

## Surfzone currents at Candolim and Miramar beaches of Goa, India: measurements and comparisons

E. M. Yadhunath<sup>1</sup>, Jaya Kumar Seelam<sup>1\*</sup>, M. Jishad<sup>1,2</sup>, R. Gowthaman<sup>1</sup>, C. Rajasekaran<sup>3</sup> & P.S. Pednekar<sup>1</sup>

<sup>1</sup>CSIR-National institute of Oceanography, Dona Paula Goa, India

<sup>2</sup>School of Oceanography, ACSIR, CSIR- institute of Oceanography, Dona Paula Goa, India

<sup>3</sup>National Institute of Technology Karnataka, Surathkal, India

\*[Email: jay@nio.org]

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Measurements in the surfzone current are often carried out using Acoustic Doppler Velocimeters, Electromagnetic current meters, as well as visual observations based on floats. A simple approach is used to install an Aanderaa current meter in water depths less than a meter and the surfzone currents are measured for a period of about 2 hours during a rising tide. Surfzone wave heights and tide were also simultaneously measured and used to compute wave induced currents based on appropriate equations. The obtained current velocity compared with measured RCM data. Measurements were carried out separately at two beaches (Candolim and Miramar) which have varying topography and different surfzone conditions.

**[Keywords:** Longshore current Velocity, shoreline, surfzone, Breaker angle, Breaker height]

### Introduction

In the nearshore region longshore currents are both generated as well as affected by breaking waves. Another factor that is important in estimating the longshore currents is the beach face slope. Near shore topography also has an important role in longshore current generating mechanism, which direct the longshore fluxes and also transforms itself according to waves and currents<sup>1</sup>. Most of the theories related to longshore currents are based on the principle of conservation of momentum or energy. Research on longshore current velocity is important because it has the ability to erode, transport and deposit sediments. Few studies are also carried out based on multiple regression analysis, and continuity relations; e.g., Galvin<sup>2,3</sup> derived an equation for longshore current velocity calculations using continuity principle.

Galvin<sup>2</sup> states that sediment transport is primarily related to the velocity of the transporting current. In Galvin's investigations the longshore currents are described and analytically predicted without considering sediment motion. Longuet-Higgins<sup>4</sup> hereinafter referred as LH70, used the concept of radiation stress for obtaining longshore current velocity equation as a function of distance from swash

line together with eddy viscosity. LH70 considered eddy viscosity to tend to be zero as the shoreline approaches but similar concept of radiation stress carried out by<sup>5</sup>, considered horizontal eddy viscosity as a constant at the shoreline. Another difference observed in Bowen's studies is that the bottom friction is assumed to be proportional to longshore velocity. Putnam et al.<sup>6</sup> assumes that unsteadiness in longshore currents on natural beaches may be due to rip currents.

Galvin<sup>2</sup> pointed out that 'For the meaningful prediction longshore currents, empirical correlation of reliable data is significant'. Harrison<sup>7</sup> obtained 98 data sets from Atlantic Ocean beaches including beach slope, breaker height, period, angle, crest length, and trough depth in August and September of 1966 and subjected them to multi regression analysis to obtain longshore current velocity using the observed wave parameters. The results obtained after first analysis implies that velocity has a prime dependence on wave angle than wave period, breaker height and beach slope. To arrive at the detailed knowledge about longshore current velocity it is important to know about the wave characteristics which are responsible for the development of bars and corresponding troughs. Komar<sup>8</sup> proposed a solution for longshore

current velocity prediction based on LH70 concept of radiation stresses.

Acceleration, deceleration, stagnation, reversal and bifurcation are the processes associated with spatial variability of longshore currents. Within the surf zone, interaction between wave, current and topography is due to multitude of velocity vectors in current field<sup>1</sup>. Longshore currents reaches their highest velocities between shoreline and breaking point<sup>2</sup>. The breaking waves approaching the straight coastline at an oblique angle results in the mean longshore currents more or less parallel to the coastline<sup>9</sup>. Most of the above theoretical and empirical formulae are presented in Table 1.

