Indian Journal of Geo-Marine Science
Vol. 39(4), December 2010, pp. 504-508

Measurement of salinity of Mandovi and Zuari estuarine waters from OCM data

Harilal B Menon* & Nutan P Sangekar
Department of Marine Science, Goa University, Goa – 403 206, India
*[E-mail: harilalm@gmail.com]

Received 20 August 2010, revised 21 December

Present study deals with a method/algorithm to retrieve salinity through optical remote sensing. The basis is the relation between one of the optically active substances of coastal and estuarine waters viz; chromophoric dissolved organic matter (CDOM) and salinity. Two important conditions for the algorithm to work are 1) CDOM should be the main light absorbing component and 2) the main source of CDOM should be fresh water discharge. Relationship between waters with salinity 26 to 35 PSU and CDOM for the Mandovi and Zuari estuaries have been developed and applied to OCM data of the year 2005, Specific algorithm developed[4]is utilized for the study. Validation of satellite retrieved salinity and *in-situ* resulted in a correlation of 0.86.

[**Keywords:** Salinity, Ocean colour monitor, Estuary, Chromophoric dissolved organic matter]

Introduction

Understanding spatial distribution of salinity in the coastal waters is an important component of the studies of sediment plume, hypoxia[1] and bio-geochemical cycle[2]. In order to get a synoptic picture of salinity, scientists interpolate *in-situ* values which always have inherent errors. In the present study, an attempt has been made to examine the feasibility of retrieval of salinity from ocean color analysis. Colour of the water is the resultant change in the characteristics of incident light while it interacts with suspended organic, inorganic and dissolved organic matters (DOM). The suspended organic matter is chlorophyll a pigment of phytoplankton while the inorganic matter is sediment. Component of DOM interacting with visible light is chromophoric dissolved organic matter (CDOM), which is produced due to disintegration of organic matters (*in-situ*) and through river discharge. The concentration of dissolved organic matter and hence the CDOM is very high in estuarine waters than in any other regions of the water body[3]. In their studies, Menon *et al.*[4] had developed an algorithm to retrieve CDOM from Ocean Colour Monitor (an optical sensor). From the analysis of spectral absorption of visible light, it was shown that there exists a linear relation between the ratio of reflection coefficients in the red and blue or blue and green part of the spectrum and CDOM absorption[5]. This study also revealed the conservative nature of CDOM in estuaries. If CDOM behaves conservatively, then its concentration should vary with the variation of river flow and should have an inverse relation with salinity. Bowers *et al.*[5] had shown that this relation works in variety of water bodies if CDOM is the main absorber of light.

Materials and Methods

Area of investigation and data

Mandovi and Zuari estuaries are a complex ecosystem joining the Arabian Sea at the central west coast of India (Fig. 1). Hydrodynamics of the estuaries is controlled by both river runoff and tides during monsoon (June—September) season and tide (semi-diurnal in nature with a range 0.2—2 m) during the non-monsoon seasons. This generates significantly different oceanographic processes between dry (non-monsoon) and wet (monsoon) seasons, resulting in the formation of homogenous, salt-wedge and partially mixed estuaries during pre-monsoon, monsoon and post-monsoon seasons.

In-situ observations

The sampling details, selection of stations and the precautions taken in the field may be seen in Menon et al.[6]. Observations were carried out from 22 hydrographic stations along the axis of the estuaries, during pre-monsoon (12th February, 18th March, 13th April and 11th May), monsoon (15th August and 17th September) and post-monsoon (11th November and 9th December) seasons during the year 2005. From each station, two water samples were collected for the analysis of sediment and CDOM. Along with the collection of water samples, observations were also carried out using Secchi Disk, CTD, Microtops II

