

Bio-Optical Studies in the Bay of Bengal Waters Off Madras Coast, India

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Bio-optical characteristics like reflectance, absorbance and backscattering of selected stations in the Bay of Bengal are studied. An attempt is made to interpret these results with reference to the chlorophyll concentrations. An existing pigment index developed for Indian waters is tested for chlorophyll retrieval and the mode best suited for low chlorophyll waters is suggested.

In satellite remote sensing, measuring the upwelling spectral radiant energy from the ocean's surface makes it possible to determine the marine pigment concentrations due to the presence of phytoplankton in ocean water. Biological constituents, particularly chlorophyll in phytoplankton and associated degraded products, play a significant role in determining the optical properties of ocean waters. The combined effect of absorption and scattering due to suspended and dissolved biogenous material establishes the 'bio-optical state' of these waters.

The inherent optical properties of interest for ocean colour studies are the scattering function β , and either the light absorption coefficient a or the light attenuation coefficient c . The scattering coefficient b and attenuation coefficient c are measured more frequently. Combined measurements of b and c permit only an approximate calculation of absorption due to particles, organic dissolved substances and pure water. It is the blue and green parts of the electromagnetic spectrum that are needed for estimation of the water column productivity and it is these wavelengths that are influenced to the maximum extent by the prevailing atmospheric column between the sensor and the ocean surface. Thus, there is a great scope for algorithm development for chlorophyll retrieval and also for comparison of models developed for different types of ocean waters.

In this paper an attempt has been made to study the various inherent optical properties of the Bay of Bengal waters Off Madras coast India, viz. reflectance, absorbance and backscattering, which define the bio-optical state, in turn related to the ocean colour. Some chlorophyll retrieval algorithms already developed have been tested with the obtained optical data and the results discussed.

Materials and Methods

Optical data were collected (Fig. 1) over the southwest Bay of Bengal (lat. $10^{\circ}30'$ – $14^{\circ}30'N$; long. 80° – $83^{\circ}E$), during December 1986 on board *FORV Sagar Sampada*. The present study pertains to open sea which comes under case 1 waters, whose optical properties are dominated by phytoplankton and their degradation products only. Quanta Spectrometer (QSM 2500) which scans continuously in the range of 400 to 750 nm was used to collect the optical data. Measurements of upwelling and downwelling irradiance were recorded on chart paper for various depths from the surface to 30 m depth. The charts were digitised manually at every 50 nm interval, for computing optical parameters.

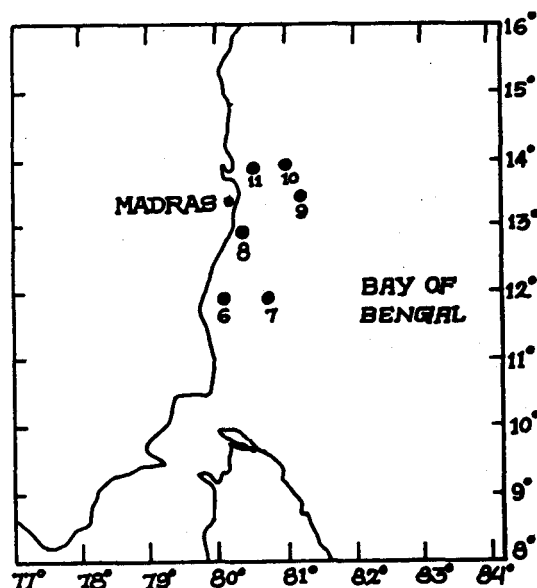


Fig. 1—Station locations

The surface diffuse reflectance is defined as the ratio of upwelling and downwelling subsurface irradiance $E\bar{u}(0)$ and $E\bar{d}(0)$ ²

$$R = \frac{E\bar{u}(0)}{E\bar{d}(0)}$$

In the present study reflectance R was computed by measuring the upwelling irradiance $E\bar{u}(0)$ just below the sea surface and downwelling irradiance $E\bar{d}^+(0)$ just above the sea surface and is given by the equation³.

$$R = \frac{E\bar{u}(0)}{E\bar{d}^+(0)}$$

Diffuse attenuation coefficient K , which is a function of both wavelength (λ , z) and depth of the water column, was calculated using the equation

$$K = \frac{1}{z} \log \left(\frac{E_0}{E_d} \right)$$

Backscattering coefficient (b_b) was calculated from the equation⁴

$$R = 0.33 (b_{b/c})$$

Simultaneously *in situ* water samples were analysed for chlorophyll concentrations using the acetone extract method.