Inman and Quinn<sup>10</sup> visually observed long shore current velocity and breaking wave parameters and concluded that because of the effect of the wind, the longshore components have more symmetrical

velocity distribution and showed that a small percentage of current moves opposite to the direction of prominent current. Lanfredi and Framiñan<sup>11</sup> suggest that for predicting longshore current velocity, most important variables are angle of incidence and longshore component of wind velocity. After including the wind effects to LH70 and Komar formulae, a better fit with observed and predicted current velocity was observed.

To arrive the detailed knowledge about longshore current velocity it's important to know about the wave characteristics which responsible for the development of bars and corresponding troughs<sup>12</sup>. Komar<sup>8</sup> proposed a solution for longshore current velocity prediction based on LH70. In their studies LH70 considered eddy viscosity tending to zero as the shoreline approaches but similar concept of radiation stress carried out by<sup>5</sup>, taking horizontal eddy viscosity as a

Table 1—Theoretical and Empirical Formulas

Equation	Author	Formulae		Basic scheme of Analysis
1	Galvin <sup>3</sup>	$V = KgmT\sin(2\alpha_b)$	K=1	Continuity
2	Longuet-Higgins <sup>4</sup>	$V = 20.7s(gH_b)^{\frac{1}{2}}\sin(2\alpha_b)$		Momentum radiation stress
3	Harrison <sup>7</sup>	$\bar{V} = -0.170455 + 0.0317376(\bar{\alpha}_b) + 0.031801(\bar{T}_b) + 0.241176(H_{bs})$	$\bar{m}$ is slope	Multiple regression
4	Brebner and Kamphus <sup>13</sup>	$V1 = 2.5 \left[ \frac{g\theta H_0}{T} \right]^{\frac{1}{3}} [\sin(1.65\alpha_0) + 0.1\sin(3.30\alpha_0)]$	$\theta$ is slope	Energy conserved
5	Brebner and Kamphus <sup>13</sup>	$V2 = 6 \left[ \frac{g\theta^2 H_0^3}{T^2} \right]^{\frac{1}{4}} [\sin(1.65\alpha_0) + 0.1\sin(3.30\alpha_0)]$		Momentum conserved
6	Putnam, Munk & Traylor <sup>6</sup>	$V = \frac{a}{2} \left( \sqrt{1 + \frac{4C\sin\alpha}{a}} - 1 \right) a = (2.61H_b m \cos \alpha) / KT$	m=Bottom slope, K=0.0078, breaking wave velocity $C = \sqrt{2.28gH}$	Momentum
7	Inman and Quinn <sup>10</sup>	$V = \left[ \left( \frac{1}{4X^2} + C\sin\alpha_b \right)^{\frac{1}{2}} - \left( \frac{1}{2X} \right) \right]^2 X = 108 \frac{H_b}{T_b} m \cos \alpha_b$		Momentum
8	Komar <sup>8</sup>	$V = 2.7U_m \sin \alpha_b \cos \alpha_b U_m \frac{1}{2} \gamma_b (gH_b)^{1/2}$	$U_m$ =Maximum wave orbital velocity $Y_b = H_b/h_b = 0.78$	Empirical
9	Bruun <sup>12</sup>	$V = C_f \left[ \frac{0.95}{\sqrt{gK}} H_b^{3/2} \frac{S \sin 2\alpha_b}{T} \right]^{1/2}$	$c_f$ is chezy's the friction coefficient	Continuity
10	Davis and Fox <sup>17</sup>	$V = 2.29s(gH_b)^{1/2}\sin\alpha_b$		Empirical
11	Pilarczyk <sup>18</sup>	$V = K_L \sqrt{gH_b} \sin 2 \alpha_b$	$K_L$ coefficient ranges between 0.3-0.6	

constant at the shoreline. Putnam et al.<sup>6</sup> included the processes associated with acceleration, deceleration, stagnation, reversal and bifurcation and derived the theoretical relationship for longshore current velocity with breaker height breaker period, angle between the breakers, beach contours, and beach slope. These results are applicable in the surf zone of straight beaches with parallel contours. Brebner and Kamphus<sup>13</sup> suggested that angle made by the breaker crest at deep water and the breaker angle is the major sources providing energy to longshore current generation. They derived a relationship between longshore current velocity and wave parameters but these findings are applicable for beaches with straight shoreline with constant slope and constant deep water wave height and period.

