

# An Algorithm To Determine Backscattering Ratio And Single Scattering Albedo

T.Suresh, Elgar Desa, S.G.Prabhu Matondkar, Antonio Mascarenhas, S.R.Nayak\*, Puneeta Naik  
National Institute of Oceanography, Dona-Paula, Goa 403004, India  
\*Space Application Centre, Ahmedabad, India

## ABSTRACT

We present here algorithms to determine the inherent optical properties of water, backscattering probability and single scattering albedo at 490 and 676 nm from the apparent optical property, remote sensing reflectance. We have used the measured scattering and backscattering coefficients and the remote sensing reflectance to obtain a relationship for the backscattering ratio, which is defined as the ratio of the total backscattering to the total scattering in terms of the remote sensing reflectance of two bands. Using the empirical relationship for the total backscattering ratios, we have also computed single scattering albedo, which is defined as the ratio of the scattering to the beam attenuation coefficient. The values of single scattering albedo obtained from measured values and those obtained from the empirical method are found to be comparable. The values of single scattering albedo derived using the algorithm are found to be comparable to the measured values obtained from the eastern Arabian Sea, with the root mean squared error of 0.078 and the mean percentage error of 9.5 % for the 490 nm and root mean squared error of 0.043 and the mean percentage error of 7.5 % for the 676 nm.

**Keywords:** Optical properties, IOP, Arabian Sea, single scattering albedo, back scattering, back scattering ratio, SeaWiFS, OCM

## 1. INTRODUCTION

The water leaving radiance plays an important role in the ocean color remote sensing as the spectral values of the water leaving radiance of the ocean provide information about the constituents of the water column. One of the apparent property that is often used with remote sensing application for the development of algorithms to retrieve parameters is the remote sensing reflectance,  $R_{rs}(\lambda) = L_w(\lambda)/E_d(\lambda)$ , where  $L_w(\lambda)$  is the water leaving radiance from the surface of water and  $E_d(\lambda)$  is the amount of solar irradiance entering the water. This apparent optical property has been modeled in terms of the inherent optical properties of water, absorption and backscattering coefficient or backscattering probability and the single scattering albedo<sup>1</sup>.

The backscattering ratio or the backscattering probability is defined as  $\tilde{b}_b(\lambda) = b_b(\lambda)/b(\lambda)$ , where  $b(\lambda)$  is the total scattering coefficient and  $b_b(\lambda)$  is the backscattering coefficient. This particulate backscattering ratio is found to be largely a function of the composition of the particulate material and can be used to derive the index of refraction<sup>2</sup>. Backscattering ratio holds strong relationship with chlorophyll concentration and it shows gradual decrease with increasing chlorophyll<sup>1,3</sup>. For most studies and models, backscattering ratio is assumed to be a constant or modeled as a function of chlorophyll<sup>1,3,4</sup>. The backscattering ratio is generally greater for smaller particles.

Single scattering probability is defined as the probability that a photon will be scattered than absorbed in water. This spectral single scattering albedo  $\omega_0(\lambda)$ , also known as the probability of the survival of photon is given in terms of the inherent optical properties, scattering coefficient  $b(\lambda)$  and beam attenuation coefficient  $c(\lambda)$  and is given as  $\omega_0(\lambda) = b(\lambda)/c(\lambda)$ . The beam attenuation coefficient is  $c(\lambda) = a(\lambda) + b(\lambda)$ , the arithmetic sum of the absorption coefficient  $a(\lambda)$  and the scattering coefficient  $b(\lambda)$ . The single scattering albedo  $\omega_0(\lambda)$  is dimensionless and it is a crucial parameter that influences the nature of the radiation transfer within the water body. The range of  $\omega_0(\lambda)$  values are within 0 and 1. If the

media is highly absorbing, the single scattering albedo,  $\omega_0(\lambda)$  will be low and closer to zero, while  $\omega_0(\lambda)$  will be closer to unity, if scattering is dominant. The influence of chlorophyll is seen more at the higher wavelength than at the blue part of the spectrum<sup>5</sup>.