The computed chlorophyll concentrations were evaluated using the pigment index, which is a ratio of the reflectances or radiances at 2 wavelengths. In this study, ratios of reflectances at 445 to 550 nm wavelengths were taken for pigment index evaluation, which signifies chlorophyll absorption maximum and minimum respectively⁵.

Results and Discussion

Spacecraft or aircraft remote sensing in the visible region is primarily based on measurements of radiance values obtained from desired sources. The chlorophyll retrieval algorithms are developed taking into consideration the ratios of radiance values of different channels which in turn give the pigment index. The ratio of the radiances considered in 2 wavelengths is proportional to the ratio of the reflectances at the respective wavelength⁶. In this study pigment index is obtained after considering the reflectance ratios at 445 to 550 nm wavelength.

The attenuation coefficient is a combined effect of absorption and backscattering coefficients. Since absorption coefficient plays a dominant role

when compared to backscattering coefficient, attenuation coefficient can be equated to absorption⁵. In this study the optical properties have been plotted considering the above assumption.

Based on the above discussions the reflectance, absorbance and backscattering coefficients versus wavelength (λ) plots are presented in Figs 2, 3 and 4 respectively, for the 3 stations considered for the present study. In all the figures the solid

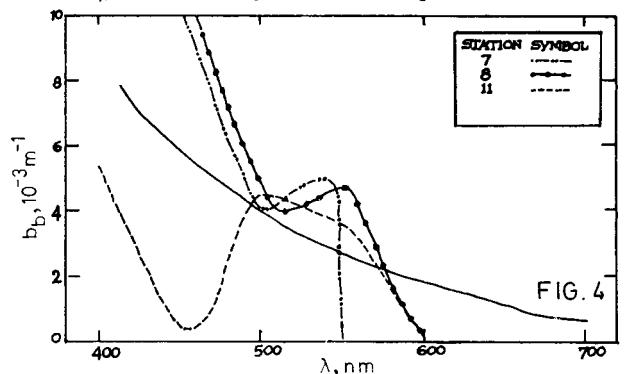
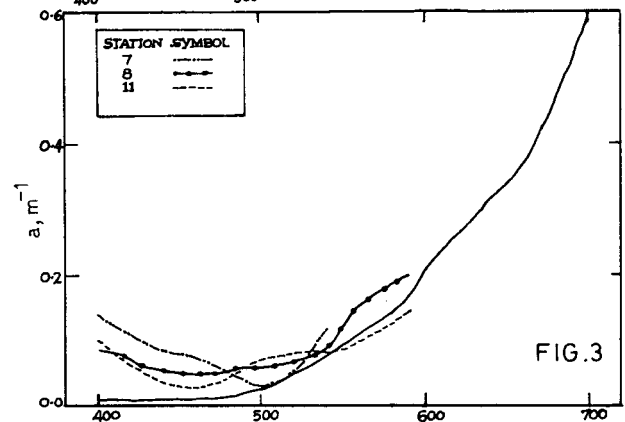
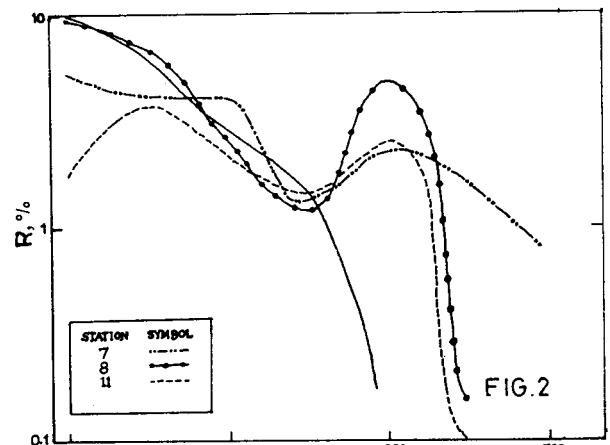


