Effect of Instrument Tilts on In-water Radiometric Measurements: A Case Study

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Abstract

In-situ radiance data collected from the underwater radiometers plays an important role in vicarious calibration, validation of the ocean colour products and can also be used for developing the bio-optical algorithms. The *in-situ* radiance will be influenced by many factors like the incidence angle orientation of the sensor and the local oceanographic conditions. This paper highlights the influence of the orientation/tilts of the sensor, in particular, the hyperspectral underwater radiometer on the *in-situ* radiance measurement. The *in-situ* data collected in the Hooghly Estuary near Diamond Harbour regions are used for the present study to assess the effect of tilt on surface radiance (L_s) and remote sensing reflectance (R_{rs}). The tilt angles from 0-30 degrees in the blue, green and red regions of the spectrum were considered which are mostly used for estimating the ocean colour or the geophysical parameters like chlorophyll concentration etc. This study shows that errors in surface radiance and the remote sensing reflectance increases with an increase in tilts. The average percentage error of <3% for the tilts 0-5 degree and 7.37 to 14% for the tilts 5-10 and the error percent increases to more than 50% beyond 15 degree tilt angles, which suggests that radiometric measurements up to 10^0 tilts can be used for retrieval of ocean color geophysical parameters in buoy mode for collecting the in-situ bio-optical parameters.

Keywords: Ocean colour, radiometer, Hooghly estuary, buoy mode.

Introduction

Ocean colour measurements from space, either from polar-orbiting or geostationary platforms, requires calibration and validation of the satellite-derived radiances both pre-and post-launch of any ocean colour sensor. Due to the changes and uncertainties in the sensor and its optical alignment after launch, utilizes the pre-launch calibration data which provides only a starting point for the follow-on post-launch vicarious calibration to characterize the sensor. After launch, the other in-situ match-up measurements are required to validate and diagnose the systematic artifacts in the sensor radiances or the top of the atmosphere (TOA) radiances (Charles, 2008). The Marine Optical BuoY (MOBY) has been one of its kinds and used as a vicarious calibration platform for over a period of two decades with its radiometric data being used by national and international researchers and federal agencies to improve the ocean colour data retrievals. However, Maintenance of the MOBY site has been labour intensive and relatively expensive, providing only a single, highly calibrated point for vicarious calibration.

In this current scenario of global ocean colour remote sensing data utility, it is now important to consider additional vicarious calibration and validation facilities and sites that augment a single-site MOBY-like facility, to cover the ranges of variability in oceanic and atmospheric conditions required for comprehensive calibration, characterizations and validations of the satellite measurement/model system. These facilities may be based on different deployment platform concepts and strategies than those used at MOBY, possibly including towers or vessel-based sortie surveys to measure in situ time-series of water-leaving radiances and their measurement accuracies. To meet these objectives, the Satlantic HyperPro-II hyperspectral radiometer has been selected as a portable radiometer of similar low radiometric uncertainty as that demonstrated for MOBY. In-situ bio-optical data or the radiance measurements can be carried out using hyperspectral underwater radiometer (HyperPro-II) in profiling mode, for the vertical distribution and buoy mode for the surface distribution or variability. Sun glint, ship movements are the source of errors in the tilt angle variations of the radiometer for such above water measurements (Silveria, 2014).

HyperPro-II Profiling Mode

The HyperPro-II is a hyperspectral profiling radiometer system, which can be operated in both profiler and surface buoy mode. The HyperPro II data is accompanied by in-air surface irradiance (E_s) reference measurements from a HyperOCR hyperspectral irradiance sensor. The HyperPro-II system typically has 138 surface irradiance channels (Es & Eu), 138 down-welling irradiance (Ed) channels and 138 upwelling radiance (Lu) channels ranging from 350 to 800nm. In general, HyperPro-II system reports the full 255 channels from 300-1100nm for stray light corrections, but only channels from 350-900nm (which are calibrated to a NIST scale) can be processed to radiometric units. The HyperPro-II also uses optical shutters for dark readings during deployment. Variable and adaptive integration times are used for all spectrometers, and the values for these integration times are included in the telemetry.

