Modeling Phytoplankton Absorption in Inland Reservoir Water

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1. Introduction

In the retrieval of inherent optical properties (IOPs) from remote sensing reflectance of water, models for the wavelength dependence of absorption and backscattering coefficients are often needed. The main constituents that affect the water leaving reflectance are the suspended particles, phytoplankton and colored dissolved organic matter (CDOM). We found that the existing model that works well for the absorption spectrum of phytoplankton in sea waters is not sufficiently accurate for the types of phytoplankton existing in the inland reservoirs of Singapore. To obtain a better fit of the measured remote sensing reflectance spectra to the computed spectra, the phytoplankton absorption spectrum is modeled by a series of Gaussian peaks from 400 nm to 750 nm which mimic the absorption due to various pigments present in phytoplankton other than chlorophyll-a. The strengths of the absorption peaks are derived from the measured remote sensing reflectance. The phytoplankton absorption model is incorporated into a semi-empirical water reflectance model for retrieving the absorption and backscattering coefficients of water constituents using the spectral optimization technique. Field measurement campaigns were conducted to obtain in-situ data of remote sensing reflectance together with water quality parameters such as the turbidity, chlorophyll concentration (Chl) and CDOM absorption spectra. The retrieved phytoplankton absorption strength near 670 nm correlates well with the in-situ Chl with a coefficient of determination (R-squared) greater than 0.9. The retrieved absorption strengths of the other absorption peaks can potentially be used for phytoplankton type identification.

2. Background

The subsurface remote sensing reflectance $r_{rs}(\lambda)$ is related to the intrinsic optical properties (IOP) by (Gordon et al. 1988)

$$r_{rs}(\lambda) = \left[g_0 + g_1 u(\lambda)\right] u(\lambda) \tag{1}$$

where g_0, g_1 are the model parameters and u is defined as

$$u(\lambda) = \frac{b_b(\lambda)}{a(\lambda) + b_b(\lambda)} \tag{2}$$

where a is the total absorption coefficient, and b_b is the total backscattering coefficient of water. The absorption and backscattering coefficients are expressed as the sums of their respective components,

$$a(\lambda) = a_w(\lambda) + a_g(\lambda) + a_\phi(\lambda) \tag{3}$$

$$b_b(\lambda) = b_{bw}(\lambda) + b_{bp}(\lambda) \tag{4}$$

where the subscripts w, g, ϕ, and p refer to water, gelbstoff (CDOM and detritus), phytoplankton and particulate matter respectively. The absorption and backscattering coefficients of water molecules are available in published literature (Pope and Fry, 1997). The absorption coefficient of gelbstoff is usually modelled by (Bricaud et al. 1981),

$$a_g(\lambda) = G\mathrm{e}^{-S(\lambda-440)} \quad (5)$$

where G is the value of a_g at 440 nm which is an indicator of the amount of CDOM in the water, and S is the spectral slope. The backscattering of suspended particles is modelled by

$$b_{bp}(\lambda) = X(550/\lambda)^y \quad (6)$$

where X is the value of b_{bp} at 550 nm which correlates strongly with turbidity and y is a spectral shape factor. There is no universal model for phytoplankton absorption coefficient as absorption by phytoplankton depends on the different types and amount of pigments present. Though chlorophyll-a is the major pigment responsible for absorption, the absorption spectrum also depends on many other factors such as the size, types and concentration of phytoplankton in the water. Nevertheless, the model of Lee et al. (1998) has proven to be useful and is commonly used in the retrieval of sea water optical properties. In this model, phytoplankton absorption is expressed as

$$a_\phi(\lambda) = Pa_0(\lambda) + P\ln(P)a_1(\lambda) \quad (7)$$

where P is the value of a_ϕ at 440 nm which is an indicator for chlorophyll-a concentration while $a_0(\lambda)$ and $a_1(\lambda)$ are empirical functions whose values are determined by fitting the measured phytoplankton absorption to the above model. Thus, the forward model (Equation 1) for computing the water reflectance can be represented as a non-linear function of the three optical parameters, P, X and G.

3. Approach

We find that the conventional model (Equation 7) for phytoplankton absorption is not able to fit the water reflectance spectra of fresh water reservoirs in Singapore. In addition to the usual chlorophyll absorption peak at 674 nm, the fresh water reflectance exhibits strong absorption around 624 nm which is not so prominent in sea water. Instead of using Equation 7, we model the phytoplankton absorption spectrum by a series of Gaussian peaks from 400 nm to 750 nm,

$$a_\phi(\lambda) = \sum_{i=1}^{N} P_i \exp\left(-\frac{(\lambda-\lambda_i)^2}{2\sigma_i^2}\right) \quad (8)$$

where N is the number of Gaussian peaks in the model, λ_i is the central wavelength and σ_i is the standard deviation of each Gaussian peak. The strengths P_i of these absorption peaks are retrieved by fitting the measured water reflectance spectra to the forward model.
Field trips were conducted at two different fresh water reservoirs, with five sampling stations at each reservoir. Above-surface remote sensing reflectance was measured using a portable spectroradiometer (GER 1500, Spectra Vista Corporation) at each sampling sttion. In-situ measurements of water turbidity in nephelometric turbidity units (NTU) were carried out. Water samples were collected and sent to accredited laboratories for measurements of chlorophyll-a and CDOM absorption.

