

Trajectory of an oil spill off Goa, eastern Arabian Sea: field observations and simulations

P Vethamony*, K Sudheesh, MT Babu, S Jayakumar, R Manimurali and AK Saran

National Institute of Oceanography, Dona Paula, Goa- 403 004, India

&

L.H Sharma, B. Rajan and M Srivastava

Indian Coast Guard, District HQ-11, MPT Old Admin Building, Mormugao Harbour, Goa 403803, India

Abstract:

An oil spill occurred off Goa, west coast of India, on 23 March 2005 due to collision of 2 vessels. In general, fair weather with weak winds prevails along the west coast of India during March. In that case, the spill would have moved slowly and reached the coast. However, in 2005 when this event occurred, relatively stronger winds prevailed, and these winds forced the spill to move away from the coast. The spill trajectory was dominated by winds rather than currents. The MIKE 21 Spill Analysis model was used to simulate the spill trajectory. The observed spill trajectory and the slick area were in agreement with the model simulations. The present study illustrates the importance of having pre-validated trajectories of spill scenarios for select eco-sensitive regions for preparedness and planning suitable response strategies whenever spill episodes occur.

Key words: Oil spill, MIKE21 SA model, Arabian Sea, spill trajectory, hydrodynamics

* Correspondence Address: mony@nio.org

Capsule of the work: This is the first time model results have been compared with real oil spill observations along an Indian coast.

1. Introduction:

Half the world's production of crude oil is transported by sea (Clark, 1992). A significant amount of oil is spilled into the sea from operational discharges, collision and grounding of tankers, well blow-outs and pipeline-breaks. 48% of the marine oil pollution is due to fuels and 29% due to crude oil. Tanker accidents contribute only 5% of marine pollution (Fingas, 2001). Due to global economic growth, the demand for petroleum products is on the rise, hence we can expect many more oil spills, especially along the tanker routes and regions surrounding the production platforms.

An oil spill occurred off Goa, west coast of India (Fig. 1), on 23 March 2005 at 0100 h (local time) from the vessel M.V. Maritime Wisdom Bulk Carrier, anchored at the location Lat:15° 30.2' N; Long: 73° 42.2' E, due to contact damage by the barge MV Prapti. The quantity of spilled Heavy Fuel Oil (HFO) was reported to be 85 tonnes. One more oil spill has been reported (Anonymous, 2000) in the coastal waters off Goa due to grounding of a vessel and "Sea Transporter" off Aguada on 5 June 1994 (1025 tonnes of diesel).

Goa has been identified as one of the major tourist destinations of the world because of its beautiful beaches and associated recreational activities. The economy of Goa depends on tourism to a large extent. The coastal population as well as the State Government are very particular about activities which are harmful in the coastal zone. In case spill-remains arrive at the beaches or islands, there will be a huge public disquiet and fall in the ongoing recreational activities (bathing, surfing, boating, diving, etc). Therefore, in this context, it is very essential to have pre-validated trajectories of spill scenarios for effective implementation of containment at any point of time.

As a part of marine pollution studies, NIO has been carrying out regular measurements of petroleum hydrocarbon concentrations (PHCs) since 1977, but these were restricted to shipping routes and select coastal regions (Sen Gupta et al, 1980). Following the major oil spills which resulted from the Gulf war (1990-91), a concern was raised in India regarding oil contamination in the waters and sediments of the northern Arabian Sea. The study confirmed that there was no increase in the hydrocarbon concentration due to these spills as the physico-chemical conditions of the Gulf might have favoured the containment (Sen Gupta et al, 1993).

Spill modelling is important to predict the trajectories and oil fate for devising suitable combating mechanisms. In the past, we have predicted hypothetical spill trajectories for the Gulf of Kachchh (northeastern Arabian Sea) for different scenarios (Desa et al, 2002), but uncertainty existed because there was no real spill data to validate the model results.

There was a fear that the present spill might reach the Grandi Island, which is sensitive - ecologically (presence of coral reefs), archeologically (ship-wrecks), economically (tourism) and strategically. Therefore, the Indian Coast Guard (CG) and other authorities immediately took initiatives to track the spill and contain it. Field data on spill position at different times were obtained by the CG, and these were used to validate the simulated paths. Measurements of tides, currents, winds and hydrography (ongoing measurement programmes) were available close to the spill location so that hydrodynamic model results could be validated.

MIKE21 SA model was used to simulate trajectories. The present work is the first modelling study for a real oil spill that had occurred in the coastal waters of India. The objectives of this study were as follows: (i) to simulate hydrodynamics of the coastal waters off Goa, (ii) to generate a trajectory for the real spill of 23 March 2005 and (iii) to validate the hydrodynamics and spill trajectory with field measurements / observations.