Longshore current velocity can be reasonably predicted with the wave data and topography of the beach using methods discussed above but the studies on longshore currents and its prediction along Indian coast line is limited in number. Among the notable works in India, Kumar et al.<sup>14</sup> compared measured data from Kannirajapuram coast, Tamil Nadu with estimated results using Galvin and LH70 equations and observed that Longuet-Higgins over predicts by 32% whereas Galvin over predicts by 6%. But<sup>15</sup> revealed that modified equations of LH70 and Komar can give better correlation as shown with the measured data from Valiyathura and Aleppey coasts, Kerala. Another approach was by<sup>16</sup> between Ratnagiri and Mangalore coasts, India according to their findings LH70 gave 25% higher values than Galvin.

This paper comprises of studies carried out at two different beaches of Goa, with different beach face and near shore morphology and different wave characteristics to understand the variation of longshore current velocity and direction using a Aanderaa<sup>®</sup> self-recording current meter and to establish the usability of longshore current velocity equations available in the literature to this coastal region through comparisons between field measurements and derived currents.

## Materials and Methods

Two beaches on the west coast of India in the state of Goa (Fig.1) are considered in this paper, viz., Candolim beach and Miramar beach, to understand the temporal variability of surfzone current system. Goa encompasses an area of 3,702 km<sup>2</sup> and lies between the latitudes 14°53'54"N and 15°40'00"N



Fig. 1—Study Area (Source: Maps of India)

and longitudes 73°40'33"E and 74°20'13"E. Candolim beach (15°30'38"N; 73°45'53"E) is located 14km North of Panaji, capital of Goa state. Miramar beach (15°28'57"N; 73°48'27"E), is a highly dissipative beach stretched within two promontories Cabo-da-Gama in the south and Fort Aguada in the north, with River Mandovi having its confluence with the Arabian Sea. Candolim beach, on the other hand is a moderately dissipative beach with a relatively shorter surfzone width compared to Miramar. Spilling waves are more common in Miramar whereas plunging and spilling waves are common at Candolim.

AANDERRA<sup>®</sup> self-recording current meter (RCM9) was used to measure and record the vector averaged flow speed and direction. RCM9 was installed at a water depth of .5m with its sensor head placed above the seabed and the body buried under the seabed. Current data was recorded for 2hr at Candolim and 3hr at Miramar with data sampled at 2s interval and averaged over 1 minute duration. A Seabird<sup>®</sup> wave and tide gauge (WTG) was deployed for 1.5hr in the vicinity of the RCM9, without obstructing the current measurement field, to record the wave heights and wave periods, with a data sampling rate of 4Hz. The surfzone waves were observed at 15 minute intervals with meaningful wave data obtained for a period of about 13 minutes for every record. The noise in each of the 13 minute wave records was filtered and the filtered wave data was subjected to zero-crossing analysis to obtain wave heights and wave periods. The wave height and wave period for every minute was averaged and further used in estimating the longshore currents. Water level

