Bio-optical properties of the Yellow Sea

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INTRODUCTION

The currently used chlorophyll algorithms are empirical algorithms; namely a statistical relationship between observed ratio of wavelengths to a constituent in the water like chlorophyll. These empirical algorithms work for Case 1 waters where optical characteristics are determined solely by phytoplankton pigments or their derived substances except the water molecules themselves. This is possible because most optical properties can be parametrized by one variable; phytoplankton . On the other hand, if there are other contituents than phytoplankton such as inorganic particles and dissolved organic matter of terrestrial origin, as Morel and Prieur (1977) termed Case 2 water, such simple relations cease to exist between the band ratios and the density of the constituents. This, mathematically speaking, is because now there are more than one independent variables that govern the in-water optical properties. To solve these multi-variable nonlinear equations, the equations have to be inverted and to do this the parameters in the equations have to be determined.

The Yellow Sea, as the name implies, is an extreme case of Case 2 water. To retrieve the constituents concentration from the ocean color images in the Yellow Sea, the basic terms of the above mentioned equations have to be measured or estimated. However, very limited number of studies exist which characterize the bio-optical properties of the Yellow Sea. Here, we report preliminary results from a bio-optic survey made for OSMI cal/val and application project.

STUDY AREA

The station map is shown in Fig. 1. The stations are juxtaposed in a 1° latitude by 0.5° longitude grid. Of these, optical measurements were made in nine daytime stations. The cruise was conducted for May 15-19, 1998.

MATERIALS AND METHODS

● In-water optics

Downwelling irradiance and upwelling radiance were profiled at 12 wavelengths using a MER2040-2041 system. The wavelengths include 340, 380, 412, 443, 490, 510, 532, 555, 589, 620, 665, and 683nm. Also scalar and cosine PAR were measured.

● Ancillary variables

A WetStar flurometer was attached to the system to provide chlorophyll fluorescence profiles, while Chelsea UV flurometer was also attached to provide profiles of dissolved organic matter. Water samples of 500ml were taken and filtered with GF/F, and chlorophyll-a and phaeopigment concentration was measured following the fluorometric method of Parsons et al. (1984). A SeaTech transmissometer was also attached to measure beam attenuation coefficients at 660 nm. Total particulate matters and inorganic matters were measured from 500 ml water samples after filtered with GF/F and incinerated. CDOM absorption was measured with GF/F filtered water sample, then the slope and a_{CDOM} (440) was calculated.

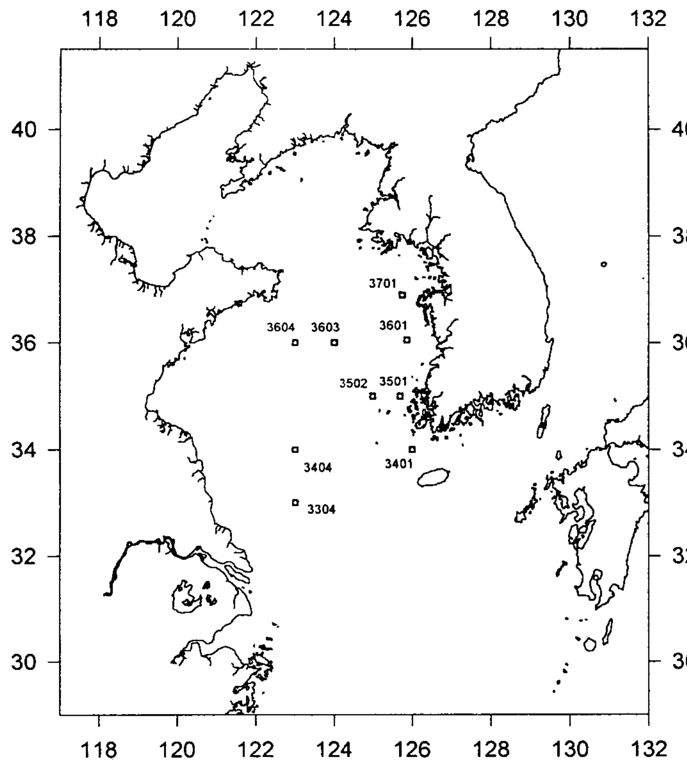

Fig 1. Station map of 1998 Yellow Sea OSMI cruise.

