MERIS OCEAN COLOR REMOTE SENSING MODEL OF CHINA BOHAI SEA BASED ON OPTIMIZATION METHOD

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ABSTRACT

Based on the known research results of inherent optical quality of ocean color constituents, this paper uses optimized parameters to put forward a remote sensing reflectance model of seawater, which is applicable in Bohai, China. A MERIS ocean color inverse model is constructed by introducing a functional extreme problem. The evaluation of this model by the in situ data shows that the model is feasible, but its practicability needs to be verified.

1. INTRODUCTION

Bohai, surrounded by the land in the north, the west and the south, is connected with Yellow Sea via Bohai Strait only in the east. Its major area belongs to typical Case II water, and the quantitative inversion of its constituent concentration is difficult in the ocean color research field. So up till now, there hasn’t been operational remote sensing inversion model and the corresponding algorithm.

ENVISAT-1 was launched on 1st, March, 2002, and Medium Resolution Imaging Spectrometer (MERIS) is its ocean color sensor. MERIS, designed mainly for ocean color detection, sets 15 channels (in Tab. 1), with ground resolution of its image being 300m. Its can revisit for 2-3 days, and its swath is 1450km. Compared with other ocean color sensors, MERIS has spatial and spectral advantages, and is more suitable to Case II water ocean color remote sensing.

<table>
<thead>
<tr>
<th>No.</th>
<th>Band center(nm)</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>412.5</td>
<td>Yellow substance and detrital pigments</td>
</tr>
<tr>
<td>2</td>
<td>442.5</td>
<td>Chlorophyll absorption maximum</td>
</tr>
<tr>
<td>3</td>
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<td>Chlorophyll and other pigments</td>
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<td>Suspended sediment, red tides</td>
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<td>620</td>
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<tr>
<td>8</td>
<td>681.25</td>
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<td>9</td>
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<td>753.75</td>
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<tr>
<td>12</td>
<td>778.75</td>
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<tr>
<td>13</td>
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<tr>
<td>15</td>
<td>900</td>
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This paper explores ocean color constituent concentration retrieval by MERIS data by developing a multi-constituent seawater reflectance model and putting forward two new models: a simulation remote sensing reflectance model with ocean color constituent concentration and an ocean color constituent concentration inversion model with seawater remote sensing reflectance by optimization method.

2. METHODS

2.1 Seawater remote sensing reflectance model

Remote sensing reflectance \( R(\lambda) \) can be approximately represented as a function of inherent optical properties\(^1\):

\[
R(\lambda) = \frac{f}{Q} \frac{t}{n^2} \frac{b_b(\lambda)}{a(\lambda) + b_b(\lambda)}
\]

where \( b_b(\lambda) \) is total backscatter coefficient of seawater, \( a(\lambda) \) is total absorption coefficient, \( Q \approx 5 \) is distribution function of optical field, \( n \) is refraction index of seawater, \( t/n^2 = 0.54 \) is transmissibility of sea-atmosphere interface, \( f \) is a function of solar zenith angle. \( f/Q \) \( (f/Q = 0.0095) \) is independent of solar zenith angle changes\(^2, 3\). Then

\[
R(\lambda) = 0.051 \frac{b_b(\lambda)}{a(\lambda) + b_b(\lambda)}
\]

Without considering absorption coefficient of suspended particle matter, seawater absorption coefficient \( a(\lambda) \) can be expressed as a sum of pure seawater, phytoplankton pigments and yellow substance absorption coefficients, that is

\[
a(\lambda) = a_w(\lambda) + a_p(\lambda) + a_y(\lambda)
\]

Here, \( a_w(\lambda) \), \( a_p(\lambda) \) and \( a_y(\lambda) \) represent absorption coefficients of pure seawater, phytoplankton pigments and yellow substance.

With the empirical model, phytoplankton pigments absorption coefficient \( a_p(\lambda) \) can be expressed as\(^4\)

\[
a_p(\lambda) = a_w(\lambda) + a_p(\lambda) \ln[a_p(440)j_p(440)]
\]

where \( a_w(\lambda) \) and \( a_p(\lambda) \) are empirical parameters. For phytoplankton pigments absorption coefficient \( a_p(440) \) at 440nm\(^5\), there is

\[
a_p(440) = 0.06P^{0.65}
\]

where \( P \) is chlorophyll-a concentration.