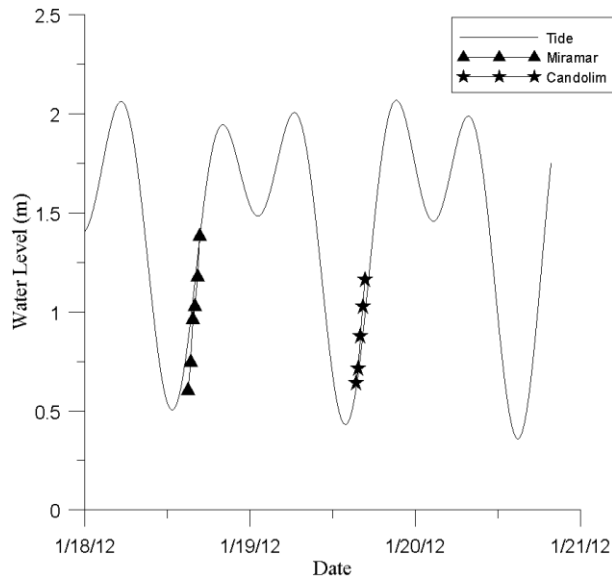


Fig. 2—Comparison of Predicted tide (solid line) and measured water levels

variation during the wave observation along with predicted tide is presented in Fig. 2. Longshore currents were estimated using the equations 1 to 10 presented in Table1 and are compared with field measurements.

The data on waves and currents as well as beach profiles were measured at these two beaches on two different dates but with similar tide and wave conditions. The wave breaker angle estimation in littoral environmental observation program is still based on a visual method and therefore is subjective. In the absence of sophisticated wave direction recording instruments a simple and practical method outlined in<sup>19</sup>, based the time lapse between the wave breaking progressively at two points along the crest parallel to shoreline presented is used (Fig. 3). If AB is the shoreline, the time taken for a wave to break from A to C is noted for 10 wave breakers and  $\Delta t$  is calculated. BC is calculated using equation:

$$BC = C_b \Delta t \tag{a}$$

where,  $C_b$  is the wave celerity using shallow water approximation.

$$C_b = 3.544 \sqrt{H_b} \tag{b}$$

where  $H_b$  is the breaker height in meter. Breaker angle can be calculated as

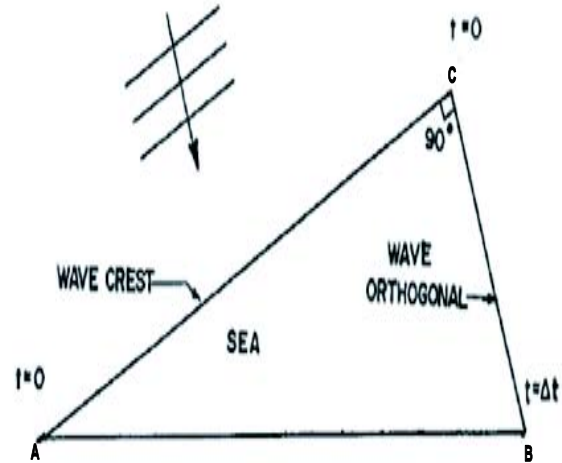


Fig. 3—Breaker angle measurement representation

$$\alpha = \tan^{-1} \left( \frac{BC}{AB} \right) \tag{c}$$

Sonu et al.<sup>20</sup> suggests that angle of wave incidence distinguishes itself as the most variable parameter in both linear and non-linear regression analysis.

**Results and Discussion**

*Longshore current velocity and Direction*

Measured longshore currents from Candolim (Fig. 4) showed an average velocity of 0.35 m/s, a maximum velocity of 0.55 m/s and a minimum velocity of 0.078 m/s with the overall direction being predominantly south-southeast. At Miramar the average current velocity was about 0.25 m/s and the maximum velocity was 0.44 m/s with predominant flow in south-southeast direction (Fig. 5). Even though the direction of currents both at Miramar and Candolim are towards south-southeast the average velocity measured from Miramar is comparatively lower than Candolim, which is attributed to the wave climate and steepness of the beach.