## 2. METHOD

### 2.1 Optical Data

The data were collected in the eastern Arabian Sea during the cruise SK-171 on board the research vessel, O.R.V. Sagar Kanya from 3 to 17 November, 2001. The measurements covered all water types from coastal to deep ocean, oligotrophic, highly productive and turbid waters. The measurements and processing of the optical data were carried-out adhering to the protocols recommended by NASA for the ocean color program. We have used the profiling instruments ac-9 (<http://www.wetlabs.com>) and Hydrosat-2 (<http://www.hobilabs.com>) to obtain the inherent optical properties and radiometer OCP-100/OCI-200 (<http://www.satlantic.com>) to measure apparent optical properties at very fine depth resolution of the water column. The instrument ac-9 provide absorption and beam attenuation data at nine discrete wavelengths of 412, 443, 488, 510, 532, 555, 650, 676 and 715 nm and Hydrosat-2 measure the backscattering coefficients at two discrete wavelengths, 475 nm and 676 nm. The ac-9 provides data without the contribution from the water molecular scattering and absorption, while Hydrosat-2 data include the scattering contribution from the water. The profiling unit of the radiometer provides downwelling irradiance and upwelling radiance at discrete wavelengths of 412.4, 442.8, 491, 509.2, 554.2, 669.4 and 683.5 nm and the reference unit at the deck provide the solar irradiance at these wavelengths. The ac-9 data is processed with salinity and temperature corrections using the CTD data obtained at the stations. Thereafter scattering corrections are applied using the Method 3 as the recommended in the protocol for the analysis of ac-9 data<sup>6</sup>. The sigma corrections are performed on the backscattering coefficient profiles using the data obtained from the ac-9. The sigma correction algorithm to correct for attenuation of the source beam<sup>7</sup> was applied using the  $a(\lambda)$  and  $c(\lambda)$  measured with the ac-9. The inherent optical properties used for the study are the values averaged over the euphotic depth. In our study, the backscattering probabilities are obtained at 470 and 676 nm using the backscattering data obtained from the Hydrosat-2 at 470 and 676 nm. The surface remote sensing reflectance values are obtained from processing the radiometer data using the proprietary software Prosoft 7.7 of the instrument.

### 2.2 Empirical method to determine $\tilde{b}_b$

The backscattering ratio or the backscattering probability is defined as

$$\tilde{b}_b(\lambda) = b_b(\lambda) / b(\lambda) \quad (1)$$

where  $b_b(\lambda)$  is the backscattering coefficient and  $b(\lambda)$  is the total scattering coefficient. The scattering and backscattering coefficients are the sum of scattering contributions due to molecular scattering from water,  $b_w(\lambda)$  and the scattering from the particulate matter in the water,  $b_p(\lambda)$ .

$$b(\lambda) = b_w(\lambda) + b_p(\lambda) \quad (2)$$

Here  $b_p(\lambda) = c(\lambda) - a(\lambda)$ , where  $c(\lambda)$  and  $a(\lambda)$  are beam attenuation and absorption coefficients measured by ac-9.

Similar relationship can be given for backscattering coefficient.

$$b_b(\lambda) = 0.5b_w(\lambda) + b_{bp}(\lambda) \quad (3)$$

Hydrscat-2 measures  $b_b(\lambda)$  at two wavelengths 470 and 676 nm. and the values include the molecular backscattering due to water, given above as  $0.5b_w(\lambda)$ .