This phytoplankton absorption model (Equation 8) is incorporated into the semi-empirical water reflectance model (Equation 1) for retrieving the parameters (G, X, P_i) from the measured remote sensing reflectance. The optical parameters are then correlated with the measured water turbidity, chlorophyll-a concentration, and CDOM absorption.

4. Results

Figure 1 shows an example of a remote sensing reflectance spectrum measured above a sampling point (black solid line). The chlorophyll-a concentration was 16.8 μg/l, turbidity was 3.22 NTU and CDOM absorption at 440 nm was 1.05 m^{-1} according to laboratory analysis of the water sample. The best-fit reflectance spectra (red dash line) computed using the conventional phytoplankton absorption model (Equation 7). The measured reflectance curve clearly shows a dip in the reflectance around 674 nm due to absorption by chlorophyll-a. There is another smaller dip around 624 nm. There are also absorption features, shown as dips in the reflectance curve, around 500 nm and 440 nm at the shorter wavelength side. The reflectance spectrum computed using the conventional model fits the overall shape of the measured spectrum. However, it does not show the finer absorption features exhibited in the measured spectrum. Figure 2 shows the same measured reflectance spectrum and the reflectance modelled using the Gaussian peaks model (Equation 8). This model can reproduce the absorption features in the reflectance curve.

The retrieved Gaussian peak strengths at 674 nm and 624 nm show good correlation with the chlorophyll-a concentration (Figure 3). The coefficients of determination (R^2) are 0.91 and 0.88, respectively. The particulate backscattering coefficient at 550 nm (X) also has high correlation with water turbidity expressed in nephelometric turbidity units (NTU) with $R^2 = 0.77$ (Figure 4). The CDOM absorption coefficient at 440 nm (G) retrieved from reflectance shows high correlation with the laboratory measured values ($R^2 = 0.83$) as shown in Figure 5. However, there seems to be a negative bias of 0.13 m^{-1}.

5. Conclusion

We demonstrated that the remote sensing reflectance of fresh water reservoirs can be fitted using an empirical model (Equation 1) with phytoplankton absorption modelled by the sum of several Gaussian peaks spanning wavelengths from 400 nm to 750 nm. The Gaussian peak strength at 674 nm correlates well with the chlorophyll-a concentration. This model is adaptable to different phytoplankton types present in the fresh water environment.

References

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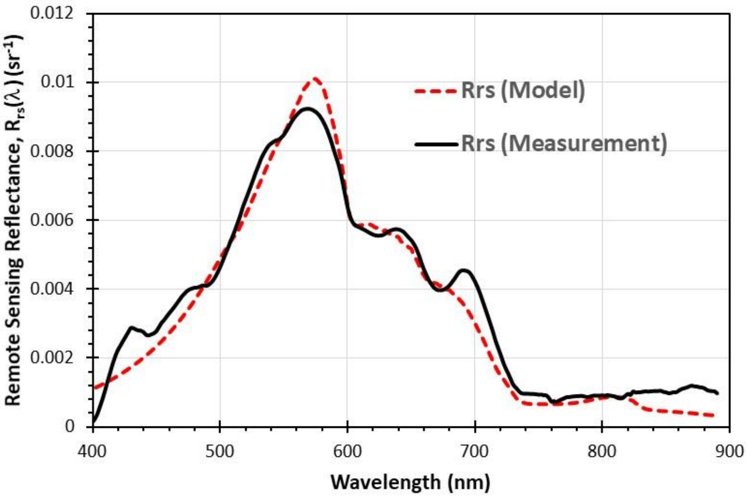

Figure 1: Measured reflectance spectrum (black solid line) and best-fit computed reflectance (red dashed line) using the conventional model for phytoplankton absorption.

