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Research Article

SIMULATION OF HYPOTHETICAL OIL SPILL TRAJECTORY MODEL FOR SOUTHERN TIP OF INDIA

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ABSTRACT

Oil spill is one of the major contributors to marine pollution. The objective of this work is to simulate the hypothetical oil spill trajectory of oil released from ship due to accidents in the southern tip of India during southwest (SW) and northeast (NE) monsoonsusing MIKE 21 hydrodynamic coupled with particle track model.The tide, wind and current data measured by tide gauge, Autonomous weather station (AWS) and recording current meter (RCM). The simulated tides and current components show good agreement with the measured values. The fate spilled oil at five different locations were studied. Spilled oil from the locations 1, 2 and 3 were reached to the shore and the oil residues at station 4 werecompletely weathered. The particles released at locations 5 were moved towards the northwest part of Sri Lanka. The results from this study will be useful to investigate the effect of oil spill and to monitor their impact on marine ecosystem.

Keywords: Oil spill, Trajectory, hydrodynamics, particle track model, Indian Ocean

INTRODUCTION

Spilled oil in the marine environmentisgreat attention because of most important energy sources in the world. The world's demand for petroleum products has been estimated about 84 mb/day in 2005 to 116mb/day in 2030 (Anon, 2006), which indirectly increases the risk of oil spill in the marine environment (Vethamony et al., 2007).IEA (2016) reported the global oil demand growth is expected to slow from 1.4 mb/d in 2016 to 1.2 mb/d in 2017.Therefore, increasing global concerns on oil spill threats, India aims to tackle the most prevalent issues after the Sundarbans spill incident occurred on 9 December 2014.

Crude oil and their refined products are transported through tanker/super tanker, has increasing the seaborne oil trade. Generally most of the large oil spill in the world primarily arisen from tanker operation.Large volume of oil transported from the Persian Gulf to Japan and China, which enters in to the Indian Exclusive Economic Zone (EEZ) (Kankara and Subramanian., 2007).In case of oil spill along the EEZ, notably causes drastic damage to marine ecosystem. The risk of major oil spill occurring along the west coast of India is considerably higher than the east coast.

One half of the world's seaborne tonnage is transported by two major trade routes: Arabian Gulf to Europe around Africa and Arabian Gulf to Japan through Malacca Straits. These direct shipping routes links the Indian Ocean, Pacific Ocean, European Union, Middle East, India, China, Japan, South and Korea (Mustaffa et al. 2014). A statistical review of world energy shows that the oil transportation from Middle East countries starts from 1973 along Arabian Sea. Eventually, Bay of Bengal tanker routes also gradually increased to transport the oil from 1982 onwards. In the last decade, several oil spill accidents/incidentsoccurred along the Indian coastal water (Desa et al., 2002;Vethamony et al., 2007). Based on the variety of physico-chemical properties and local met-oceanic conditions, the released oil into the ocean have undergone to various weathering processes includingspreading, evaporation, dissolution, photo-oxidation, emulsificationand biodegradation (Bonn Agreement, 2015; Zhang et al., 2015; Cunha et al., 2016). The surface current (includes advection, spreading and turbulent diffusion)and wind (oil-air interface) haveplayed a mojor role to transport the oil (Han et al., 2001).

The study of oil spill trajectory modelling along the Indian coast is economically important for emergency response planning and environmental impact assessment, as they are in the major traffic zones of oil transport (Mani Murali and Kumar., 2009). Therefore, spill can occur anywhere along the shipping routes. Suneel et al. (2013, 2014) reported that the spill/tanker wash and offshore oil exploration cause the tar ball formation, which beached along the Goa and south Gujarat coast.The east and west coast of India are ecologically and economically more important region. Though many numerical modeling studies for oil spill risks have been carried out along the east and west coast of India, no information is available in the southern tip of India. Therefore, the present study of hypothetical oil spill trajectory modeling is necessary for the effective decision making, oil spill contingencyplanning and prevention (ITOPF, 1986) etc.,The aim of this study is to simulate the hypothetical oil spill trajectory model for understanding the crude oil spill transport under weathering processes in southern tip of India during NE and SW monsoon seasons.

STUDY AREA

The southern tip of India is situated in southern most part of coastal region of Tamil Nadu and Kerala state,whichis sourrounded by the Gulf of Mannar (GoM), Arabian Sea (AS) and Indian Ocean (IO). In order to cover the tanker routes, model domain is extended from Ambalapuzha (9°22'12.34''N- 76°21'7.67''E) in the southwest coast of India to Mandapam (9°16'54.29''N- 79°11'19.45''E) in the southeast coast of India (Figure 1), over the distance of ~455 km.

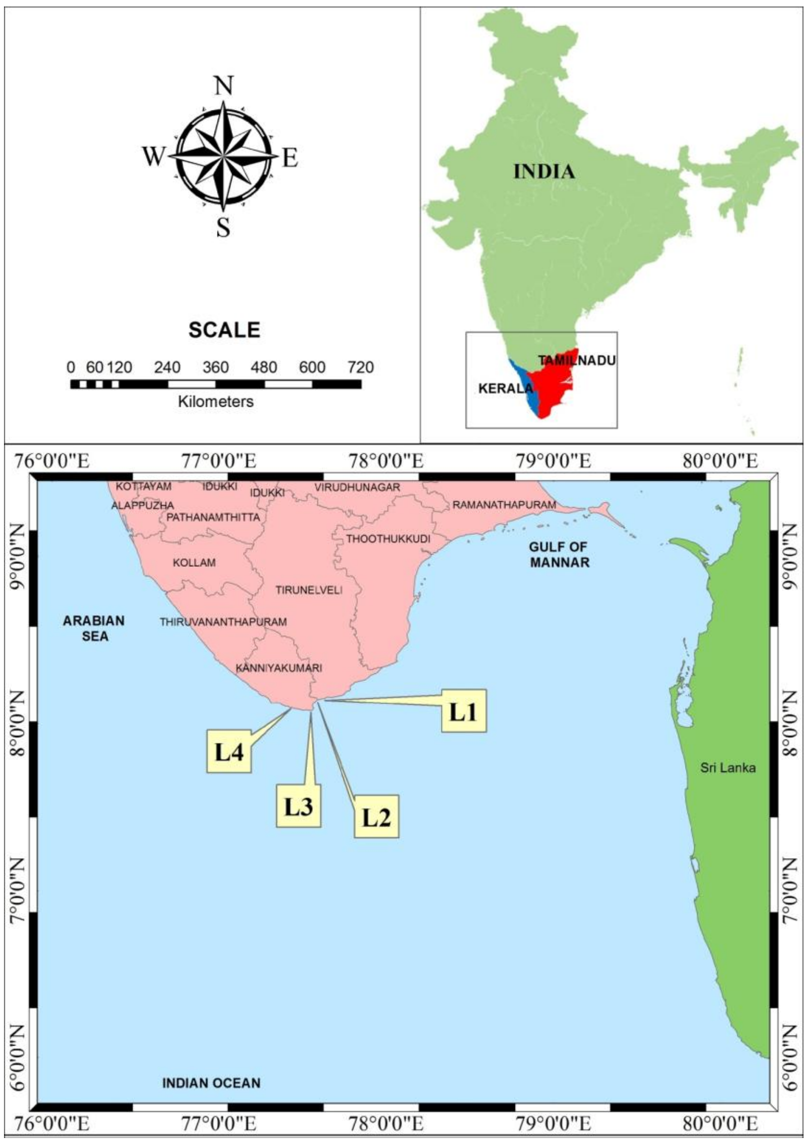

Figure 1: Study area and deployment locations

The GoMis one of the high productive areas,since GoM comprises variety of sensitive marine habitats like coral reefs, mangroves and sea grasses, it has been declared as Marine Biosphere reserve in 1989.This is the most dynamic ecosystem compressing21 Islands from Tuticorinto Rameswaram, which endowed with a wide variety of extensive coral reef ecosystems, estuaries, mangroves, seaweed and seagrass. An unexpected large volume of oil may potentially impact coral reef ecosystem. However, frequent transportation of oil tanker increases the risk of accident along the study area, which could damage the GoM ecosystem.

