Hindcasting and Validation of Mumbai Oil Spills using GNOME

Prasad SJ[1]*, Balakrishnan Nair T.M[1], Francis P.A[1] and Vijayalaksmi T[2]
[1]Indian National Centre for Ocean Information Services, Hyderabad, INDIA
[2]Jawaharlal Nehru Technological University, Hyderabad, INDIA

Abstract

Oil spill trajectory forecasting became mandatory for providing advisory services to the regulatory authorities during the event of oil spill, for planning their remediation and clean up measures. The present study describes a method to simulate the trajectory of the spilled oil using GNOME and validating it using available Radar data. The trajectory forecasting of two oil spill events, happened in mumbai high region, during 2010- 2011 has been executed in hindcast mode using General NOAA Operational Modeling Environment. The forcing parameters such as, forecasted European Center of Medium Range Weather Forecast winds and Regional Ocean Modeling system currents were used for the execution. The likely areas which are to be affected are found from the prediction. The trajectory obtained from GNOME is compared with oil spill signatures obtained from the radar data of a particular time step. The observed oil slicks were found within the average distance of 3.73 km and 4.16 km from the prediction for MSC chitra spill and Mumbai uran trunk pipeline spill respectively. This trajectory model can be used for making the contingency plans, conducting the mock drills and during oil spill response & preparedness operations.

Keywords: Oil spill, GNOME, modeling, trajectory, radar remote sensing, ocean modeling.

Introduction

India possessing sensitive ecosystems and aquatic organisms along its coastline comprising estuaries, lagoons, mangroves, backwaters, salt marshes, mudflats, rocky shores, sandy structures and known for its coastal and marine biodiversity[1-3]. The demand for petroleum has been increasing day by day due to the economical growth which contributes to oil spills along the tanker routes. The coastal waters of Mumbai region including the creek and harbour are always at high risks of oil spills. The marine habitats are being affected due to the oil spills caused due to vessel collisions and illegal discharges[4]. To prevent and mitigate the impact of oil spills on the marine environment[5], an oil spill trajectory prediction system is required, which can protect the marine habitats and sensitive ecosystems. The present study considers the simulation and validation of two cases.

MSC Chitra collision: An oil spill occurred after the collision of MSC Chitra and MV Khalijia near Mumbai on 07.08.2010 around 10.00 hrs. MSC Chitra while leaving the Mumbai port has collided with MV khalijia-3. Approximately 700 Tons of fuel oil spilled after the collision at 18°51'59" N,72°48'48" E. Signs of oil were found at various coastline of the Mumbai metropolitan region from the very next day of the collision, as if the spillage has traveled long distances. The coastal sediments and the mangrove stretch were affected along the shoreline.

Mumbai Uran Trunk pipeline leak: A rupture in the trunk pipeline, caused an oil spill off the Mumbai coast on 21.01.2011 at 19°7'3" N, 72°6'33" E. About 70 tons of crude oil was spilled due to the rupture and it has spread upto 3 square km. Due to the calm condition of the sea and the wind was blowing in the direction opposite to Maharashtra coast, the spill has not reached the coast. However the spill was contained and the rupture was fixed by the concerned authority.

The above said two cases were considered for the model execution and validation. Figure-1 represents the location map of the study area.

Details of the trajectory model: The oil spill trajectory prediction includes the execution of the trajectory model which generates the spill trajectory. Validation of the model with an observation is very vital to use the model results in real scenario. GNOME, a spill trajectory model developed by National oceanic and Atmospheric Administration (NOAA) is used for the prediction. GNOME is operated in three modes, viz standard mode, GIS output mode and diagnostic mode. In standard and GIS output modes, a location file assists the user in setting up the model through an expert system that converts the input into model parameters. In diagnostic mode, the user is responsible for all model fields and parameters which means the necessary inputs has to be fed by the user to generate his own oil spill trajectory[6]. The present study considered diagnostic mode of operation for Indian waters.

Movers, are any physical parameters that cause movement of the pollutant parcel in the water, generally currents, winds and diffusion. Movers fall into two categories. Universal movers apply everywhere and usually consist of winds, currents and diffusion. All other movers apply only to the map to which they

are attached. The use of multiple maps is really a legacy from a previous incarnation of the model, written at a time when computers lacked sufficient memory to read-in a single map for an entire coastal region.

