Characteristics of Chlorophyll *a* Absorption in Case 2 Water for Using Remote Sensing Data

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Abstract: In this study, spectroradiometer data were coupled with fluorometer data to find out the best suited bands ratio to monitor the chlorophyll *a* concentration for inland water. Remote sensing reflectance measurements were used to evaluate the performance of several default ocean color chlorophyll algorithms for SeaWiFS data. This study shows that the chlorophyll *a* concentration from fluorometer and reflectance from spectroradiometer lies in exploiting the signal provided by the chlorophyll *a* red absorption peak near 670nm. Two-band ratio based on a ratio of reflectance 670 and 700nm provided a good correlation for a linear model, compare with blue-green two band ratio.

Key Words: *chlorophyll a, remote sensing reflectance, spectroradiometer data, fluorometer data*

1. Introduction

Chlorophyll *a* retrieval in case 2 waters, where the optical properties of inorganic suspended matter and colored dissolved organic matter (CDOM) must also be considered, is still a matter of intense research activity, and a few convincing example are available of satellite-derived chlorophyll *a* concentrations for such water [1],[2]. This study may help to overcome the constraints by providing an alternative idea to use remote sensing technique for water quality monitoring over a range of temporal and spatial scale. In this study, spectroradiometer and fluorometer data were collected for Lake Abashiri, Hokkaido, Japan. These data sets were also used to check the validity of the derived chlorophyll algorithms by using the same band ratio of SeaWiFS, and finally organized the data sets to find out the correlation between spectral index and chlorophyll *a* concentration.

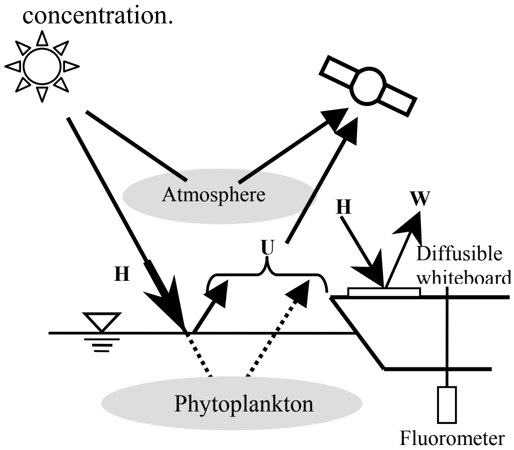

Fig. 1. Measurements of water surface reflectance and fluorometer data

2. Data collection and preparation

Fluorometer data for *in situ* measurements and spectroradiometer data were collected from 1997 to 2000 for Lake Abashiri. The spectroradiometer data set ranges from 350 to 900nm by resolution of 1nm. The spectroradiometer data set was accompanied by fluorometer data for chlorophyll *a*, turbidity, temperature in different water depths, and Secchi disk data. Two kinds of spectral radiation data were measured; the downward spectral irradiance (solar radiation, H in Figure 1) and upward water surface spectral radiance (U in Figure 1). The water surface reflectance data represent the ratio of reflected energy to incident energy with values ranging from 0 to 1. The upward water surface radiation is composed of two components; the direct reflected radiation at water surface and the scattered radiation from transferred light under water surface which possess water quality information. Solar radiation was measured by upward radiation from diffusible whiteboard. Water transparencies were measured by using Secchi disk depth. The average chlorophyll *a* concentration and turbidity were calculated for 0~1m, 0~2m and 0~transparency depth from fluorometer data.

3. Methodology

1) Estimation of remote sensing reflectance from spectroradiometer

The measuring system is shown in Figure 1. **H**($\mu w\ cm^{-2}\ nm^{-1}$) and **U**($\mu w\ cm^{-2}\ sr^{-1}\ nm^{-1}$) represent the spectral irradiance (downward) and radiance (upward). Solar radiation can be measured by knowing amount of **H,** while reflection constituents from water surface and under water surface can be measured by knowing the amount of **U**. Upward radiation from diffusible whiteboard is measured for solar radiation which can be considered equal to solar radiation due to the reflectance 1 to all direction. Therefore, we measured reflected energy **W** ($\mu w\ cm^{-2}\ sr^{-1}\ nm^{-1}$) from the diffusible whiteboard by using spectroradiometer for measuring solar energy. Reflectance (R_r) for any particular wavelength can be estimated by

$$R_r = \frac{\pi U}{H} \quad (1)$$

$$H = \pi W \quad (\mu w\, cm^{-2} nm^{-1}) \quad (2)$$

Therefore, remote sensing reflectance can be measured by

$$R_{rs} = \frac{U}{H \cos\theta_0} \quad (sr^{-1}) \qquad (3)$$

where, θ_0 is solar zenith angle.

