

Use of IRS-P4 Ocean Color Monitor (OCM) images for tracing the red edge of the terrestrial vegetation reflectance spectrum

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Abstract. A methodology is put forward to retrieve the red edge for terrestrial vegetated regions of IRS P4 Ocean Color Monitor (OCM) images. The objective is to utilize land-related portions of the archived OCM images that contain a significant amount of digital information on land cover. OCM band data were simulated from spectroradiometric reflectance of fresh green leaves and hyperspectral reflectance of vegetated regions derived from EO-1 Hyperion images. The red edge recovered from these model data using numerical techniques of Lagrange interpolation and inverted Gaussian was compared with the original one and reasonable accuracy was obtained. The technique was then applied to the actual red and near-infrared bands of OCM images, and red edge reflectance curves were computed for evergreen, deciduous and mangrove forest regions of the images for winter and spring seasons. Consistent results were obtained for seasonal changes, and vegetated and non-vegetated areas could be distinguished.

1. Introduction

The ocean color monitor (OCM) sensor on board the Indian remote sensing satellite IRS P4 was launched in 1999 as an ocean observing system [1]. The sea surface images procured by OCM served the purpose of various oceanographic studies, such as ocean colour measurement [2], assessment of marine chlorophyll distribution [3], detection of reef banks [4] and coastal environmental changes [5]. At the same time the OCM images have recorded a significant amount of land cover data. Much of that huge collection has been unexplored for more than a decade. The present work suggests further utilization of the archived OCM images and presents a method for determining the red edge of the reflectance spectra of terrestrial vegetated regions in these images. The red edge represents the sharp increase in vegetation reflectance from red to near-infrared wavelength [6]; it is useful for assessing chlorophyll content [7-8], stressed conditions [9] and other vegetation parameters [10], as well as for land use classification [11] and land cover mapping [12]. A number of algorithms have been put forward for estimating the red edge position [13, 14]. However, it appears that use of OCM image in estimating the red edge has not been reported earlier. Since the spatial resolution of OCM image is of the order of 360 m, it is suitable for observing large vegetated land areas, such as forests.

The present work puts forward a methodology to assess the red edge of forested regions imaged by the OCM. Two standard numerical techniques for red edge determination, namely inverted Gaussian [12, 14] and Lagrange interpolation [13, 14], were tested for suitability with OCM bands. Two



independent sets of spectral data, namely spectroradiometric reflectance of fresh green leaves and hyperspectral reflectance of vegetated regions derived from Hyperion satellite images, were used to generate model OCM wavebands. Both spectral data sets contained the actual red edge; the red edges retrieved from the simulated bands using the above-mentioned techniques agreed well with the actual spectral range. Then the red edges were determined with actual OCM bands using the inverted Gaussian technique for evergreen, deciduous and mangrove forest regions. The method can detect seasonal change and discriminate vegetated and non-vegetated regions.

