

Retrieval of sea surface velocities using sequential ocean colour monitor (OCM) data

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Abstract

The Indian Remote Sensing Satellite, IRS-P4 (Oceansat-I) launched on May 26, 1999 carried two sensors on board, i.e., Ocean Colour Monitor (OCM) and a Multifrequency Scanning Microwave Radiometer (MSMR) to study both biological and physical parameters of oceans. OCM collects data for a wide swath of 1420 km, in eight spectral bands (Visible/NIR region) with 20/40 nm bandwidths and two days repeatability. The OCM data is found to be extremely useful in retrieving and monitoring biophysical parameters like chlorophyll-a, suspended sediments, yellow substance and aerosol optical depth at regional scale.

Sequential data of IRS-P4 OCM has been analysed over parts of both east and west coast of India and a methodology to retrieve sea surface current velocities has been developed. The method is based on matching suspended sediment dispersion patterns, in sequential two time lapsed images. The pattern matching is performed on atmospherically corrected and geo-referenced sequential pair of images by Maximum Cross-Correlation (MCC) technique. The MCC technique involves computing matrices of cross-correlation coefficients and identifying correlation peaks. The movement of the pattern can be calculated knowing the displacement of windows required to match patterns in successive images. The technique provides actual flow during a specified period by integrating both tidal and wind influences. The current velocities retrieved were compared with synchronous data collected along east coast during GSI cruise ST-133 of R.V. *Samudra Kaustubh* in January 2000. It is observed that coefficient of determination, R-squared is 0.99 for both magnitude (cm/s) and direction (deg.).

The technique may find useful applications in providing inputs to hydrodynamic modeling of coastal processes such as computation of long-shore transport, pollutants dispersion rates, siltation etc. under different tidal cycles and wind influences.

1. Introduction

The IRS-P4 (OCEANSAT-1) satellite launched on May 26, 1999 by Indian Space Research Organisation (ISRO), carried two oceanographic payloads, i.e., Ocean Colour Monitor (OCM) and Microwave Scanning Multi-frequency Radiometer (MSMR). The first payload OCM is designed to measure ocean colour, the spectral variation of water leaving radiance that can be related to concentration of phytoplankton pigments, suspended matter, coloured dissolved organic matter i.e., yellow substance or gelbstoff and aerosols. The technical characteristics of OCM sensor are given in Table 1.

In India, many areas are being eroded and threaten the life and property of local population. Information on coastal processes of erosion, deposition, sediment transport, flooding and sea level changes that continuously modify the shoreline is required for planning coastal protection work. Information of sea surface velocities in conjunction with sediment concentration is required to understand the sediment dynamics of a

region such as regional sediment dispersal patterns, long-shore transport, etc. A methodology to retrieve advective velocities from sequential satellite data has been developed. It involves a pattern matching method based on maximum cross-correlation. The velocities retrieved are time-averaged velocities between the data sets used. This methodology retrieves velocities in terms of rate of transport of sediments. The retrieved velocities were validated using synchronous data collected along east coast during GSI cruise ST-133 of R.V. *Samudra Kaustubh* in January 2000. The technique will find useful applications in providing inputs to hydrodynamic modeling of coastal processes such as computation of long-shore transport, pollutants dispersion rates, siltation, etc. under different tidal cycles and wind influences.

2. Materials and Methods

2.1 Selection of sequential data

Sequential OCM data has been utilized for the study. Care has been taken while selecting the data sets. The

Table 1. Technical characteristics of IRS-P4 OCM payload

Parameters	Characteristics
1. Spectral range	402-885 nm
2. Number of channels	8
3. Wave lengths	Channel 1: 402-422 nm Channel 2: 433-453 nm Channel 3: 480-500 nm Channel 4: 500-520 nm Channel 5: 545-565 nm Channel 6: 660-680 nm Channel 7: 745-785 nm Channel 8: 845-885 nm
4. Spatial resolution	360 m
5. Swath	1420 km
6. Repitivity	2 days
7. Quantisation	12 bits
8. Equatorial crossing time	12 noon
9. Along track steering (to avoid sun glint)	20°
10. MTF (at Nyquist)	>0.2
11. Satellite altitude	720 km
12. Transmission frequency	X-band
13. Data rate	20.8 Kbps

procedure requires two time-lapsed sequential imagery for implementation. It was also noted that there should be persistence of features in the sequential data sets like a sediment plume. Applying the procedure sequentially on i.e., 1-3, 3-5, 5-7 day imagery, we derived vectors over an image data set spanning for a week. However, it should be noted that the vectors thus derived from any two imagery would be an average for the two days.