The particulate backscattering ratio is given as

$$\tilde{b}_{bp}(\lambda) = b_{bp}(\lambda) / b_p(\lambda) \quad (4)$$

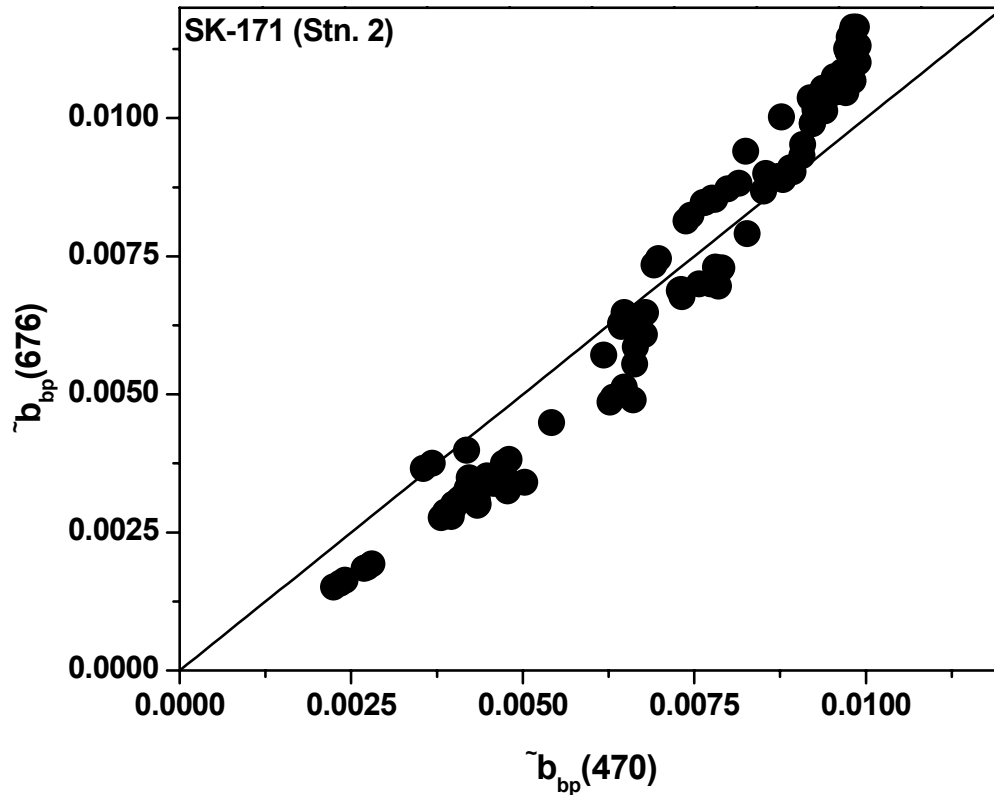


Fig.1 Backscattering ratio at 470 and 676 nm from the measured data.

The particulate backscattering ratios are found to be spectrally independent in the visible spectrum<sup>4</sup> and the same are observed for our measured data. (See Fig. 1). This is not true of the backscattering ratio. Here we derive an empirical relationship derived for backscattering ratio as a function of the ratio of the remote sensing reflectance at two wavelengths. The backscattering ratios are derived for the wavelengths 490 and 676 nm, which are close to the bands of the radiometer and also the satellite sensors SeaWiFS and IRS-P4 OCM. Since backscattering is measured at 470 nm, we use the following relationship to derive the backscattering coefficient at 490 nm.

$$b_b(\lambda) = 0.5b_w(\lambda) + b_{bp}(\lambda) \left[ \frac{470}{\lambda} \right]^{np} \quad (5)$$

We determine the index  $np$  that determines the spectral variation of particulate backscattering coefficient using the measured backscattering data at two wavelengths, 490 and 676nm and then using the backscattering coefficient at 470 nm and the relation given in equation 5 above, we determine the backscattering coefficient using at 490 nm.

Using a robust fit and removing the outliers, the empirical relationship for the backscattering ratio at 490 nm is given as (See Fig. 2a).

$$\tilde{b}_b(490) = X \left( \frac{Rrs(670)}{Rrs(555)} \right)^Y \quad (6)$$

where  $X = 0.000764$  and  $Y = -1.555$ . ( $r^2 = 0.73$ ).