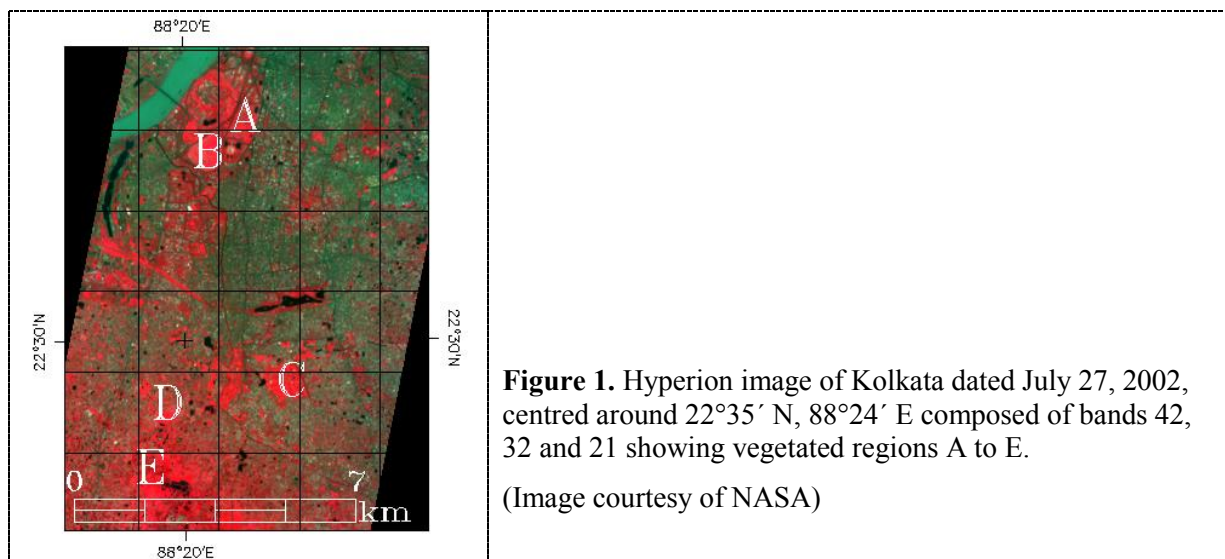


Table-1. Technical specifications for the IRS P4 OCM and the EO-1 Hyperion payloads.

OCM pushbroom CCD sensor, spatial resolution 360 m, revisit 2 days, altitude 720 km			Relevant Hyperion bands closest to OCM bands (X means not relevant)		
Spectral Bands	Wavelength range (nm)	Assumed band centre (nm)	Spectral band	Specified central wavelength (nm)	Assumed band centre (nm)
B1	404 – 424	414	X	X	X
B2	432 – 452	441	X	X	X
B3	479 – 499	486	X	X	X
B4	502 – 522	511	X	X	X
B5	547 – 567	556	X	X	X
B6	660 – 680	669	B31 B32 B33	660.85 671.02 681.20	671
B7	748 – 788	769	B39 B40 B41 B42 B43	742.25 752.43 762.60 772.78 782.95	763
B8	847 – 887	865	B49 B50 B51 B52 B53	844.00 854.18 864.35 874.53 884.70	864

2. Materials and method

The work contains both spectroradiometric measurement and analysis of OCM and Hyperion satellite images (table 1). Ocean Color Monitor (OCM) image procured by Indian Remote Sensing Satellite IRS P4 is the actual topic of investigation. The EO-1 Hyperion image was used as a reference for generating model data to test the suitability of the proposed method. The spectroradiometric reflectance measurement served the same purpose, as mentioned below.

2.1. Generating model data

The reflected radiation from fresh green pumpkin leaves were measured under solar illumination at solar noon with an Analytical Spectral Devices (ASD) FieldSpec spectroradiometer. The measurements were collected throughout the ultraviolet-visible-near infrared (350-900 nm) region with 1 nm resolution. The reflectance spectra of ten individual leaves were averaged for each wavelength so as to represent a typical green leaf reflectance spectrum over the eight wavebands corresponding to those of OCM so as to simulate the reflectance obtained from OCM images.

Another set of model wavebands was generated from the EO-1 Hyperion hyperspectral image of Kolkata (around 22°35' N, 88°24' E) using ENVI 4.7 image processing software. The vegetated regions were identified by using the Minimum Noise Fraction (MNF) transform [15] and Pixel Purity Index (PPI) [16] techniques and by cross-checking with normalized difference vegetation index (NDVI) images. Five such vegetated regions of the image were randomly selected; their locations A, B, C, D and E are indicated in figure 1. The reflectance spectra throughout the visible and near-infrared wavebands were derived from digital number (DN) values by using a standard method [17] for more than one hundred pixels of each region and averaged for the vegetated regions so as to represent a typical vegetation reflectance spectrum obtained from the Hyperion image. The typical spectrum was then averaged over the available wavebands closest to the OCM bands (table 1).

2.2. Mathematical formulae

Since only three OCM wavebands are available relevant to the red edge position, namely B6, B7 and B8, a Lagrange interpolation of second order given by

$$R(\lambda) = \sum_{m=1}^3 R(\lambda_m) \prod_{\substack{n=1 \\ n \neq m}}^3 \frac{\lambda - \lambda_n}{\lambda_m - \lambda_n} \quad (1)$$

was implemented to determine the reflectance $R(\lambda)$ corresponding to any intermediate wavelength λ , where $R(\lambda_m)$ represents the reflectance corresponding to the central wavelength (λ_m) of the given m^{th} waveband (equation 1).