2. Data and methodology:

2.1. Environmental conditions:

The climatic information compiled from 40 years of observations showed that in March, the mean highest temperature is 34⁰C and the mean lowest temperature is 20⁰C. Though average humidity varies from 65 to 80%, March is a fair weather month with no rainfall and clear sky. Winds were measured continuously at Dona Paula (close to the oil spill region) using Autonomous Weather Station. In general, winds along the coastal region varied between north and east in the morning hours and between west and northwest in the evening hours.

The spill region forms part of the Mandovi-Zuari estuarine system, which is one of the prominent estuaries of the west coast of India. Qasim and Sen Gupta (1981) studied the

general hydrography and chemistry of this estuarine system, and Shetye et al (1995) described the tidal propagation in this estuary.

Currentmeters were already in place at the point, Lat: $15^{\circ} 30.968'$ N; Long: $7^{\circ} 38.874'$ E (water depth = 30 m), which was close to the spill location, and currents for the period 22 - 30 March 2005 were extracted from the data of these currentmeters. Currents measured in the estuary during the periods April 1999 to April-May 2002 showed that current speeds reach upto 1.1 and 1.0 m/s, respectively (Sawkar K et al, 2003). As southwest monsoon winds pick up from April, we find relatively stronger currents in April-May. Otherwise, during fair weather season, we can expect currents of the order of 0.1 to 0.2 m/s only.

2.2. Observations of spill trajectory:

Coast guard recorded the co-ordinates of the spill continuously from 23 March (1220 h) onwards. Meteorological information had been collected from the CG vessel as well as Naval Meteorological Office, Goa. Oil leakage was stopped at 0400 h on 23 March 2005, that is in 3hours time.

Initially, the spill moved in the southeasterly direction with a speed of 0.25 to 0.50 m/s, spreading in an area of $\approx 6.0 \text{ km}^2$. It was observed on 24 March 2005 at 0640 h that the slick moved in a southerly direction (9.2 km south off Grandi Island and 10.0 km from the coast). At 1220 h, a few patches of thin oil film with a maximum radius of about 1.8 km were observed around $15^{\circ} 14.26'$ N; $073^{\circ} 48.71'E$. At 1305 h, a few patches with an average size of 50 m x 25 m were seen at a distance of 13.0 km away from the coast, moving in a southerly direction. Winds (speeds of the order of 3.5 m/s in the NNE direction) favoured movement of the spill away from the coast.

Subsequently, the thickness of oil and number of patches reduced, and on 25 March at 0630 h, only a very few small patches were observed around $15^{\circ} 0.6'$ N; $73^{\circ} 52.5'E$. The remaining area was generally clear. However, the Coast Guard continued the observations till 30 March 2005, and it was noticed that the oil film was insignificant in size.

Combating mechanism:

Mechanical response using booms and skimmers has its own distinct limitations in combating oil spills, especially when the spills are large and the sea is rough. In such cases, spraying of oil dispersant is the only option available to respond to spill.

In the present case, Advance Offshore Patrol Vessel (AOPV) Sagar, Offshore Patrol Vessel (OPV) Vighraha, Interceptor boats C-133 and C-140 and CG's Dornier aircraft were deployed in combating the spillage by spraying OSD chemicals through spill spray arm from 24 March 2005 (0400 h). The patches were disintegrated into granular nodules by high speed churning and wave action. After the successful combating operation, the pollution response was withdrawn on 26 March by all CG units.

3. Spill modelling:

Along with weathering processes, gravitational, viscous and surface tension decide the spread of oil spill and its fate. Light fractions of the oil evaporate and dissipate quickly depending on meteorological and oceanographic conditions. This is followed by dissolution of soluble components and emulsification of immiscible components in the water column. In view of the limited understanding of the oil spill processes, the accuracy of simulations must be viewed with some reservation (Xiaobo Chao et al, 2001).

Several oil spill models have been developed based on transport and weathering processes (Mackay et al., 1980, Huang, 1983, Howlett et al., 1993, Kolluru et al., 1994, Yapa et al., 1994, Spaulding, 1995, Li and Mead, 1999, Reed et al., 1999, Brebbia, 2002 & 2004, Tkalicj et al., 2003). The Oil Weathering Model, OWM (Daling and Strøm, 1999) and the Oil Spill Contingency and Response model system, OSCAR (Aamo et al., 1997) are used in contingency planning. The spill model, SINTEF OWM has been field tested extensively with laboratory and experimental spills (Daling and Strom, 1999, Daling et al. 2003). Price et al (2004) calculated thousands of oil-spill trajectories over extended areas of US waters using the OSRA model, and tabulated the frequencies with which the simulated oil spills contact the geographic boundaries of designated natural resources within a specified number of days.

Elliott (2004) modelled transport processes dominated by advection, assuming a simple decay to represent weathering. This approach was suitable for short term operational prediction of an actual spill trajectory. Wanga (2005) used a Lagrangian discrete particle algorithm to simulate transport of oil slick, assuming the slick as a large number of small particles. The discrete path and mass were followed and recorded as functions of time.