2) OC2-V2 and OC4-V4 algorithms

The OC2-V2 and OC4-V4 algorithms are used in TeraScan system and SeaDAS software to estimate chlorophyll *a* concentration by using SeaWiFS data. The fundamental equations for OC2-V2 and OC4-V4 are as follows:

$$Chla = 10^{(a0 + a1*R + a2*R^2 + a3*R^3)} + a4 \qquad (4)$$

$$R = Log\{R_{rs}(490)/R_{rs}(555)\}$$

$$a = [0.2974, -2.2429, 0.8358, -0.0077, -0.0929]$$

$$Chla = 10^{(a0 + a1*R + a2*R^2 + a3*R^3 + a4*R^4)} \qquad (5)$$

$$R = Log\{\max[R_{rs}(443), R_{rs}(490), R_{rs}(510)]/R_{rs}(555)\}$$

$$a = [0.366, -3.067, 1.930, 0.649, -1.532]$$

where, $R_{rs}(443)$, $R_{rs}(490)$, $R_{rs}(510)$ and $R_{rs}(555)$ are remote sensing reflectance for SeaWiFS band center 443, 490, 510, and 555nm with band width 20nm, respectively. And ***R*** is the logarithmic value of remote sensing reflectance ratio for two selective bands.

3) Assimilation of spectroradiometer data to SeaWiFS band for chlorophyll *a*

We prepared the spectral data corresponding to the wavelength of 443, 490, 510 and 555nm to assimilate with SeaWiFS bands. Remote sensing reflectances can be estimated by using equation (3). But for the logarithmic value for the ratio of remote sensing reflectance (***R***) for two selective bands were estimated by

$$R = Log\left[\frac{R_{rs}(\lambda 1)}{R_{rs}(\lambda 2)}\right]$$

$$= Log\left[\frac{\dfrac{U(\lambda 1)}{W(\lambda 1)\cos\theta}}{\dfrac{U(\lambda 2)}{W(\lambda 2)\cos\theta}}\right] = Log\left[\frac{U(\lambda 1)}{U(\lambda 2)}\frac{W(\lambda 2)}{W(\lambda 1)}\right] \qquad (6)$$

The estimated chlorophyll a by using equation (4), (5) and (6) from spectroradiometer reflectance to assimilate to the SeaWiFS band are shown in Figure 2. The *in situ* measurements show higher values compared with estimated results.

4) Selection of band wavelength for chlorophyll *a* concentration measurements

Many empirical models, with varying degrees of complexity, have been proposed within the last two decades to relate the backscattering properties observed to the concentration of dissolved substances in the water

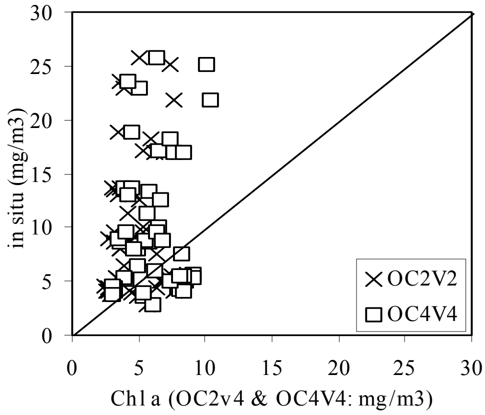

Fig. 2. Comparison among the estimated chlorophyll *a* concentration with *in situ* data in Lake Abashiri, 1997-2000

column. Normally, most of algorithms were developed for case 1 water by using blue-green two band ratio. Field measured spectral reflectance for the absorption of different concentration of chlorophyll *a* in Lake Abashiri is shown in Figure 3. Chlorophyll *a* is a phytopigment present in all algae groups in inland waters and shows absorption bands in the blue wavelength at 440nm and in the red wavelength near at 670nm (Figure 3), leaving a maximum green reflectance at 570nm due to an electron excitation process. But the bands range near at 670nm shows the distinct absorption for this case. The red edge ascent near at 700nm that is narrowed to a peak by growing water absorption in the near infrared is also correlated to increasing chlorophyll *a* contents.

At 400-500nm spectral range the absorption from tripton (particulate matter after removal of phytoplankton pigments) is generally greater than phytoplankton absorption and the total particulate absorption coefficients shows an exponentially decreasing form for the 400-570nm range, typical of tripton (detrital) absorption [1]. Considering that a satellite-based sensor sees only the effect of the total absorption coefficients (particulate plus dissolved matter plus pure water), it is clearly important to be able to

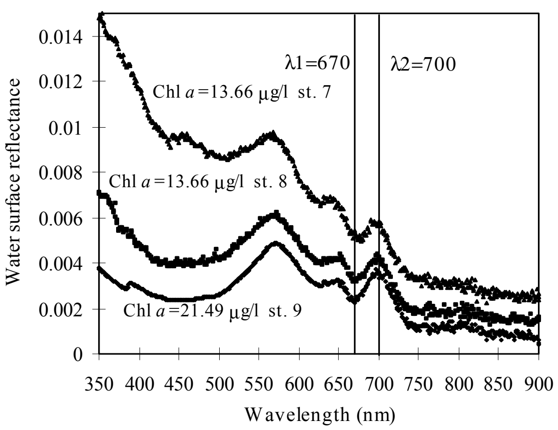

Fig. 3. Reflectance spectra for known chlorophyll *a* average from 0 to 2m in Lake Abashiri, 21 August 1997