Yellow substance absorption coefficient \( a_y(\lambda) \) can be expressed as\(^6\)

\[
a_y(\lambda) = 0.014(\lambda - 440)
\]
where $Y = a_Y(440)$ is yellow substance absorption coefficient at 440 nm.

Without considering backscattering coefficient of yellow substance, seawater backscattering coefficient $b_Y(\lambda)$ can be expressed as a sum of pure seawater and suspended particle matter backscattering coefficients

$$b_Y(\lambda) = b_{sw}(\lambda) + b_{sp}(\lambda)$$

(7)

where $b_{sw}(\lambda)$ and $b_{sp}(\lambda)$ are the backscattering coefficients of pure seawater and suspended particle matter.

For pure seawater backscattering coefficient, there is

$$b_{sw}(\lambda) = 0.5 b_s(\lambda)$$

(8)

where $b_s(\lambda)$ is scattering coefficient of pure seawater, and by Smith[7]

$$b_s(\lambda) = 0.00586 \left(\frac{40000}{\lambda}\right)^{4.322}$$

(9)

For the backscattering coefficient of suspended particle matter, there is[8]

$$b_{sp}(\lambda) = B_s b_s(\lambda) C_1 + B_l b_l(\lambda) C_2$$

(10)

where $B_s = 0.039$ is backscattering probability of small-diameter suspended particles, $B_l = 0.00064$ is backscattering probability of large-diameter suspended particles, $b_s(\lambda)$ and $b_l(\lambda)$ are specific scattering coefficients of small-diameter and large-diameter suspended particles, and $C_1$ and $C_2$ are concentrations of small-diameter and large-diameter suspended particles. The specific scattering coefficient is given by the following two equations[9]

$$b_s(\lambda) = 0.001151\left(\frac{40000}{\lambda}\right)^{1.7}$$

$$b_l(\lambda) = 0.000341\left(\frac{40000}{\lambda}\right)^{5.44}$$

(11)

Hydrosol scattering is linear superposition of scattering from detritus caused by terrigenous deposit and plankton activity. The terrigenous deposit detritus are small-diameter suspended particles, and plankton activity-induced detritus are large-diameter suspended particles[10].

In the above expressions, the unit of absorption and scattering coefficients is $m^{-1}$, that of chlorophyll-a concentration $P$ is $mg/m^3$, that of suspended particle concentrations $C_1$ and $C_2$ is $mg/m^3$, that of band length is nm. To sum up, the seawater remote sensing reflectance can be worked out when $P$, $Y$, $C_1$ and $C_2$ are known.

2.2 Optimization of the seawater remote sensing reflectance model

Although the above model can calculate seawater remote sensing reflectance, its applicability is restricted by the empirical parameters in the research area--Bohai Sea. Usually, these parameters are fixed in a local area.
In Fig. 1, the dashed line is in situ remote sensing reflectance spectrum from optical experiment cruise in Bohai in June, 2005, and the solid line is the simulated spectrum of the model. The trend of the simulated result agrees with that of the in situ spectrum, but there is a big difference in quantity, with an average relative error of 21.49%. Obviously, a remote sensing reflectance model with fixed parameters lacks universality.

![Fig. 1. Measured remote sensing reflectance spectrum and modeled remote sensing reflectance spectrum](image)

In order to obtain the remote sensing reflectance model parameters applicable to the research area, we introduce a departure function between in situ and simulated spectra to calculate the parameters by use of iteration numerical method.

