse Distance Weighted (IDW), Kriking, Spline, Trend, Viarogram.

Parameter inversion module embraces two kinds of algorithm, one conducts concentration based on characteristic band fit coefficients from in situ measurements; the other is global water parameter inversion model published from National Aeronautics and Space Administration (NASA), specifically about chl-α and SST.

The comprehensive HABs inversion model is on the foundation of parameter inversion results, forecasting the proper position of HABs through the threshold of SST and chl-α parameters.

Output module stores all of the images above the upper model and converts them into screen-picture format and animation format, which convenient users to observe changeable sequences. And monitoring report summarizes the HABs position information according to the HABs comprehensive model algorithm.

In order to realize automatic detection of whether the red tide occur and take into account the actual production needs, this tool also offers other scientific analysis ability, that is adjust the view parameters according to the scientist needs. Taking the data stream as an example, the data collected in the field work can modify the parameter inversion. This function, along with the increasing tool running time, can greatly improve the inversion model of the accuracy. The data sources are also diverse, including ship test, in situ measurement.

The HABs monitor tool, in addition to providing a good half-automation interface, but also help scientists to do some analysis simply. In the data stream output, we broaden the output format of the range, including the static graph, dynamic graph and text data, which convenient scientists for the long-term monitoring of red tide, and systematic, profound analysis.

3. Key technologies of tool design

For achieving the aims of RS data process, geological data browse, data fitting, ocean property measurement data interpolation, this tool utilizes ArcGIS Engine Component (AE) and ENVI/IDL (Environment for Visualizing Images/Interactive Data Language) Component as program-developing tools, in which AE provides map control and operation function and ENVI/IDL makes it convenience to manipulate the raster data set [8], and MODIS data format-Hierarchical Data Format (HDF). Our tool selects Visual Basic.Net (VB.net) as programming language, which seamless connect with SQL Server (Structured Query Language). After combined with third party controls to optimize its interface, the tool eventually becomes friendly and artistic.

The following content emphasizes the significant modules, water parameter inversion module, HABs monitoring module and database design.

3.1. Water parameter inversion and HABs monitoring module

Our tool monitors HABs from the threshold of chl-α and SST inversed value via RS image. Both parameters are computed from two algorithms, as is showed in Fig. 2. This article will elaborate the details about the solutions for basic theory and realization.

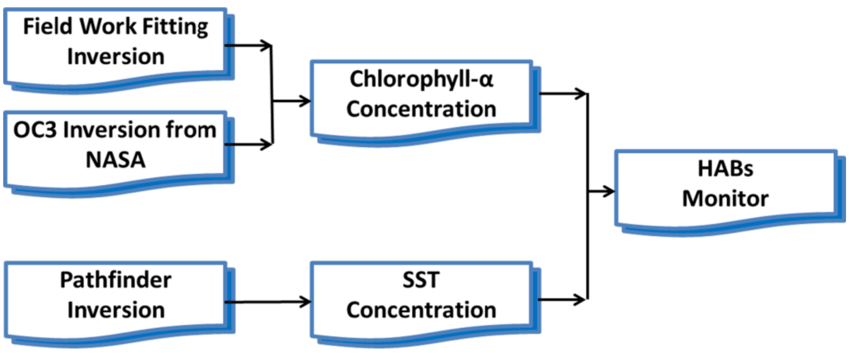

Figure 2. HABs monitoring module process: field work fitting inversion means that it uses fitting equation coefficients, which is computed from input files (e.g., *.txt) by user via work field measurement, into the inversion equation.

OC3 is an empirical algorithm summarized from NASA ocean-color program, which is the most optimized one compared with several empirical models according to more than 900 global ocean observation stations in situ chl-α data(0.01< chl-α<75 mg·m^{-3}). It adopts MODIS ocean band reflectance ratio, the maximum of *Rrs (443)/Rrs(551)* and *Rrs (448)/Rrs (551)*, to model building of biquadratic inversion:

$$C_{chl-\alpha} = 10^{0.283-2.753R+1.457R^{2}+0.659R^{3}-1.403R^{4}} \quad (1)$$

Where, $R = lg\left|\frac{Rrs(443) > Rrs(448)}{Rrs(551)}\right|$, the number in the parenthesis is wavelength and *Rrs* is remote sensing reflectance.