Table 1. The concentration of CDOM, pigments, and SS

station	a*(440)¶	S	chlorophyll a†	phaeo-pigment†	TSS *	SS *
3304	0.151	0.006	3.672	1.721	11.2	7.2
3401	0.117	0.005	1.353	0.745	11.2	7.2
3404	0.137	0.006	1.005	0.593		
3501	0.124	0.010	1.456	0.781	22.4	19.4
3502	0.096	0.013	3.762	2.031	13.8	9.8
3601	0.100	0.015	2.873	1.232	11.2	7.2
3603	0.027	0.037	0.438	0.161	13.8	8.8
3604	0.082	0.018	0.222	0.002	10.0	9.0
3701	0.084	0.019	5.992	2.698	17.0	12.0

¶ Units m^{-1}

† Units μg $liter^{-1}$

* Units mg $liter^{-1}$

● K_d and R

Reflectance was calculated from estimates of subsurface downwelling $E_{d(0)}$ and upwelling irradiance $E_{u(0)}$ by extrapolating the $K_d(\lambda)$, $K_u(\lambda)$ values. These values were estimated to depths where the fit to the Beer-Lambert equation was best. Subsurface upwelling irradiance was converted from upwelling radiance by multiplying a factor 5.0 as suggested by Kirk (1994) based on his Monte Carlo simulation for waters with *b/a* values in the range 1.0 to 5.0.

● Estimation of absorption coefficients

Morel and Prieur (1975) derived the following equation to estimate absorption coefficients from measurements of in-water optics.

$$a(\lambda)=\frac{K_d(\lambda)[1-R(\lambda)]\cos j}{0.6+[0.47+2.5R(\lambda)]\cos j}$$

$Kd(\lambda)$ is the diffuse downwelling attenuation coefficient and $R(\lambda)$ is reflectance. j is the solar zenith angle. The calculation was made only for the stations where solar elevation was higher than 45°. From the total absorption, a_w was subtracted using the values from Pope (1993).

● Estimation of backscattering coefficient

Since Gordon et al. (1975), many authors studied the relationship between reflectance and inherent optical properties like *a* and b_b (cited in Sathyendranath and Platt, 1997). The results from these studies can be expressed as a general form as follows.

$$R(\lambda,0)=r\frac{b_b(\lambda,0)}{a(\lambda,0)+b_b(\lambda,0)}$$

Although in Case 1 water, a value of 0.33 has been used, in coastal waters where particulate scattering has different volume scattering function, r value could be different, as analytically shown by Sathyandranath and Platt (1997). We used the values for coastal waters from Kirk (1984) as a function of sun elevation. In the same manner with absorption, from the total backscattering, b_{bw} was subtracted using the values from Pope (1993).

RESULTS

At all the stations including st 3501, vertical structure was formed in the water column. The vertical profiles of chl-a indicate that in all the stations phytoplankton growth is in middle or later stage of spring bloom. The concentration of the major constituents are shown in the Table 1.

Reflectance curves are shown in Fig. 2. Three patterns are distinctive. A somewhat flat curve of very high values with a peak around 535-550nm (st. 3501). Curves with peaks at 550nm (st. 3701, 3304) where chl concentration is high. Sathyendranath and Prieur (1989) simulated the reflectance of water bodies to see the effect of chl-a, SS, and CDOM, respectively. In pure water they added different level of each constituent separately, which resulted in a very distinctive group of curves. The shape of the curves from the current study are very complicated in that the absolute level of reflectance was higher than typical chl-dominated water, while the peaks are located in longer wavelength than SS-dominated water. The shape of the curves are somewhat similar to that of CDOM-dominated water while the absolute level was again much higher. Therefore, in all the stations these three constituents were predominant.

Absorption coefficient was calculated for the five stations where solar elevation was higher than 45° (Fig. 3). The values are after the $a_w(\lambda)$ is removed. While st3701 is with the highest chlorophyll-a