In the present study, we used a two-dimensional MIKE21 Spill Analysis (SA) model (Anonymous, 2001) developed by the Danish Hydraulic Institute (DHI), Denmark to simulate spill trajectories. SA simulations take care of the decaying processes due to heat transform (evaporation), dissolution and entrainment. The dominant physico-chemical properties of the oil that determine the spreading are density and dispersion coefficients. Viscosity has a role in spreading immediately after the spillage. Wind friction coefficient corresponds to surface speed of fluid, and for varying winds the coefficient will also vary. Both currents and winds were used in the drift of the oil. All the available information of HFO have been compiled (Table1).

The model domain (Fig.1) is bounded by $14^{\circ} 48'N - 15^{\circ} 00'N$ latitudes and $73^{\circ} 28' E - 74^{\circ} 00'E$ longitudes. Bathymetry of the domain was taken from CMAP data provided by DHI. Winds measured using Autonomous Weather Station at Dona Paula, Goa during 22-26 March 2005 were given as input to the model. Three boundaries of the domain were kept open. Tide elevations were predicted from the Tide Predictor utility of MIKE 21, and interpolated at all grid points along the boundaries.

A Cartesian coordinate system was selected with x-axis = 110 km and y-axis = 140 km, and the model domain was divided into 550 x 700 square grids with a grid size of 200 m. The tides along the open boundary were generated from the toolbox available in the MIKE software by predicting water elevation from four major constituents M2, S2, K1 and O1 at the coastal tidal stations - Karwar in the south and Vengurla in the north. Subsequently, the tidal elevations required along the model boundaries were interpolated and used to drive the model. The model was run for a period of 6 days, and from the results, the water level and velocity components were derived. The time step used in the model was 4 s for hydrodynamics and 100 s for spill analysis.

4. Results and discussion:

The spill location is shown in Fig. 1. For modelling purpose, winds measured during 22-26 March 2005 were extracted and analysed. Wind analysis indicated that winds were variable: N-NE direction with a speed of 1.5 m/s in the morning hours and W-NW direction with a speed of 2.5 – 5.0 m/s in the evening hours (Fig. 2a), and predominantly in the northwest direction (Fig. 2b). On an average, the wave heights were of the order of 1 – 1.5 m (direction: between W and NW).

A comparison between the modeled and predicted tides (Fig. 3) for the period 22-26 March 2005 at Mormugao harbour showed that the model reproduced the phase as well as the amplitude closely with the predicted tides. The simulated currents were slightly higher than the measured currents. The currents were of very low intensity (of the order of 0.1 m/s), and hence we could not find an exact match between the model and measured values (Fig. 4). But, the range matches.

The Coast Guard tracked the spill movement, and reported the position, approximate area, thickness and extend of the spill patches along with environmental conditions such as winds, waves, sea surface temperature, cloudiness and visibility. This has enabled us not only to validate the model results, but also to verify the input parameters. The positions and arrival times observed by CG had been used to validate the trajectory obtained from the model.

It was observed on 24 March 2005 at 0640 h that the spill was essentially moving towards south with the action of winds and currents, and it was \approx 9.2 km south of Grandi Island and 10.0 km away from the coast. When the position of the spill was checked from the model trajectory, it agreed closely to the observed values (Fig. 5). The model results showed that the spill did not hit the island (more clear in the spill movement animation), and this had been proved by the observations. We could find some differences in the positions and arrival times of the spill between the model results and observed data (Fig. 5), and this could be attributed to several complexities involved in the physical and chemical weathering processes and the difficulty in modelling these factors. The oil concentration had also reduced considerably, as reported by the Coast Guard. Only the positions and arrival times

of the first few days have been used to validate the numerical results as CG has initiated the combating mechanism by then.

The maximum flow was due to winds rather than currents. Usually, fair weather prevails along the west coast of India in March. Winds and currents are also relatively weak and consequently, the spill would have moved slowly. But, this particular year when the incident occurred (March), the winds and waves were relatively stronger. Therefore, the winds forced the spill to move away from the coast, and subsequently, the spill trajectories mostly followed the winds. Moreover, as the currents inside the estuaries are stronger (reaches upto 1.0 m/s) than the coastal currents, the spill could not enter into it. As the patches virtually disappeared after 25 March due to the prevailing environmental conditions and spraying of OSD, we have not proceeded further in modelling the trajectory.

On the first day, we could observe only one patch which later splits into a few patches because of physico-chemical conditions and spraying of OSD. We compared the few values of observed oil slick area with those of model values (Table 3), and the model values, in general, agreed with the observations of CG.

5. Conclusions:

We could not collect all information of the spill in view of some limitations. However, we found that the spill features observed by the CG were in agreement with the model simulations. This has given us an opportunity to understand the capabilities of the model, and use of this model in predicting possible spill scenarios for the west coast of India for preparedness and planning suitable response strategies.