The study area is influenced by two remarkable seasonally reversal wind system, which are termed as NE (November- Febraury) and SW (June- September) monsoon. These seasonally reversing wind cause the major circulation pattern in northern Indian Ocean(Shankar et al., 2002). In other hand, this region has more productive area due to the results of upwelling (Avinash et al., 2016). Therefore, the coastal region of the present study area has considered as more ecologically sensitive marine environment. Moreover, the national and international oil tanker routes in the study area may cause oil spills which makes serious environmental issues and ecological imbalance.

DATA COLLECTION

Bathymetry of the present study area was prepared by extracting depth data from MIKE CMAP and Naval Hydrographic Office (NHO) charts. The domain for the numerical model is covering an area of GoM, BoB and IO. Hence, the computational domain of the modelis extended from 76.3° to 80.3°E longitude and 6.0° to 9.3° N latitude. The triangle element mesh techniques have applied in this model, which provides the maximum flexibility of the model. The element size varies from 150 m in the nearshore to 20 km in deep sea. The depth values of model domain are ranged from 0 to 3500 m (figure 2).

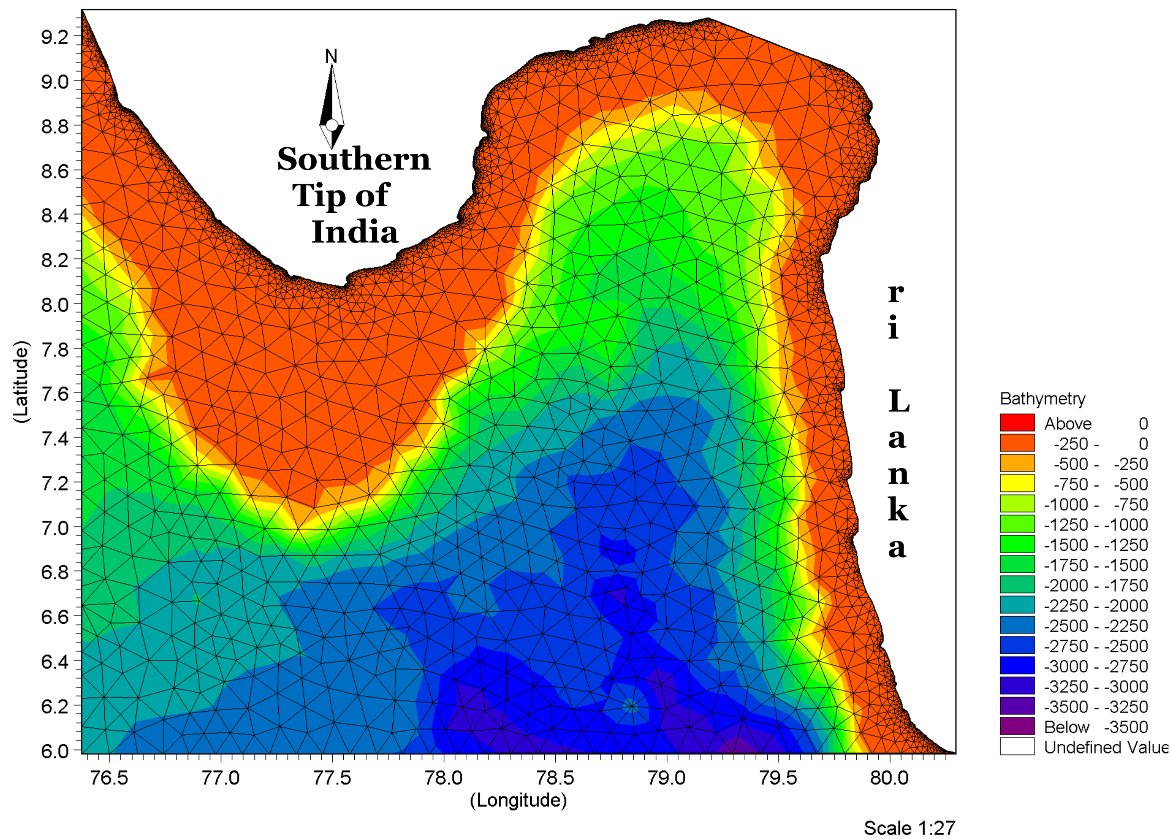

Figure 2: Mesh and bathymetry of the model domain

The present model domain consist of three open boundariessuchaseast (head of Gulf of Mannar),west (Arabian Sea) and south (Indian ocean), whereas the northern boundary is marked by land.The highly valuable hydrodynamic model results are validated with available tides and current meter data, which are collected using MIDAS Tide gauge and RCM (Recording Current Meter). RCM current meters deployed along with tide gauge instrument. Wind data is collected using automatic weather station (AWS). The deployment locations aregiven in table 1.

Sl. No.	Monsoon Seasons	Name of the location	Geographical location		Name of the Instrument and serial number	Depth of Deployment(m)
			Lat (^{0}N)	Long (^{0}E)		
1	North East	Near Chettikulam	**No Data**			
2		Vattakkottai	80 07.909′	77^0 35.323′	Valeport (Tide Gauge-24503) and RCM (1061)	9
3		Kanyakumari tip	8^0 04.188′	77^0 33.017′	Valeport (Tide Gauge-23079) and RCM (1059)	12
4		Off Pallam	8^0 05.446′	77^0 25.860′	Valeport (Tide Gauge-19036) and RCM (1119)	12
5	South West	Near Chettikulam	8^0 08.004′	77^0 37.808′	Valeport (Tide Gauge-21163) and RCM (1119)	12
6		Vattakkottai	80 07.909′	77^0 35.323′	Valeport (Tide Gauge-35317) and RCM (90)	9
7		Kanyakumari tip	8^0 04.188′	77^0 33.017′	Valeport (Tide Gauge-19031) and RCM (239)	12
8		Off Pallam	**No Data**			

Table 1: Deployment deatail along the Kanyakumari coast

MODEL DESCRIPTION

Now a days, several numerical models have been developed to simulate the trajectory of spilled oil. Spill model is consisted of two main module techniques: hydrodynamic modeling (flow model) and transport-fate model.

Flow Module Technique:

The Mike-21 FM (HD) model has been applied successfully to simulate the hydrodynamics of the southern tip of Indian coast during NE and SW monsoon season.It is widely used to simulate currents and water level variationsin a x and y axis (DHI, 2011; Panda et al., 2013; Al Hakim et al., 2015).Mike-21 FM 2D hydrodynamic model simulates the currents by solving shallow water depth averaged Navier-Stokes equation, which consistsof continuity, momentum, temperature, salinity and density equations. The following equations are used in this hydrodynamic flow module.