2.2 Atmospheric correction

The data was corrected for atmospheric variability. It is well known that in case of oceanic remote sensing, the total signal received at the satellite altitude is dominated by radiance contribution through atmospheric scattering processes and only 8-10% signal corresponds to oceanic reflectance. Therefore, it becomes mandatory to correct for atmospheric effect for retrieving any quantitative information from space. It has been shown that for NIR channels the water leaving radiance coming out of ocean can be approximately put equal to zero. The top of the atmosphere (TOA) radiance in OCM channels seven (765 nm) and eight (865 nm), mainly corresponds to contribution coming only from the atmosphere, since water leaving radiance L_w (765 and 865 nm) can be safely assumed to be zero. The Rayleigh scattering L_r is computed using well-established theory. Once L_r is known then L_a is assumed

to be equal to L_a , i.e. the aerosol path radiance. A relationship has been obtained for the spectral behaviour of the aerosol optical depth using channels 765 nm and 865 nm of OCM data. An exponential relationship for spectral behaviour of aerosol optical depth has been used in the atmospheric correction algorithm. The aerosol optical thickness has been extrapolated to visible channels using this exponential relationship. The OCM data was analysed using the atmospheric correction and bio-optical algorithms developed initially for IRS-P3 MOS data (Mohan et al., 1998) and later on modified for OCM data at SAC. It may however be noted that very accurate recovery of water leaving reflectance is not crucial for retrieving advective velocities as the method is based on pattern matching. The purpose of the atmospheric correction is to remove patterns in the image data sets, which are of atmospheric origin.

2.3 Geometric correction

The geometric correction to the data sets was applied. It is obvious that this step is very crucial. It is essential for the success of cross-correlation technique that the two images of a pair be co-registered as accurately as possible. A rotation between the images reduces the matching coherency and a translation shift reduces the matching accuracy. A two-stage approach was followed. First of all geometric correction was applied separately on individual data sets to remove image distortion and bring them to a standard geographic projection, with modified Everest datum. In the second stage co-registration was done by warping one image on the other using polynomial transformation. The transformation was defined by matching more than 25 pairs (as many as possible) of Ground Control Points (GCPs) on the images, selected from identifiable coastline features surrounding the area under study. The resampling at both the stages were performed by cubic convolution interpolation techniques to keep the spatial distortions minimum.

4.4 Retrieval of suspended sediments

The suspended sediment concentrations in the coastal areas have been derived using water-leaving radiance in band 490, 555 and 670 nm. The algorithm initially proposed by Tassan (1994) has been used to compute suspended sediments from OCM data. It has following mathematical form:

$$\text{Log } S = 1.83 + 1.26 \text{ Log } X_s \text{ for } 0.0=100.0 \text{ mg/l } S$$

X_s is suspended sediment concentration in mg/l and X_s is variable defined as

$$X_s = [R_{rs}(555) + R_{rs}(670)] * [R_{rs}(490) / R_{rs}(555)]^{-0.5}$$

R_{rs} is remote sensing reflectance in respective wavelengths.

2.5 Implementation of Maximum Cross Correlation (MCC) pattern matching technique

The Maximum Cross Correlation (MCC) pattern matching method is based on calculating cross-correlation coefficients. Statistically cross-correlation is a measure of the linear relation of two random variables. The cross correlation coefficient is given by

$$\rho = \text{COV}(x, y) / \{(\text{VAR}(x) \text{VAR}(y))^{0.5}\}$$

where x and y represent random variables from a two dimensional population, and VAR, COV are the variance and covariance of the random variables. By definition $-1 \leq \rho < 1$.