Acknowledgements:

We thank Dr S.R Shetye, Director, NIO for his interest in initiating this work. We are grateful to our colleagues Drs Loka Bharathi, Classy D'Silva and Z.A Ansari for joining in discussions with the Coast Guard, and Drs Y.K Somayajulu and P Mehra for providing current and wind data, respectively. This is NIO contribution No. 4178.

References

Aamo, O.M., Reed, M., Lewis, A., (1997): Regional contingency planning using the OSCAR oil spill contingency and response model. In: Proceedings of the 1997 AMOP Technical Seminar. Environment Canada, Ottawa, Canada, pp. 289–308.

Anonymous (2004): MIKE 21 & MIKE 3 PA/SA, Particle analysis and oil spill analysis module user guide, DHI Water & Environment, Danish Hydraulic Institute, Denmark

Blue Waters, Vol.1, issue 1, p.6

Brebbia, C.A., (2002): In: Brebbia, C.A. (Ed.), Oil and Hydrocarbon Spills III: Modelling, Analysis and Control (Oil Spill 2002). In: Water Studies, 11. Wessex Institute of Technology, UK, pp. 480, ISBN: 1-85312-922-4.

Brebbia, C.A., (2004): In: Brebbia, C.A. (Ed.), Coastal Environment V (Coastal Environment 2004 and Oil Spill 2004). In: Environmental Studies, 10. Wessex Institute of Technology, UK, pp. 484, ISBN: 1-85312-710-8.

Chao X, N. Jothi Shankar, Hin Fatt Cheong (2001): Two- and three-dimensional oil spill model for coastal waters, Ocean Engineering, 28, 1557–1573.

Clark, R.B. (1992): Marine Pollution (3rd ed.), Gookcraft Ltd., Great Britain, UK, 50–60.

Daling P.S. and Strøm T (1999): Weathering of oils at sea: model/field data comparison. Spill Science & Technology Bulletin, No. 5, 63-74.

Daling, PS, Merete Overli Moldestad, Oistein Johansen, Alun Lewis & Jon Rodal (2003): Norwegian Testing of Emulsion Properties at Sea: The Importance of Oil Type and Release Conditions Spill Science & Technology Bulletin, 8 (2), 123 –136.

Desa, E., M.D., Zingde, P.Vethamony (2002): Marine environmental management strategies for the Gulf of Kachchh. Report No. NIO/SP-13/2003, National Institute of Oceanography, Goa.

Elliott A.J. (2004): A probabilistic description of the wind over Liverpool Bay with application to oil spill simulations, Estuarine, Coastal and Shelf Science 61, 569 –581.

Fingas, M. (2001): The basics of oil spill cleanup. Lewis Publishers.

Howlett, E., Jayko, K., Spaulding, M.L., (1993): Interfacing real-time information with OILMAP. In: Proceeding of the 16th Arctic and Marine Oil Spill Program Technical Seminar, Environment Canada, Ottawa, 517–527.

Huang, J.C., (1983): A review of the state-of-the-art of oil spill fate/behavior models. In: Proceedings of the 1983 Oil Spill Conference, Washington, DC., pp. 313–322.

Kolluru, V.S., Spaulding, M.L., Anderson, E.L., (1994): A three-dimensional oil dispersion model using a particle based approach. In: Proceeding of 17th Arctic and Marine Oil Spill Program Technical Seminar, Environment Canada, Ottawa, pp. 867–894.

Li, Z., Mead, C.T., (1999): Prediction of the behavior of marine oil spills: application based on the random walk techniques. In: Lee, Jayawardena, Wang (Eds.) Environment Hydraulics. Balkema, Rotterdam.

Mackay, D., Paterson, S., Trudel, K., (1980). A mathematical model of oil spill behavior. Environmental Protection Service, Fisheries and Environment Canada. Maritime and Port Authority of Singapore (MPA), 1997. 1997 Singapore tide tables and port information. Singapore.

Price, J.M., W.R. Johnson, Z.G. Ji, C.F. Marshall, and G.B. Rainey (2004). Sensitivity Testing for Improved Efficiency of a Statistical Oil Spill Risk Analysis Model. Environmental Modelling & Software 19, 671–679.

Qasim SZ and Sen Gupta R (1981): Master Plan for Pollution Control of the Rivers Zuari and Mandovi, submitted to Central Board for the Prevention and Control of Water Pollution, Govt. of India, NIO Technical Report No. 02/79.

Reed, M., Johansen, O., Brandvik, P.J., Daling, P., Lewis, A., Fiocco, R., Mackay, D. and Prentki, R. (1999). "Oil Spill Modelling Toward the Close of the 20th Century: Overview of the State of the Art", *Spill Science and Technology Bulletin*, 5, 3–16. 44(11), 1219–1229.

