

# Cross Calibration Of IRS-P4 OCM Satellite Sensor

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## ABSTRACT

We present here the cross calibration of ocean color satellite sensor, IRS-P4 OCM using the radiative transfer code, with SeaWiFS as a reference. Since the bands of IRS-P4 OCM are identical to those of SeaWiFS and SeaWiFS has been continuously and rigorously calibrated, SeaWiFS is used as a reference for the cross calibration of IRS-P4 OCM. Calibrations coefficients for each band of IRS-P4 OCM are derived by comparing the actual radiances detected by the satellites at top of the atmosphere and those obtained from the radiative transfer simulations of IRS-P4 OCM and SeaWiFS. The chlorophyll a values derived using the calibrated IRS-P4 OCM are found to be comparable with those derived from SeaWiFS and in close agreement with the measured values. The relative root mean square error (RRMSE) between measured chlorophyll a and those derived from the satellites are found to be 0.28 and 0.26 for SeaWiFS and IRS-P4 OCM respectively.

**Keywords:** OCM, IRS-P4, cross-calibration, vicarious calibration, 6S, SeaWiFS

## 1. INTRODUCTION

We report here the results of the cross calibration carried-out of IRS-P4 OCM (Ocean Color Monitor) sensor using radiative transfer model with SeaWiFS as a reference satellite sensor.

IRS-P4 Ocean Color Monitor, IRS-P4 OCM is the first satellite sensor developed and launched by India for ocean color applications on 26 May 1999<sup>1</sup>. The system is devoid of any supplementary method for calibration, such as sun or moon and depends only on the internal source. Sea-viewing Wide Field-of-view Sensor, SeaWiFS was launched by NASA and Orbital Science Corporation, USA. (<http://seawifs.gsfc.nasa.gov>) on 1 August 1997, more than a year prior to the launch of IRS-P4 OCM. The characteristics of the satellite sensors IRS-P4 OCM and SeaWiFS are given in Table 1. Since SeaWiFS had bands similar to IRS-P4 OCM and its calibrations were carried-out at regular intervals, it was decided to use SeaWiFS for the vicarious calibration of the IRS-P4 OCM. SeaWiFS has a much longer and rigorous calibration history<sup>2</sup> and it is continuously monitored for variations in all channels using direct method<sup>3</sup> and using well calibrated instruments at MOBY buoy site close to Hawaii<sup>4, 5</sup>. In absence of any ground facilities such as buoy, an inter-comparison of satellite sensor is often the best choice for calibrating a satellite sensor. Ocean color satellite sensor IRS-P3 MOS was calibrated using SeaWiFS as reference<sup>6</sup>. In an earlier study of deriving calibration coefficients for IRS-P4 OCM, using SeaWiFS, data obtained for the satellites passes were used, when they both had very close ground track for the day, with minimum time differences between their satellite passes. The radiances of co-located pixels were compared to derive calibration coefficients of all bands of OCM with reference to SeaWiFS<sup>7, 8</sup>.

In this method we have used the radiative transfer code 6S (Second Simulation Of The Satellite Signal In The Solar Spectrum)<sup>9</sup>, that simulate the satellite sensors IRS-P4 OCM and SeaWiFS to provide TOA radiances for all bands. We have compared the derived product, chlorophyll a obtained from IRS-P4 OCM after applying the calibration, with those derived from SeaWiFS and the measured values in the Arabian Sea.

Table 1. Sensor Specifications of satellite sensors, SeaWiFS and IRS-PR OCM

Parameters	OCM	SeaWiFS
Band 1	404-424 nm	402 – 422 nm
Band 2	432-452	433- 453
Band 3	479-499	480-500
Band 4	502-522	500-520
Band 5	547-567	545-565
Band 6	660-680	600-680
Band 7	748-788	745-785
Band 8	847-887	845-885
Quantization bits	12	10
Sensor type	Pushbroom linear array CCD	Whiskbroom scan mirrors
Orbit Type	Sun synchronous	Sun synchronous
Altitude	720 Km	705 Km
Equator Crossing	Noon +20 min, Descending	Noon +20 min, Descending
Tilt	Along track, +20,0,20	Along track +20, 0 -20
Swath	1420 Km	2801 Km
Spatial Resolution	0.36 Km along track 0.236 Km cross track	1.1 Km
Revisit	2 days	1 Day
Calibration	Internal Lamp	Sun, Moon