The computation method for deriving sea surface advective velocities consists essentially of identifying the maximum cross correlation in a lagged matrix between two sub areas of a pair of sequential scenes. The first image is divided into continuous sub areas called template window. The size of this window is taken as 64×64 . For the template, a large searching window was identified in the second image, having the template as its centre. In the Cartesian coordinate system $f(x, y)$ and $g(x+p, y+q)$ denote a possible pair of similar patterns in two time lapsed images. The vector (p, q) represents a possible spatial displacement of the original pattern between the two images.

$$\rho(p, q) = \text{COV} \{f(x, y), g(x+p, y+q)\} / \{[\text{VAR} \{f(x, y)\}, \text{VAR} \{g(x+p, y+q)\}]^{0.5}\}$$

where, $\text{COV} \{f(x, y), g(x+p, y+q)\}$

$$= 1/R \iint_R (f(x, y) - f) (g(x+p, y+q) - g(p, q)) dx dy$$

and the variances are computed by

$$\text{VAR}(f(x, y)) = 1/R \iint_R (f(x, y) - f)^2 dx dy, \text{ and}$$

$$\text{VAR}(g(x+p, y+q)) = 1/R \iint_R (g(x+p, y+q) - g(p, q))^2 dx dy$$

where, R is the image area.

Since the computation of the cross-correlation matrix is time consuming, a significant reduction of computational effort can be achieved by working in the frequency domain using the fast Fourier transform.

Fourier's theorem: Any function $f(t)$ can be expressed as sum of infinite number of sinusoidal terms.

$$F(t) = a_0 + \sum_{n=1}^{\infty} (a_n \cos nt + b_n \sin nt)$$

Fourier transform can be represented:

$$F1(w) = \int f1(t) e^{-iwt} dt$$

where $f1(t) e^{-iwt} = f(t)$, i.e.,

$$F(w) = \int f(t) dt \quad (1)$$

Convolution:

$$f1(\tau) * f2(\tau) = \int_{-\infty}^{\infty} f1(\tau-t) f2(t) dt \quad (2)$$

Convolution theorem:

$$f1(\tau) * f2(\tau) = \int_{-\infty}^{\infty} f1(\tau-t) f2(t) dt = F1(w) \cdot F2(w) \quad (3)$$

Cross-correlation using Fourier Transform:

$$C12(\tau) = \int_{-\infty}^{\infty} f1(t-\tau) f2(t) dt = -(f1(\tau) * f2(\tau)) = -F1(w) \cdot F2(w) \quad (4)$$

It is from above (1), (2), (3), cross-correlation coefficients, between the template and searching kernels are calculated. For 128×128 searching window and 64×64 template window, a matrix of 65×65 cross-correlation coefficients are calculated. From this matrix, maximum cross-correlation coefficient and corresponding x lag (p_{max}), y lag (q_{max}) are found. Fig. 1 shows the schematic of feature trekking using the above approach.

The MCC method indicates the actual flow during a specific period (average of two time lapsed images), i.e., Integrating tidal and wind influences.

2.6 Output of velocities in terms of magnitude and direction

The relative displacement (p, q) between the template and the searching windows of the sequential scenes when the cross-correlation has it's maximum value determines the advective velocity vector, the magnitude is given,

$$C = [(p_{max} \Delta x)^2 + (q_{max} \Delta y)^2]^{0.5} / \Delta t$$

The direction of motion, θ is given by

$$\theta = \arctan(q_{max} \Delta y / p_{max} \Delta x)$$

2.7 Overlay of vector on imagery

The retrieved information about vectors along with corresponding geographic co-ordinates was put as database in Grapher and a plot of vectors was generated. This plot was utilized to overlay on the imagery.