Linear fitting of the red edge was obtained by using equation (2) where λ_r and λ_{nir} represent the central wavelength for red and near-infrared band, respectively, and R_r and R_{nir} indicate the corresponding reflectance values.

$$R(\lambda) = \frac{\lambda(R_{nir} - R_r) + \lambda_{nir}R_r - \lambda_rR_{nir}}{\lambda_{nir} - \lambda_r} \quad (2)$$

Here $R(\lambda)$ is the reflectance for any intermediate wavelength λ between λ_r and λ_{nir} .

The inverted Gaussian formula for determining the reflectance $R(\lambda)$ corresponding to any intermediate wavelength λ is given in equation (3) by

$$R(\lambda) = R_{nir} - (R_{nir} - R_r) \exp[-((\lambda_r - \lambda)/2\sigma)^2] \quad (3)$$

where R_r is the low reflectance at the central wavelength (λ_r) of the red waveband, R_{nir} is the high reflectance at the central wavelength of the near-infrared waveband just after red, and σ is the Gaussian shape parameter determining the sharpness of bending of the curve. For higher values of σ , the curve is flat.

2.3. OCM data extraction

Figure 2 contains OCM images of the same region for two subsequent seasons, namely winter (15 December, 2006) and spring (31 March, 2007), shown in the left and the right panel, respectively. The vegetated and non-vegetated regions were investigated for the changes in red edge due to the seasonal change in vegetation vigour. Several vegetated regions were identified for both seasons using the same method that was mentioned earlier. The DN values were averaged over more than 300 pixels of each region. The average reflectance for each region in each waveband was calculated as

$$R(\lambda_n) = \frac{\overline{DN_n} \cdot g(\lambda_n)}{DN_{\max} \cdot E(\lambda_n)} \quad (4)$$

where $\overline{DN_n}$ is the average DN value for the n^{th} waveband of the selected vegetated zone, $DN_{\max} = 65535$ is the upper limit of 16 bit, $g(\lambda_n)$ is the sensor gain for the n^{th} waveband, and $E(\lambda_n)$ is the average extraterrestrial radiance over that band (equation 4).

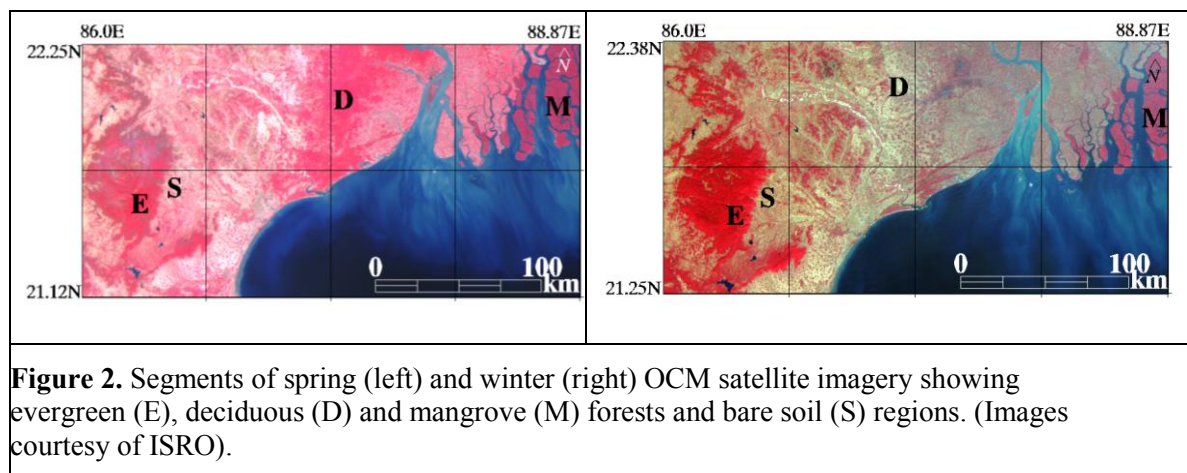


Figure 2. Segments of spring (left) and winter (right) OCM satellite imagery showing evergreen (E), deciduous (D) and mangrove (M) forests and bare soil (S) regions. (Images courtesy of ISRO).