HyperPro-II: surface buoy mode

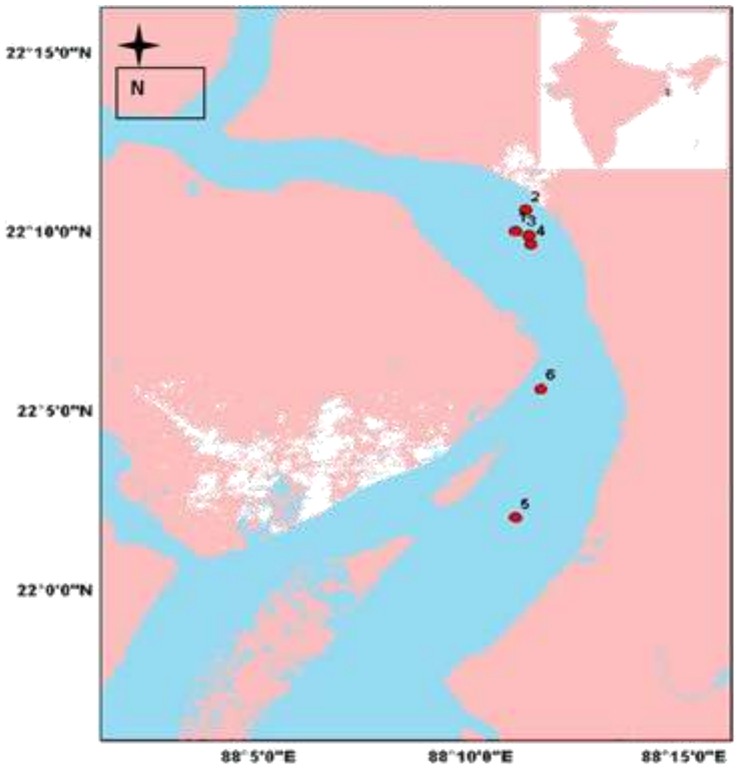
The HyperPro-II can be operated in buoy mode to obtain upwelling radiance and irradiances near the surface at sub-wave period sampling rates, away from vessel perturbations in the optical light field. To switch the profiler into this configuration, the $E_d(\lambda)$ sensor is inverted to measure $E_v(\lambda)$. The sensor is placed in such way that the Ev/Lu offset is 0.0cm. It is important to set these distances correctly for data processing, particularly in coastal waters. The HyperPro II irradiance sensor is inverted and placed at the same depth as the Lu radiance sensor to measure upwelling irradiance, E_v (λ), near the surface. Coincident above water measurements of the surface downwelling irradiance (E_s (λ)) are also made by a HyperOCR (sensor code HSE) mounted to the ship (shown in figure 2). These measurements provide data for the computation of key quantities needed to characterize the near-surface light field, such as reflectance, attenuation coefficients (modelled), spectral water-leaving radiance and remote sensing reflectance. The in-situ data has been processed using ProSoft V7.7.19 for getting level-1 to level-4 raw and calibrated radiances to the final product such as chlorophyll concentration. The present study represents the work carried out to study the effect of tilt angles on the in-situ reflectance values and the final geophysical product chlorophyll as an example obtained in buoy mode.

Study Area

The study area comprises of Hooghly Estuarine Environment or Bhagirathi-Hooghly River (namely Ganga) is a ~260 km long tributary in West Bengal, India. The second-largest hydrological basin is the Ganga-Brahmaputra Meghna (GBM) river basin (Heileman et al., 2010; Maes et al., 2004, Dutta et al., 2016). The numerous research studies in this Hooghly estuary showed dissolved organic nutrients, organic matter and stable nitrogen isotopes as indicators of human impact (Fisher et al., 2016); changes in the hydrological parameters (Mitra et al., 2011); Geo-environmental studies (Anirban, Thesis); studies on Ecological fluxes, fishery resources and production potential (Nath et al., 2004); coastal dynamics and sediment transport (Guha, 2015); seasonal variability of the physic-chemical parameters such as pH, salinity, dissolved oxygen, eddy diffusion coefficient etc. (Sadhuram et al., 2005); ecosystem structure by Dutta et al., (2017).

In-situ data was collected in the Hooghly estuarine system 21^{0}5'00''N-22^{0}15'00''N latitude and 88^{0}0'0''E - 88^{0}15'0''E longitude, at 17 stations (figure 1) covering the upper reaches of Hooghly to Diamond harbor on a coastal cruise. However, the data collected near the diamond harbour regions have been used in this present study for assessing the effect of tilt on *in-situ* radiance measurements collected from 26th Feb to 02nd Mar 2016. The average water column depth of the study area is ~8m with high sediment dominated waters and the water level changes according to the tidal cycle in a given day.

Fig.1. Study area map showing in-situ sampling locations in Hooghly Estuary (Diamond Harbour), India.



Materials and Methods

Processing of Hyperpro-II Data

All field data is processed with ProSoft V7.7.19, which has special processing features for buoy mode. These include stray light correction, thermal responsivity correction, multicast processing, and Thuillier SOLSPEC9 extraterrestrial solar irradiance. Additional processing for multicast, automated selection of extrapolation depth per wavelength to a user-selected number of optical depths, data filtering at a given number of standard errors (SEs), smoothing of E_s spectrum time series and normalization of profile data with E_s data to correct for the change in solar angle during the cast. Details of processing buoy mode data can be found in ProSoft User's Manual (Prosoft V7.7.19) to generate calibrated, and time and depth binned/averaged data products for further statistical analysis. This processing involves the processing of raw data from Level 1 (raw data) to Level 4 (derived products) using proper calibration files, time- or depth-binning, and deriving the Geophysical products.

Tilt - Operation in HyperPro-II

The correction and editing of the tilt either for profiler or in buoy mode can be carried out either interactively or automatically for removing the tilt contaminated records. Manual mode of tilt correction involves the logged data profile plot along with profiler tilts (if available) and the corresponding profiler velocity as a function of depth. Interactive graphical editors will be used to edit the tilt where the upper and lower limits of the depths will be defined upper z_{min} and lower depth z_{max} (assuming the z coordinate is directed downwards, i.e. depth is z_{min} surface and z_{max} at the bottom of a profile). The data above z_{min} or below z_{max} will be removed from the processing by setting the default is 5 degrees tilt as the threshold. During this process the missing tilts of the sensor is considered in free-fall mode using the velocity of the profiler either zero or negative velocity and is assumed as high tilt. Whereas, in automated editor modules the z_{min} and z_{max} can be set as the 10% of the upper and lower depths of profiler measurements. The "Surface Products" represent measurements carried out just below the sea surface (0^-) from a common depth horizon (Sanwlani et al., 2010). For buoy mode operations, upwelling radiance is considered from a depth of 0.15m from the surface.

