Oceanic chlorophyll *a* algorithm for several cases of waters

Toru Hirawake

Center for Antarctic Environment Monitoring, National Institute of Polar Research
9-10 Kaga 1, Itabashi, Tokyo 173-8515, Japan
hirawake@nipr.ac.jp

Abstract: Characteristics of bio-optical relationships (chlorophyll *a* versus remote-sensing reflectance) for oceanic, turbid, high chlorophyll and polar region waters (n=129) were confirmed and an algorithm using a ratio of four bands (ratio of sum of two bands) was developed . The band-ratio algorithm performed well for oceanic waters and high chlorophyll waters (RMSE = 0.161). However, only the data in the southern ocean and the yellow sea of less than 1.5 mg chl.*a* m^{-3} were not combined with the other one and were needed to deal with separately. Filtering the data using remote-sensing reflectance ratios was effective for the separation.

Introduction

Main primary producer in the ocean is phytoplankton. Although biomass of phytoplankton is extremely less than terrestrial plants, aquatic primary production by phytoplankton almost corresponds to those of the latter (Schimel, 1995). Therefore global accurate estimation of phytoplankton biomass and their primary production in the ocean is required to predict the global carbon flux and global climate change such as the greenhouse effect.

Ocean color remote sensing is effective procedure to estimate chlorophyll *a* concentration as an index of phytoplankton biomass widely, simultaneously, repeatedly and continuously. However, bio-optical algorithms to estimate chlorophyll *a* concentration have some problems. One of the problems is that the most of historic algorithms consisted of small number of data from limited geographic region. Indeed the standard algorithm for the Coastal Zone Color Scanner (CZCS) (Gordon *et al.*, 1983) was developed with the bio-optical data around the North American Continent.

Ocean color which is spectrum of radiance or reflectance depend on the inherent optical properties (IOPs) such as absorption and scattering coefficient. The relationship between absorption coefficient and chlorophyll *a* concentration and also the scattering coefficient is not constant in the world ocean. Therefore the relationship between ocean color and chlorophyll is not invariable.

Although it has been suggested that the polar region water and turbid case 2 (Morel and Prieur, 1977) water occur the large error in the chlorophyll estimation, the bio-optical algorithm for new sensors, SeaWiFS and OCTS did not be taken these waters into consideration. In this study, the global algorithm for some cases of waters was developed.

Materials and Methods

Chlorophyll a concentration and underwater spectral radiation was carried out in the Indian Ocean, Persian Gulf, Southern Ocean, East China Sea, Japan Sea, Pacific Ocean, Osaka Bay, and Yellow Sea (Fig. 1). Total number of data utilized for analysis was 129.