Six wave records from Miramar and five wave records from Candolim were analyzed (Fig. 2). Each wave record gives corresponding wave height and wave period after zero crossing analysis. Comparison of wave height and wave period between Miramar and Candolim beaches show that the average wave periods from both the study areas are more or less the same ~11s, but the average wave height at Candolim is about 32.25% greater than that at

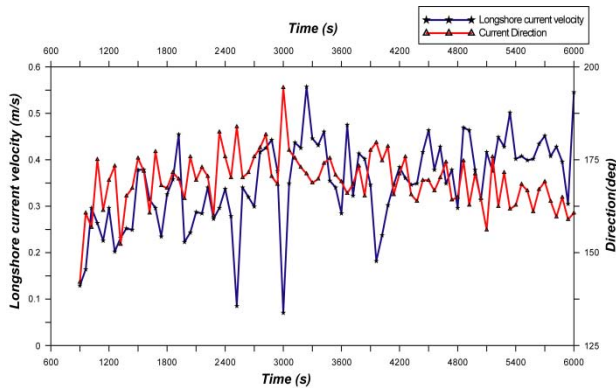


Fig. 4—Longshore current velocity and Direction changes obtained from Candolim on 19/1/12

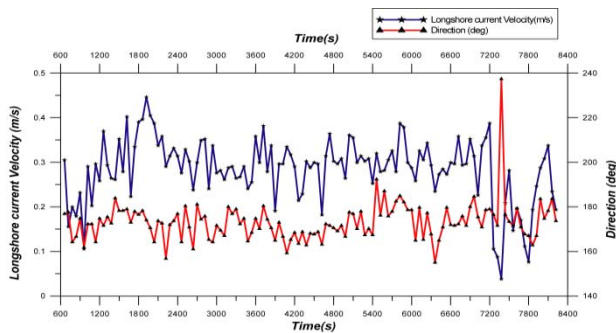


Fig. 5—Longshore current velocity and Direction changes obtained from Miramar on 18/1/12

Miramar (Figs 6 and 7). Wave height at Candolim ranges between 0.2 m and 0.41 m, but at Miramar it is about 0.11 m and 0.35 m. And the measured wave period at Candolim ranges from 7.92-15 s but at Miramar it is about 8.5-16.65 s, somewhat higher than at Candolim. In this study it is observed that wave height and period are inversely related to each other (Figs 6 and 7). From the beach profiles measured from Miramar and Candolim it is observed that Candolim is 67% steeper than Miramar (Fig. 8).

Comparing Wave height and Period from Miramar and Candolim implies that average wave periods from both the study areas more or less same in magnitude of 10 s, but differences in average wave height observed from Candolim about 0.31 m and from Miramar is about 0.22 m which is less than that of Candolim (Figs 6 and 7). Height is more dependent variable than period even though the period of the waves was same as from Candolim and Miramar due to difference in height the velocity variations observed.

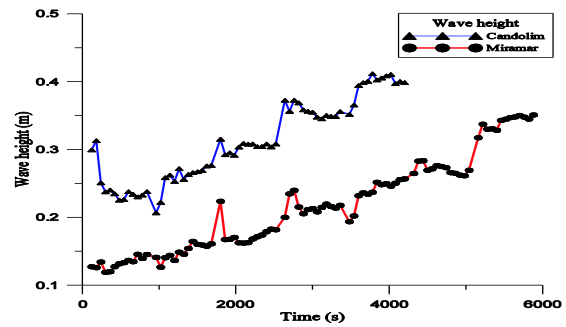


Fig. 6—Wave height variations with time along Candolim and Miramar

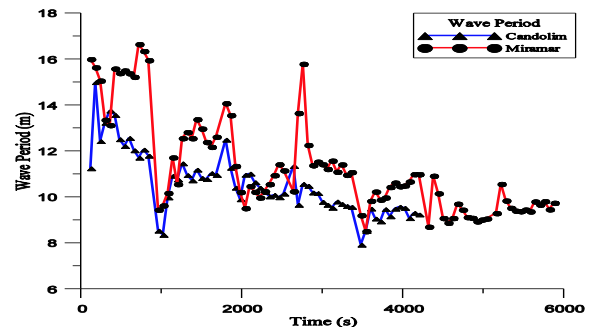


Fig. 7—Wave period variations with time along Candolim and Miramar

*Comparison between measured and theoretical estimation*

Comparison of averaged measured current meter data and average computed data for different wave records for the four equations viz., LH70, Inman and Quinn, Pilarczyk and Komar, for Candolim and Miramar are presented in Figs 9 and 10 respectively. At Candolim empirical relation of Komar gives better matching results; whereas at Miramar, none of the estimated methods predicted good results for the default values. The other equations of Galvin, Harrison, Bruun, Brebner (both momentum and energy approaches), Davis and Fox<sup>17</sup> failed to estimate reliable longshore currents as compared to other methods. These equations either under predicted or over predicted the longshore currents by a large margin.