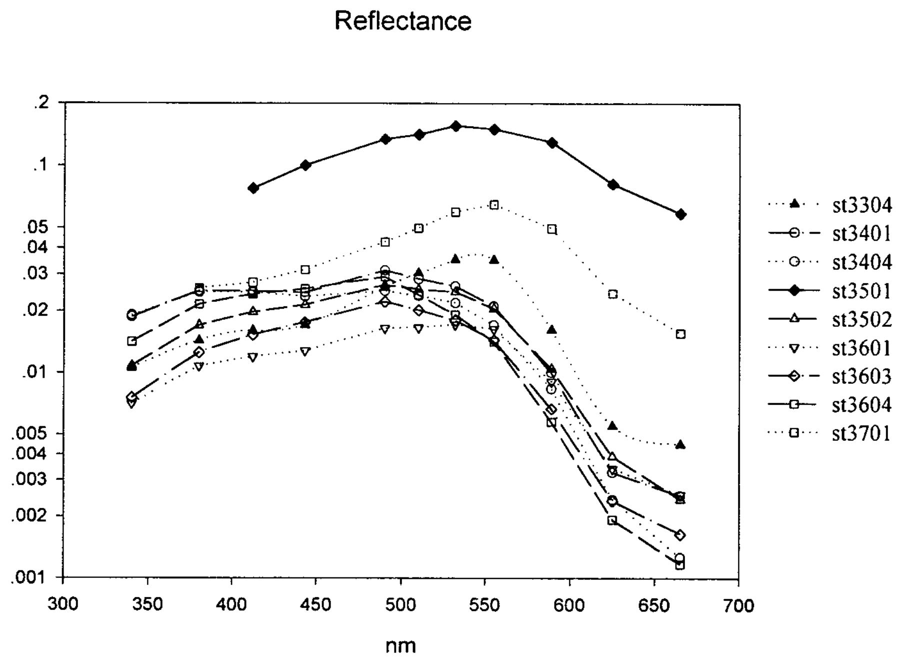

Fig 2. Below-surface reflectance at 9 stations.

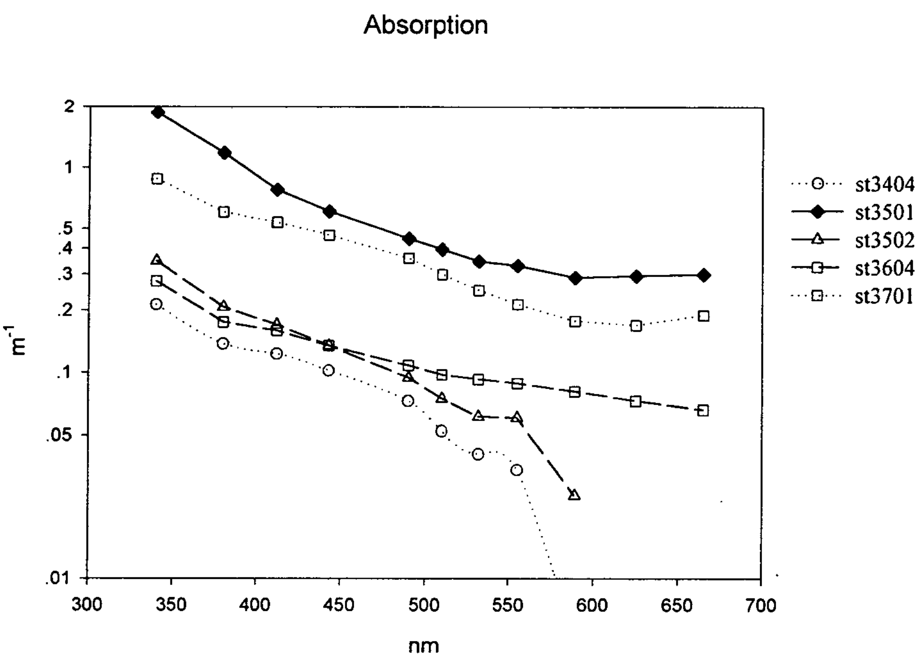

Fig 3. Absorption coefficient after water absorption is removed.

value but st3501 has a lower value (Table 1), yet its absorption value is the highest. The curves show a strong influence of CDOM. Backscattering coefficients and corresponding chlorophyll-a values are shown in Fig 4. Here, the values are plotted against the expected values for Case 1 water using Morel (1980) model. Only one station falls on the boundary and others are far from Case 1. The surface distribution of $a_{CDOM}(440)$ values is in Fig. 5. The value is the lowest near the central region and high near the coastal area. It is interesting to note that the highest region is southern part where the Changjiang river runoffs could influence.

DISCUSSION and SUMMARY

During winters, the water column in the Yellow Sea even in the central region is totally mixed. In springs, as insolation is increasing, water column gets stabilized. Typically, spring blooms occur in April and continues to May. The stratification strengthens in a spreading fashion from central to the nearshore region where tidal mixing is strong. CZCS Chlorophyll images show chlorophyll concentration in the central part of the Yellow Sea to be less than 0.5 mg/m^3 in summers, which is in a similar range with in-situ values. This indicates that during summers when the stratification prevents dissolved and particulate matter coming from the lower layer into the upper mixed layer, the surface water behaves like quasi-Case 1 water.