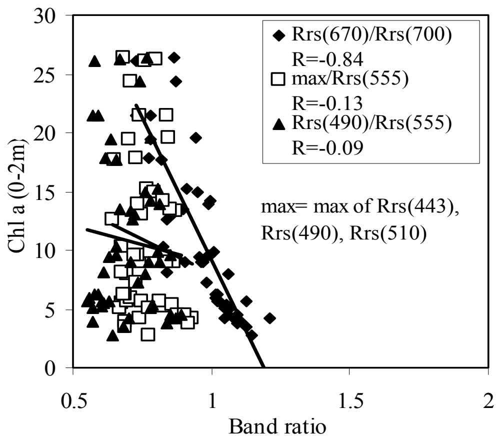

Fig. 4. Correlation of chlorophyll *a* with two band ratio ranges from 443-555 and 670-700 in Lake Abashiri for 1997-2000

distinguish phytoplankton-related features at least in the total particulate absorption spectrum. Study shows that satellite-derived total absorption coefficient divided into components arising from phytoplankton and other material will clearly be difficult without use of the 670-700nm chlorophyll *a* absorption features, where the absorption of phytoplankton is nearly equal to the total particulates [1]. Normally the band ratios used in phytoplankton retrieval algorithms have a good correlation for case 1 water [3].

Therefore, we examined spectral bands ratio against the measured chlorophyll *a*. Bands ratio (670/700) shows good correlation compared with other bands ratios those were used in OC2-V2 and OC4-V4 algorithms in Figure 4.

(5) Correlation for a model to retrieve chlorophyll *a*

Based on the correlation with the *in situ* data, one of the most important relationships observed in this study was the relationship between spectral bands ratio and the average of chlorophyll a concentration from water surface to the depth up to the water transparency. Water transparency was measured by using Secchi disk depth. The transparency (Secchi disk depth) is negatively correlated with turbidity (R=-0.64). We have estimated average of chlorophyll *a* concentration from 0 to 1m, 0 to the depth of water transparency and 0 to 2m depth. The correlation between band ratio (670/700) and chlorophyll *a* concentration average from 0 to 2m depth is shown in Figure 4. The average value for chlorophyll *a* from 0 to the depth of transparency shows the correlation R=-0.82 for the band ratio (670/700), while correlation R=-0.84 is shown for the average value from 0 to 2m depth. But the average value of chlorophyll a concentration from 0 to 1m shows the correlation R=-0.82 with band ratio (670/700). The average transparency of Lake Abashiri is 1.60m. Therefore, there is not significant difference between the correlations with chlorophyll *a* average value obtained for the depth to transparency and 2m, though the average value from 0 to 2m shows comparatively better correlation. Hence, chlorophyll *a*, obtained average from 0 to 2m depth, was appeared to correlate better with band ratio (670/700).

4. RESULTS AND DISCUSSIONS

Sigmoid form of the OC2-V2 and OC4-V4 algorithms are very sensitive to small variations of Rrs(490)/Rrs(555) or max[Rrs(443), Rrs(490), Rrs(510)]/Rrs(555), and then estimate unrealistically high or low chlorophyll *a* in cases of high gelbstoff, detrital and/or accessory pigment absorption. These two algorithms show high estimation for lower ranges and low estimation for higher range of chlorophyll *a* concentrations in Lake Abashiri (Figure 2). Therefore, it is concluded that blue-green two band ratio algorithm does not show good adaptations for case 2 water, though which is popular for case 1 water.

Chlorophyll *a* is a phytopigment present in all algae groups in Lake Abashiri shows distinct absorption bands in the red wavelength near at 670nm (Figure 3), leaving a maximum green reflectance. The red edge ascent near at 700nm that is narrowed to a peak by growing water absorption in the near infrared is also correlated to increasing chlorophyll *a*. Based on the correlation *in situ* data, the ratio of band 670 and 700nm wavelength produced a good correlation (R=-0.84) with chlorophyll *a* concentration average from 0 to 2 m depth (Figure 4). Using this linear model, a chlorophyll *a* distribution map can be produced for Lake Abashiri.

Therefore, hand-held spectroradiometer data have been used successfully to assimilate the spectral band to the remote sensing technique for the estimation of chlorophyll *a* concentration for case 2 water in Lake Abashiri. This study suggests that blue-green two band ratio could not be used for the monitoring of chlorophyll *a* in case 2 water. The ratio of bands wavelength ranges from 670 to 700 would be better to monitor the chlorophyll *a* for inland and high turbid water.

Acknowledgement

The authors gratefully acknowledge Japan Society for Promotion of Science (JSPS) providing the fellowship to first author.

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