3. Results and Discussion

Figure 3 shows the spectroradiometric reflectance spectra of some randomly measured green leaves. The mean of such reflectance spectra was averaged over the eight wavebands corresponding to those of the OCM, as indicated. Figure 4 illustrates the fitting of such simulated band for the red edge with the second order Lagrange interpolation (equation 1). The fitted portion (dashed line) of the red edge is of interest; other regions are not considered. The fitted portion is compared with the linear joining (dotted line) of red and near-infrared reflectance data points using equation (2). The comparison with the actual red edge (solid line) of the reflectance spectrum suggest that the linear and second order polynomial fittings with the OCM bands can approach the actual condition almost to the same extent. The percentage deviation of the fitted curve from the actual red edge curve is calculated from the ratio of the difference of areas under the two curves to the area under the original curve. In the ideal case of full congruence of two curves, difference is zero, and hence the percentage deviation is zero. The percentage deviations for both types of fitting are given in table 2.

The average reflectance spectrum of the vegetated regions of the Hyperion image is shown in figure 5. The positions of the atmospheric oxygen absorption band (O_2 -A) and water vapour absorption band (H_2O) are indicated. It also displays the discrete reflectance values in red and near-infrared wavelengths, indicated by black dots, obtained by averaging over the available wavebands closest (table 1) to the OCM bands. It may be noted that the average reflectance for band No. 7 is remarkably smaller than that of band No. 8 because of the strong O_2 -A absorption at around 760 nm. The actual OCM band (B7) also contains that absorption band and suffers from such decrease in

reflectance so that the Hyperion model dataset is closer to the actual situation than that obtained from leaf reflectance. Similar to Figure 4, the red edge was fitted with Lagrange interpolation of second order (dashed line) using equation (1). The fitted portion of only the red edge is of interest, which is compared with linear joining (dotted line) of red and near-infrared reflectance data points using equation (2). The linear and second order polynomial fittings approach the actual red edge (solid line) up to almost the same extent and the percentage deviations are mentioned in table 2.

The inverted Gaussian formula of equation (3) was applied to the fitting for red edge with discrete reflectance values obtained from both ground reflectance of green leaf and Hyperion-derived reflectance of vegetation, as illustrated in figure 6 and figure 7, respectively. In both the cases, only the segment of the Gaussian curve corresponding to the red edge was considered. It is interesting to note that although the red edge of vegetation reflectance in figure 6 and that in figure 7 have completely different origin and have different reflectance values, both can be fitted reasonably well with the same shape of inverted Gaussian having a value of σ around 25. The inverted Gaussian fitting yields generally better result than Lagrangian interpolation for red edge retracing with OCM bands (table 2). Therefore, this value of σ was used in the analysis of the actual OCM data (figure 8).

Figures 8 (a), (b) and (c) illustrate the fitting for red edge with inverted Gaussian (equation 3) using the red and near-infrared reflectance values for evergreen, deciduous and mangrove forested regions, respectively. The reflectance values for two different seasons are shown; the fitting curves in all the three cases are for the spring season. The deviation of reflectance in winter is noticeable. These plots

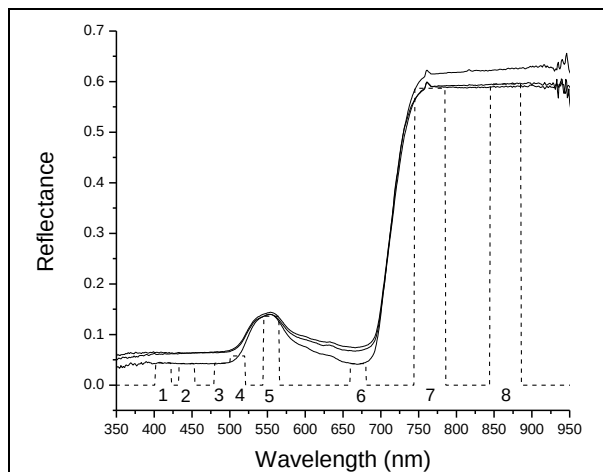


Figure 3. Measured reflectance spectra of green leaves (solid lines) compared with the ranges of OCM bands 1 to 8 (dashed lines).