Fig. 2. The structure of underwater HyperPro-II radiometer (Left) and its field operation carried out during the cruise (Right)

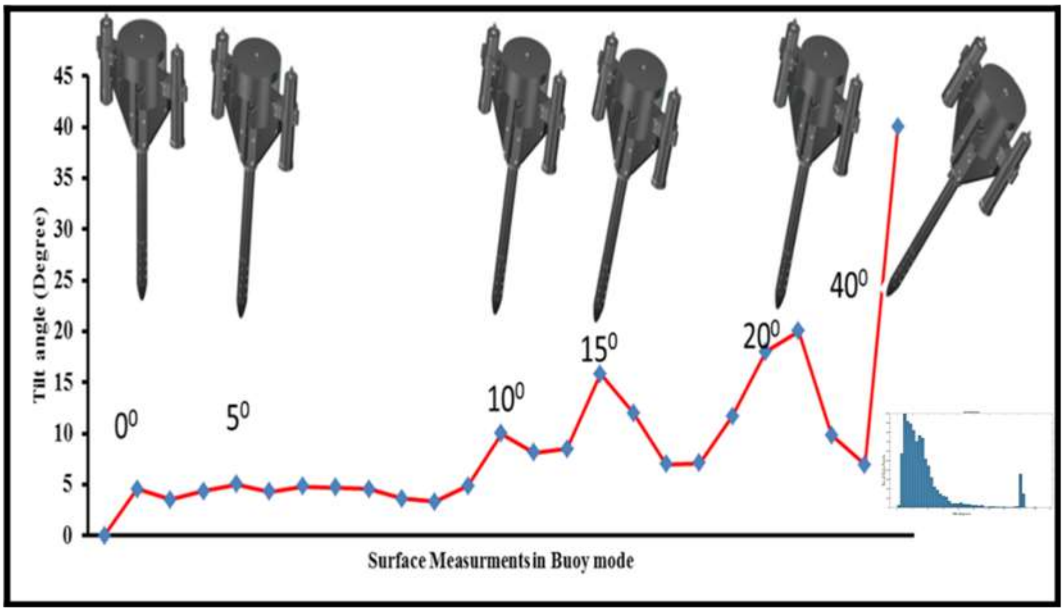


Fig. 3. Sensor orientation as a function of tilt in buoy mode operations during the in-situ data collection and the distribution of the data points for each tilt angle is therein.

Results and Discussion

In this present study initially, the *in-situ* bio-optical data was collected using HyperPro-II in the Diamond harbour, Hooghly estuary in profile mode for collecting the bio-optical data. Due to the underwater currents, data collection has become very difficult and the measurements in profiler mode resulted in higher tilts, hence carried out the experiments in buoy mode for in-situ bio-optical data collection. The effect of tilt in profile mode has been extensively studied by Silveira et al. (2014). Still, the effect of tilt on buoy mode operation has not been reported much, resulting in carrying out the present study. The instrument setup in the field site and different methods of operation in buoy mode is shown in figure 2.The entire data set has been processed using Prosoft V7.7.19, and the tilt option has been removed / disabled to ensure that all the tilt angles get processed to study in precise the effect of tilt from the minimum to maximum tilt angles. Distribution of the tilt during the entire cruise period in buoy mode operations is shown in figure 3. The effect of tilt on the *in-situ* radiance (Ls) and remote sensing reflectance (R_{rs}) has been analyzed for all the stations for the VNIR spectral bands. However, the error analysis results are discussed for those bands used to estimate the chlorophyll concentration in various ocean colour algorithms such as OC2, OC3M, OC3V and OC4E (O'Reilley et al., 1998 & 2019; Moutzouris et al., 2021). The spectral bands considered to study the effect of tilt both on remote sensing reflectance and chlorophyll retrieval include 443, 486, 488, 490, 510, 547, 550, 555 and 560nm for varying tilt angles from minimum 0.1 to maximum 30 degrees and up to 50 degrees for few locations (depending on the data availability) . For better understanding and clear visibility, the entire tilt range has been segregated into six ranges, i.e., 0-5, 5-10, 10-15, 15-20, 20-25, 25-30 degrees. The surface radiance (L_S) and the remote sensing reflectance (R_{rs}) measured at the six stations for varying tilts as a function of wavelength is shown in figures 4 & 5, respectively.