In this study LH70 theoretical equation with its default values failed to predict better correlation with measured current velocity. Therefore, the constant 20.7 in the equation [2] was replaced by 2.69 for data set of Candolim and 9.10 for the data sets from Miramar after subjecting the measured data to regression analysis. Hameed et al<sup>15</sup> used a value of 7.4 instead of 20.7 and Gourlay<sup>21</sup> used 3.72 and 2.87 to obtain a better correlation between measured and computed velocities.



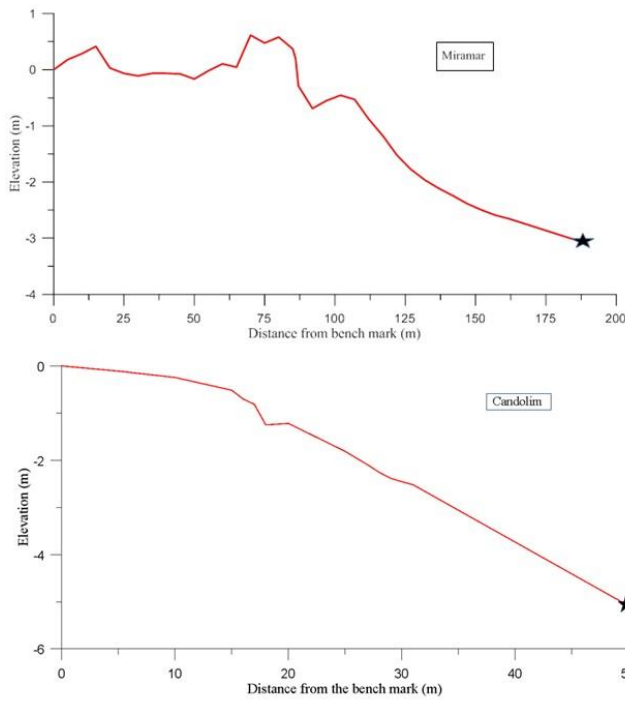


Fig. 8—Representative beach profile of Miramar and Candolim with location of deployed current meter and WTG

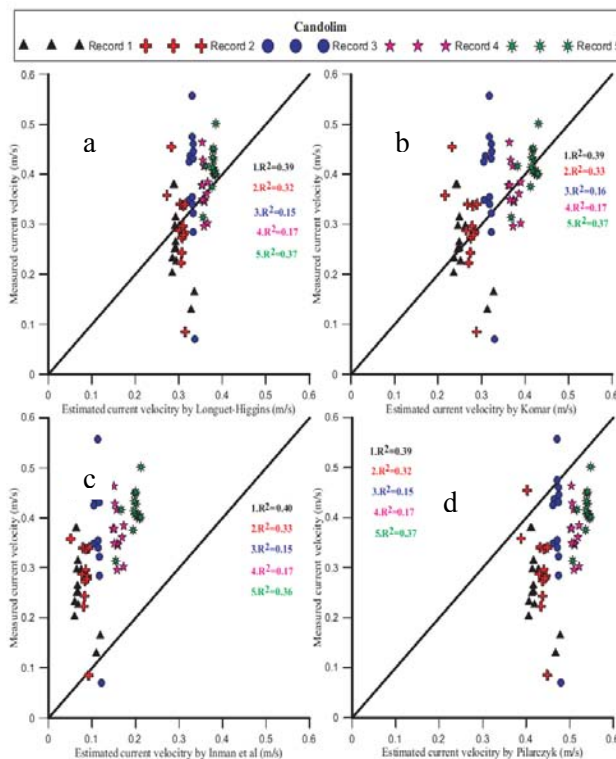


Fig. 9—Comparison between the measured and estimated current velocities from Candolim on 19/1/12