The backscattering ratio at 676 nm is given as (See Fig. 2b).

$$\tilde{b}_b(676) = X \left( \frac{Rrs(670)}{Rrs(510)} \right)^Y \quad (7)$$

where  $X = 0.000153$  and  $Y = -1.43$ . ( $r^2 = 0.79$ ).

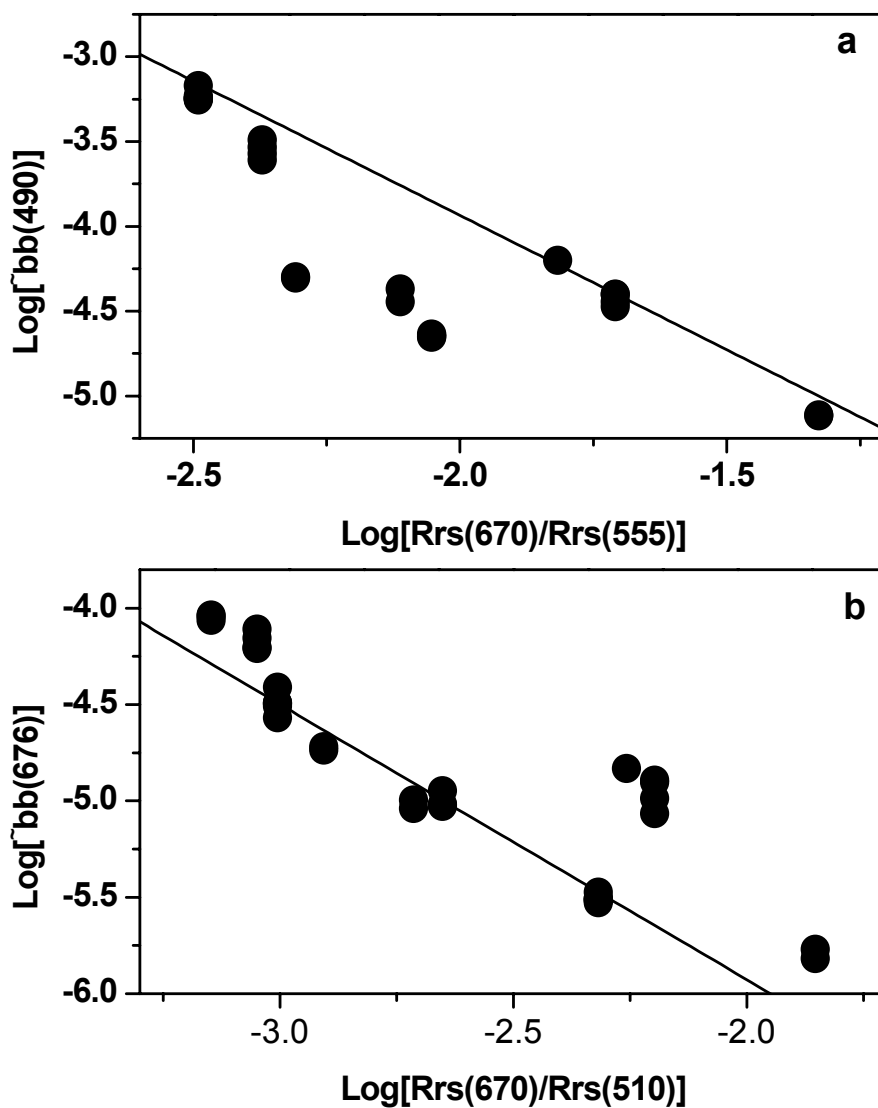


Fig. 2 a) Empirical relationship to determine  $\tilde{b}_b(490)$  and b)  $\tilde{b}_b(676)$

### 2.3 Empirical algorithm to determine $\omega_0(\lambda)$

Model developed from simulations for remotes sensing reflectance is well-accepted relationship based on backscattering and absorption coefficients<sup>1,8</sup>.

$$Rrs(\lambda) = K \frac{b_b(\lambda)}{a(\lambda) + b_b(\lambda)} \quad (8)$$

where  $K = (f/Q)(t/n)^2$

The factor K is simplified by assuming spectral independence over relatively small angles of sun-satellite geometry. t is the transmittance of the air-sea interface and n is the refractive index of seawater. The values used in the model are  $f/Q = 0.0949$  and  $t/n = 0.54^{1,5}$ .