In addition to chl-α inversion, the other important parameter is SST for HABs monitor. Pathfinder considered Split window algorithm (SWA) could eliminate influence of atmosphere absorbance via two infrared reflectance band which hardly infected by solar reflectance, therefore the Pathfinder inversion can deduce SST from the equation [9]:

$$SST = c_1 + c_2 \times T_{31} + c_3 \times |T_{31} - T_{32}| + c_4 \times (\sec\theta - 1)(T_{31} - T_{32}) \quad (2)$$

Where, T_i is brightness temperature of band i, θ is satellite zenith angle, and c_1, c_2, c_3, c_4 is regression coefficients, which can be searched in the following table 1 suiting for ESC [10].

Table. 1. Regression coefficient for SST calculation.

	SST(Terra)A.M.	SST(Terra) P.M.	SST(Aqua)A.M.	SST(Aqua)P.M.
C1	1.052	1.886	1.152	2.133
C2	0.984	0.938	0.960	0.926
C3	0.130	0.128	0.151	0.125
C4	1.860	1.094	2.021	1.198

For MODIS data, we should transfer infrared image emission radiation to brightness temperature for use according to Planck radiation equation:

$$T_B(\lambda_i) = \frac{C_2}{\lambda_i \times In\left[\frac{C_1}{\lambda_i^5 \cdot \pi \cdot I(\lambda_i)} + 1\right]} \quad (3)$$

Where, C_1=3.74151×10-22($W \cdot m^2$), C_2=0.00143879 ($m \cdot K$), $I(\lambda_1)$ is infrared emission radiation, and λ_1 is the center length of the band.

The equation mentioned above computes the water parameters. Chl-α is the main photosynthetic pigment of ocean primary producers phytoplankton cells, which, therefore, reflects the quantities of phytoplankton directly [11]. With the increasing of water fluxes into estuary, expanding eutrophication results in the possibilities of HABs, which makes chl-α much more than normal water, attaining reach up to several times or even hundreds of times [12]. So abnormal highly chl-α concentration is a significant index for measuring water eutrophication, and probably an important environmental factor of HABs [13]. SST is also a main factor, which influences the growth and distribution of HABs directly or indirectly. Thus, it can be seen that chl-α and SST meant much for HABs scientifically. This tool chooses the threshold of chl-α > 6 mg·L-1h-1, 27□ < SST < 29.5□ to judge whether the harmful algae blooms, according to the articles by several authors [14-16].

When using ENVI to achieve HABS detection, this tool have good operability, high efficiency for raster data operation and help to complete the work quickly. IDL support for reading and manipulating HDF data format, which considers remote sensing images as matrix data and calculate them by the simple built-in code.

3.2. Database Management Module

Another feature of this tool is the backstage supporter-database management, which, as possible as not to repeat, offers the best way for several specific organizations toward a variety of applications. Through it, the data structure is independent of the application modules, where data add, data delete, data check and data modify are totally supervised and controlled by the unified software - SQL Server. Through the security control within SQL Server, the huge amount of original disorder data gain clearly distribution and well management. The tool built-in process control simplifies the user data selection about complex queries, optimizes the user operation processes and reduces operation time.

Figure 3 demonstrates the model diagram designed for the database, a one-to-one relationship through the mesh model, which not only reflects the rich involved features, but also shows the complicated relationships between data. The field work data contains the storage of several data, which takes a phenomenon view through our tool, and browses the spatial distribution characteristics via calculation and interpolation between them. RS Image data, after pretreatment, combined with average of fitting coefficients by the regression model, get the water SST, and then monitor the red tide based on inversion threshold analysis.