In terms of correlation between measured data and estimated velocities, equations based on LH70, Komar, Inman and Quinn and Pilarczyk provided better correlation than other methods. At Candolim LH70 (Fig.9a), Komar (Fig.9b) and Pilarczyk (Fig.9d) give correlation of 39% and 37% with measured for first and last wave record data but Inman and Quinn give 40% and 36 % of better correlation than other equations (Fig.-9c). But at Miramar LH70 and Pilarczyk give 58% and 60% correlation with measured current velocity for second and last wave record data (Fig. 10a and 10d). But Inman and Quinn give only 45 % for second wave record and 63% for last wave record (Fig. 10c) and Komar also predicted same correlation for last wave record and 57% for the second wave record (Fig. 10b).

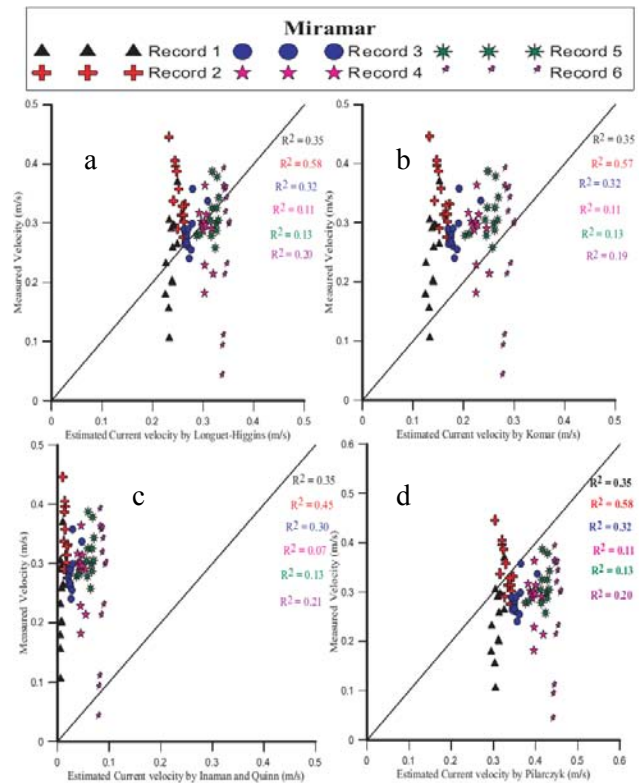


Fig. 10—Comparison between the measured and estimated current velocities from Miramar on 18/1/12

However, it can be seen that considering both the predicted values and correlation between the measured velocity and estimated velocity, Komar and LH70 estimated better values than other methods. Earlier studies in the surrounding coastal regions indicate that LH70 equation is appropriate for the prediction of longshore current velocity at Anzali coast, Iran<sup>22</sup>.

### Conclusions

Longshore current velocity measured from Candolim is observed to be higher than that of Miramar, since the wave activity is greater as well as the beach slope is steeper at Candolim. Maximum longshore velocity of 0.55 m/s observed at Candolim but at Miramar it is only about 0.44 m/s. Wave height measured from both the areas showed that at Candolim even though the breaker height is more than that of Miramar, but the period has similar magnitude of about 11s. Therefore, the variations in current speed and direction along these areas are mainly due to variation in wave height, and oblique wave approach. Comparing the results including average current velocity and correlation coefficient values modified Longuet-Higgins and Komar equations predicted better results at Candolim and Miramar. Energy and Momentum based equations gave very small longshore current velocity compared to measured data. In this study Longuet-Higgins equation can be said to have given better results after modification. Further studies are needed to arrive at a better longshore current equation for Indian coasts.

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