The continuity equation is

$$\frac{\partial \zeta}{\partial t}+\frac{\partial p}{\partial x}+\frac{\partial q}{\partial y}=\frac{\partial d}{\partial t} \qquad \textbf{Equation (1)}$$

The momentum equation in x-direction is

$$\begin{aligned}&\frac{\partial p}{\partial t}+\frac{\partial}{\partial x}\left(\frac{p^2}{h}\right)+\frac{\partial}{\partial y}\left(\frac{pq}{h}\right)+gh\frac{\partial \zeta}{\partial x}\\&+\frac{gp\sqrt{p^2+q^2}}{C^2.h^2}-\frac{1}{\rho_w}\left[\frac{\partial}{\partial x}(h\tau_{xx})+\frac{\partial}{\partial y}(h\tau_{xy})\right]-\Omega_q\\&-fVV_x+\frac{h}{\rho_w}\frac{\partial}{\partial x}(p_a)=0\end{aligned} \qquad \textbf{Equation (2)}$$

The momentum equation in y-direction is

$$\begin{aligned}&\frac{\partial q}{\partial t}+\frac{\partial}{\partial y}\left(\frac{q^2}{h}\right)+\frac{\partial}{\partial x}\left(\frac{pq}{h}\right)+gh\frac{\partial \zeta}{\partial y}\\&+\frac{gq\sqrt{p^2+q^2}}{C^2.h^2}-\frac{1}{\rho_w}\left[\frac{\partial}{\partial y}(h\tau_{yy})+\frac{\partial}{\partial x}(h\tau_{xy})\right]+\Omega_p\\&-fVV_y+\frac{h}{\rho_w}\frac{\partial}{\partial y}(p_a)=0\end{aligned} \qquad \textbf{Equation (3)}$$

Where, ζ is the water level (m); p and q are fluxed densities in x and y directions ($m^3\ s^{-1}m^{-1}$); t is time (s); x and y are space coordinates (m). The x and y-momentum are given in Eq. (2) and Eq. (3), respectively. h is water depth (m); f is the wind friction factor (dimensionless), V, V_x, and V_y are wind speed and components in x and y directions ($m\ s^{-1}$), respectively; Ω_p is the Coriolis parameter (s^{-1}); p_a is atmospheric pressure ($kg\ m^{-1}\ s^{-2}$); ρ_w is the density of water ($kg\ m^{-3}$); and τ_{xx}, τ_{xy} and τ_{yy} are components of effective shear stresses (Nm^{-2}).

Oil Spill Modeling Techniques:

Numerical modeling is an important tool to examine the transport and behavior of an oil spill in a marine environment.MIKE-21 flow model (FM) coupled with Eco Lab/ Oil spill module, which is used to describe the water quality, eutrophication, heay metal, ecology by process oriented formulation. This process oriented description can also support the individual particles like oil parcels.ThisLagrangian model is based on a widely used Random walk technique(Korotenko et al., 2004; Wang and Shen., 2010; Suneel et al., 2013; Nagheeby and Kolahdoozan, 2010).MIKE-21 Eco Lab/ Oil spill module simulate the transport of concentration of oil particles under weathering processes, which includes a variety of processes such as spreading, evaporation,oil thickness, emulsion and sedimentation.These processes are highly dependent on the oil type and ambient conditions. The oil properties and input of oil spill model are shown in table 2.

Parameter's	Description	Values
Oil type	Statfjord oil	Light crude oil
Oil density	Density o released oil	755 kg/m³
Spill location	Co-ordinates of the oil release	SP1: 8.30000°N; 76.44800°E SP2: 7.64934°N; 76.99806°E SP3: 7.33596°N; 77.69196°E SP4: 7.19719°N; 79.30806°E SP5: 7.20614°N; 78.55597°E
Spill type	Continues spill at one point	1 hr Continues spill
Time step	Time step used for model	60 sec
Duration	Total days of simulation	10
Number of particles	Number of particles released	100000: Large spill
Period	Simulation period	NE: 25/01/2011 09:00 am SW: 04/08/2011 09:00 am

Table 2: Inputs to the model simulation

The basic governing equation of mass transport is given as follows,

$$\frac{\partial 0}{\partial t}+\frac{\partial u\theta}{\partial x}+\frac{\partial y\theta}{\partial y}=\frac{\partial}{\partial x}\left(Dx\frac{\partial\theta}{\partial x}\right)+\frac{\partial}{\partial y}\left(Dy\frac{\partial\theta}{\partial y}\right)\pm S\rho \qquad \textbf{Equation (4)}$$

Where θ = Pollutant concentration of dissolved constituent (C) or temperature (T). Sp = Source or Sink term.

In general, most of the oil spill model uses drift factor approaches for the consideration of advection. In that case, mean drift velocity of the surface oil can be written as the sum of wind velocity and depth averaged current. That is,

$$V = V_W\alpha_W + V_C\alpha_C \qquad \textbf{Equation (5)}$$

Where, Vw= the wind velocity at 10 m above the water surface, Vc= the depth averaged velocity, αw= the wind drift factor, αc=current drift factor.

RESULT AND DISCUSSION

Hydrodynamics:

The hydrodynamic simulation for the southern tip of India is carried out during NE and SW monsoon seasons.Indian ocean has seasonally reversing trade wind, which causes the unique nature of hydrodynamics (Shankar et al., 2002; Vinayachandran et al., 2005; Joshi and Rao., 2012). During the NE monsoon currents flow is westward from Bay of Bengal to Arabian Sea, whereas during the SW monsoon, flow is eastward from western Arabian Sea to Bay of Bengal due to the wind.Thus, the water flux from Palk Bay (PB) to Gulf of Mannar (GoM) during NE monsoon is less than the SW monsoon water flux from GoM to PB (Jegadeesan et al., 2013). Similarly, the present model results also showed the higher water level and strong currents during SW monsoon season and are well compared with the measured tides and currentcomponents (Table 3 and 4).

NE monsoon							
Name of the location	Name of the constituents	Amplitudes (m)		Error	Phase (degree)		Error
		Observed	Modeled		Observed	Modeled	
L1	NO DATA						
L2	M_2	**0.191**	**0.200**	-0.009	49.190	40.960	8.230
	S_2	0.124	0.162	-0.038	104.250	97.710	6.540
	K_1	0.111	0.097	0.014	54.850	47.880	6.970
	O_1	0.047	0.044	0.003	61.440	69.310	-7.870
L3	M_2	**0.190**	**0.195**	-0.006	45.610	37.040	8.570
	S_2	0.121	0.152	-0.031	102.880	95.260	7.620
	K_1	0.115	0.109	0.006	55.530	52.270	3.260
	O_1	0.049	0.044	0.005	64.280	63.160	1.120
L4	M_2	**0.178**	**0.187**	-0.009	39.400	31.420	7.980
	S_2	0.117	0.145	-0.029	99.940	92.840	7.100
	K_1	0.122	0.121	0.001	56.900	52.450	4.450
	O_1	0.052	0.047	0.005	67.730	60.200	7.530
SW monsoon							
L1	M_2	**0.176**	**0.200**	-0.164	39.540	41.170	-1.630
	S_2	0.106	0.173	-0.162	96.590	94.780	1.810
	K_1	0.072	0.088	-0.040	37.550	56.870	-19.320
	O_1	0.070	0.045	-0.038	76.520	55.940	20.580
L2	M_2	**0.181**	**0.198**	-0.017	36.620	40.710	-4.090
	S_2	0.112	0.172	-0.061	91.760	94.610	-2.850
	K_1	0.095	0.089	0.006	38.960	56.600	-17.640
	O_1	0.053	0.045	0.008	86.040	65.130	20.910
L3	M_2	**0.178**	**0.192**	-0.015	35.870	36.670	-0.800
	S_2	0.107	0.163	-0.056	91.430	92.390	-0.960
	K_1	0.097	0.092	0.004	40.620	53.970	-13.350
	O_1	0.058	0.049	0.009	77.000	60.580	16.420
L4	NO DATA						