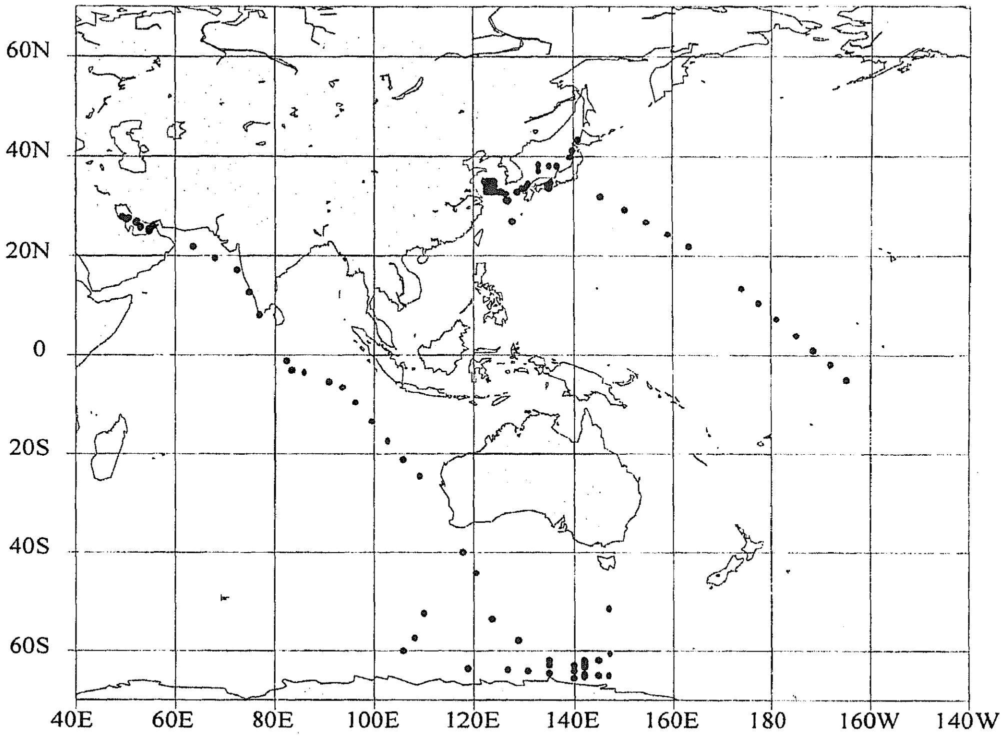

Fig. 1. Sampling station

Chlorophyll *a* concentration was determined fluorometricaly (Parsons et al., 1984) with a fluorometer (Turner Designs). Spectral downwelling irradiance, $E_d(\lambda, z)$ and upwelling radiance $L_u(\lambda, z)$ was measured with spectroradiometers, MER-2020A, MER-2040 and PRR-600 (Biospherical Instruments).

Normalized water-leaving radiance $L_{wn}(\lambda)$ and remote sensing reflectance $R_{rs}(\lambda)$ were calculated from measured $E_d(\lambda, z)$ and $L_u(\lambda, z)$ for development of bio-optical algorithm.

Results and Discussions

The two-bands ratio algorithm of the CZCS was tested for the data set in this study to know the overview of the relationship (Fig. 2).

Based on the distribution in Fig. 2, five cases were determined as following:

(1) Indian Ocean, Japan Sea and Pacific Ocean (Clearer Case 1 waters)
(2) Clearer Case 1 waters + Persian Gulf and Osaka Bay (Case 1 waters)
(3) Southern Ocean and JARE (Southern Ocean)
(4) Yellow Sea and Osaka Bay (Case 2 waters)

(5) All oceanic region.

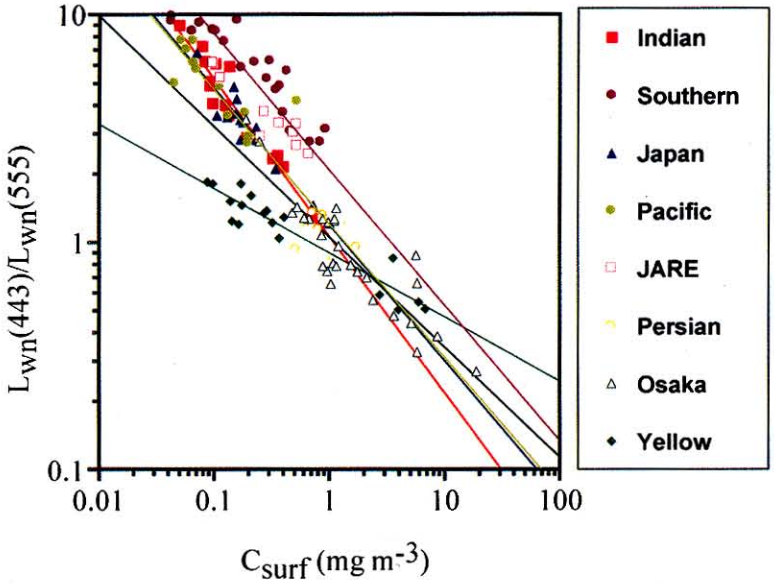

Fig. 2. Relationship between chlorophyll *a* concentration and two-bands ratio (443:555)

For these five cases, tow bands (λ_1 and λ_2) with the highest R^2 value (Table 1) were found with least square fitting to consider the wavelength which should be used in the new algorithm.