Sawkar, K, Vethamony, P, Babu, MT, Dias, C, Mesquita, A, Fernandes, B, Moses, S, Padmavati, M and Naik, S (2003): Measuring, modelling and grading the health of water bodies. In Coastal tourism, environment, and sustainable local development (Eds. Noronha, L, Lourenco, N, Lobo-Ferreira, JP, Lleopard, A, Feoli, E, Sawkar, K and Chachadi, A., Tata Energy Research Institute, New Delhi, India), 179-210.

Sen Gupta R., S.P.Fondekar and R.Alagarsamy (1993), State oil pollution in the northern Arabian sea after the 1991 Gulf oil spill, *Marine pollution bulletin*, volume27, pp.85-91, 1993.

Sen Gupta R., S.Z.Qasim, S.P.Fondekar and R.S.Topgi (1980), Dissolved petroleum hydrocarbons in some regions of the Northern Indian Ocean, *Marine pollution bulletin*, Volume11, pp.65-68.

Shetye S. R., Gouveia A. D., Singbal S. Y., Naik C. G., Sundar D., Michael G. S., and Nampoothiri G. (1995): Propagation of Tides in the Mandovi – Zuari Estuarine Network, *Proc. Indian Academy of Science (Earth & Planet Science)*, Vol. 104, No. 4, 666 – 682.

Spaulding, M.L., (1995): Oil spill trajectory and fate modeling: State-of-the-art review. In: Proceeding of Second International Oil Spill Research and Development Forum, IMO, London, UK.

Tkalicj, P., Huda, M.K., Gin, K.Y.H., (2003): A multiphase oil spill model. *Journal of Hydraulic Research* 41 (2), 115 –125.

Wanga, S.D., Y.M. Shena, Y.H. Zhengb (2005): Two-dimensional numerical simulation for transport and fate of oil spills in seas, *Ocean Engineering* 32, 1556–1571.

Yapa, P.D., Shen, H.T., Angamma, K., (1994): Modelling oil spills in a river–lake system. *Journal of Marine System* 4, 453 – 471.

Table 1 Properties of spilled Heavy Fuel Oil

Density @15°C	997.9 kg/m ³
API grade	13.12
Viscosity @ 50°C	365.8 cST
Upper pour point	25°C
Carbon residue	11.99 %wt
Flash point	>65°C
Minimum transfer temperature	43°C
Injection temperature (for 13 cST viscosity)	133°C

Table 2 Input parameters for simulations

Simulation period	6 days
Grid size	200 m
No of grids	X axis 550
	Y axis 700
Simulation time step	100 s
Area covered	15400 km ²
No. of sources	1
Particles per time step	36
Spill time step	5 min
Spill quantity	85 tonnes
Winds	10 min interval
Air temperature	30°C
Cloudiness	0.01
SST	28°C
Salinity	33.5 psu
Dispersion coefficients:	
	Longitudinal 1.2 m ² /s
	Latitudinal 0.5 m ² /s

Table 3 Typical values of instantaneous slick area obtained from model and observations

S.No	Date and Time (local time)	Area (km ²)	
		Model	Observation
1	23 March 05 1345 h	3.21	4.40
2	23 March 05 1425 h	3.00	4.60
3	24 March 05 0815 h	8.05	9.40