For the most part, a single map is now sufficient and all movers can be placed on that map. To get the overall movement the *u* (east-west) and *v* (north-south) velocity components from currents, wind, diffusion, and any other movers are added together at each time-step, *i*, using a forward Euler scheme (a 1st-order Runge-Kutta method). The movers at a given point (x,y,z,t_i) causes a displacement $(\Delta x, \Delta y, \Delta z)$ at t_i

Calculation of zonal, meridonal, and vertical displacement by movers.

$$\Delta x = (u * \Delta t)/(111120.00024 * \cos y) \tag{1}$$

$$\Delta y = (v * \Delta t)/(111120.00024) \tag{2}$$

Where: Δx is the zonal displacement in m, Δy is the meridonal displacement in m, $\Delta t = t_i - t_{i-1}$ is the time elapsed between time-steps *i*; *y* is the latitude in radians; 111,120.00024 is the number of meters per degree of latitude (assumes 1' latitude = 1 nautical mile everywhere); and $(\Delta x, \Delta y)$ are the 2-D longitude and latitude displacement, respectively, at the given depth layer *z*.

At present, movement in GNOME cannot occur between depth layers (thus the vertical displacement, Δz equals zero). The calculation of total movement is a simple vector addition of the displacement of a given pollutant particle by each mover over the time-step. There is typically significant uncertainty in the accuracy of the input forecast and/or measured data. Also, in general these inputs to the model are gridded data which result in non-smooth velocity fields – limiting the utility of employing higher-order Runge-Kutta methods (if additional accuracy is desired, decreasing the model time-step often produces much the same improvement as would using a more complex higher-order method). Each mover present in the model setup may be active or inactive at any given time. Only movers marked active will be used in the model calculation. (Source: GNOME technical documentation v4.2)

Material and Methods

Input parameters for trajectory prediction: The necessary details like, location of the spill, date and time of the oil spill, type and quantity of the oil spilled are obtained from Indian Coast Guard/Regulatory authority. The forecasted winds are obtained from European Centre for Medium- range Weather forecasts (ECMWF). Current pattern is obtained from Regional Ocean Modeling System (ROMS) of INCOIS. Figure-2 depicts the methodology of simulation and validation.