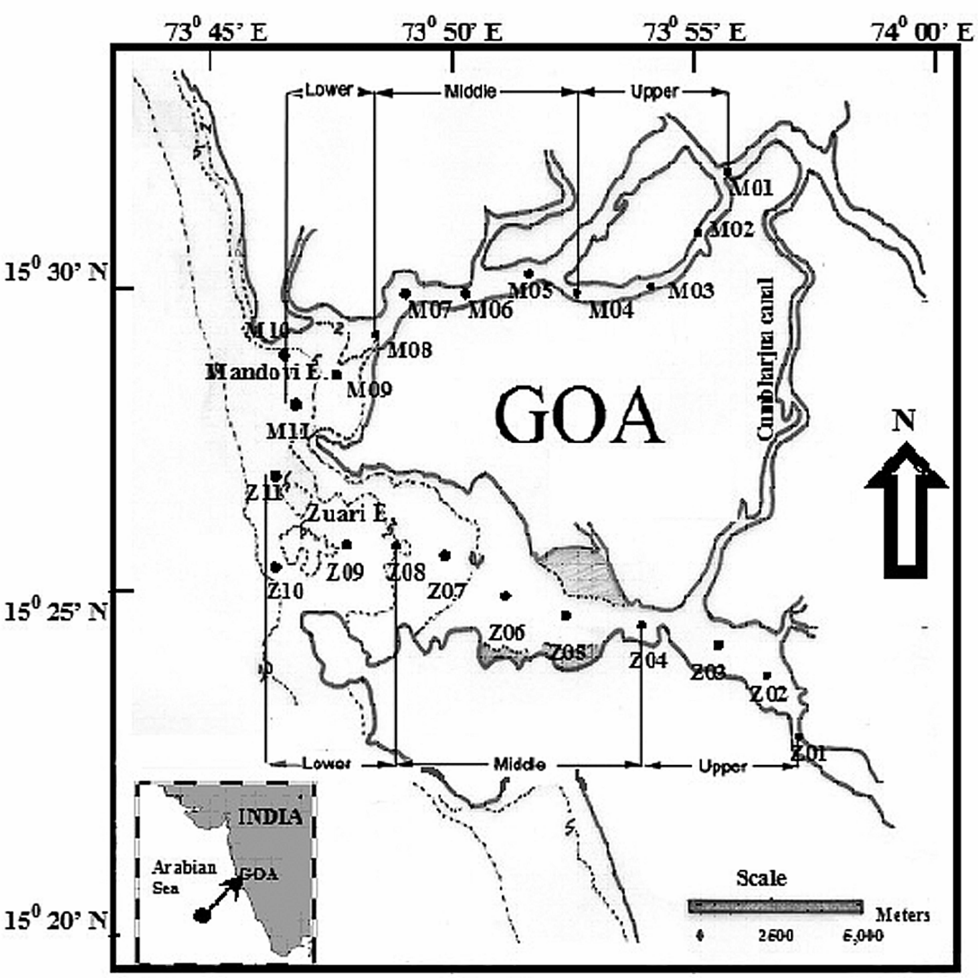


Fig. 1- Map of the study area showing hydrographic stations in different zones of Mandovi and Zuari estuaries of Goa.

sunphotometer, temperature and humidity at each station. Vertical distribution of salinity, at each station, was measured using a CTD. Underwater irradiance was measured using a seven-channel irradiance meter (Satlantic inc).

Suspended sediment from the water sample was measured by gravimetric analysis using pre-weighed 0.45 μm membrane filter. The filters were rinsed in distilled water to remove the salt, allowed to dry, reweighed and kept in oven at 500°C for 3 h. After cooling, once again the filter was weighed for a final analysis. Absorption spectrum of CDOM was measured by Perkin—Elmer dual beam spectrophotometer after filtering samples through 0.2 μm membrane filter. Distilled water was used as a reference. The absorption coefficient was calculated in the way described by Menon *et al.*[4]. Absorption coefficient at 440 nm was considered as the index of CDOM concentration.

Satellite data processing

Synoptic analysis of salinity was carried out using the data obtained from Ocean Colour Monitor (OCM) flown on board Indian Remote Sensing satellite–P4 (IRS – P4). OCM has six visible and two NIR bands in the range 402 – 885 nm centered at 412, 443, 490, 510, 555, 670, 765 and 865 nm. The spatial resolution and spectral range of the visible bands of OCM are 360 m and 20 nm respectively. The images were geo-referenced using ground control points and the study area was extracted from the full scene through ERDAS Imagine 8.4. Atmospheric correction of data, obtained remotely through an optical sensor, involved elimination of rayleigh and aerosol components. Rayleigh component was computed and removed from each pixel using Doerffer's method[7]. As the water in the study area was turbid, pixels of NIR bands of OCM could not be used to remove aerosol path radiance. Hence aerosol radiance was computed by deriving aerosol optical depth (AOD) through a Microtops II sunphotometer[8] having filters at 380, 440, 500, 675 and 870 nm. Subsequently, aerosol correction was carried out to each pixel of OCM and water leaving radiance was derived for selected bands. Then applying the algorithm developed by Menon *et al.*[4], a_{CDOM} (440) was retrieved from OCM. This was carried out using a calibrated radiative transfer model[9,4]. Algorithms for the retrieval of CDOM and salinity are given below.