Using the relationship  $a(\lambda) = c(\lambda) - b(\lambda)$  and  $\omega_0(\lambda) = b(\lambda)/c(\lambda)$ , from the above equation 8 for  $Rrs(\lambda)$ , we have the following empirical model for  $\omega_0(\lambda)$  as

$$\omega_0(\lambda) = \frac{Rrs'(\lambda)}{[B + Rrs'(\lambda)(1 - B)]} \quad (9)$$

where  $Rrs' = Rrs(\lambda)/K$  and  $B = \tilde{b}_b(\lambda)$

### 3. RESULTS

The values of  $\omega_0(\lambda)$  derived from the empirical algorithm given here using the  $Rrs(\lambda)$  data measured by the radiometer at various stations and the values of  $\omega_0(\lambda)$  obtained from the measured values of  $c(\lambda)$  and  $b(\lambda)$  at the same stations, are found to be comparable. (See Fig.3). The root mean squared error between the model and the actual measured is 0.08 and the mean percentage error is 9.5% for  $\omega_0(490)$  and the root mean squared error between the model and the actual measured is 0.043 and the mean percentage error is 7.5% for  $\omega_0(676)$ .

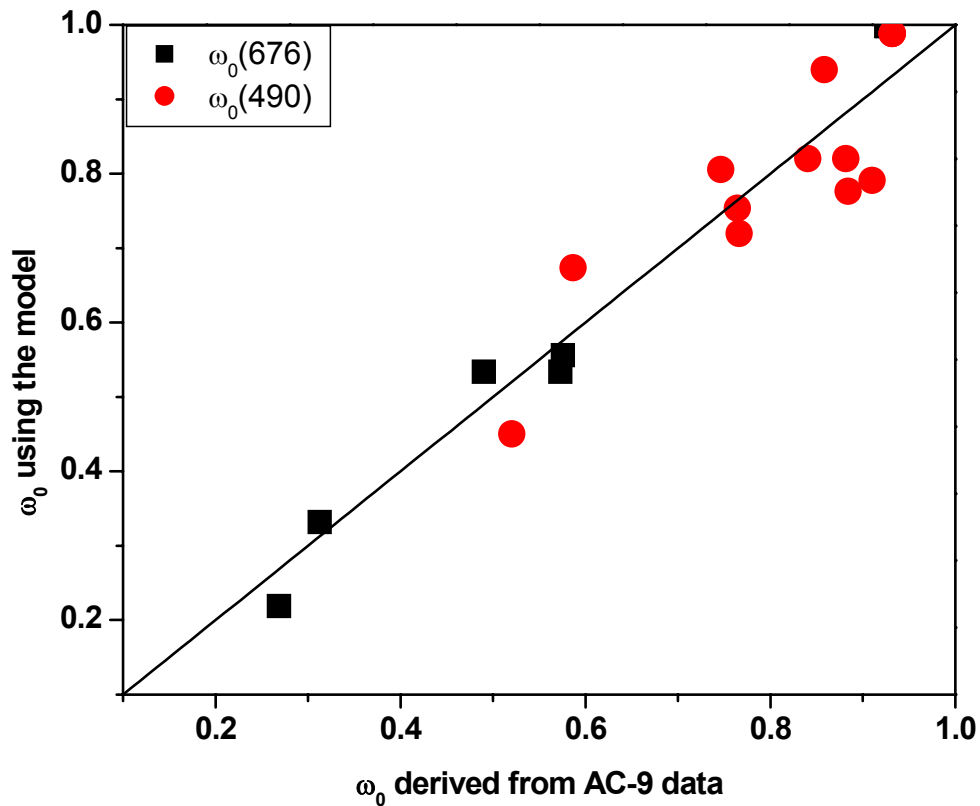


Fig. 3 Comparison of the values of  $\omega_0$  derived from the measurement and the empirical model.