Fig. 2—Observed spectra of reflectance $R\%$ [Solid line represents pure seawater]

Fig. 3—Absorption coefficient (a) [Solid line represents pure seawater]

Fig. 4—Backscattering coefficient (b_b) [Solid line represents scattering due to pure seawater]

lines represent the respective parameters for pure seawater. Some of the stations have not been considered for the present study due to chlorophyll concentrations being below detectable levels and instrumental noise in Quanta Spectrometer.

The reflectance curve plotted for the 3 stations indicate that the reflectance value decreases in shorter wavelength region i.e. 400 to 450 nm, with increase in chlorophyll concentration. The variation in reflectance at 550 nm is not very significant though it increases with increase in chlorophyll concentration. At 600 nm a reflectance peak is observed in almost all stations, with st 8 showing the maximum reflectance. This peak is independent of the chlorophyll concentration and cannot be attributed to any single factor governing the colour of the ocean. This may be due to instrumental noise. However, in nature, both the concentrations of particles and absorbers change and very complicated spectra are recorded with an almost infinite variety of shapes and amplitudes³. The absorption coefficient versus wavelength shows that absorption coefficient in shorter wavelength is higher than the clear ocean waters. This may be attributed to the presence of chlorophyll, suspended and dissolved substances. The absorption coefficients in the shorter wavelength cannot be explained due to very low concentrations of chlorophyll, which is characteristic of open ocean (case 1 waters). However, in general the absorption coefficient after 500 nm is found to be increasing towards longer wavelength region. This agrees well with the open ocean absorption coefficient curve.

The backscattering coefficient curve shows that backscattering is higher in the shorter wavelength region and decreases towards longer wavelength region. However, backscattering is minimum at 450 nm for st 11 which can be attributed to relatively higher concentration of chlorophyll and yellow substance. The backscattering decreases with increasing wavelengths in case 1 waters.

Pigment index—Three modes for computation of pigments index and 2 types of empirical equations have been developed during the ocean color study in the Arabian Sea⁵ (Table 1). In the present study only Mode 1 could be tested due to non-availability of optical data in the 750 nm region. Taking pigment index (PI) of Mode 1, empirical equations type 1 and 2 were tested to evaluate chlorophyll concentration. The coefficients of least square analysis of A, B of type 1 and C, D of type 2 are given in the Table 1. Based on the above algorithms, chlorophyll concentrations have been calculated and presented in Table 2. In com-

Table 1—Coefficient of Least Square Analysis

Mode	Pigment Index (PI)
1	$L(445)/L(550)$
2	$L(445)+L(670)/L(550)+L(750)$
3	$L(445)+L(670)/L(550)-(750)$
Type	Co-efficients
1	Chl = A PI ^B A = 0.66, B = -2.43
2	Chl = Cexp (D.PI) C = 14.18, D = -2.9

Table 2—Computed Chlorophyll Concentrations

St No	PI Mode 1	Calculated chl. conc. mg.m ⁻³		Observed chl. conc. mg.m ⁻³
		Type 1	Type 2	
7	3.04	0.04	0.002	0.03
8	5.68	0.01	0.0	0.02
11	2.59	0.1	0.008	0.1

parison with observed chlorophyll concentrations in the respective stations, Mode 1 type 1 was found to be the best fit.

Based on the results obtained it can be concluded that Mode 1 and type 1 can be applied successfully for chlorophyll evaluation from remotely sensed data, especially for open ocean waters which are generally low in chlorophyll concentration. Further, until all possible parameters are considered for bio-optical assessment' it may be difficult to arrive at a conclusion. Paucity of good quality optical data hampers the ability to relate it to the pigment concentration and other substances which contribute to the bio-optical nature of the waters taken for study.

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