$$a_{CDOM}\,(440) = 2.9393\,(L_w412/L_w670)^{-2.2486} \quad \dots (1)$$

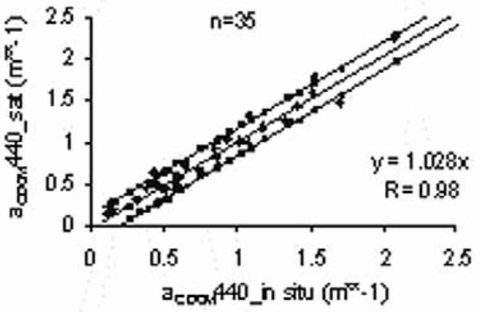
$$\text{Salinity} = (-\,2.5355 \times a_{CDOM}(440)) + 34.68 \quad \dots (2)$$

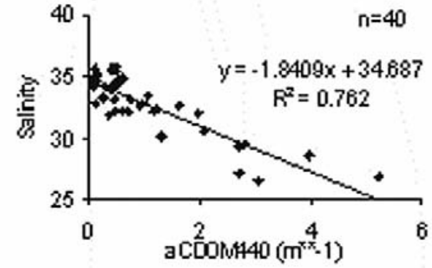
Applying the above relation, salinity during the entire year of 2005, except the monsoon season, was retrieved from OCM (Fig 3). Cloud free scenes of OCM on 8th January, 12th February, 18th March, 13th April, 11th May, 23rd September , 6th October, 11th November and 9th December of the year 2005 were used to study the spatial and temporal variability of salinity.

Results

OCM – *in-situ* comparison

In order to validate salinity retrieved from OCM, the accuracy of OCM derived CDOM values was first examined. For the validation, *in-situ* data of CDOM were chosen in such a way that widths of the stations were more than 3 times 360 m, the spatial resolution of OCM. This precaution was taken to avoid overlapping of water pixels with land pixels. Along with the correlation analysis, root mean square (RMS) and bias of the data were also calculated. The data sets were logarithmically transformed (base 10) to calculate RMS and bias. The RMS log error is 14.25% and log difference bias is 3.89%. A good correlation with R equals 0.98 (Fig. 2a), less error and bias further explained the ability of the algorithm in retrieving the sequential variation of CDOM concentration in association with the hydrodynamics of the estuaries. Similarly a good correlation (R = 0.86, Fig. 2c), between salinity retrieved from OCM and *in-situ* values revealed the robustness of salinity algorithm.





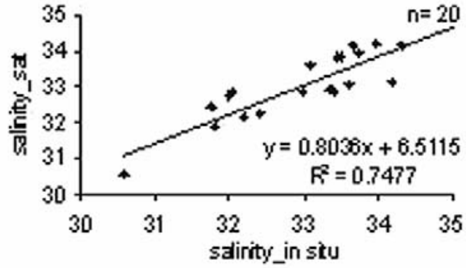


Fig. 2a—Correlation between in-situ and satellite derived a_{CDOM} (440) (the dotted lines in the figure show 95% confidence level).

Fig. 2b—Regression of CDOM and salinity (PSU).

Fig. 2c—Validation satellite retrieved salinity and in-situ measured salinity in of PSU.

Synoptic analysis of salinity from OCM data

To accomplish the task of remotely sensing salinity, it is required to know how the concentration of CDOM in the region varies with salinity. Fig 2b shows a strong linear inverse relation between CDOM and salinity. This relation has been established from 40 points from Mandovi and Zuari estuaries. Salinity is ranging from 26 to 35 PSU. Figure 2b proves that CDOM behaves conservatively with respect to salinity and hence could be used as a proxy to salinity. But it is worthwhile to mention that the slope of the regression line varies depending on the concentration of CDOM for 0 PSU. This means, the slope can vary with respect to season and also geographically. To incorporate this variability and thus to map salinity, normalized absorption of CDOM at 440 nm, which is the ratio of $a_{CDOM}(440)$ of the station to $a_{CDOM}(440)$ corresponding to salinity 0 PSU, should be used to develop relation with salinity. Also fine tuning the coefficient on the basis of the entire data set will help in an algorithm for a region which could work irrespective of the season.