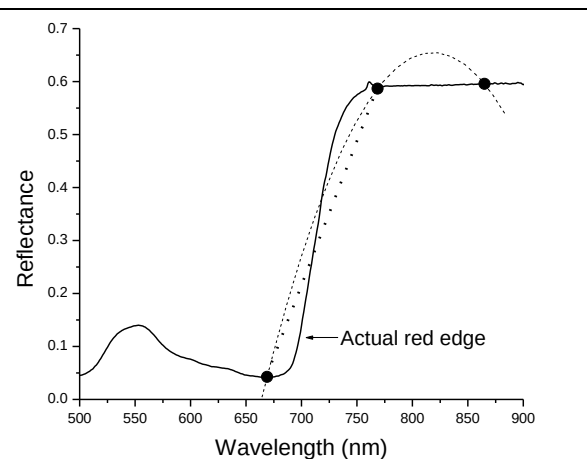


Figure 4. Average reflectance spectra of green leaf (solid line), discrete reflectance values obtained by averaging over the wavelength ranges similar to OCM bands (black dots) and red edge fitted with 2nd order Lagrange interpolation (dashed line), and linear joining (dotted line).

Table 2. Average percentage deviation from actual red edge while fitting with Lagrange interpolation and inverted Gaussian curve.

Red edge fitting technique	Percentage deviation from actual red edge	
	Spectroradiometric data (figure 4)	Hyperion data (figure 5)
Second order polynomial	5.48	22.5
Linear	7.47	18.16
Inverted Gaussian ($\sigma = 25$)	1.79	12.3

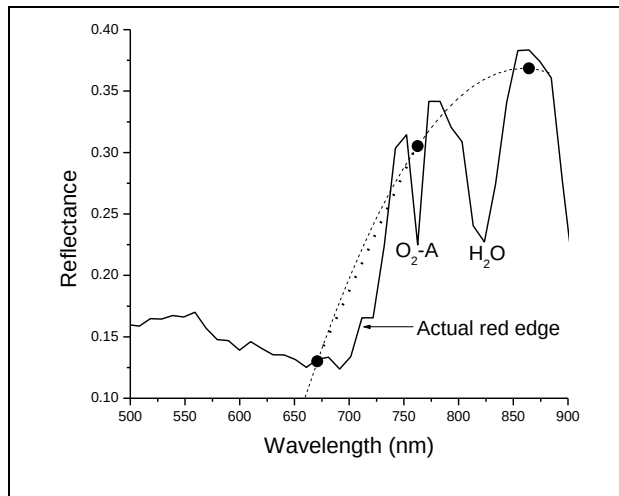


Figure 5. Average reflectance spectrum for vegetated regions derived from Hyperion imagery (solid line), discrete reflectance values obtained by averaging over the available wavebands closest to OCM bands (black dots), and red edge fitted with 2nd order Lagrange interpolation (dashed line) and linear joining (dotted line).

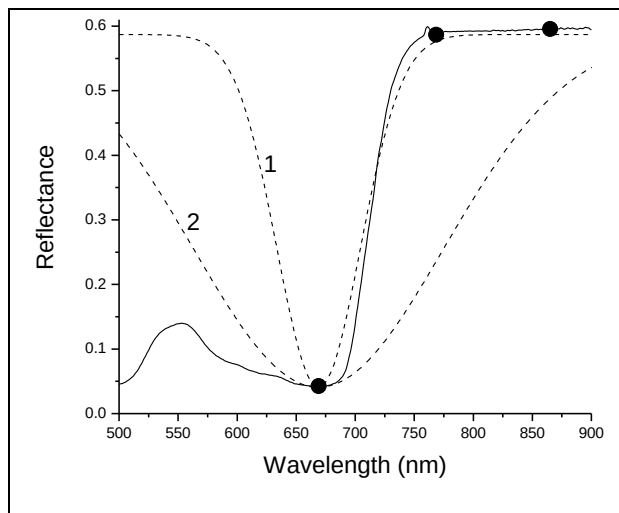


Figure 6. Reflectance spectrum of green leaf (solid line) and fitting for red edge of the discrete reflectance values (black dots) obtained by averaging over the OCM bands with inverted Gaussian curves (dashed lines, $\sigma = 25$ for curve 1 and $\sigma = 75$ for curve 2).