Table 3: Amplitude and phase values of observed and modeled tidal constituents for the locationsof L1

(Chettikulam), L2 (Vattakottai), L3 (Kanyakumari tip) and L4 (Pallam)

Name of the location	NE monsoon												
	Name of the constituents	Major axis (m/s)		Error	Minor axis (m/s)		Error	Inclination (deg)		Error	Phase (deg)		Error
		Observed	Modeled		Observed	Modeled		Observed	Modeled		Observed	Modeled	
L1	NO DATA												
L2	M_2	0.027	0.016	0.011	0.002	0.000	0.002	37.60	46.00	-8.40	330.70	324.00	6.700
	S_2	0.006	0.007	-0.001	0.000	0.000	0.000	31.80	51.500	-19.70	288.30	256.30	32.00
	K_1	**0.033**	**0.030**	0.003	0.003	0.000	0.003	20.80	35.60	-14.80	66.40	88.90	-22.50
	O_1	0.010	0.002	0.008	0.001	0.000	0.001	21.30	46.00	-24.70	89.10	56.30	32.80
L3	M_2	**0.116**	**0.111**	0.005	0.004	-0.001	0.005	172.30	162.10	10.20	128.80	148.20	-19.40
	S_2	0.047	0.042	0.005	0.003	-0.001	0.004	169.70	142.70	27.00	183.40	150.90	32.50
	K_1	0.040	0.113	-0.073	0.007	0.000	0.007	172.70	152.10	20.60	241.80	205.40	36.40
	O_1	0.012	0.020	-0.008	0.005	0.000	0.005	4.200	1.600	2.600	177.20	142.30	34.90
L4	M_2	**0.099**	**0.089**	0.010	0.002	0.002	0.000	156.70	165.30	-8.600	181.40	176.30	5.100
	S_2	0.032	0.033	-0.001	0.004	0.001	0.003	162.70	165.90	-3.200	194.40	215.70	-21.30
	K_1	0.071	0.088	-0.017	0.001	0.001	0.002	156.10	165.10	-9.000	285.70	292.70	-7.000
	O_1	0.039	0.020	0.019	0.001	0.000	0.001	157.30	163.90	-6.600	306.30	281.20	25.10
SW monsoon													
L1	M_2	0.036	**0.037**	-0.001	0.004	0.001	0.003	16.300	26.00	-9.700	359.00	352.20	6.800
	S_2	0.011	0.014	-0.003	0.002	0.001	0.001	35.500	35.40	0.100	42.200	26.200	16.00
	K_1	**0.048**	0.032	0.016	0.000	0.001	-0.001	15.000	20.10	-5.100	144.60	107.30	37.30
	O_1	0.007	0.017	-0.010	0.000	0.001	-0.001	6.000	20.40	-14.40	79.400	98.000	-18.60
L2	M_2	**0.040**	**0.028**	0.012	0.001	0.002	-0.001	38.300	48.800	-10.50	352.60	327.90	24.70
	S_2	0.014	0.010	0.004	0.002	0.002	0.000	65.100	59.900	5.200	13.100	27.000	-13.90
	K_1	0.032	0.019	0.013	0.003	0.002	0.001	32.600	42.600	-10.00	146.20	176.70	-30.50
	O_1	0.011	0.013	-0.002	0.002	0.001	0.001	47.400	43.400	4.000	25.600	56.600	-31.00
L3	M_2	**0.129**	**0.130**	-0.001	0.006	0.004	0.002	2.800	6.000	-3.200	5.600	8.800	-3.200
	S_2	0.059	0.054	0.005	0.004	0.002	0.002	3.300	6.900	-3.600	50.100	31.600	18.50
	K_1	**0.129**	0.104	0.025	0.000	0.002	0.002	1.400	4.700	-3.300	146.30	119.40	26.90
	O_1	0.056	0.051	0.005	0.002	0.001	0.003	170.50	156.10	14.40	270.20	299.80	-29.60
L4	NO DATA												

Table 4: The major axis, minor axis, inclination and phase of observed and modeled tidal current constituents or the locations of L1(Chettikulam), L2 (Vattakottai), L3 (Kanyakumari tip) and L4 (Pallam)

The accuracy of the model results (tidal and current component) was evaluated using error and correlation coefficients.The order of major tidal constituents isfollowed as: M_2> S_2> K_1> O_1.The ratio of four major amplitudes ($F = M_2+S_2/O_1+K_1$)concluded that the nature of tides are mainly mixed semidiurnal (NE: 0.54 m; SW: 0.52 m), which are varying with geographical positionsdue to thenonlinear shallow water effects (Gurumoorthi et al., 2015; Kankara et al., 2013).The maximum values of tidal constituents M_2 and $S_2$are 0.2m and 0.162 during NE monsoon, whereas during SW monsoon M_2 and S_2values are0.2m and 0.173 m, respectively.A good comparison of water level variation reproduces the more appropriate flow in the study area. A time series comparison of observed versus simulated tides and currents (u and v flow)are shown in figure 3-8.