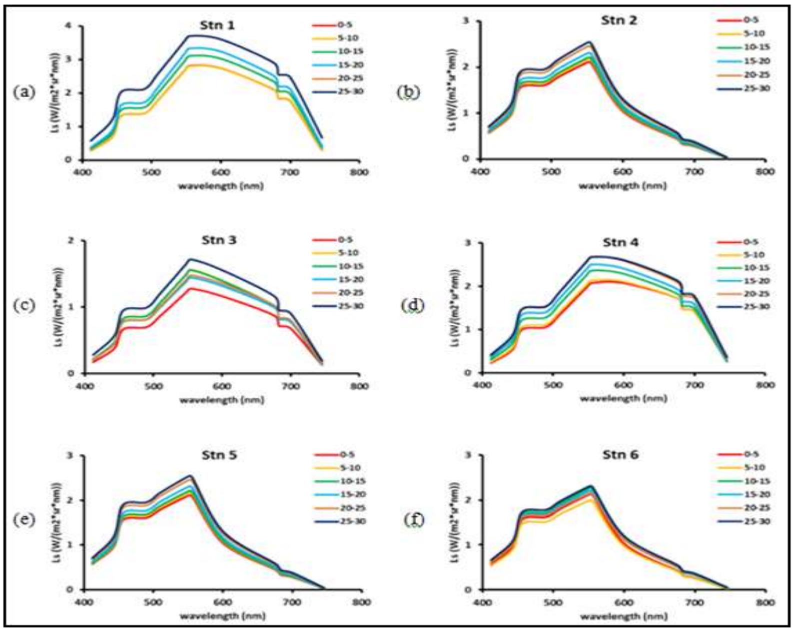


Fig. 4. Spectral **v**ariability of surface radiance (L_S) for varying tilts from 1 to 30 degrees for the six stations (a) to (f) respectively in Hooghly Estuary.

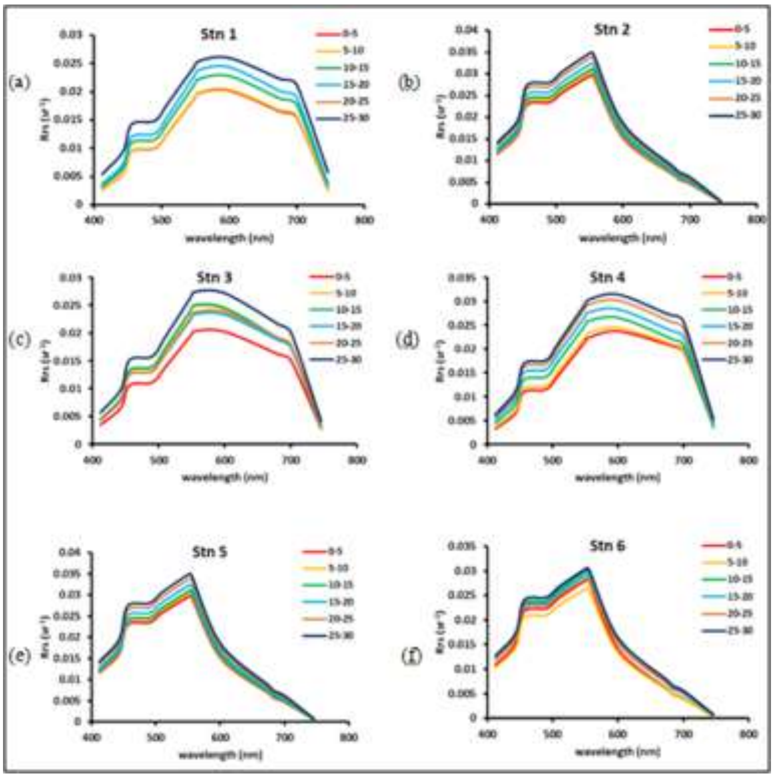


Fig. 5. Spectral **v**ariability of remote sensing reflectance (R_{rs}) for varying tilts from 1 to 30 degrees for the six stations (a) to (f) respectively in Hooghly Estuary.

From the figures 4 & 5, it is observed that the spectral variability or the difference in the spectral value also increases at all the stations as the tilt angle increases. The variability or the difference in the radiance/reflectance value is minimal in the blue and red regions of the spectrum compared to the green region except for station 3, where the shallow water bathymetry is observed and more scattering in blue light might have resulted in such variability.

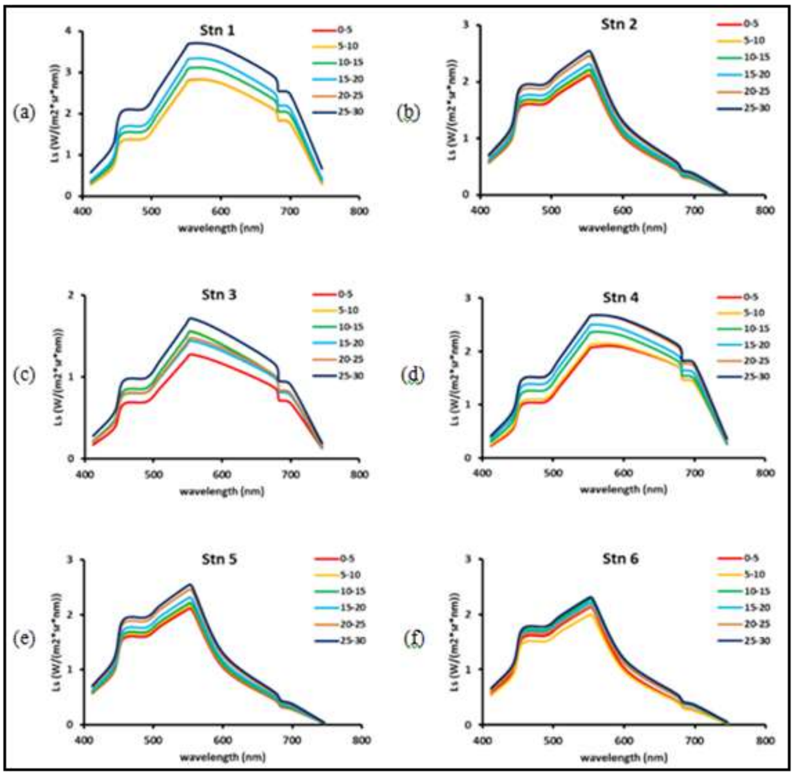


Fig. 4. Spectral **v**ariability of surface radiance (L_S) for varying tilts from 1 to 30 degrees for the six stations (a) to (f) respectively in Hooghly Estuary.

