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Bio-optical properties in the Yellow Sea

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다목적 실용위성관측을 위한 황해의 생물학적 · 광학적 특성

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Abstract

A bio-optic survey was made in the Yellow Sea in May, 1998 for OSMI cal/val and application project. Optical measurements were made in nine stations. From these measurements, apparent and inherent optical properties such as K_d, R, a, and b_b were estimated. The patterns of reflectance indicated that all three major constituents, namely, chlorophyll-a, suspended sediments, and CDOM were active in determining the optical properties in the Yellow Sea. Their relative contribution was different among the stations. All the stations had high backscattering and their values fell in Case 2 category. Although the total absorption was very high, it could not be explained by the level of CDOM concentration. It is suggested that the suspended sediment might be highly absorptive and further study is needed to investigate the optical properties of the suspended sediments.

요 약

1998년 황해에서 OSMI 검-보정 및 활용과제를 위한 생물광학 조사가 수행되었다. 9 개의 조사정점에서 광학 측정이 이루어졌다. 이들 측정치에서 K_d, R, a, and b_b와 같은 외관성 및 내재성 광학특성이 산출되었다. 반사도의 유형을 볼 때 광학특성이 엽록소, 부유사, CDOM과 같은 모든 주요 구성성분에 의해 결정되고 각각의 기여도는 정점마다 달랐다. 모든 정점의 역산란계수는 Case 2 수역 범주에 속하였다. 전체 흡광계수는 매우 높았으며 CDOM 농도로는 충분히 설명되지 않는다. 부유사가 상당히 흡광력이 높을 가능성이 있으며 이에 대한 추후 연구가 바람직하다.

1. 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 parameterized 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.

2. Materials and Methods

1) The 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.

2) 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, respectively. Also scalar and cosine PAR (photosynthetically available radiation) were measured.

3) Ancillary variables

A WetStar flurometer was attached to the system to provide chlorophyll fluorescence profiles, while Chelsea UV fluorometer 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 the 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 (colored dissolved organic matter) absorption was measured with GF/F filtered water sample, then the slope and a_{CDOM} (440) was calculated.

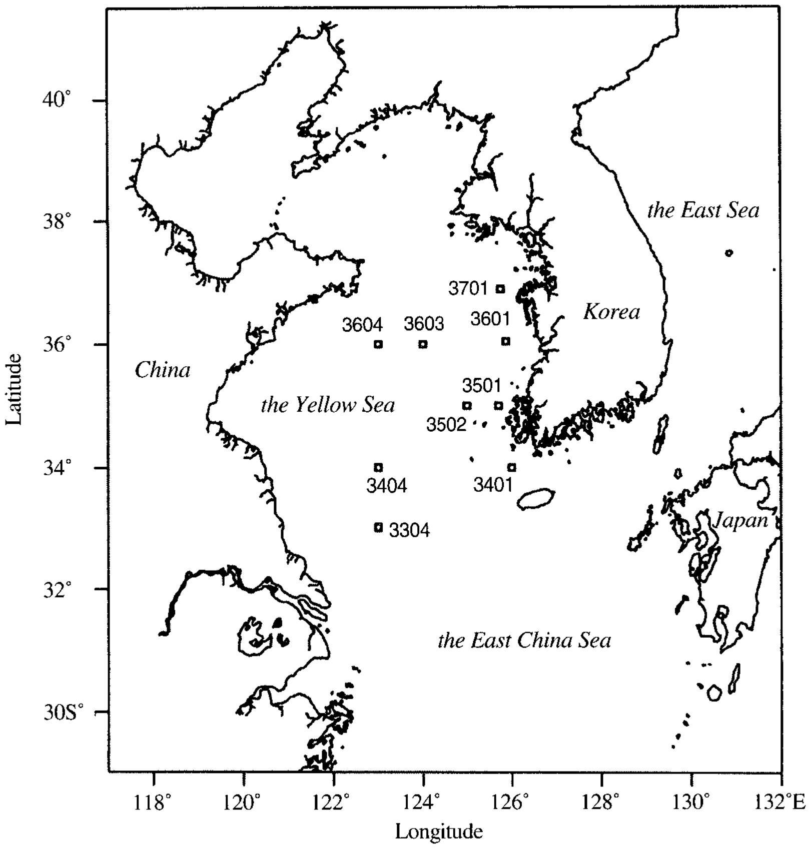

Fig. 1. Station map of the OSMI cruise 1998.