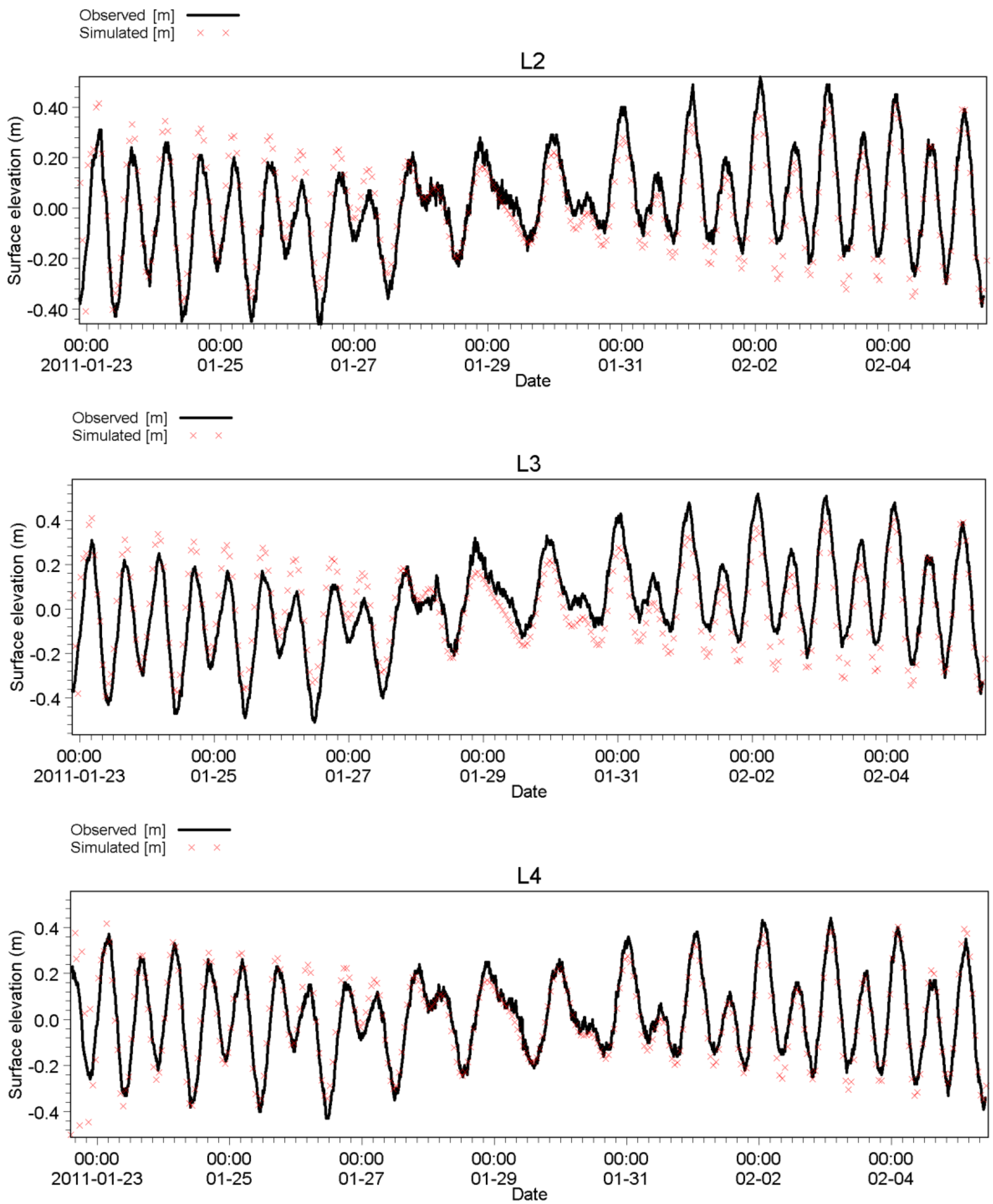

Figure 3: Comparison of observed and simulated surface elevation during NE monsoon period in L2, L3 and L4 locations. The black line and red dots indicate observed and simulated time series surface elevation

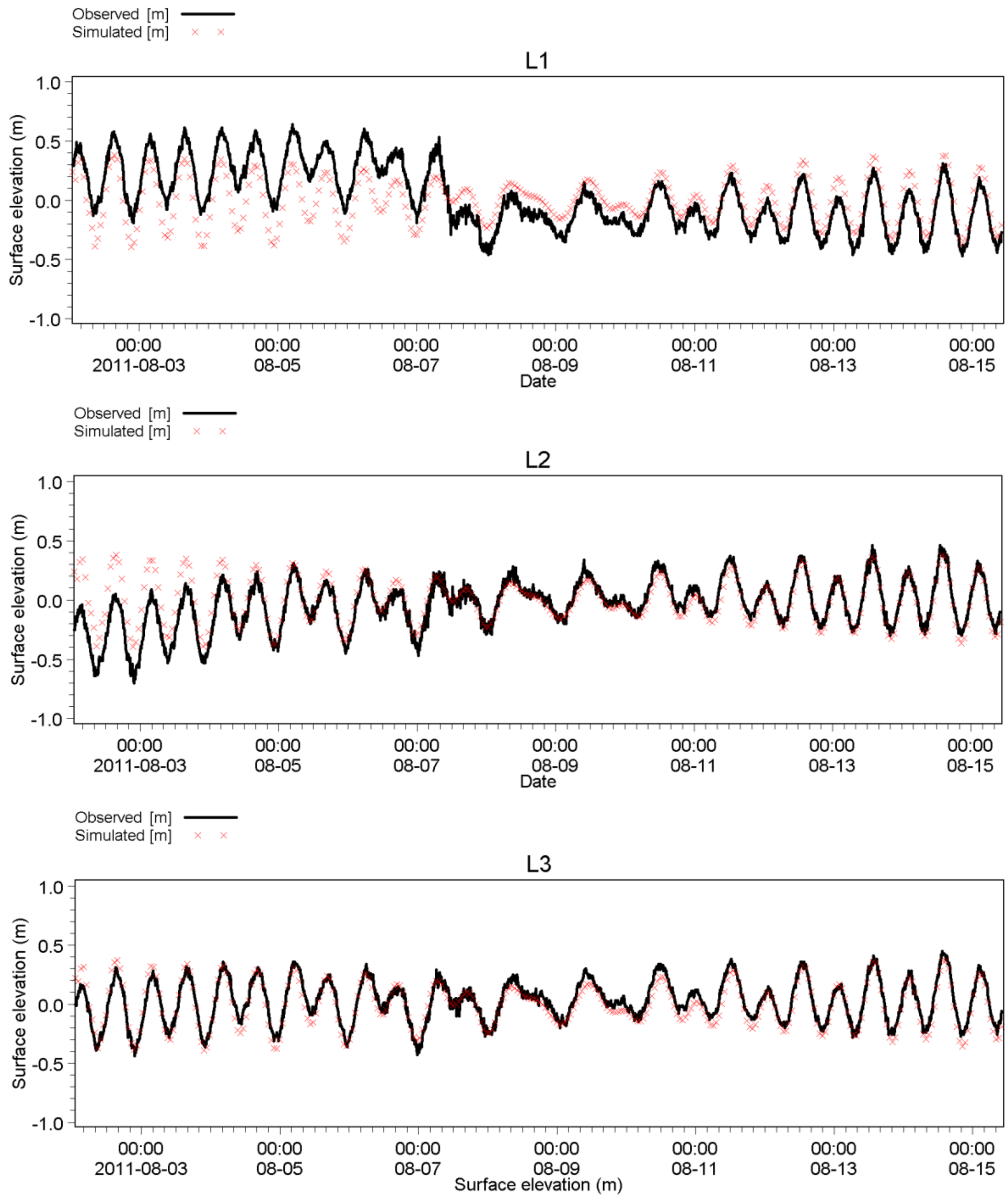

Figure 4: Comparison of observed and simulated surface elevation during SW monsoon period in L1, L2 and L3 locations. The black line and red dots indicates observed and simulated time series surface elevation