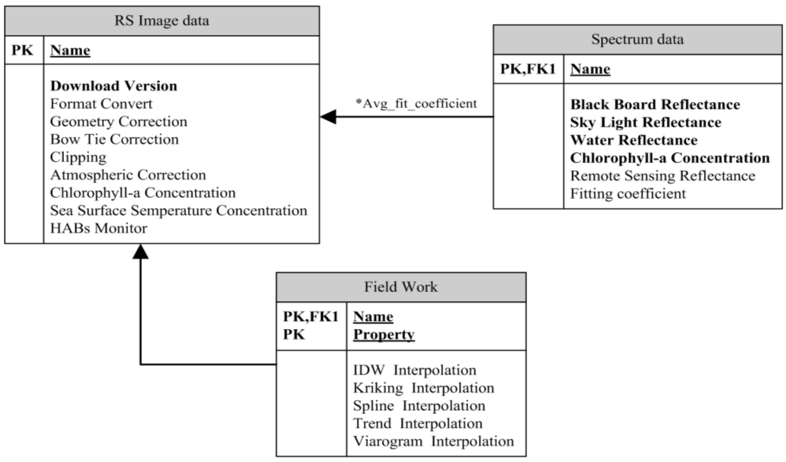

Figure 3. The database model image for this tool: the Name in all those lists are demanded strictly to be Year-Month-Date-Hour-Minute (e.g., 2007-09-27-16-30) that makes it same to compare. All the items in bold-type letter are that users need to prepared, and other ones can gain calculation in our tool. All recorded ones are store paths except Name and Property in list Field Work.

In the actual procedures, database management makes data process more clearly, defines precedence relationship constraints, such that the pretreatment process is geometric correction, bow correction, tailoring, and atmospheric correction. This tool uses conditional inquiry restrictions, enabling users to select the data operation which only fit for this step. This limitation greatly optimizes user operation process and time. In addition to the satellite data pretreatment process, water quality parameter inversion module, red tide monitoring module, field work data module also entirely apply the inquiry conditions limit, at users convenience.

4. Tool application

This tool is applied when making use of MODIS L1B image detects red tide. The following is a case of MODIS/Terra on September 27, 2007, resolution of 250m to present the effectiveness of this tool.

Figure 4 displays the usage of this tool to a great extent, which is pithy, and artistic. The Data Management in the upper-right of the interface operates the interaction between users and database, represents the data storage, and simplifies data progress. The user interface (UI) of this tool refers from Office 2007; the toolbar involves nine tags, which represents main module classifications; the column bar in the left of window is for layer browse, the middle window for image display, the upper-right one for database inquiry and status, and the bottom-right for layer feature inquiry.

From the Figure 4 we can see some key steps and modules in the running process of the tool, which provides a clear impression toward this tool. Through multi-source data process, this tool integrates several functions to scientific researches, e.g., work field data analysis and calculation, remote sensing image preprocess and inversion. Moreover, our tool can notify the red tide and catch the position in the ESC, which verifies the practicality and scientificity of it, according to the Red Tide report on research [17] published in 2007, ESC.