### 1.1 6S

The radiative transfer model 6S (version 4.1) is used to derive the satellite signals in the spectral range 0.25 to 4.0  $\mu\text{m}$  for a cloudless atmosphere. This model derives the satellite signal received by the sensor, known as top of the atmosphere (TOA) due to the scattering and absorption of solar light in the atmosphere and the target on the ground. The 6S has been used for the cross-calibration of sensor MVIRS on board of the FY-1D meteorological satellite using MODIS as a reference sensor<sup>10</sup>, Meteosat radiometer solar channel<sup>11</sup> and GLI onboard the ADEOS-2 with multiple satellite sensors<sup>12</sup>.

## 2. METHOD

We determine the calibrations coefficients for IRS-P4 OCM in two processes:

1. Determine the linear relationship of the TOA radiance of all bands of SeaWiFS retrieved for the station location and the TOA radiance determined from 6S. These allow admeasuring the SeaWiFS equivalent radiances for the corresponding radiances calculated by the simulation using 6S.

2. Determine the IRS-P4 OCM TOA radiance for the same stations using 6S. Now using the relationship determined from above, these radiance values obtained using 6S are used to determine the radiance equivalent to the SeaWiFS. These radiance values are now assumed to be the precise radiance measured from a calibrated IRS-P4 OCM sensor. Now these radiance values can be used to arrive at linear relationships for all bands for any measured TOA radiance by the IRS-P4 OCM bands.

## 2.1 Modifications in the 6S code

We have modified the 6S code as indicated below and added additional routines to cater to SeaWiFS and IRS-P4 OCM and to use the in-situ measured water leaving radiance values.

The additional routines allow calculating the band-averaged values for SeaWiFS and IRS-P4 OCM using the spectral response functions of SeaWiFS ([http://oceancolor.gsfc.nasa.gov/DOC/RSR/SeaWiFS\\_RSR.txt](http://oceancolor.gsfc.nasa.gov/DOC/RSR/SeaWiFS_RSR.txt)) and IRS-P4 OCM<sup>13</sup>. The spectral response functions of the SeaWiFS and IRS-P4 OCM are used to calculate  $F_0(\lambda)$ , the extra terrestrial solar irradiance values for the bands. The spectral values of  $F_0(\lambda)$  which were till recently used from Neckle and Labs<sup>14</sup>, are replaced by the values from Thuillier<sup>15</sup>.

The Bi-directional Reflectance Distribution Function (BRDF) determines the variations of radiance as a function of illumination and viewing geometry<sup>16</sup>. We have modified the routine to calculate the BRDF reflectance for the ocean, by replacing the water leaving reflectance that was calculated based on bio-optical model in the 6S, with the actual measured spectral values.

## 2.2 6S Inputs

The data used for the simulation of the satellite signals were measured during three cruises in the Arabian Sea for the specific task of the validation experiment of IRS-P4 OCM satellite sensor. These cruises were on the research vessel; *ORV Sagar Kanya* and they are SK-149C (15 to 29 November, 1999), SK-152 (30 March to 12 April, 2000) and SK-171 (3 to 17 November, 2001). The cruise stations included varied water types with turbid and productive coastal stations to deep oceanic oligotrophic sites and also locations with *Trichodesmium spp.* and diatom blooms. The measured parameters that were used in 6S were water-leaving reflectance obtained from the data measured by the radiometer, processed by the proprietary software of the instrument ProSoft. (<http://www.satlantic.com>) and f/Q correction applied<sup>17</sup>, the spectral values of aerosol optical depths (AOD) measured at the stations using sunphotometer MICROTOPS-II and interpolated to obtain the AOD at 0.550  $\mu\text{m}$ . (<http://www.solar.com>), the vector average of the wind for the period 1000 to 1400 hrs local time provide the wind speed and wind direction and salinity from CTD casts at the cruise stations.

The SeaWiFS data acquired from the HRPT station HGOA at National Institute of Oceanography, Goa are processed to LIB using SeaDAS 4.8 to determine the top of the radiance (TOA) in all the bands. The IRS-P4 OCM is processed using the in-house developed module integrated in SeaDAS to derive the TOA radiances using the satellite data acquired from National Remote Sensing Agency, Hyderabad. Since the pixel resolutions were not compatible, for comparison with the SeaWiFS, the average of 3X3 pixel radiance were used for IRS-P4 OCM.