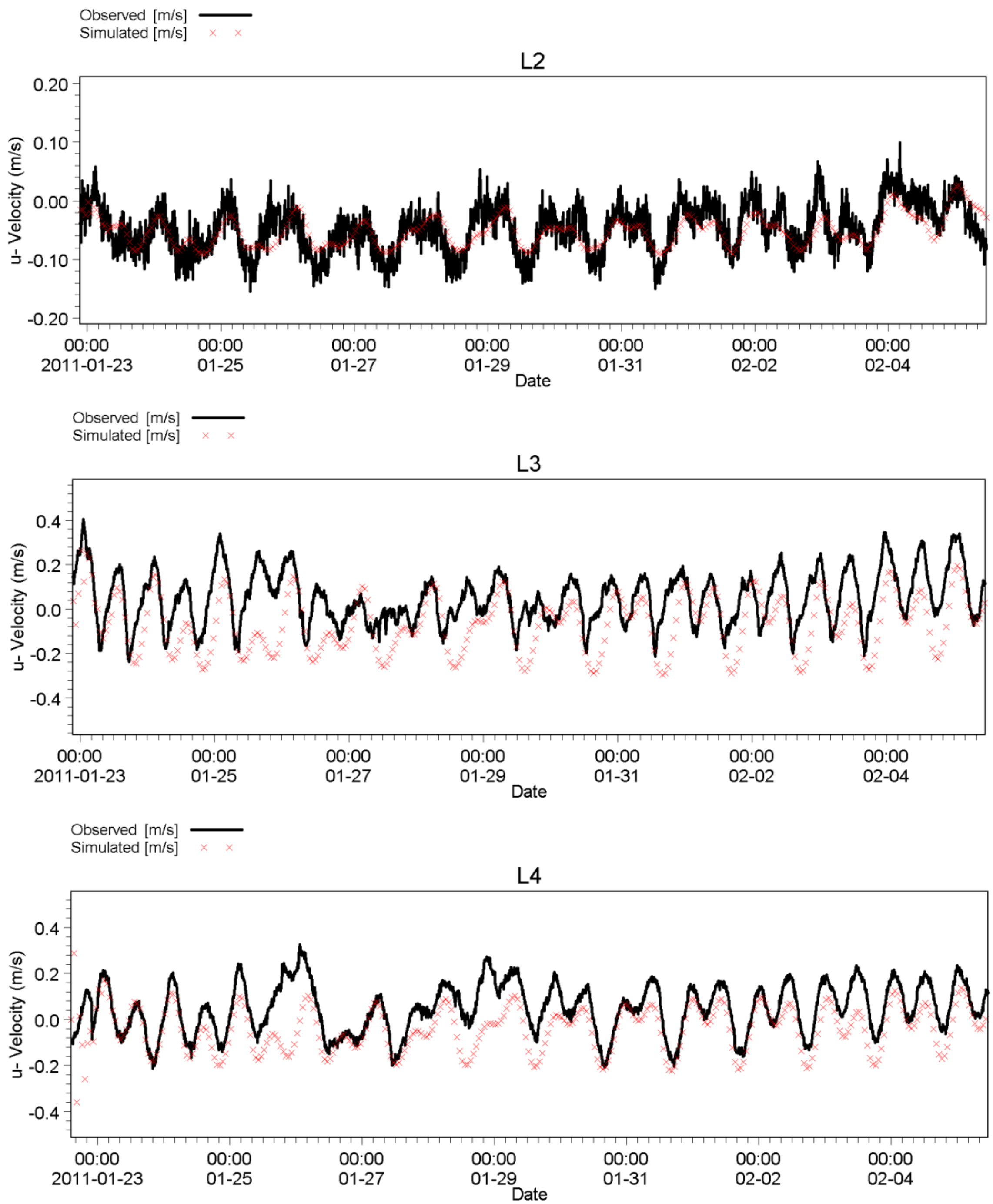

Figure 5: Comparison of observed (black line) and simulated u- component velocity (red dot) during NE monsoon period in L2, L3 and L4 locations

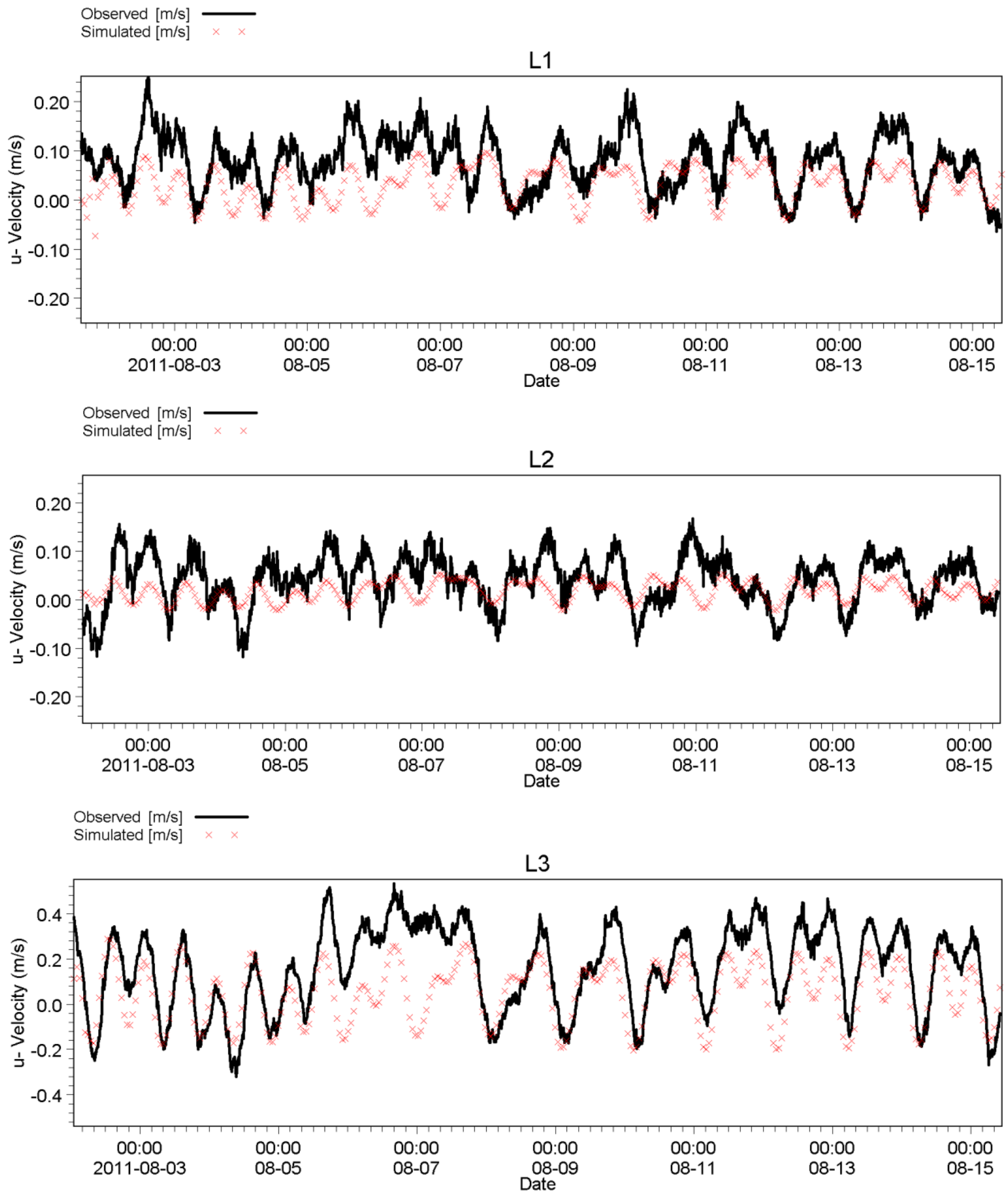

Figure 6: Comparison of observed (black line) and simulated u- component velocity (red dot) during SW monsoon period in L1, L2 and L3 locations