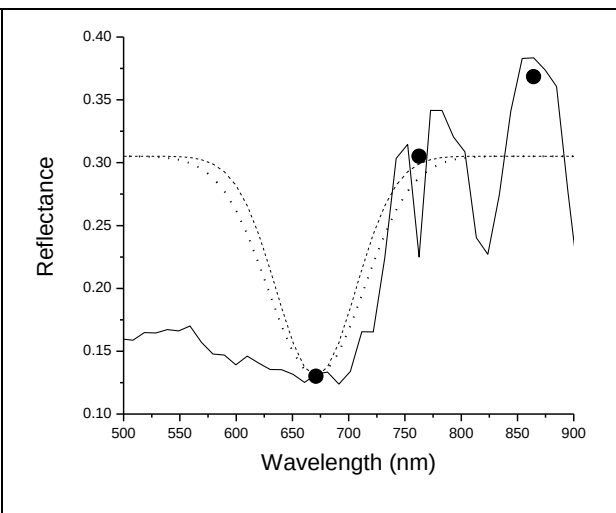


Figure 7. Reflectance spectra derived from Hyperion imagery (solid line) and fitting for the red edge of the discrete reflectance values (black dots) obtained by averaging over the available wavebands closest to OCM bands with inverted Gaussian curves ($\sigma = 25$, dashed line; and $\sigma = 30$, dotted line), obtained by averaging over the available wavebands closest to the OCM bands.

actually demonstrate the distinction between vegetated and non-vegetated cases, i.e., the presence and absence of red edge. Figure 8(a) is the case of evergreen forest, where the green vegetation persists both in spring and winter seasons. Consequently, the reflectance values do not deviate much, and the fitted curve for spring is almost acceptable for the winter case as well. The situation is remarkably different in the case of deciduous and mangrove forests where reflectance of green vegetation is diminished during winter. It is apparent from both figures 8 (b) and (c) that the curve fitting for spring deviates much from the reflectance values in winter when depletion, or desiccation, of vegetation occurs and the red edge disappears. This is illustrated in figure 8(d), which compares the red and near-infrared reflectance for vegetated and adjacent non-vegetated regions in spring. The inverted Gaussian

fitting of the reflectance of the vegetated region (having red edge) is far away from the reflectance values of the non-vegetated region where no red edge exists.