### 3. RESULTS

The TOA radiances of SeaWiFS for all bands determined using 6S are found to be well correlated with the TOA radiances extracted from the L1B data of SeaWiFS. See Table 2 below. These comparisons provide relationships for all bands, to determine the equivalent radiance of SeaWiFS, for TOA radiance derived from 6S. These relationships can now be used to calibrate any satellite sensor with similar bands, by calculating the TOA radiance from 6S for that satellite sensor.

Table 2. Relationship between 6S derived TOA radiance derived from the L1B data of SeaWiFS.  $Y = A + B \cdot X$ , where  $Y$  = TOA radiance of SeaWiFS and  $X$  = TOA radiance calculated by 6S.

Band	A	B
1	1.489	0.8179
2	1.053	0.8312
3	0.829	0.7930
4	0.478	0.8237
5	0.215	0.8201
6	0.157	0.7164
7	0.058	0.6591
8	0.047	0.6110

#### 3.1 OCM Calibration coefficients

We determined the TOA for the IRS-P4 OCM bands using 6S code. Using earlier relationship between 6S and SeaWiFS, these TOA radiances from 6S were converted to equivalent radiances observed by SeaWiFS sensor. These are considered to be the exact radiances as observed by a calibrated IRS-P4 sensor. In order to determine the calibration coefficients, these corrected radiances were related to the actual radiance values as observed by the IRS-P4 OCM sensor. See Fig. 1. These calibration coefficients for the calibration of IRS-P4 OCM are given in Table 3.