Table 1. Tow bands with the highest R^2 value

Area	λ_1	λ_2	R^2	a	b
Clear Case I	443	510	0.877	0.592	-2.317
Southern Ocean	443	510	0.879	1.770	-3.353
Case I	443	555	0.917	1.164	-1.517
Case II	490	555	0.783	1.720	-2.834
ALL	443	555	0.748	1.057	-1.293

λ_1 and λ_2 smoothly shifted from 443 to 490 nm and from 510 to 555 nm, respectively. Therefore, these shifts should be applied and the new bio-optical algorithm was developed as following:

$$C_{surf} = a \times \{[R_{rs}(\lambda_1) + R_{rs}(\lambda_2)] / [R_{rs}(\lambda_3) + R_{rs}(\lambda_4)]\}^{b}, \quad (1)$$

where C_{surf} is chlorophyll a concentration at the sea surface, R_{rs} is remote sensing reflectance, λ_1 to λ_4 are 443, 490, 510 and 555 nm. This algorithm performed well for the all data except the Southern Ocean and Yellow Sea data, and its equation was,

$$C_{surf} = 1.291 \times \{[R_{rs}(443) + R_{rs}(490)] / [R_{rs}(510) + R_{rs}(555)]\}^{-2.621}$$
$$\text{RMSE}=0.161,\ R^2 = 0.924 \qquad (2)$$

The results of the analysis using the semi-analytical method (Carder et al., 1999) suggested that the incorrect estimation in the Southern Ocean and the Yellow Sea in the concentration less than 1.5 mg m^3 was attributed to:

(1) Low specific absorption coefficient of phytoplankton and non co-variation of absorption coefficients of non-algal matters with chlorophyll *a* concentration in the Southern Ocean

(2) High specific absorption coefficients of phytoplankton and non-algal matter in the Yellow Sea.

Therefore, variation of the band ratio $R_{rs}(443)/R_{rs}(555)$ indicating chlorophyll *a* concentration and $R_{rs}(412)/R_{rs}(443)$ indicating non-algal matter with their concentrations depend on the waters. This variation can be utilized to separate the waters (Fig. 3).

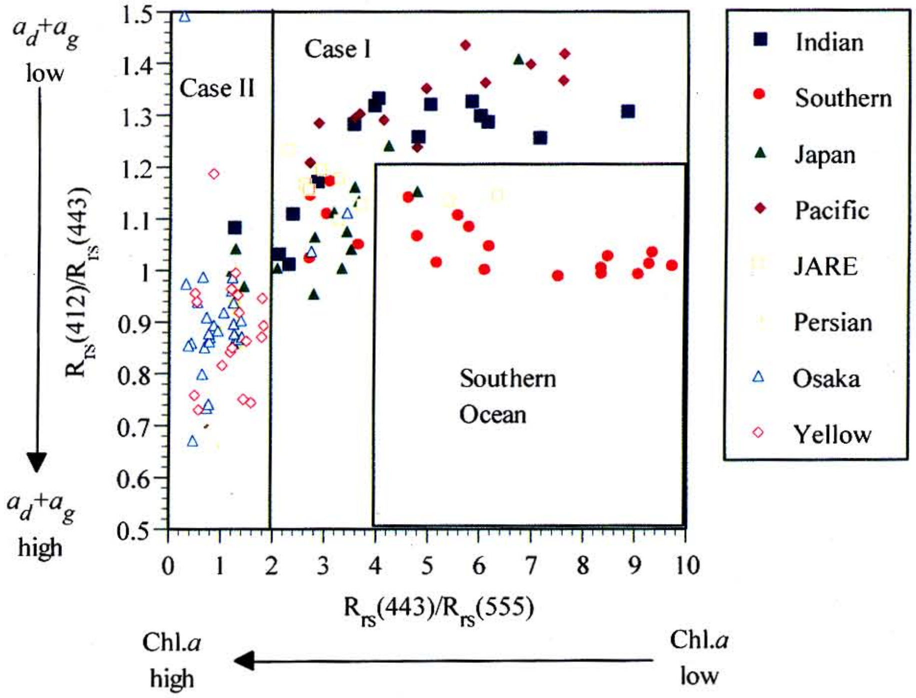

Fig. 3. Separation of waters using the bands ratios $R_{rs}(443)/R_{rs}(555)$ and $R_{rs}(412)/R_{rs}(443)$