The parameters to be optimized consist of \(x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8, x_9\) and \(x_{10}\), all of which can be found in the following expressions:

\[
R(\lambda) = x_1 \frac{b_1(\lambda)}{a(\lambda) + b_1(\lambda)}
\]  

(12)

\[
a_x(440) = x_2 P^{x_2}
\]

(13)

\[
a_x(\lambda) = x_3 \exp(-0.014(\lambda - 440))
\]

(14)

\[
b_{1x}(\lambda) = x_4 b_1(\lambda) C_1 + x_5 b_2(\lambda) C_2
\]

(15)

\[
b_1(\lambda) = x_7 \left(\frac{400}{\lambda}\right)^{x_7}
\]

(16)

\[
b_2(\lambda) = x_9 \left(\frac{400}{\lambda}\right)^{x_9}
\]

Then the simulated remote sensing reflectance spectrum \( R_i \) is a function with ten arguments. We introduce a departure function

\[
E(x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8, x_9, x_{10}) = \sqrt{\sum_{\lambda_i} [R_i(\lambda_i) - R(\lambda_i)]^2}
\]

(17)
where $R_m$ is in situ remote sensing reflectance spectrum, $R_e$ is simulated remote sensing reflectance spectrum and $n$ is band number. Then the ten parameters can be obtained through the following optimization problem

$$\min E(x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8, x_9, x_{10}) = \frac{\sum_{i=1}^{n} [R_m(\lambda_i) - R_e(\lambda_i)]^2}{\sum_{i=1}^{n} [R_m(\lambda_i)]^2}$$  \hspace{1cm} (18)

The Fig.2 shows the in situ and best-fitted spectra. We can see that the two spectra exhibit similar trend, and more important, their difference is largely narrowed. The optimization of the parameters is obvious because the average relative error between two spectra is 8.32%, much less than 21.49%.

![Fig. 2. In situ remote sensing reflectance spectrum and best fitted remote sensing reflectance spectrum](image)

2.3 Ocean color constituent concentration inversion model

The numerical simulation of seawater remote sensing reflectance is a forward problem, i.e., to calculate remote sensing reflectance by ocean color constituent concentration, and to retrieve ocean color constituent concentration by remote sensing reflectance is an inverse problem. Just as we did with parameters optimization, here we introduce a cost function

$$E(P, C) = \frac{\sum_{i=1}^{n} [R_m(\lambda_i) - R_e(\lambda_i, P, C)]^2}{\sum_{i=1}^{n} [R_m(\lambda_i)]^2}$$  \hspace{1cm} (19)

where $P$ is seawater chlorophyll concentration, $C$ is suspended particle concentration, $R_m$ is in situ remote sensing reflectance spectrum, $R_e$ is remote sensing reflectance spectrum calculated by the forward problem, $n = 10$ is the number of MERIS channels used for inversion calculation, and central wavelength of the channels are 412.5nm, 442.5nm, 490nm, 510nm, 560nm, 620nm, 665nm, 681.25nm, 708.75nm and 753.75nm respectively. Then seawater chlorophyll concentration can be retrieved by the following optimization problem

$$\min E(P, C) = \frac{\sum_{i=1}^{n} [R_m(\lambda_i) - R_e(\lambda_i, P, C)]^2}{\sum_{i=1}^{n} [R_m(\lambda_i)]^2}$$  \hspace{1cm} (20)

where the parameters $x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8, x_9$ and $x_{10}$ in $R_e$ adopt the optimized results of the
3. RESULTS

To optimize seawater remote sensing reflectance, we use the ocean color constituent concentration data obtained from 16 stations of the optical experiment cruise in Bohai in June, 2005. The optimization results are in Tab. 2. We take average value of the results in each station as parameters of inversion model.