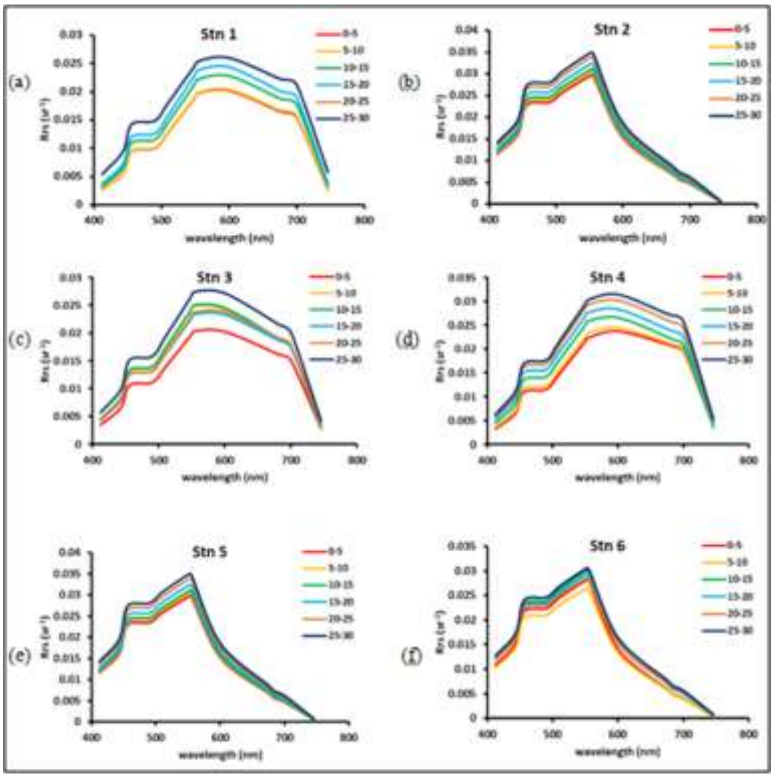


Fig. 5. Spectral **v**ariability of remote sensing reflectance (R_{rs}) for varying tilts from 1 to 30 degrees for the six stations (a) to (f) respectively in Hooghly Estuary.

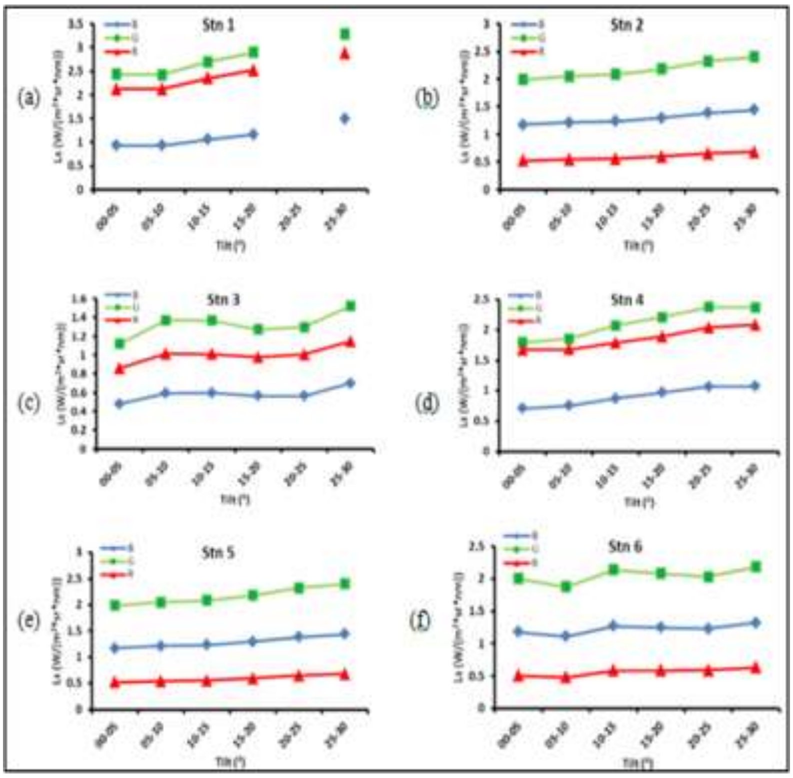


Fig. 6. Tilt effects on three bands (Blue, Green, and Red) of surface radiance (L_S) for the six stations (a) to (f) respectively in Hooghly Estuary.