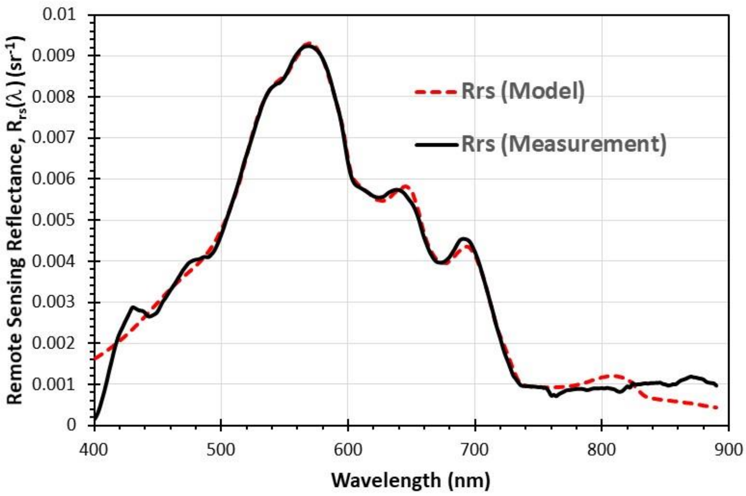

Figure 2: Measured reflectance spectrum (black solid line) and best-fit computed reflectance (red dashed line) using the Gaussian peaks model for phytoplankton absorption.

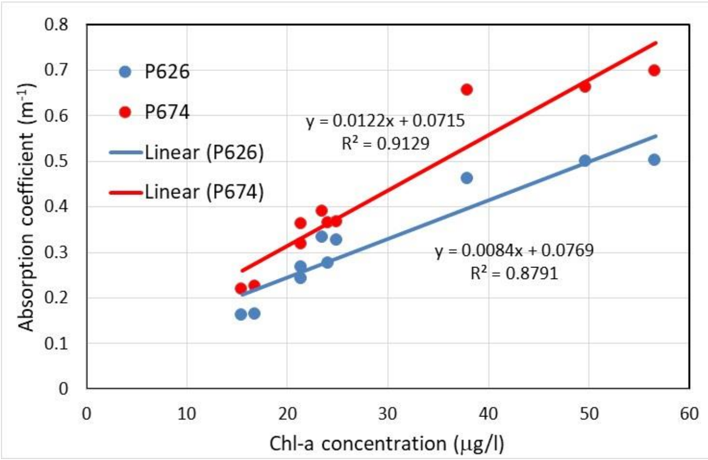

Figure 3: Regressions of the Gaussian peak strengths at 674 nm and 626 nm with chlorophyll-a concentration.

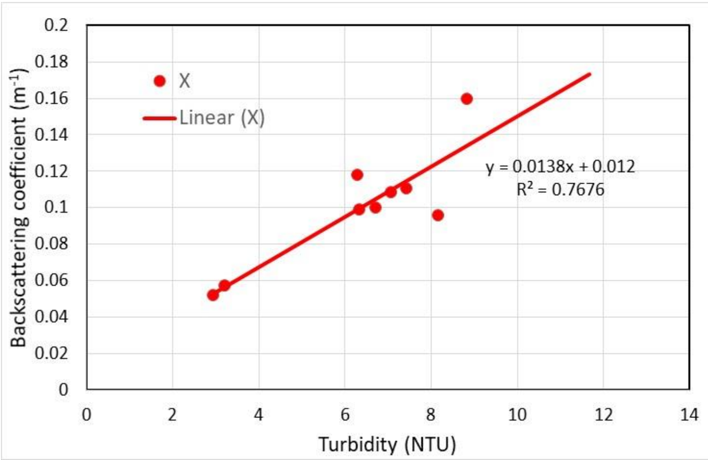

Figure 4: Regression of particulate backscattering coefficient with water turbidity.

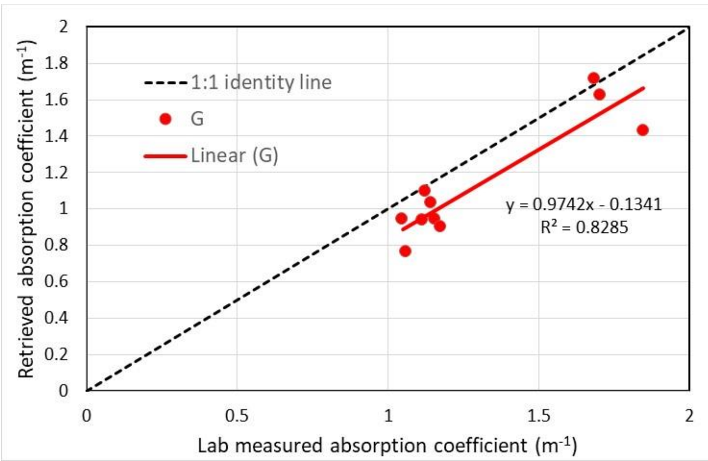

Figure 5: Regression of CDOM absorption coefficient retrieved from reflectance with Lab-measured CDOM absorption.