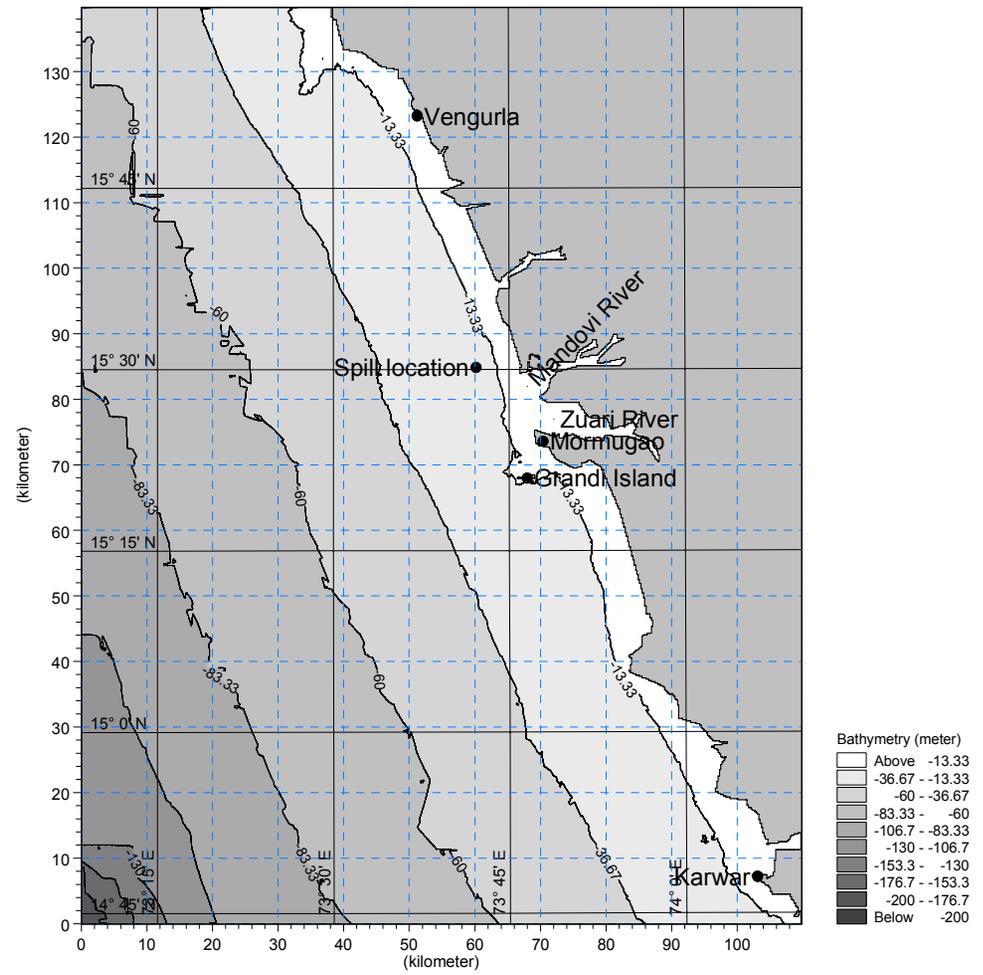
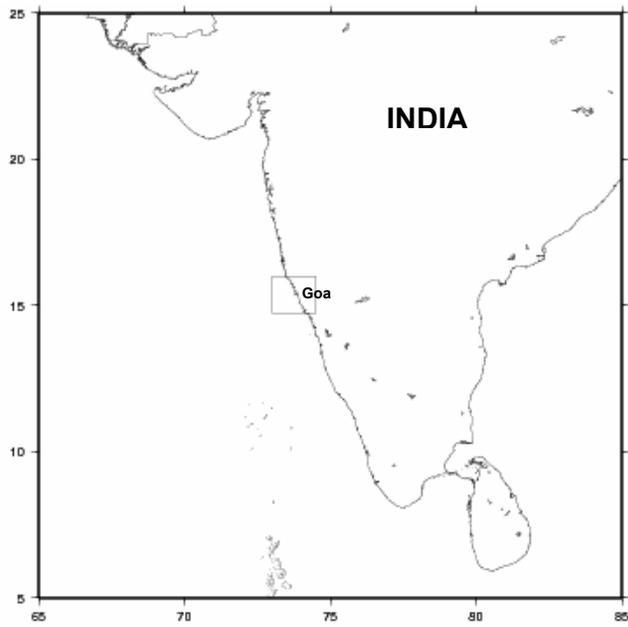


Fig. 1 Model domain with initial spill location

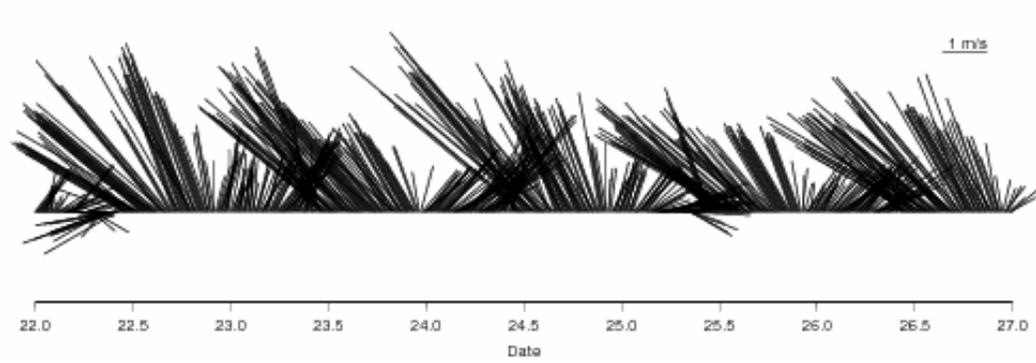


Fig. 2(a) Winds measured at Dona Paula, Goa using AWS (22 – 26 March 2005)