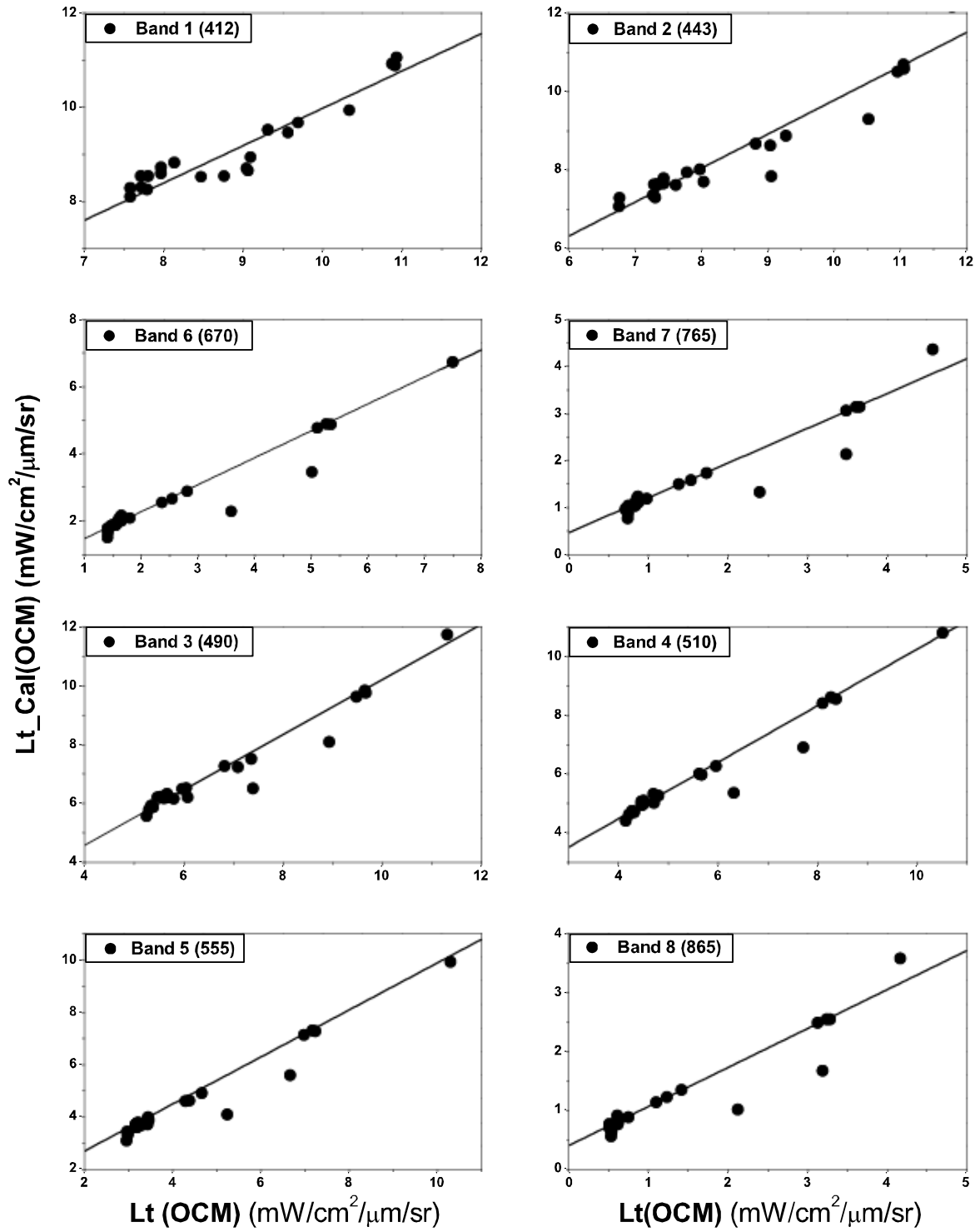


Fig. 1. Calibration coefficients derived from the relationships between corrected radiance and actual radiance values for IRS-P4 OCM

The error analysis of TOA radiances obtained applying the calibration coefficients listed by Chauhan<sup>8</sup> and those obtained here using 6S are given in Table 4. The chlorophyll a were derived using SeaDAS from the SeaWiFS data and the calibrated IRS-P4 OCM data. The SeaWiFS data were analyzed using SeaDAS 4.8 (<http://seadas.gsfc.nasa.gov>), while IRS-P4OCM data are processed using an in-house developed software module and integrated in SeaDAS. While processing these satellite data in SeaDAS, meteorological and ozone data of the day are used. (<ftp://oceans.gsfc.nasa.gov>). All options were kept the same while processing the data from both the satellites in SeaDAS. These chlorophyll a values from SeaWiFS and IRS-P4 OCM were compared with the measured values of chlorophyll a. The values of chlorophyll a from SeaWiFS and the calibrated IRS-P4 OCM are found to be comparable as shown in Fig. 2. The chlorophyll a derived from SeaWiFS and IRS-P4 OCM and the measured values at various cruise stations are shown in Fig. 3. The chlorophyll a derived from SeaWiFS are found to be overestimated (mean value of ~ 50%), which is in agreement with the earlier studies in the Arabian Sea<sup>18</sup>, while it is marginally overestimated for IRS-P4 OCM. The mean percentage absolute deviations from the measured values are 50% for SeaWiFS and 37% for IRS-P4 OCM. For comparison of chlorophyll a between the satellite derived and the measured values, the root mean square error (RMSE) obtained are 0.13 for SeaWiFS and 0.14 for IRS-P4 OCM and the relative root mean square error (RRMSE) are found to be 0.28 and 0.26 for SeaWiFS and IRS-P4 OCM respectively.

Table 3. Calibration coefficients to determine the corrected TOA radiance for IRS-P4 OCM.

$$L_t\_Corrected(\lambda) = Gain(\lambda) * L_t(\lambda) + Offset(\lambda)$$

Band	Offset	Gain	r2
1	2.071	0.7910	0.86
2	1.148	0.8634	0.92
3	0.826	0.9378	0.95
4	0.648	0.9581	0.95
5	0.787	0.8974	0.95
6	0.671	0.8031	0.93
7	0.466	0.7399	0.90
8	0.408	0.6611	0.89

Table 4. Root mean square error (RMSE) and relative root mean square error (RRMSE) for the vicarious calibration methods.

Band	RMSE		RRMSE	
	Chauhan <sup>8</sup>	This Method	Chauhan <sup>8</sup>	This Method
1	0.70	0.42	0.077	0.041
2	0.51	0.40	0.063	0.046
3	0.62	0.39	0.094	0.055
4	0.49	0.39	0.090	0.066
5	0.50	0.40	0.119	0.090
6	0.59	0.39	0.217	0.149
7	0.48	0.30	0.292	0.193
8	0.55	0.27	0.386	0.220