<table>
<thead>
<tr>
<th>Station</th>
<th>$x_1$</th>
<th>$x_2$</th>
<th>$x_3$</th>
<th>$x_4$</th>
<th>$x_5$</th>
<th>$x_6$</th>
<th>$x_7$</th>
<th>$x_8$</th>
<th>$x_9$</th>
<th>$x_{10}$</th>
</tr>
</thead>
<tbody>
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<td>LDW-01</td>
<td>0.0243</td>
<td>0.0374</td>
<td>0.4083</td>
<td>0.1000</td>
<td>0.0095</td>
<td>0.1299</td>
<td>0.2933</td>
<td>0.4076</td>
<td>0.3414</td>
<td>0.3000</td>
</tr>
<tr>
<td>LDW-02</td>
<td>0.0108</td>
<td>0.0580</td>
<td>0.7776</td>
<td>0.2308</td>
<td>0.1866</td>
<td>0.0006</td>
<td>0.2448</td>
<td>2.4750</td>
<td>0.3411</td>
<td>0.3000</td>
</tr>
<tr>
<td>LDW-03</td>
<td>0.0120</td>
<td>0.0714</td>
<td>0.5861</td>
<td>0.1000</td>
<td>0.0278</td>
<td>0.0018</td>
<td>0.9086</td>
<td>1.0742</td>
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</tr>
<tr>
<td>LDW-04</td>
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<td>0.7113</td>
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<td>0.3000</td>
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<td>0.8194</td>
<td>0.3411</td>
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<td>LDW-06</td>
<td>0.0227</td>
<td>0.0464</td>
<td>0.3000</td>
<td>0.1613</td>
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<td>0.0046</td>
<td>0.6197</td>
<td>1.4831</td>
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<td>0.3000</td>
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<tr>
<td>LDW-07</td>
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<td>0.0785</td>
<td>0.6040</td>
<td>0.1936</td>
<td>0.0338</td>
<td>0.0058</td>
<td>0.8881</td>
<td>1.9969</td>
<td>0.3411</td>
<td>0.3000</td>
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<tr>
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<td>0.4957</td>
<td>0.0283</td>
<td>0.0011</td>
<td>0.0994</td>
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<tr>
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<td>0.0073</td>
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<tr>
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<td>0.0097</td>
<td>0.0059</td>
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<td>0.0005</td>
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<td>0.3411</td>
<td>0.3000</td>
</tr>
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<td>0.0300</td>
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<td>0.4596</td>
<td>0.0151</td>
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<td>1.0648</td>
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<tr>
<td>QHD-06</td>
<td>0.0624</td>
<td>0.0300</td>
<td>0.5424</td>
<td>0.7481</td>
<td>0.0253</td>
<td>0.0006</td>
<td>0.6104</td>
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<td>0.3000</td>
</tr>
<tr>
<td>QHD-07</td>
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<td>0.0544</td>
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<td>0.0184</td>
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<td>0.0000</td>
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<td>0.3000</td>
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<td>0.0012</td>
<td>0.5564</td>
<td>0.0000</td>
<td>0.3411</td>
<td>0.3000</td>
</tr>
</tbody>
</table>

To verify the inversion model effectiveness, the paper chooses the seawater reflectance data and ocean color constituent concentration data obtained in June, 2005 in Liaodong Bay of Bohai Sea. According to the central position of 10 MERIS channels, we simulate $\text{mR}$ in Eq. 20 by the measured seawater optical spectra. The inversion results are in Tab. 3. The average relative error Chlorophyll-a concentration is 24.82%, and that of inorganic suspended matter concentration is 28.92%.

<table>
<thead>
<tr>
<th>Station</th>
<th>Chl-a concentration</th>
<th>Inorganic suspended matter concentration</th>
</tr>
</thead>
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<tr>
<td></td>
<td>Inversion value</td>
<td>Measured value</td>
</tr>
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<td>LDW-09</td>
<td>2.25</td>
<td>2.99</td>
</tr>
<tr>
<td>LDW-10</td>
<td>4.04</td>
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<tr>
<td>LDW-11</td>
<td>5.01</td>
<td>3.59</td>
</tr>
<tr>
<td>LDW-12</td>
<td>3.02</td>
<td>3.35</td>
</tr>
<tr>
<td>QHD-09</td>
<td>2.50</td>
<td>1.91</td>
</tr>
<tr>
<td>QHD-10</td>
<td>2.43</td>
<td>3.59</td>
</tr>
<tr>
<td>QHD-11</td>
<td>10.47</td>
<td>9.83</td>
</tr>
</tbody>
</table>

4. CONCLUSION AND DISCUSSION

This paper introduces an optimized seawater remote sensing reflectance model according to the departure function.
between in situ and stimulated spectral curves. The error analysis shows that the parameter-optimized model is more applicable to Bohai Sea.

Based on the seawater remote sensing reflectance model used in Bohai Sea, this paper presents a MERIS ocean color constituent inversion model through functional optimization. The verifying case shows that the inversion model is feasible. But its practicability needs validation by MERIS image data.

Because the data for optimization calculation in this paper is obtained from Liaodong Bay of Bohai alone, the application of this model may be restricted.

5. ACKNOWLEDGEMENT

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6. REFERENCES