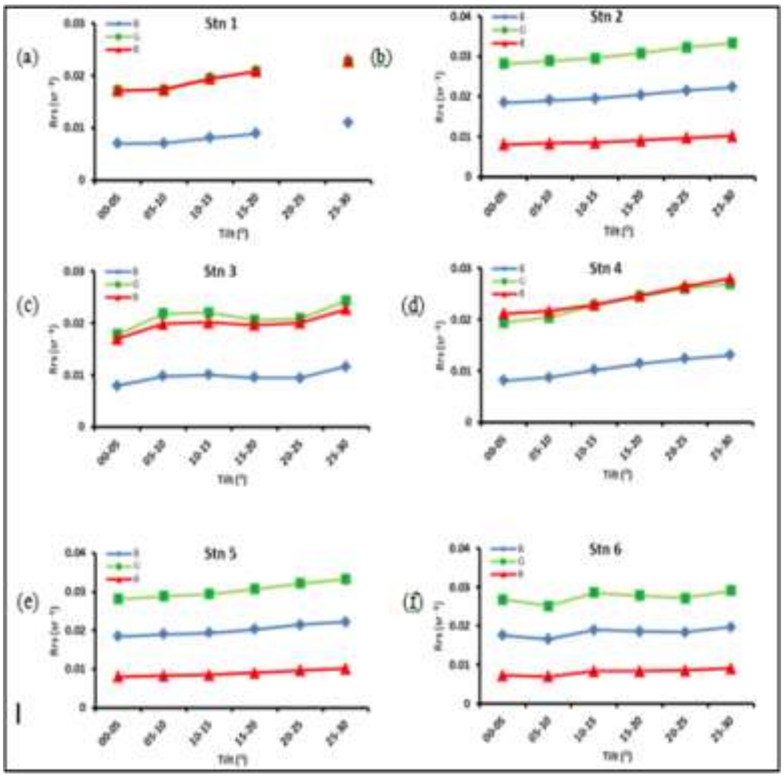


Fig. 7. Tilt effects on three bands (Blue, Green, and Red) of remote sensing reflectance (R_{rs}) for the six stations (a) to (f) respectively in Hooghly Estuary.

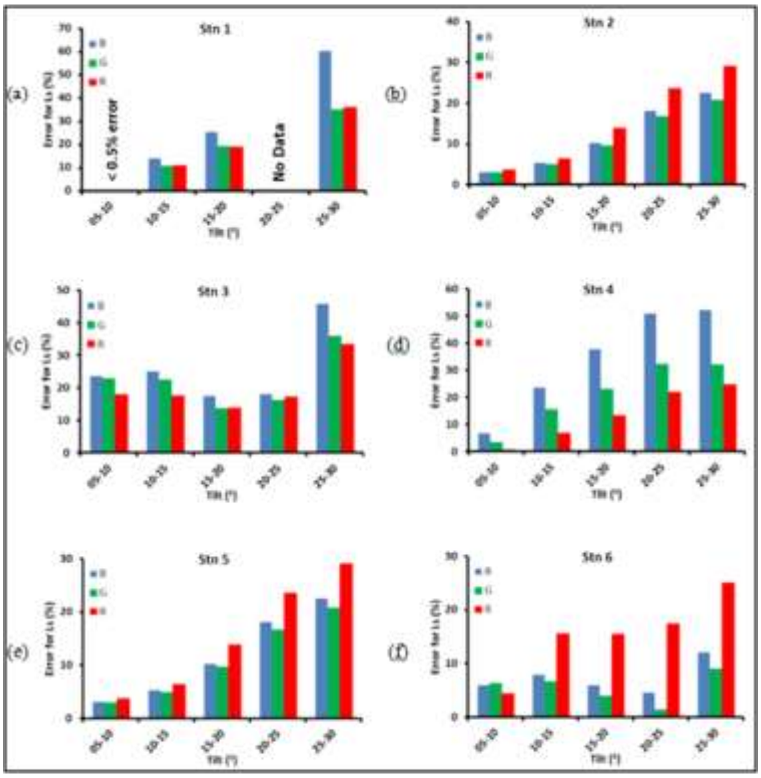


Fig. 8. Percentage **e**rrors for three bands (Blue, Green, and Red) of surface radiance (L_S) at different tilts of the six stations (a) to (f) respectively in Hooghly Estuary.

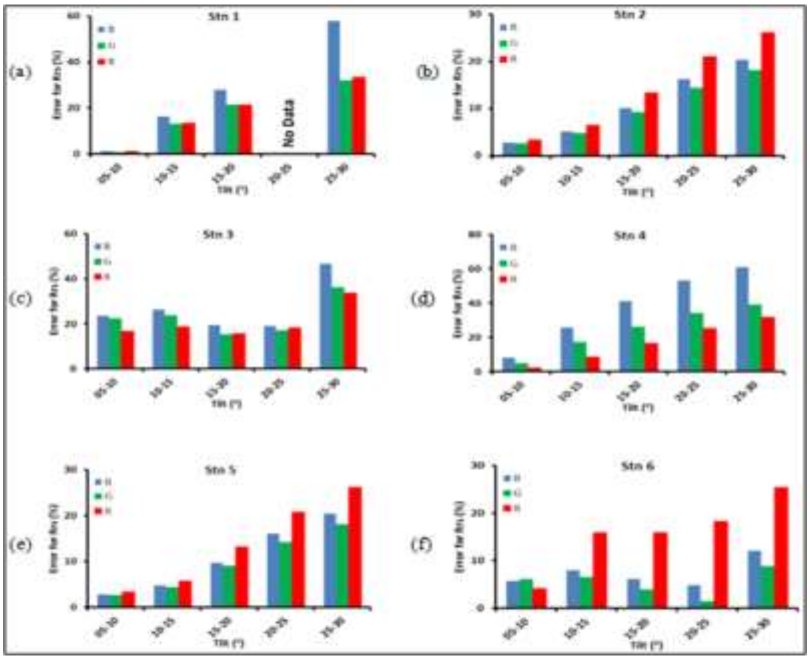


Fig. 9. Percentage **e**rrors for three bands (Blue, Green, and Red) of remote sensing reflectance (R_{rs}) at different tilts of the six stations (a) to (f) respectively in Hooghly Estuary.