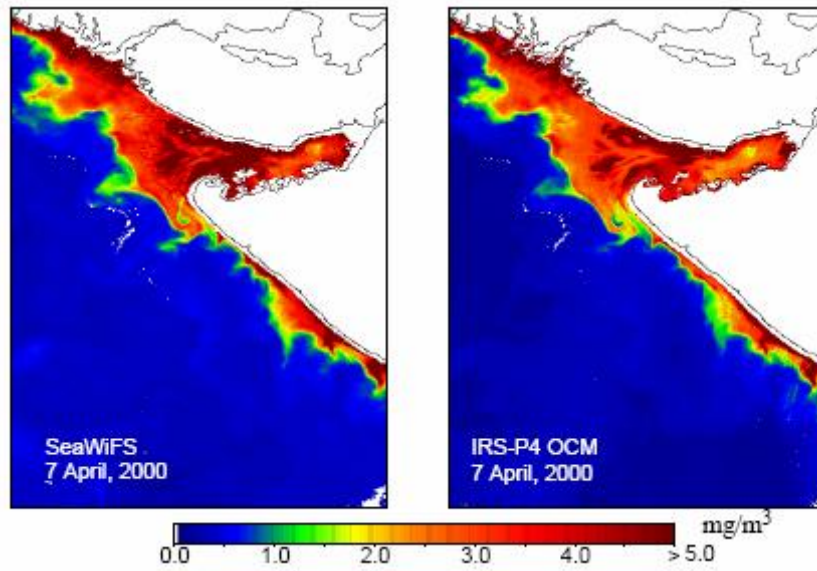


Fig. 2. Comparison of Chlorophyll a obtained from SeaWiFS and IRS-P4 OCM.

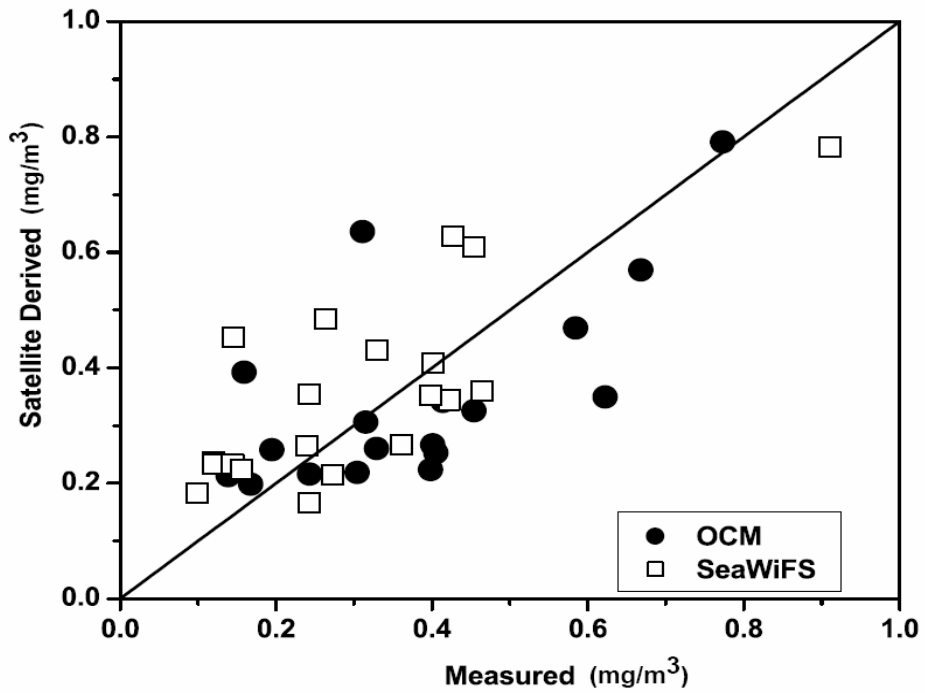


Fig. 3. Comparison of Chlorophyll a derived from SeaWiFS and IRS-P4 OCM with the measured Chlorophyll at various stations.

## 4. CONCLUSION

The IRS-P4 OCM is the only ocean color satellite sensor presently available to provide high pixel resolution data and thus it will find tremendous applications in monitoring on a finer scale.

Devoid of any facility onboard the IRS-P4 OCM for calibration by constant source such as sun and ground calibration facilities, vicarious calibration using a calibrated source such as SeaWiFS is assessed to be a cost effective solution.

Simulation by radiative transfer code 6S, which has been used for calibration of various types of satellite sensors and other applications, is used here to obtain the calibration coefficients for the IRS-P4 OCM.

The measure of the efficacy of the calibration coefficients derived here is proved from the close agreement of the chlorophyll a values derived from IRS-P4 OCM with the measured values and those derived from SeaWiFS.

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