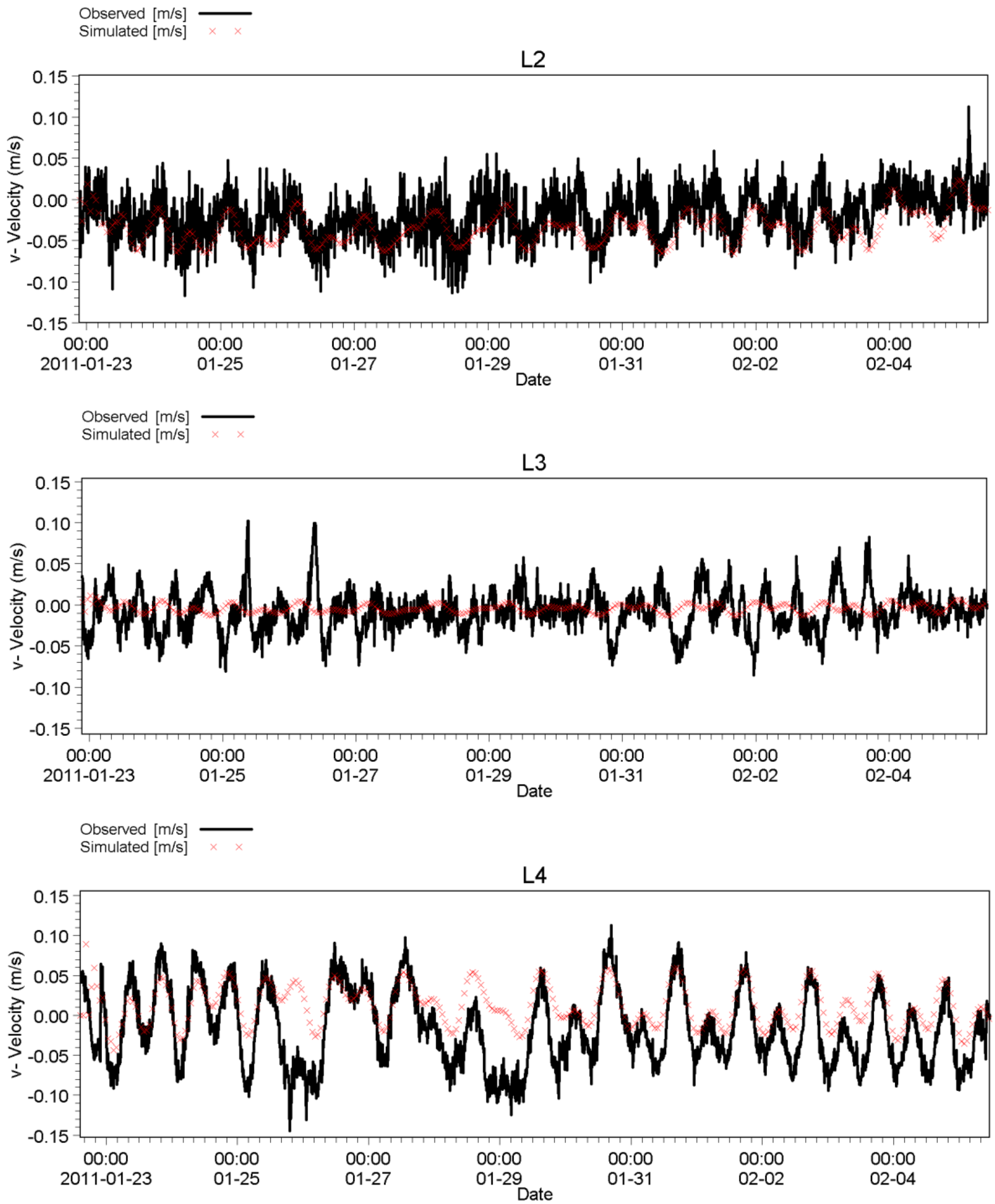

Figure 7: Comparison of observed (black line) and simulated u- component velocity (red dot) during the NE monsoon period in L2 L3 and L4 locations

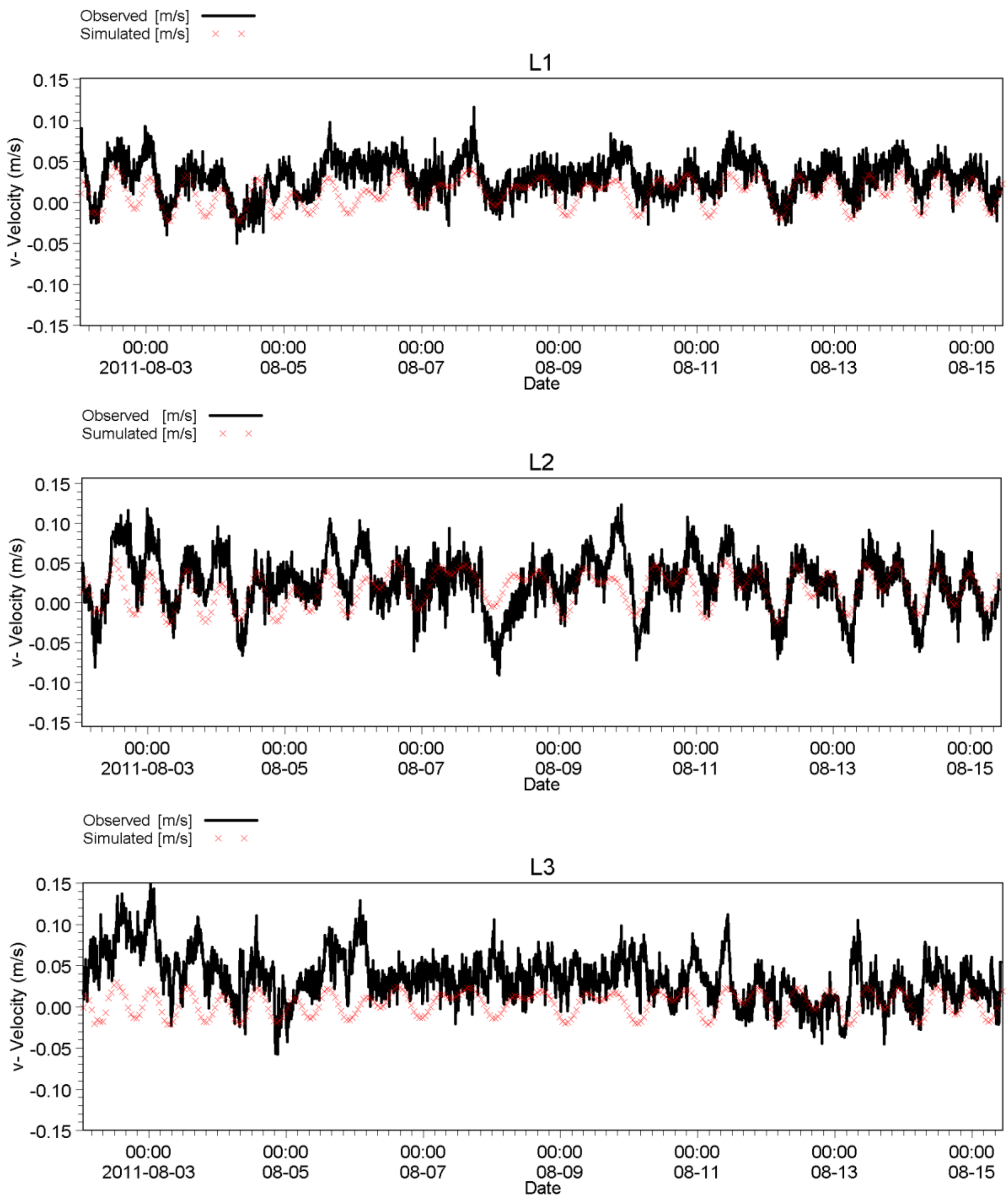

Figure 8: Comparison of observed (black line) and simulated v- component velocity (red dot) during the SW monsoon period in L1, L2 and L3 locations

The u-component of the current was more dominant than the v-component at all the stations (except at L2 during the NE monsoon). Jineesh et al. (2015)havereported the same alongthe Kerala coast. The seasonal variation in u-component of currents during the SW monsoon was stronger than the NE monsoon.The maximum current speed at southern tip of Kanyakumari (L3) shows0.405 and 0.532 m/swith an average of 0.05 and 0.162 m/sduring NE and SW monsoon respectively. The harmonic analysis of currents was performed to seperate the tidal and residual currents. M_2 constituent have ranged from 0.027–0.116 and 0.036–0.129m/s during NE and SW, respectively. It is close to the values 0.03-0.05 m/s along Bay of Bengal (Pulin and Centurioni, 2015). The depth-averaged circulation plotsshowed that the currents during SWmonsoon are strongerthan the NE monsoon season (Figure 9), which is consistent with the seasonal changes in the wind field.