The effect of tilt in three major/important spectral regions (Blue, Green, and Red) were calculated separately in the selected tilts ranges for all the stations for the surface radiance, and remote sensing reflectance are shown in figures 6 & 8 respectively. The overall trend of increasing value in the radiance/reflectance spectra from low to high tilt angles is observed very clearly for blue, green and red spectral regions where blue and red spectra show almost all the times low variability compared to blue and green. Quantification of the difference in the three spectral regions was assessed by estimating the percent error for the given spectral range for specified tilt angles of all the stations individually for the surface radiance (Es) (figure 7) and remote sensing reflectance (R_{rs}) (figure 9).

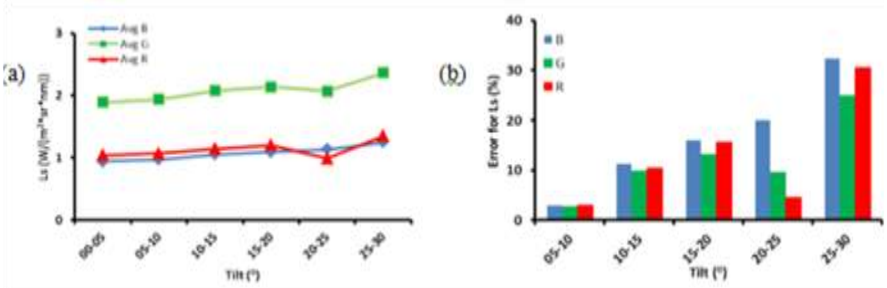


Fig. 10. Tilt effect (a) and percentage error (b) on average of three bands (Blue, Green, and Red) of surface radiance for all stations in Hooghly Estuary.

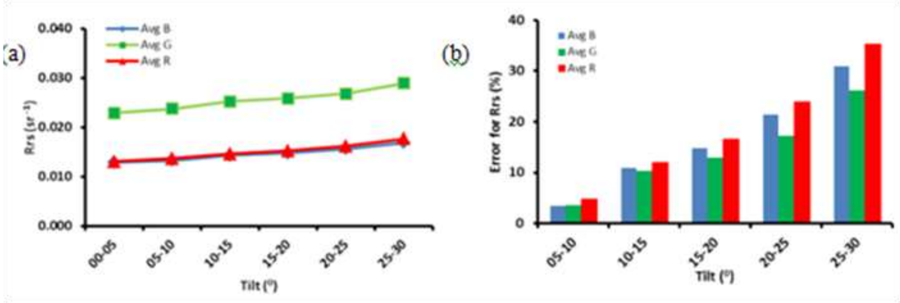


Fig. 11. Tilt effect (a) and percentage error (b) on average of three bands (Blue, Green, and Red) of remote sensing reflectance for all stations in Hooghly Estuary.

The study further carried out in this paper and calculated the average value and percentage error of all stations for three major spectral regions of radiance and reflectance to assess the overall effect of tilts as shown in figure 10(a) & 11(a) and figure 10(b) & 11(b) respectively. This study inferred that the error at 5-10 degree tilt window region is less than 3% whereas it increases to ~32% for the 25-30 degree tilt window for the surface radiance (figure 10(b)) and less than 4% in 0-5 degree tilt and ~35% in 25-30 degree tilt window region for remote sensing reflectance (figure 11(b)). Further the error analysis for the remote sensing reflectance in the red wavelength region specifically in 670nm band has been carried out (figure 12) apart from the blue green and red bands which were used to estimate the chlorophyll algorithm such as MERIS Chl_OC4E and VIIRS Chl_OC3V as shown in figure 13.

Summary & Conclusions

Bio-optical measurements in the river and estuarine water systems are more complex due to shallow water depths, turbulent river flow and tidal effects. In such environments, it is difficult to operate the underwater radiometer in profile mode as the sensor drifts away with the water flow and which in turn influences the tilt of the sensor leading to inaccurate measurements of the *in-situ* bio-optical variables.

From the analysis, it is clearly observed that the value difference in the blue and NIR spectral regions is less compared to green and red regions. The percentage error is increasing from 0-5 and 5-10 degree tilt window from <3%, 7.37 – 14% and >50% error for the tilt angles beyond 15 degrees. The average percent error for all the six spectral (Rrs) bands mentioned in the discussion that are used for estimating the chlorophyll concentration from 0-5 degree tilt is ~12% and from 5-10 degree tilt is ~18% and from 10-15 it is 40% and increasing beyond for the tilt angles greater than 15 degrees. Thus from the observations in this study, it is suggested that the radiometric measurements can be used up to 10-degree tilt angle for estimation of ocean colour geophysical parameters in buoy mode operations.