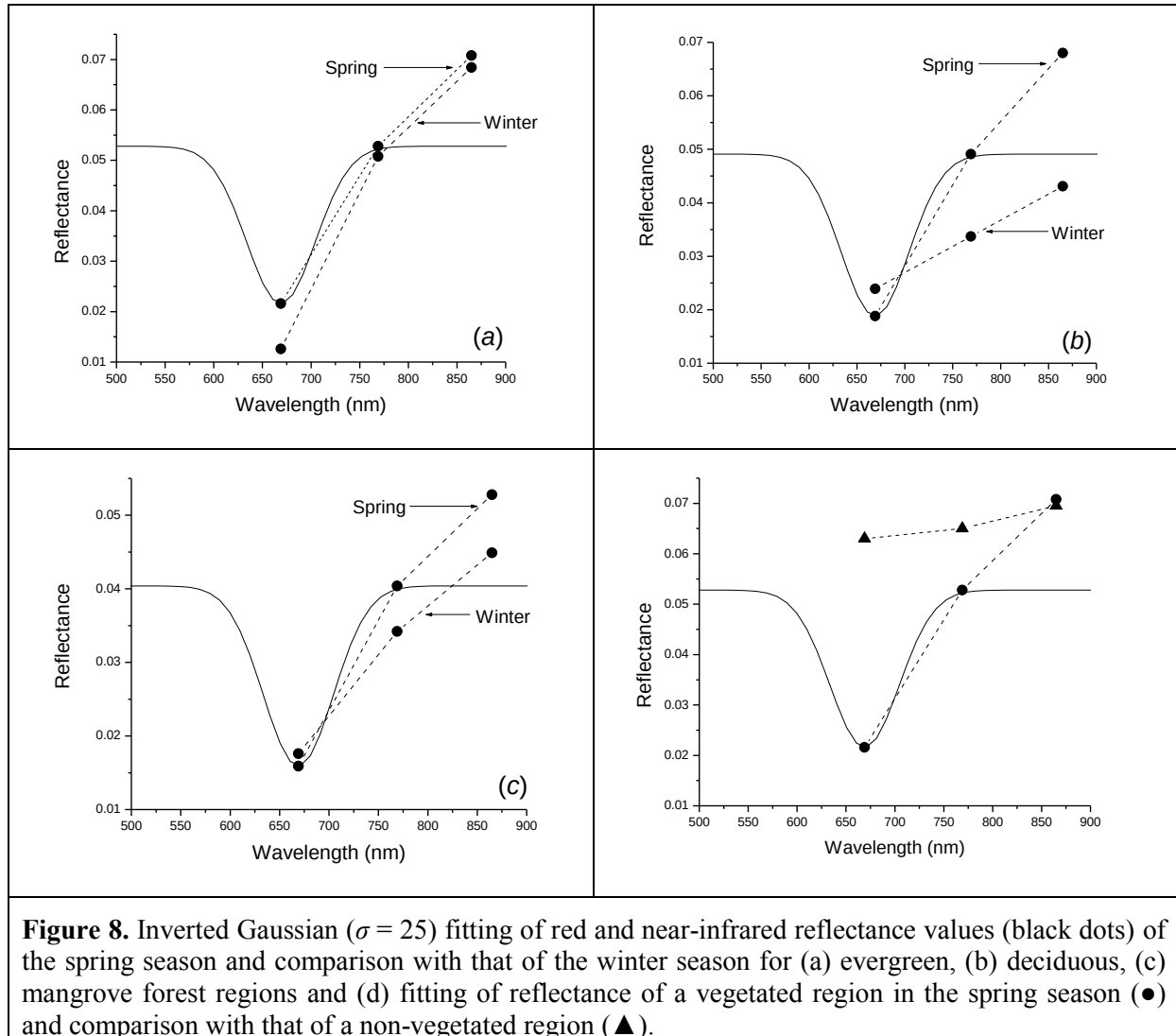


Figure 8. Inverted Gaussian ($\sigma = 25$) fitting of red and near-infrared reflectance values (black dots) of the spring season and comparison with that of the winter season for (a) evergreen, (b) deciduous, (c) mangrove forest regions and (d) fitting of reflectance of a vegetated region in the spring season (●) and comparison with that of a non-vegetated region (▲).

Table 3. Comparison of NDVI values for vegetated regions with that obtained from the inverted Gaussian fitted curve				
Season	Fitted	Evergreen	Deciduous	Mangrove
Spring	0.415	0.419	0.446	0.435
Winter	0.598	0.602	0.170	0.320

The deviation from the red edge is also quantified in terms of normalized difference vegetation index (NDVI), defined as $(R_{nir} - R_r)/(R_{nir} + R_r)$. The NDVI values calculated from the red and near-infrared reflectance of the OCM bands for different vegetated regions are compared with that calculated from the fitted reflectance, as summarized in table 3. It is apparent that the evergreen region matches well for both the seasons, whereas the other two deviate much in winter when the green vegetation is much less in evidence. Thus the red edge for green vegetation with full vigour can be

recovered with reasonable accuracy by fitting the red and near-infrared reflectance of the OCM bands with Lagrange interpolation and inverted Gaussian techniques.

4. Conclusion

A methodology is proposed for tracing the red edge of the reflectance spectrum of terrestrial vegetated areas obtained from IRS-P4 OCM imagery. The objective is to utilize the land cover portions of the archived OCM images originally meant for oceanic observations. In order to verify the applicability of two standard fitting techniques –Lagrange interpolation and inverted Gaussian in the present case– two independent sets of model OCM data were simulated, one from spectroradiometric reflectance of fresh green leaves and the other from hyperspectral reflectance of vegetated areas derived from Hyperion imagery. Both contained the actual red edge, and reasonable accuracy was obtained in both cases when compared with the red edge recovered from the model data. Thus, it was inferred that the red edge for healthy green terrestrial vegetation can be reliably retrieved from the red and near-infrared OCM bands. The other part of the investigation was the distinction between vegetated and non-vegetated areas. Fitting for red edge with inverted Gaussian using OCM red and near-infrared reflectance values for evergreen forest areas in spring were found to approach that recorded in winter. In the case of deciduous and mangrove forest regions, where depletion of green vegetation takes place in winter, the curve fitting for the spring season deviated much from the winter reflectance values. A similar deviation was found for non-vegetated regions where no red edge exists. Thus, the methodology is sensitive to the presence and absence of red edge.

5. References

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