3. Results and Discussion

The patterns of ocean colour on sequential images are used as a tracer to measure displacement of surface waters. The velocity derived as a measure of this transport is known as advective velocity. Gracia and Robinson (1989) analysed sequential CZCS data to derive sea surface velocities in shallow seas, in particular eastern English Channel. Sea Surface

Temperature (SST) data provided by Advanced Very High Resolution Radiometer (AVHRR) data has also been utilized to retrieve advective velocities by Wu et al. (1992). However, the spatial resolution was one of the major constraint for achieving the desired accuracy. During the course of the present study OCM data with improved spatial resolution and distinct signatures of suspended sediments acting as tracer was

analysed to derive the advective velocities. Fig. 2 shows the velocity vectors overlaid on suspended sediment concentration map derived from OCM data of January 13, 2000. The current velocities retrieved were compared with synchronous data collected along east coast during GSI cruise ST-133 of R.V. *Samudra Kaustubh* during January 2000. Table 2 shows the in-situ current vectors (13, 14, 15 January, 2000 off Dhamra estuary, north Bay of Bengal) and advective velocity vectors derived by maximum cross correlation pattern matching method applied on sequential (January 13 and 15, 2000) OCM data. Fig. 3 show that observed that coefficient of determination, R-squared is 0.99 for both magnitude (cm/s) and direction (deg.).

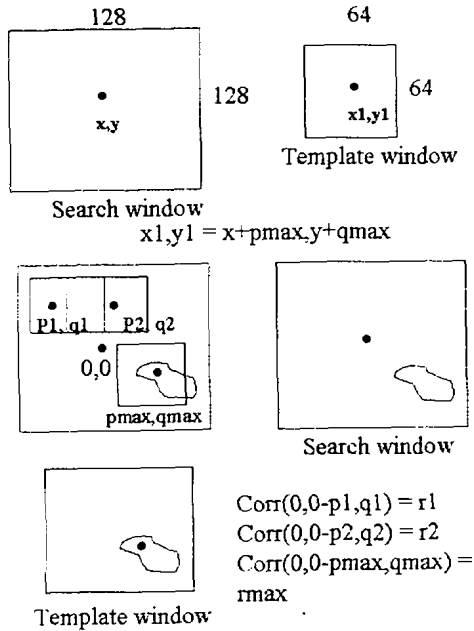


Fig. 1. Feature tracking using maximum cross correlation pattern matching.

4. Conclusions

The study demonstrates feasibility of applying maximum cross-correlation method to sequential OCM data in order to generate vector fields representing the transport velocity of optically visible near surface tracers. The retrieved velocities can be utilized for various applications like prediction of regional dispersal patterns of suspended sediment with respect to seasonal variations, calculation of tidal flux parameters (tidal influx volume, tidal zone and velocities), calculation of long shore transport of sediments, calculation of sediment deposition rates (siltation) in coastal areas, deriving a relationship between shoreline changes, surface sediment distribution and hydrodynamic energy regimes and prediction of coastal areas likely to be affected by accretion and erosion.