Table 1. Stations and Sampling time

Station	Latitude	Longitude	Depth (m)	Time	Day
3304	33° 00′ 08″	123° 00′ 00″	28	07:46	05/16/98
3401	33° 59′ 89″	125° 59′ 96″	77	08:10	05/15/98
3404	33° 59′ 97″	123° 00′ 04″	65	15:06	05/16/98
3501	34° 59′ 97″	125° 42′ 02″	25	15:47	05/17/98
3502	34° 59′ 91″	124° 59′ 92″	85	10:48	05/17/98
3601	36° 02′ 78″	125° 51′ 97″	50	07:46	05/18/98
3603	35° 59′ 99″	124° 00′ 01″	74	16:35	05/19/98
3604	36° 00′ 02″	122° 59′ 95″	68	10:35	05/19/98
3701	36° 53′ 64″	125° 45′ 20″	29	15:10	05/18/98

Table 2. The concentration of CDOM, pigments, and SS

station	a∗(440) (m^{-1})	S1)	chlorophyll a (μg liter^{-1})	phaeo-pigment (μg liter^{-1})	TSS(mg liter^{-1})	SS(mg liter^{-1})
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

1) The slope of CDOM absorption curve

4) 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 (1981) based on his Monte Carlo simulation for waters with b/a values in the range 1.0 to 5.0.

5) Estimation of absorption coefficients

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

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

$K_d(\lambda)$ 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).

6) 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 (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 Sathyendranath 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).

3. 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-*a* concentration is high, and curves of rather low values without pronounced peaks. The resultant patterns in reflectance with varying concentrations of chl-*a*, SS, and CDOM have been studied by various authors(e.g., Sathyendranath and Prieur, 1989). 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 st. 3701 is with the highest chl-*a* value but st. 3501 has a lower value (Table 2), yet its absorption value is the highest. The curves show a strong influence of CDOM. Backscattering coefficients and corresponding chl-*a* values are shown in Fig 4. Here, the values are plotted against the expected values for Case 1 waters using Morel' s model (1980). Only one station falls on the boundary and others are far from Case 1 waters. 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.

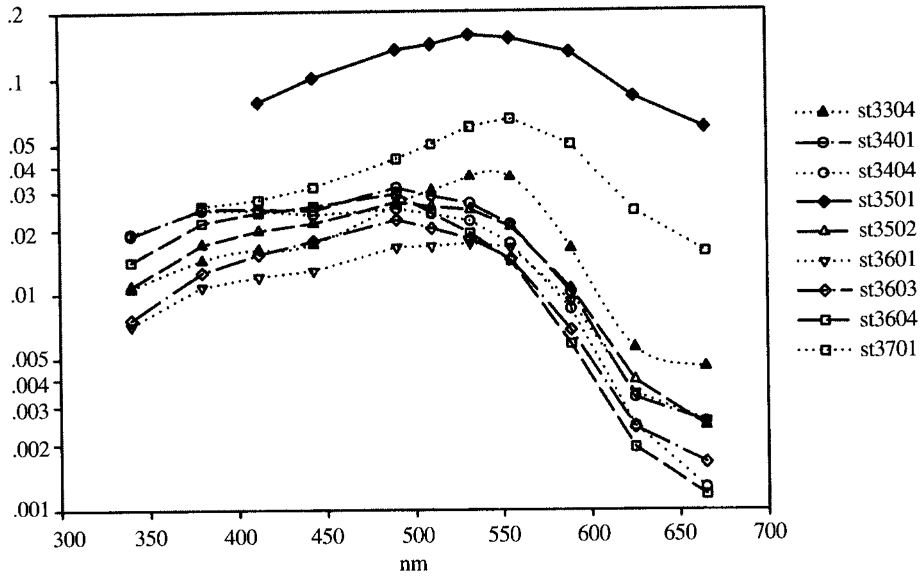

Fig. 2. Below-surface reflectance at 9 stations.