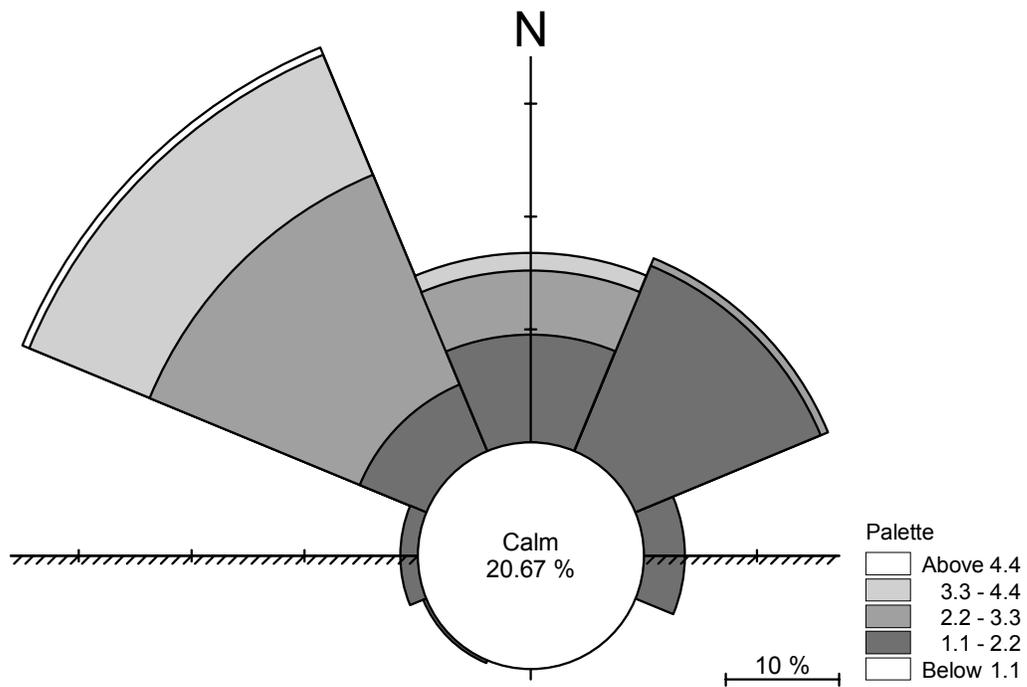


Fig. 2(b) Wind rose diagram (22 – 26 March 2005)

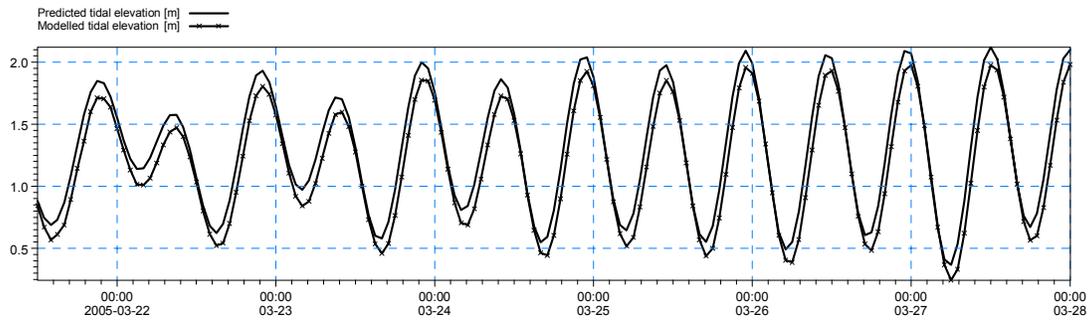
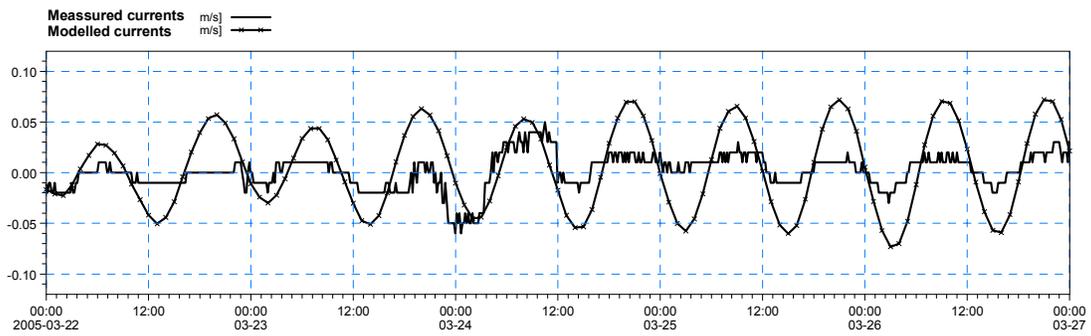
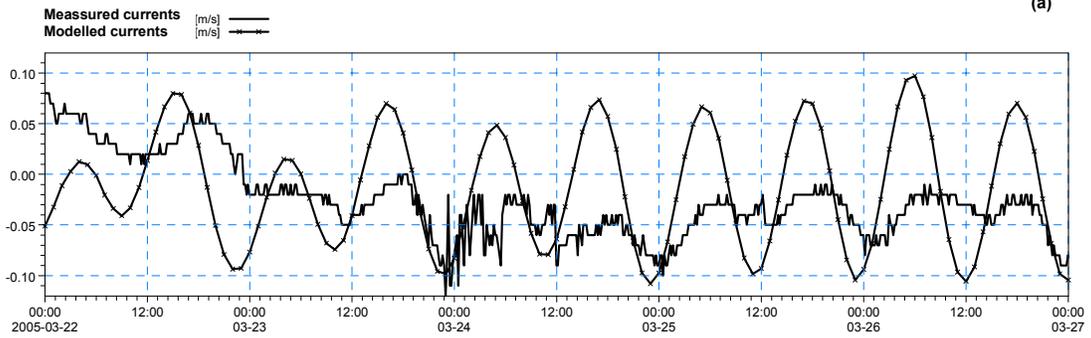