In this study, the waters were determined as $R_{rs}(443)/R_{rs}(555) \leq 2$ for case 2 waters, and $R_{rs}(443)/R_{rs}(555) \geq 4$ and $R_{rs}(412)/R_{rs}(443) \leq 1.2$ for the Southern Ocean, respectively. When the each separated data was input to their local algorithm (Fig. 4), the estimation of chlorophyll *a* concentration for all data was largely improved (RMSE=0.236, R^2=0.834).

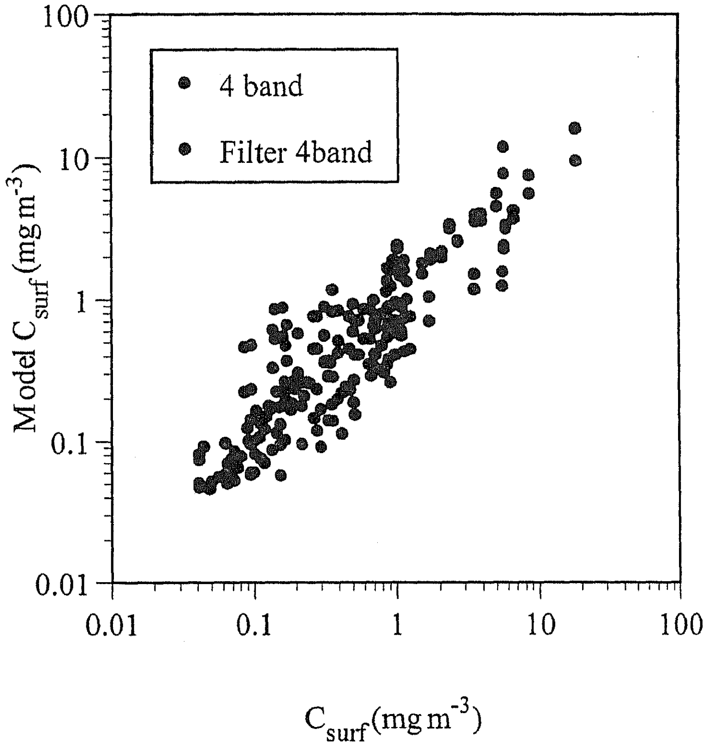

Fig. 4. Relationship between measured and modeled chlorophyll *a* concentration.

This procedure was effective for the global estimation of chlorophyll *a* concentration, because it needs only remotely sensed data.

Acknowledgements

We thank the officers and crews of the T/V Umitaka-maru III and Shinyo-maru, Tokyo University of Fisheries, for their cooperation during the cruise

References

Carder, K. L., F. R. Chen, Z. P. Lee, S. K. Hawes, and D. Kamykowski (1999) : Semianalytic Moderate-Resolution Imaging Spectrometer algorithms for chlorophyll a and absorption with bio-optical domains based on nitrate-depletion temperatures. *J. Geophys. Res.*, **104**, 5403-5421.

Gordon, H. R., D. K. Clark, J. W. Brown, O. B. Brown, R. H. Evans, and W. W. Broenkow (1983) : Phytoplankton pigment concentrations in the Middle Atlantic Bight: comparison of ship determinations and CZCS estimates. *Appl. Opt.*, **22**, 20-36.

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

Parsons, T. R., M. Takahashi, and B. Hargrave (1984) : Biological oceanographic processes. Pergamon Press, 330 pp.

Shimel, D. S. (1995) : Terrestrial ecosystems and the carbon cycle. *Global Change Biol.*, **1**, 77-91.