The empirical algorithm was applied to OCM data and salinity for the entire year was mapped (Fig. 3). Salinity distribution revealed some interesting oceanographic features. Three prominent features are 1) a secluded low salinity plume in the offshore of Zuari estuary, 2) The diffusion of the low salinity plume as

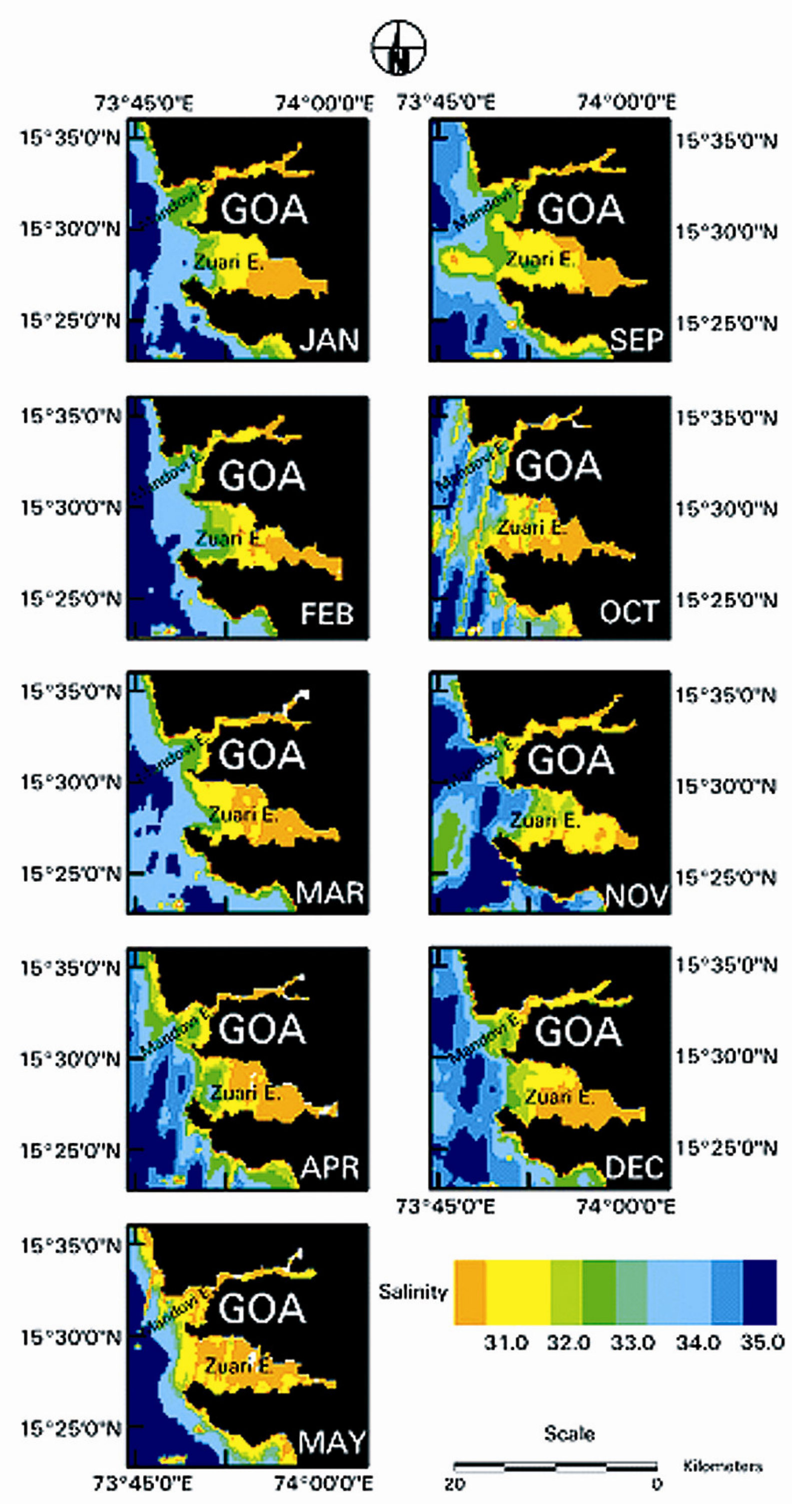


Fig. 3- OCM images of salinity from January to December 2005.

post-monsoon season advances, 3) The transformation of the estuaries from a partially mixed type to homogeneous between February and May.