Fig. 3 Comparison between predicted and simulated tides



(a)



(b)

Fig. 4 Comparison between (a) U-component and (b) V-component of measured and modeled currents

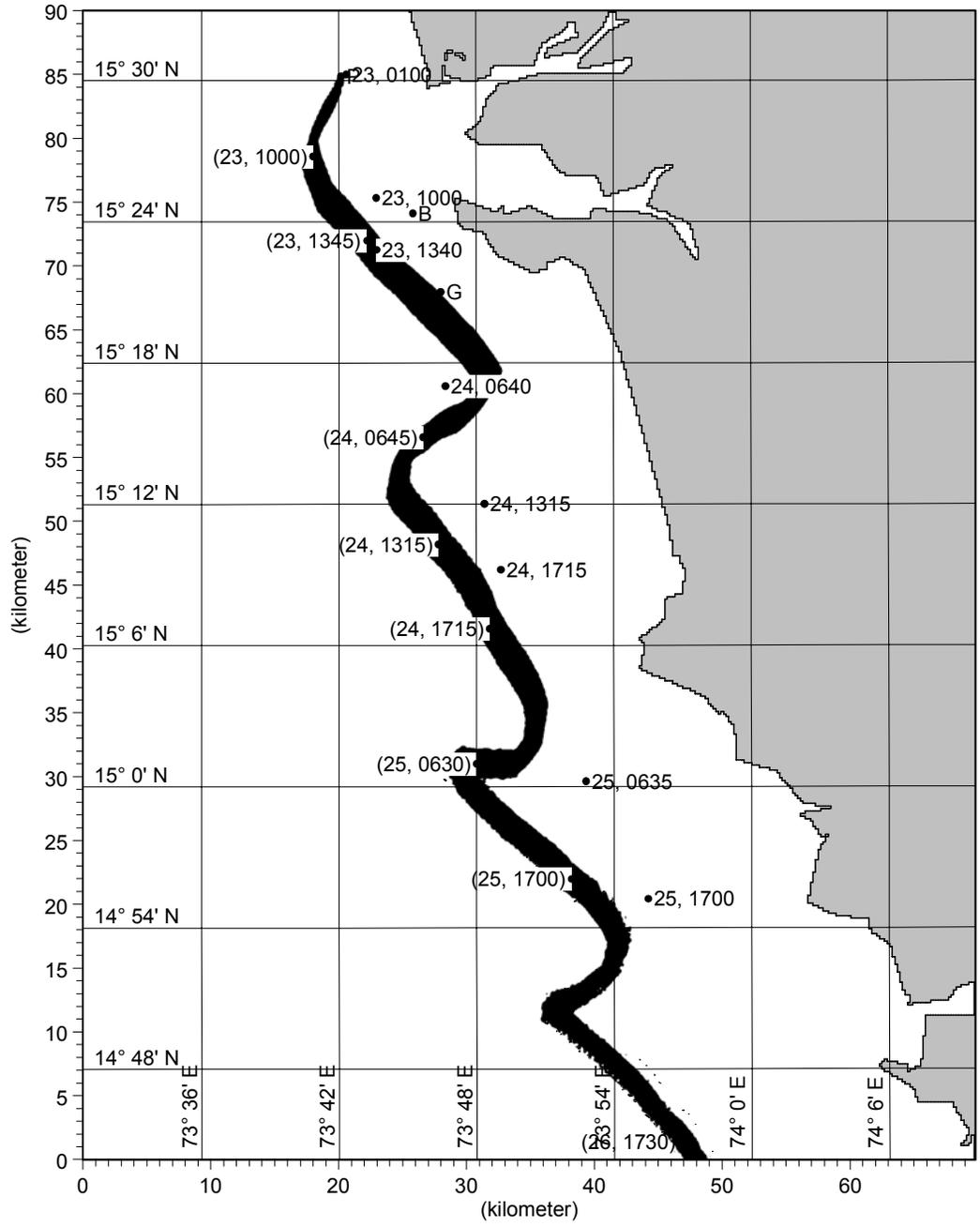


Fig. 5 Simulated trajectories of oil spill validated with observations [date & time given in brackets are from model]. The width of the trajectory does not represent oil slick area.