#### 4. CONCLUSION

We have obtained a simple empirical method to derive back scattering ratio and the single scattering albedo from the in-situ radiometric measurements of waters of the Arabian Sea. The single scattering albedo derived from the empirical method is found to be agreeable with the measured optical data. This algorithm can be used to determine the scattering ratio and the single scattering albedo from the satellite derived radiometric data. It will also find application in the classification of water types, detection of blooms, development of various empirical algorithms related to marine optics and ocean color remote sensing.

#### Acknowledgement

We are thankful to Director, National Institute of Oceanography, Goa for the kind support. We are also grateful to our colleagues, Ms. Ancy Rodrigues, Mr. K. Ramdas and Miss Madhubala Shet for their help in analyzing the data and preparing the manuscript. Authors are indebted to Dr. Ehrlich Desa, Ex-Director, National Institute of Oceanography for his guidance and encouragement. This study was carried-out with the financial support from Space Application Center (ISRO), Ahmedabad., under the IRS-P4 OCM program.

## REFERENCES

1. H. R. Gordon, O. B. Brown, R. H. Evans, J. W. Brown, R. C. Smith, K. S. Baker, D. K. Clark, "A semi-analytic radiance model of ocean color", *Journal of Geophysical Research*, **93**, 10909–10924, 1988.
2. M. Twardowski, E. Boss, J. B. Macdonald, W. S. Pegau, A. H. Barnard, J. R. V. Zaneveld, "A model for estimating bulk refractive index from the optical backscattering ratio and the implications for understanding particle composition in case I and case II waters", *Journal of Geophysical Research*, **106**, 14129–14142, 2001.
3. Morel, "Optical modeling of the upper ocean in relation to its biogenous matter content (Case I waters)", *Journal of Geophysical Research*, **93 (C9)**, 10749-10768, 1988.
4. O. Ulloa, S. Sathyendranath, T. Platt, "Effect of the particle-size distribution on the backscattering ratio in seawater", *Appl. Opt.*, **33**, 7070–7077, 1994.
5. Morel, B. Gentili, "Diffuse reflectance of oceanic waters. II. Bidirectional aspects", *Appl. Opt.*, **32**, 6864–6879, 1993.
6. S. Pegau, J.R. Zaneveld, J.L. Mueller, "Volume absorption coefficients: instruments, characterization, field measurements and data analysis protocols", Chapter 3, "*Ocean optics protocols for satellite ocean color sensor validation, Revision 4, Volume IV, Inherent optical properties : Instruments, characterizations, field measurements and data analysis protocols*", Mueller J.L, Fargion G.S., MacClain C.R., NASA/TM-2003-2111621/Rev.4 –Vol. IV, 27-38, 2003.
7. R. A. Maffione, D. R. Dana, "Instruments and methods for measuring the backward-scattering coefficient of ocean waters", *Appl. Opt.*, **36**, 6057–6067, 1997. M. Twardowski, E. Boss, J. B. Macdonald, W. S. Pegau, A. H. Barnard, J. R. V. Zaneveld, "A model for estimating bulk refractive index from the optical backscattering ratio and the implications for understanding particle composition in case I and case II waters", *Journal of Geophysical Research*, **106**, 14129–14142, 2001.
8. Z. P. Lee, K. L. Carder, C. D. Mobley, R. G. Steward, J. S. Patch, "Hyperspectral remote sensing for shallow waters: 1. A semianalytical model", *Applied Optics*, **37**, 6329–6338, 1998.