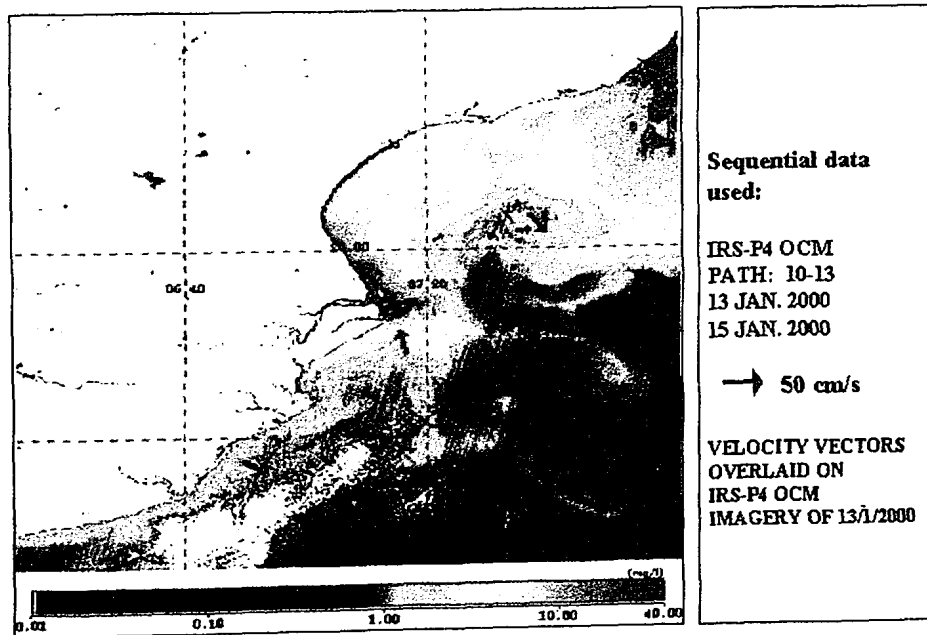


Fig. 2. Advective sea surface velocities derived from sequential IRS-P4 OCM suspended sediment imagery over Dhamra estuary, North Bay of Bengal.

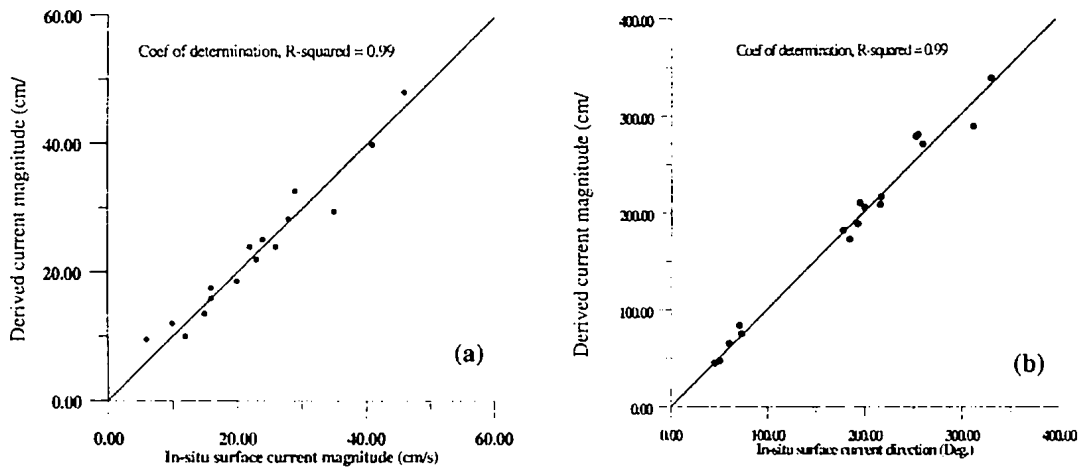


Fig 3. (a) Variation of in-situ surface current magnitude with derived surface current magnitude, (b) Variation of in-situ surface current direction with derived surface current direction.

Table 2. Comparison of in-situ current vectors and advective velocity vectors derived by maximum cross correlation pattern matching method applied on sequential (January 13 and 15, 2000) OCM data covering north Bay of Bengal

Sr. No.	Latitude	Longitude	In-situ Magnitude (cm/s)	Derived Magnitude (cm/s)	In-situ Direction (°)	Derived Direction (°)
1.	19.05	85.47	6	9.5	195	210
2.	20.97	87.16	12	10.0	312	288
3.	20.02	87.21	10	12.0	71	84
4.	21.07	87.16	15	13.5	185	172
5.	20.83	87.21	15	13.6	60	65
6.	20.97	87.26	16	15.9	73	75
7.	21.07	87.26	16	17.5	217	216
8.	20.91	87.26	20	18.6	253	278
9.	20.97	87.31	23	21.9	45	45
10.	20.71	87.31	26	23.9	255	280
11.	20.91	87.31	22	23.9	330	338
12.	21.08	87.21	24	25.0	193	188
13.	20.96	87.21	28	28.2	50	47
14.	19.12	85.60	35	29.4	260	270
15.	20.66	87.28	29	32.6	200	205
16.	20.97	87.36	41	39.8	216	208
17.	20.02	87.36	46	48	178	181

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