Method of validation: Due to the availability, regardless of weather conditions and its ability to penetrate cloud cover, Synthetic Aperture Radar data (SAR) data was mostly used to detect the oil slick. The observed oil slicks from the available radar data is taken for the comparison.
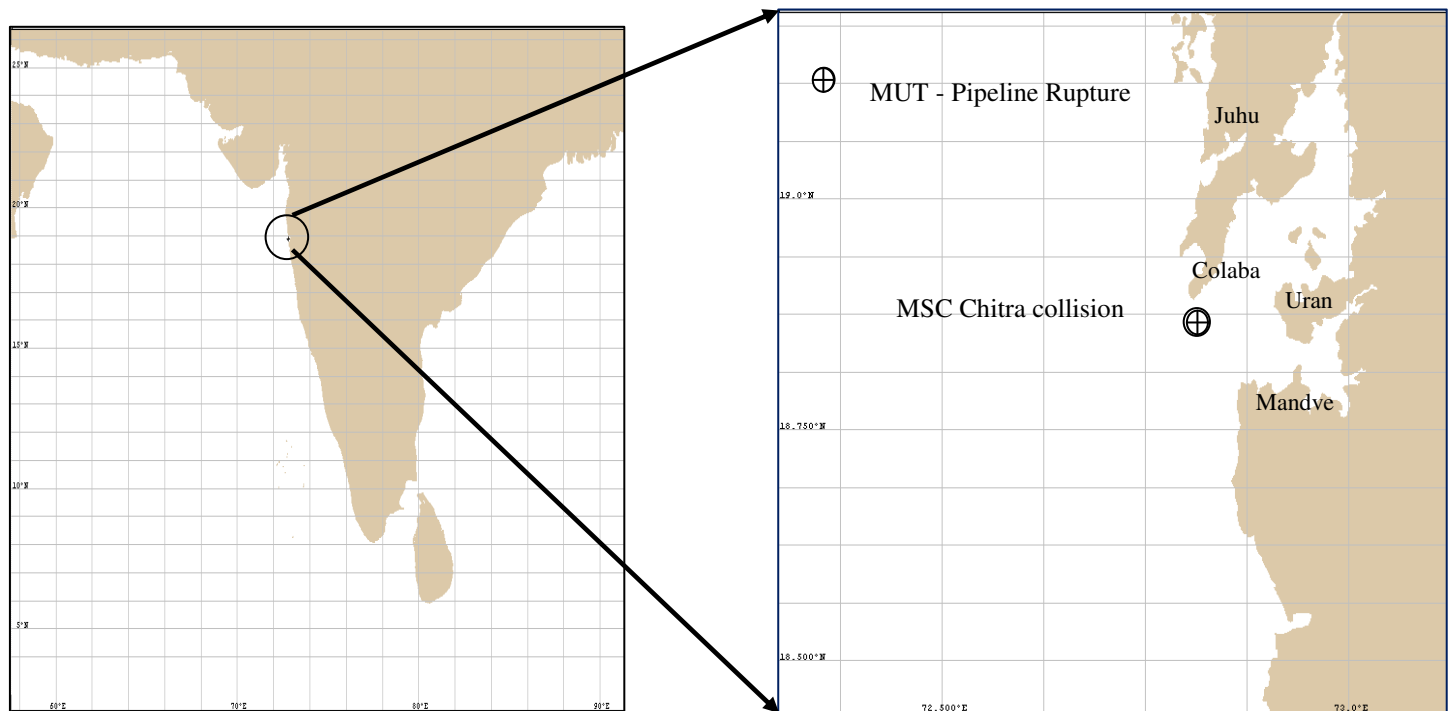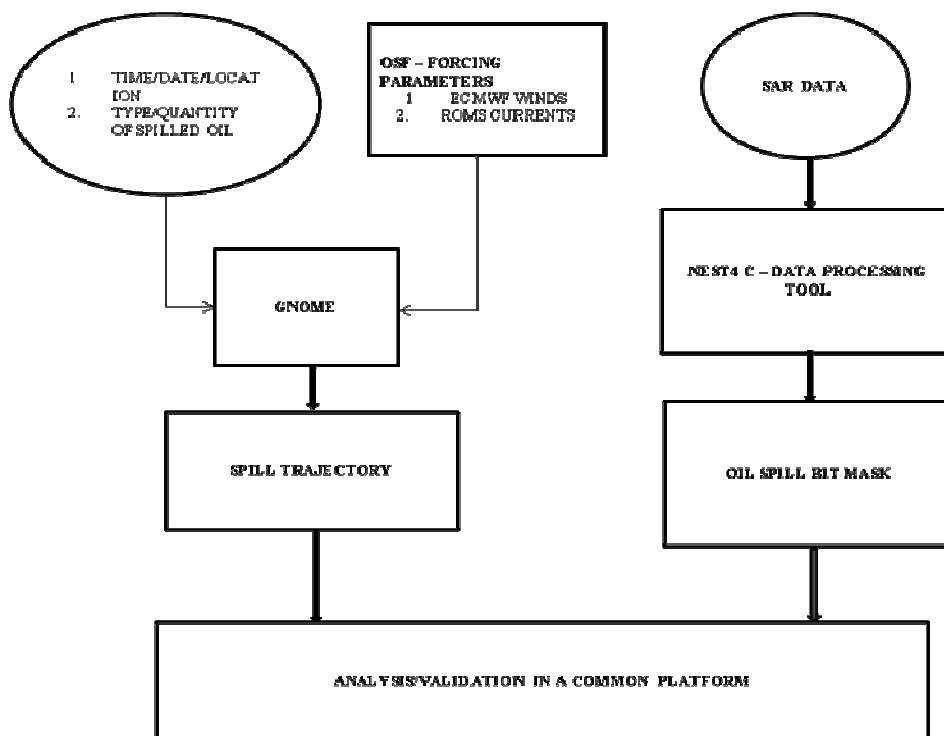