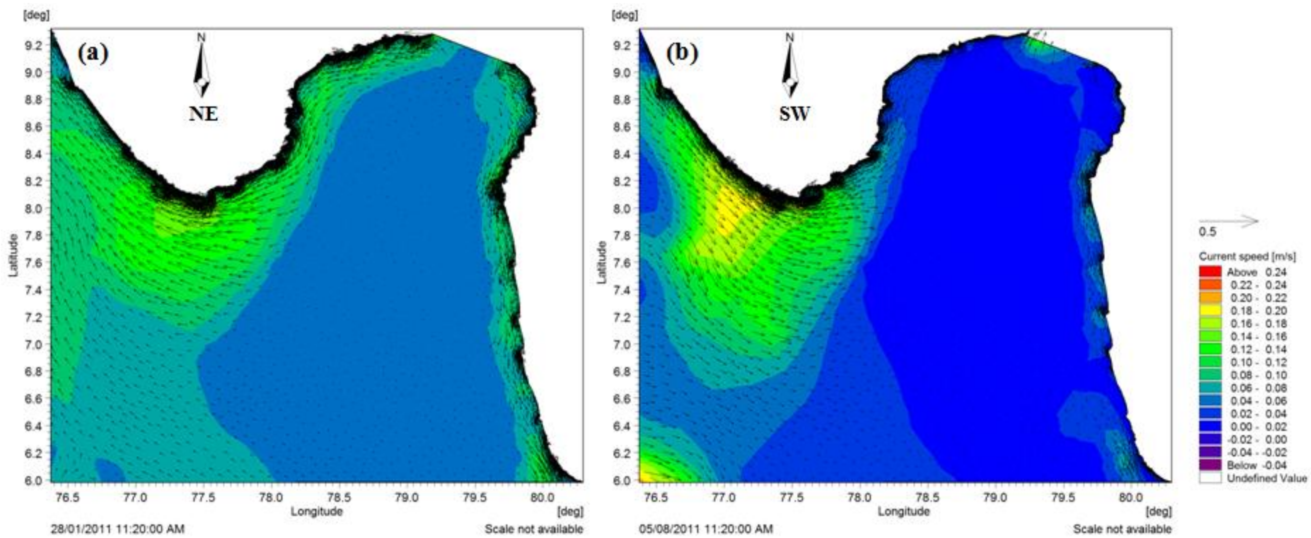

Figure 9: Seasonalsurface currents (m/s) during NE (a) and SW (b) monsoon season

The modelresultsalso confirmed that the two opposite flow directions are corresponding to NE andSW monsoon. Fig. 9 (a and b) showed the flow speed and direction off Southern tip of India, during NE and SW monsoon in 2011. The maximum current speed in this seasons is varying from0.405 and 0.532 m/sin L3 (tip of Kanyakumari) during NE and SW monsoon respectively. Current direction along the coast is modulated by bottom topography and morphodynamics of the region.Similar values are obtained in the GoM varying from0.04 to 0.41 m/s during the NE and SW monsoon (SSCP Repot, 2004)

Oil Spill Scenario:

Hypothetical oilspills were initially released at 00:09 h on 25thJanuary (NE) and 4th August (SW) 2011,due to the engine malfunction in oil tankerand collided with other ship. In this case, an attempt has been made to study the hypothetical oil spill trajectory modeling. Initially, 100000 particlesrepresented by1000 tones of light crude oil (Statfjord oil)were released instantly at five locations. Spill locations are listed in Table 2.After the successful validation of model result, it was coupled with the oil spill model to compute the oil spill transport of accidental/disaster spillages.The spill model was employed for a 10 days from the above mentioned date. In order to understand the seasonal variation of wind effect on the movement of oil particles, NE and SW monsoon were imposed on the model (Figure 10).

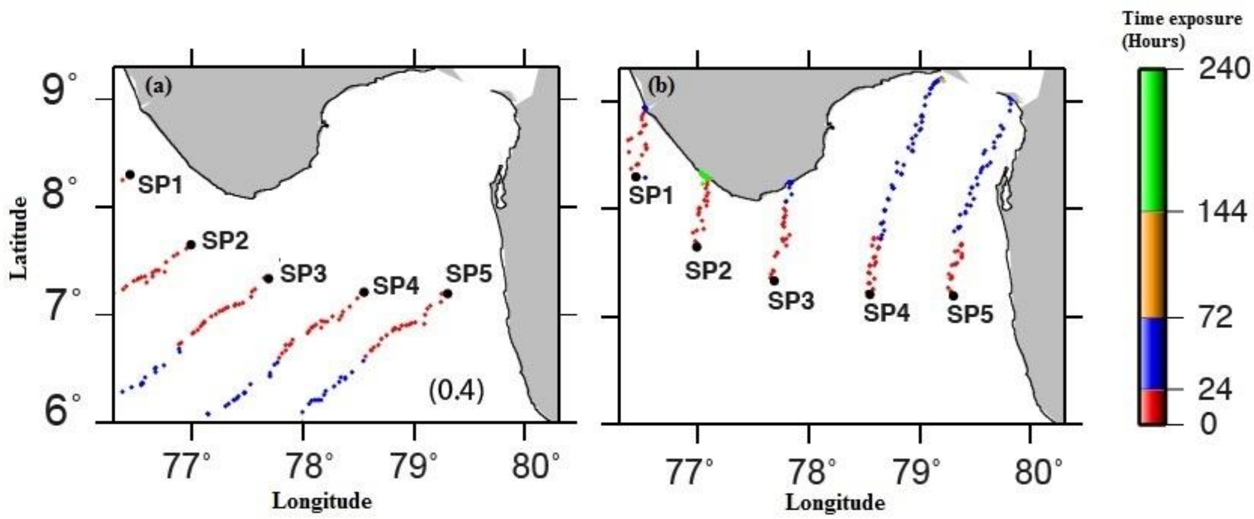

Figure 10: Stat fjord light crude oil spill trajectory with current and wind. Here, (a) and (b) indicates the NE and SW monsoon season

The trajectory results in the present study are obtained by setting up of proper environmental conditions.Here,widely acceptable values 2-3% of wind factor is given for the model simulation (Dietrich et al., 2012).The prevailing wind and currents have driven the slicks essentially towards north/north-eastward shoreline.In other monsoon oil slick moves toward south westward, and it was moving toward open ocean.Risk of the spilled oil is rises the adverse impact on environment, particularly when the spilled oil patch reaches the shoreline (Kankara et al., 2016).Oil particles were released in five different locations and their tracks were observed (Figure 10). Among these five locations, oil residues from 1, 2 and 3 locations were reached to shore, whereas released oil from the remaining locations 4 and 5 were not reached the shore. Thus coastal areas are considered to be highly vulnareble.Oilpartiles from the spill location 4 havereached the Ramashwaramnearshore water within 72 hours, however those particles were not reached to the shore. The direction of the spill movement are due to the wind and currents, and also the selection of spill location. The maximum flow of oil particles was due to winds rather than currents. Similar results have observed along the Goa coast, east Arabian Sea, India (Vethamony et al., 2007).

CONCLUSION

The present study provides an overview of the oil spill scenario simulated during the NE and SW monsoon season in the southern tip of India. The current data were measured using RCM from four different locations in the southern tip of India. Wind data have also obtained using AWS. The results of simulated tides and current values were showed good agreement with the measured values. Oil particles have released in five different locations three scenarios were showed oil residues were moved towards the coast of India and one moved towards the coast of Sri Lanka, whereas one more scenario showed oil particles were completely weathered.The information obtained from this study can be used to improve the emergency management systems in order to protect coastal management and marine ecosystem.

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