Discussion

The paper explains a new approach for the synoptic analysis of surface salinity from estuarine waters, having large influence of fresh water discharge, from OCM, an optical sensor, flown onboard IRS – P4. Through a radiative transfer computation, it was shown that major colour components such as chlorophyll a, sediment and CDOM could be retrieved from an optical sensor[1,4]. In the present paper, the work of Menon *et al.*[4], in retrieving CDOM has been extended to retrieve salinity from OCM data. On the basis of an empirical relation, this was carried out for an entire year 2005. A major requirement for the success of such an empirical relation is that the colour of the water is mainly controlled by this component (CDOM) while the variation of other components is within a range with low sensitivity. Though the colour ratio works well to retrieve salinity from the area of study, the algorithm may not work elsewhere with large variability of other colour components. In such cases, the algorithm can be functional with a new coefficient, when it is tuned with the *in-situ* data of the area of study. Since the spatial resolution of OCM sensor is 360 m, it is ideal to apply the algorithm in any in-land water bodies with wide range of salinities. But, being a converging funnel shaped estuaries, OCM data could be applied 8 km from the mouth of the estuaries. Hence salinity in the range 30–35 PSU (Fig. 2c) could only be retrieved from OCM data. Unique measurement of salinity from space will enable the oceanographers to study the ecosystem on the basis of synoptic data rather than from point measurements. The advantage of observing salinity of estuaries from space is very significant in the study related to carbon flux to the coastal waters and hence climate.

Conclusion

The study has shown the potential of satellite data for the retrieval of salinity from an optical sensor. This is for the first time that salinity in these estuaries has been analyzed, for an entire year, remotely through an optical sensor having spatial resolution of 360 m. The study could also assess the fate of secluded low salinity plume in the offshore region during the initial phase of post-monsoon. This revealed that it is possible to analyze the salinity pattern, synoptically through an optical sensor, if equipped with good site specific algorithm. A success in mapping salinity and studying for its temporal variation in estuaries will help in developing a basic tool to understand and monitor the discharge of dissolved organic matter from non-point sources which is responsible to make a coastal region hypoxic.

Acknowledgements

The first author HBM wishes to thank Naval Research Board (NRB) and Indian Space Research Organisation (ISRO) for the financial support.

References

1 Kuo, A.Y. & Nielson, B.J., Hypoxia and salinity in Virginia estuaries, *Estuaries*, 10(4)(1987) 277 – 283.

2 Turner, A. & Millward, G.E., Suspended Particles: Their Role in Estuarine Biogeochemical Cycles, *Estuarine, Coastal and Shelf Science*, 55(6)(2002) 857-883.

3 Kirk J.T.O, *Light and photosynthesis in aquatic ecosystems*, (Cambridge, Cambridge University Press) 1994, pp. 509.

4 Menon, H.B., Lotliker, A.A. & Nayak, S.R., Analysis of estuarine colour components during non-monsoon period through Ocean Colour Monitor, *Estuarine, Coastal and Shelf Science*, 66(2006) 523 – 531.

5 Bowers, D.G., Harker, G.E.L., Smith, P.S.D. & Tett, P., Optical properties of a region of fresh water influence (the Clyde sea), *Estuarine, Coastal and Shelf Science*, 50(2000) 717 – 726.

6 Menon, H.B., Lotliker, A.A. & Nayak, S.R., Pre-monsoon bio-optical properties in estuarine, coastal and Lakshadweep waters, *Estuarine, Coastal and Shelf Science*, 63(2005) 211-223.

7 Doerffer, R *Imaging spectroscopy for detection of chlorophyll and suspended matter*, (In GKSS 92/E/54) 1992, pp. 215-257.

8 Chylek, P., Henderson, B. & Mischchenko, M., Aerosol radiative forcing and the accuracy of satellite aerosol optical depth retrieval, *Journal. of Geophysical. Research, R.,.*, 108(2003) 4764.

9 Menon, H.B., Calibration of an optical equation to analyse the atmospheric turbidity and water quality of an estuarine environment, *Photonirvachak*, 32(3)(2004) 287 – 300.