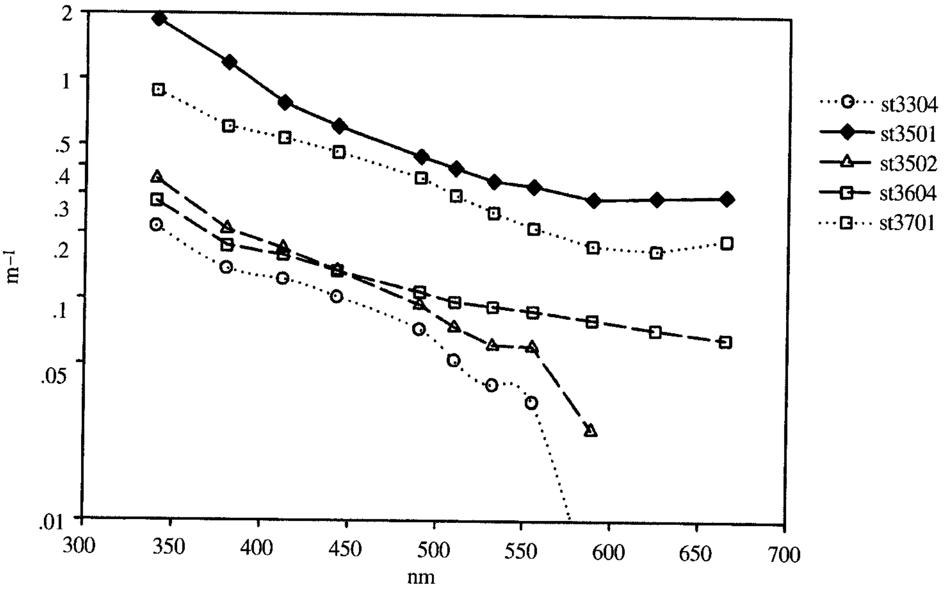

Fig. 3. Absorption coefficient after water absorption is removed.

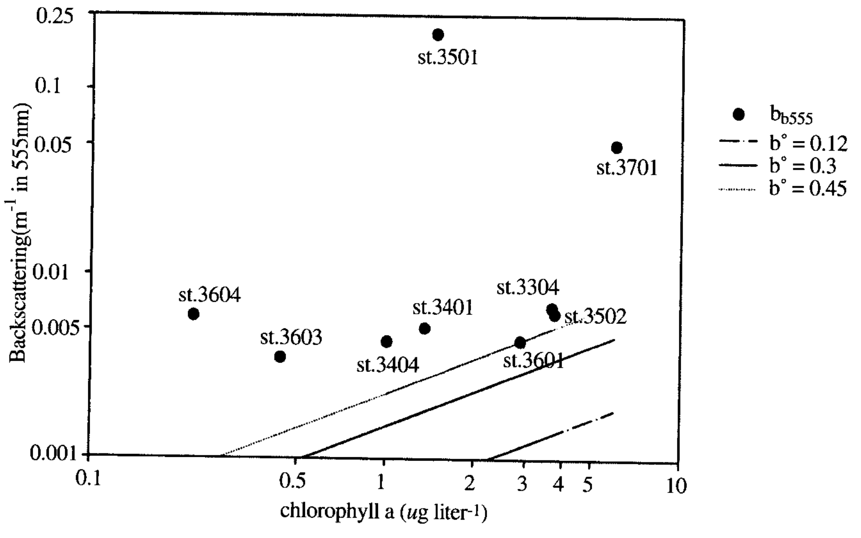

Fig. 4. Chlorophyll-a vs $b_{b(555)}$. $b_{b(555)}$ was compared with $b(550) = b° \cdot C^{0.62}$ (Morel, 1980). The ratio of backscatter to scattering coefficient, b′, is assumed to be 0.5%.

4. Discussion and Summary

During winters, the water column is totally mixed even in the central region of the Yellow Sea. In spring, 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 with strong tidal mixing. CZCS (Coastal Zone Color Scanner) 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 summer when the stratification prevents dissolved and particulate matter coming from the