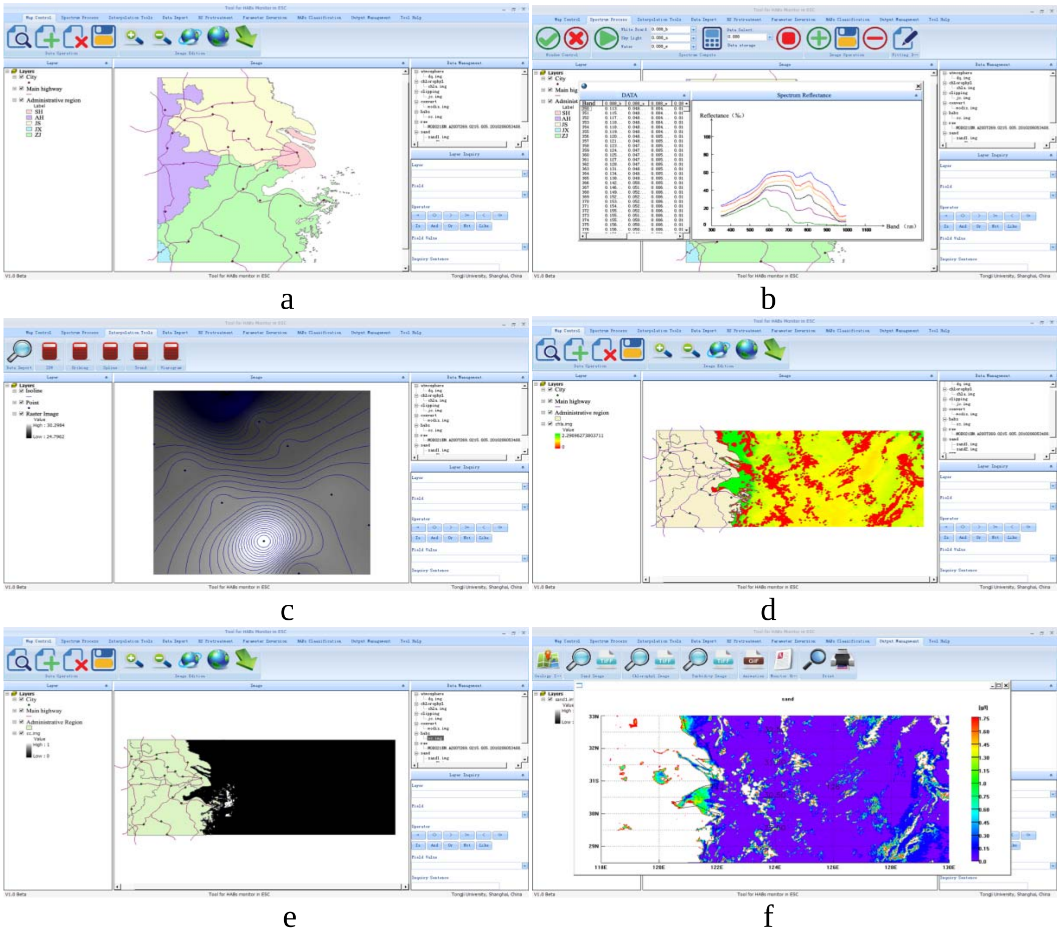

Figure 4. The function display of this tool: Figure 4a. is the browse of administrative map from special geo-database; Figure 4b is several interpolation methods showing special distribution toward aerial survey data; Figure 4c demonstrates the spectrum reflectance calculation from field work source , the image drawing and the storage of characteristic band data for fitting; Figure 4d shows the water parameter inversion from empirical module which is saved in the Figure 4c, or from published module that is introduced in section 3; Figure 4e displays the HABs detection result through chlorophyll-α and sea surface temperature value threshold, and computes the position of it; Figure 4f open ups graphics capacity including title, legend, coordinate axes.

5. Conclusion

With practical function, multisource data input, surrounding function exploration at the core of the HABs monitor, this tool realize the original design aim. It enforces comprehensive administration about multisource data, realizes the HABs detection, builds relationship between multisource information to obtain more exact conclusion and provides functions of browse and analysis toward multisource data.

However, with the development of science & technology, this system still has something to complement.

1) By the limitation of in situ measurement in ESC, it exists bigger errors in global model inversion. With the increasing of real measurement database and complement of empirical

model, we can lift up the application coverage and accuracy for the system catering to different seasons in diverse climate in ESC.

2) Enhancing diversity of obtaining satellite data; this system merely carries on MODIS data and gives priority to ocean color for the occurrence and development of HABs, not to mention of forecasting. Many articles reported that HABs has highly correlation with sea surface wind, therefore we can joint wind situation to predict the HABs after gaining SAR information.
3) We still not consider about metadata control, nevertheless it becomes more and more important along with the growth of information in database, the metadata management is proved to be a key link for database safety.

Last but not least, it is important to note that the accuracy of results largely depend on the input data and the empirical model, which makes the quality of RS information top priority. For the purpose of research and educational only, this tool is just a basic version.

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