Acknowledgement

The authors would like to thank Director, NRSC, Deputy Director, ECSA and senior scientists at ECSA for their consistent support and guidance to carry out this work. We thank all the support rendered by NICES program office for funding to collect the *in-situ* data and also thank all the participants and support personnel of the cruise and their respective institutions for supporting this activity.

References

1. Charles, T., 2008. SORTIE-2 Final Radiometric Data Report. WET-DN-00519.
2. Dutta, S., Chakraborty, K., Hazara, S., 2017. Ecosystem structure and trophic dynamics of an exploited ecosystem of Bay of Bengal, Sundarban Estuary, India. Fisheries Science, DOI: 10.1007/s12562-016-1060-2.
3. Dutta, S., Chanda, A., Akhand, A., Hazra, S., 2016. Correlation of Phytoplankton Biomass (Chlorophyll-a) and Nutrients with the Catch Per Unit Effort in the PFZ Forecast Areas of Northern Bay of Bengal during Simultaneous Validation of Winter Fishing Season. Turk. J. Fish. Aquat. Sci. 16: 767-777. https://doi.org/10.4194/1303-2712-v16_4_03.
4. Fisher, P., Unger, D., Anup, Palit., Einsporn, M.H., Lara, R. J., 2016. Dissolved inorganic nutrients, organic matter and stable nitrogen isotopes as indicators of human impact in two contrasting estuaries in West Bengal, India, during winter monsoon. Indian Journal of Geo-Marine Sciences, Vol. 45(1), pp-16-28.
5. M. Tholkapiyan, A.Mohan, Vijayan.D.S, A survey of recent studies on chlorophyll variation in Indian coastal waters, IOP Conf. Series: Materials Science and Engineering 993 (2020) 012041, 1-6.
6. Heileman, S., Bianchi, G., Funge-Smith, S. 2010. VII-10 Bay of Bengal: LME#34.

7. Maes, J., Van Damme, S., Meire, P. Ollevier, F. 2004. Statistical modeling of seasonal and environmental influences on the population dynamics of an estuarine fish community; Marine Biology 145 1033–1042. 10.1007/s00227-004-1394-7
8. M. Tholkapiyan, A.Mohan, Vijayan.D.S, A survey of recent studies on chlorophyll variation in Indian coastal waters, IOP Conf. Series: Materials Science and Engineering 993 (2020) 012041, 1-6.
9. Tholkapiyan, M., Mohan, A., Vijayan, D.S. Spatial And Temporal Changes Of Sea Surface Phytoplankton Pigment Concentration Over Gulf Of Manner, India Oxidation Communications, 2021, 44(4), pp. 790–799
10. Dharmar, S., Gopalakrishnan, R., Mohan, A. Environmental effect of de nitrification of structural glass by coating TiO2, Materials Today: Proceedings, 2020, 45, pp. 6454–6458
11. O'Reilly, John E., and P. Jeremy Werdell. "Chlorophyll algorithms for ocean color sensors-OC4, OC5 & OC6." *Remote sensing of environment* 229 (2019): 32-47.
12. D. S. Vijayan , A. Mohan , C. Nivetha , Vidhyalakshmi Sivakumar ,Parthiban Devarajan , A. Paulmakesh , and S. Arvindan, Treatment of Pharma Effluent using Anaerobic Packed Bed Reactor, Journal of Environmental and Public Health, Volume 2022, Article ID 4657628, 6 pages, https://doi.org/10.1155/2022/4657628
13. M. Tholkapiyan , A. Mohan, D. S. Vijayan.,Variability Of Sea Surface Temperature In Coastal Waters Of Gulf Of Manner, India, Oxidation Communications 45, No 3, 562–569 (2022) .
14. Sadhuram, Y., Sarma, V V S S., Raman Murthy, T V., Prabhakara Rao, B P, 2005. Seasonal variability of physic-chemical characteristics of the Haldia channel of Hooghly estuary, India. Journal of Earth System Science, Vol. 114(1), pp.37-49.
15. A Jothilakshmi, M. , Chandrakanthamma, L. , Dhaya Chandhran, K.S. , Mohan Flood control and water management at basin level-at orathur of Kanchipuram district International Journal of Engineering and Advanced Technology, 2019, 8 , International Journal of Engineering and Advanced Technology 8 (6), 1418-1421
16. Sanwlani, N., Chauhan, P., Navalgund, R. R. (2010). Atmospheric Correction Over Coastal Turbid Waters of Bay of Bengal Using OCEANSAT-I Ocean Colour Monitor (OCM) Data. *Journal of the Indian Society of Remote Sensing*, *38*(4), 617–626. https://doi.org/10.1007/s12524-011-0058-6
17. Mohan, A., Saravanan, J.., Characterization Of Geopolymer Concrete By Partial Replacement Of Construction And Demolition Waste – A Review., Journal of the Balkan Tribological Association, 2022, 28(4), pp. 550–558.
18. Silveira, N., Suresh, T., Madhubala, T., Elagar, D., Prabhu Matondkar, S. G., Aneesh, L., 2014. Sources of errors in the measurements of underwater profiling radiometer. Indian Journal of Geo-Marine Sciences 89, 88-94.