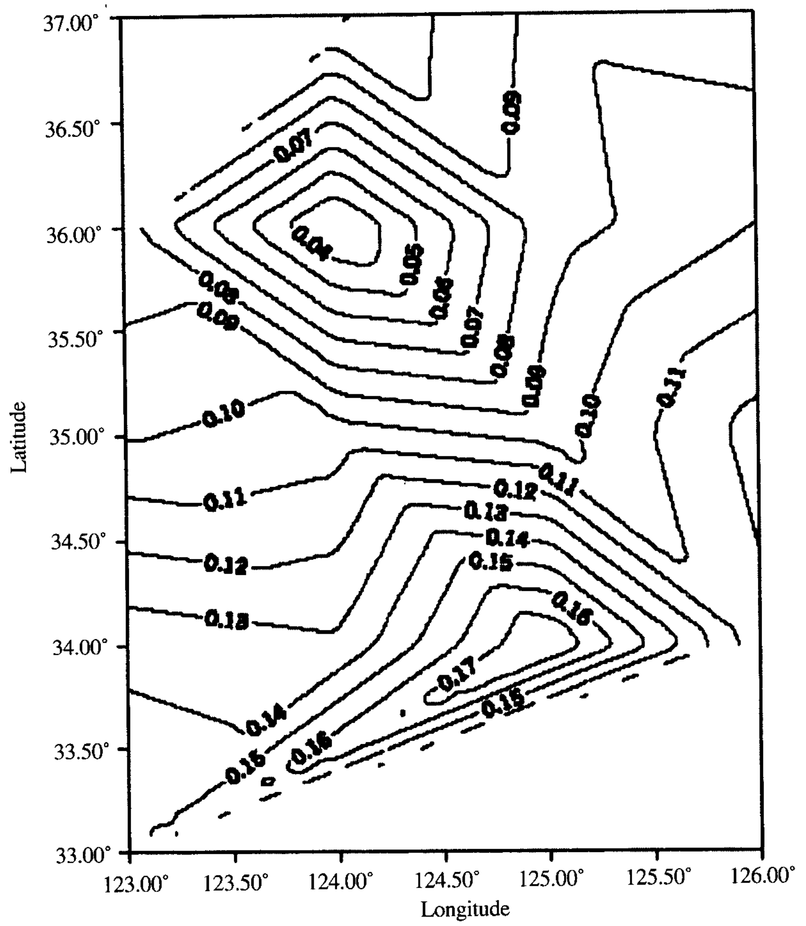

Fig. 5. a*(440) values in the surface layer.

lower layer into the upper mixed layer, the surface water behaves like quasi-Case 1 waters. The thickness of the upper mixed layer in summer is in the range of 20 ~ 30m.

The survey in this study was made in mid May when spring bloom is under way and the optical characteristics were distinctively different from Case 1 waters 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 alone cannot explain the total absorption. For example, in St. 3501, where permanent tidal mixing is present, a(440) was very high, while $a_{CDOM}(440)$ was not. This indicates 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.

References

Gordon, H. R., O. B. Brown, and M. M. Jacobs. 1975. Computed relationships between the inherent and apparent optical properties of a flat, homogeneous ocean. Appl. Opt. 14:417-427.

Kirk, J. T. O. 1981. Monte Carlo procedure for simulating the penetration of light into natural waters. Aust. C. S. I. R. O. Div. Plant Ind. Tech. Pap. 36:1-16.

Kirk, J. T. O. 1984. Dependence of relationship between inherent and apparent optical properties of water on solar altitude. Limnol. Oceanogr. 29(2):350-356.

Morel, A., and L. Prieur. 1975. Analyse spectrale des coefficients d' attenuation diffuse, d' absorption et de retrodiffusion pour diverses regions marines. Center Rech. Oceanogr. Villefranche-sur-Mer Rapp. 17. 157p.

Morel, A., and L. Prieur. 1977. Analysis of variations in ocean color. Limnol. Oceanogr. 22:709-722.

Morel, A. 1980. In-water and remote measurement of ocean color. Boundary Layer Meteorol. 18:343-355.

Parsons, T. R., Y. Maita and C. M. Lalli. 1984. *A manual of chemical and biological methods for seawater analysis*. Pergamon Press.

Pope, R. M. 1993. Optical absorption of pure water and sea water using the integrating cavity absorption meter. Ph. D. thesis. Texas A&M Univ. College Station.

Prieur, L., and S. Sathyendranath. 1981. An optical classification of coastal and oceanic waters based on the spectral absorption curves of phytoplankton pigments, dissolved organic matter, and other particulate materials. Limnol. Oceanogr. 26(4):671-689.

Sathyendranath, S., L. Prieur, and A. Morel. 1989. A three-component model of ocean colour and its application to remote sensing of phytoplankton pigments in coastal waters. Int. J. Remote Sensing 10(8):1317-1394.

Sathyendranath, S., and T. Platt. 1997. Analytic model of ocean color. Appl. Opt. 36(12):2620-2629.