The survey in this study was made in mid May when spring bloom is under way and the optical characteristics was distinctively different from Case 1 water although the water column in all the stations was stratified. In reflectance and absorption coefficient curves, a complicated pattern of signatures of all the major constituents was present.

While optical closure was not completed, the results show that in turbid region, CDOM cannot explain the total absorption. For example, in St. 3501, where permanent tidal mixing is present, a(440) was very high, but $a_{CDOM}(440)$ was not that high. This indicate the particulate absorption due to inorganic particles with organic film on the surface might be very high. Further efforts should be made to quantify the particulate absorption.

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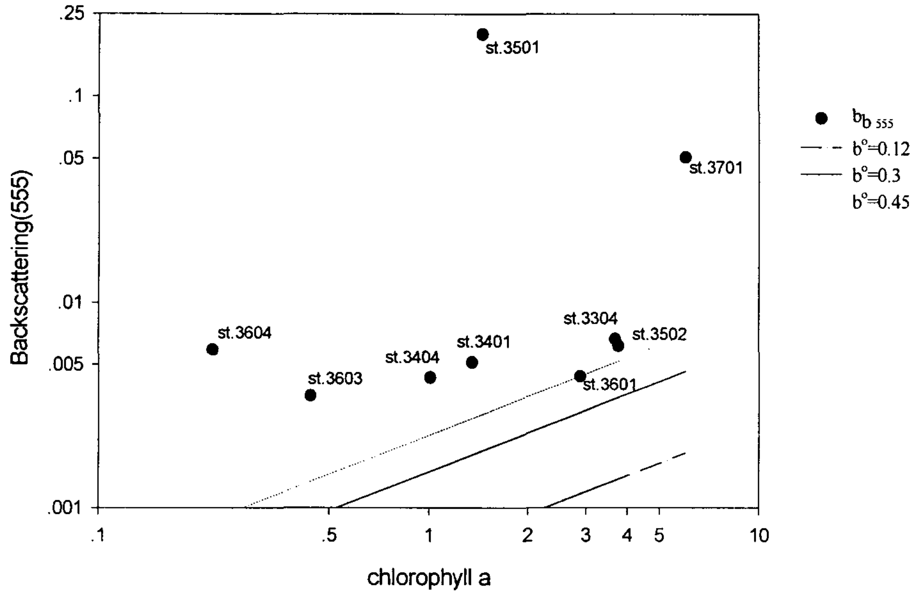

Fig 4. Chlorophyll-a vs $b_{b(555)}$. $b_{b(555)}$ was compared with $b(550) = b^{o} \cdot C^{0.62}$ (Morel, 1980). The ratio of backscatter to scattering coefficient, b', is assumed to be 0.5%.

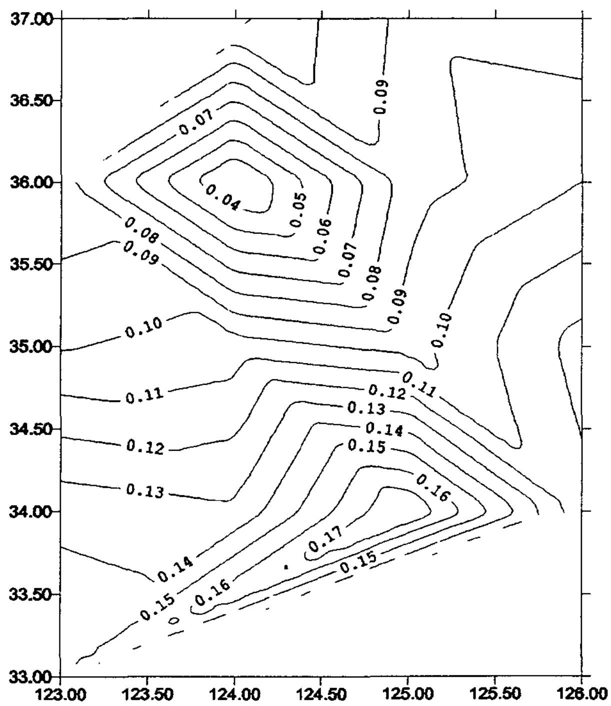

Fig 5. Contour of a*(440) values in the surface.