Figure-1
Location map of the study area

Figure-2
Method of simulation and validation

Utilization of SAR Data: Satellite imagery is used for oil spill strategic planning rather than tactical planning[7]. Many countries in northern Europe use a combination of satellite sensors and airborne sensors for oil spill surveillance in the marine environment[8]. Airborne sensors are used for short term or tactical response. Radar Sensor of Envisat from European space agency and Radarsat of Canadian space agency were found appropriate for oil-spill applications[9]. However, SAR has a number of limitations that restrict its operational use. One is the narrow range of wind speeds (3–10 m/s) available for oil-spill detection[10]. The dark spot in SAR images are due to low-wind areas and natural phenomena in the upper ocean, which are, in some respects, similar to oil spills. Oil spills can often be identified by their characteristic shape, size, edge and contrast properties and by using contextual information or a geo-information approach[10,11]. Radarsat-1 is a multi mode SAR equipped satellite which also carries the C - band operated in different swath and resolution modes. The SAR datasets and images are of practical interest for oceanographers and the oil industry due to the fact that, using SAR, the sea surface can be observed in all weather conditions, i.e though the clouds and independent of sun illumination. Synthetic Aperture Radar Data is widely used for oil spill detection[12-14].

SAR Data processing: The Next ESA SAR Toolbox (NEST) is used for reading, post-processing, analyzing and visualizing the large archive of data (from Level 1) of ESA SAR missions including ERS1 and 2, ENVISAT, as well as third party SAR-data from JERS SAR, ALOS PALSAR, Terra SAR-X, Radarsat-1and 2 and Cosmo-Skymed. NEST helps the remote

sensing community by handling ESA SAR products and complimenting existing commercial packages. The data processing includes the major steps like preprocessing, land sea masking, dark spot detection and finally clustering & determination. The dark spots are detected using an adaptive thresholding method which involves the detection of the pixels that has lower values than the threshold shift set. Pixels detected as part of the dark spot are clustered and then eliminated based on the dimension of the cluster and user selected minimum cluster size. The obtained oil spill signatures are taken for the comparison. The spill trajectory and the oil spill signatures are exported to a common platform for the ease of comparison.

Criteria for oil spill signature: Homogeneity, contrast and dissimilarity were used to discriminate oil spill from their look-alikes[15]. Certain factors for discrimination are considered in the study. The probability of oil spill is increased, if the surrounding areas are homogeneous, if the contrast between the slick and the neighboring region is high, and when the dissimilarity between the dark slick and the surrounding area is high. The probability of look-alikes is increased if the surrounding areas are heterogeneous, if the contrast between the slick and the neighboring region is low and when the dissimilarity between the dark slick and the surrounding area is low. Oil slicks are also differentiated from dark spots based on the following factors: i. Dark homogeneous spots in a uniform windy area. ii. Linear dark areas, not extremely large, with abrupt turns i.e. most likely abrupt turns due to wind directions change or surface current. iii. Near ship or rig; or Locations of ship lane. Based on these factors, the oil slick is identified. The properties of the spiled pollutants are provided in table-1.

Table-1
The properties of the spilled pollutant
(A) Properties of Fuel Oil # 6

|	
Appearance	Black liquid
Odor	Oil-type odor
Specific Gravity (water=1)	0.946
Flash Point (degrees C)	65
Boiling Point	400°-1200°F (204°-649°C)
Vapor Pressure (mm Hg)	0.2
(B) Properties of Crude oil	
Boiling Point	AP -54°F to 1100°F
Vapor Pressure, Temp. (Method)	AP 1 to 2 at 100°F
Volatile Characteristics	Appreciable
Specific Gravity (H2O = 1)	0.88
Solubility in Water	Negligible
Appearance	Thick light yellow to dark black colored liquid.
Odor	Petroleum hydrocarbon odor.

Results and Discussion

Model execution for MSC chitra collision: The above said case study is executed in hind cast mode using GNOME. The forcing parameters like forecasted ECMWF winds and ROMS tidal currents were tuned to unique resolution and the model was triggered. The wind rose plot of the forecasted ECMWF winds is shown in figure-3. The magnitude and direction of the predicted tidal currents is also shown in the form of rose plot in Figure - 4. The predominant wind direction was predicted to be from SW to NE and the wind speed was found to be in the range of 4.6 m/s to 5.7 m/s. The magnitude of the tidal current was in the range of 0.18 m/s to 0.26 m/s. The trajectories generated during the study period were shown in figure-5 and figure-6. The spill was found to move into the Elephanta Island of thane creek due to the strong tides and winds.

Comparison with the SAR data: The model was executed for a period of nine days (during 07.08.2010, 10.00 hrs to 16.08.2010, 10.00 hrs). Due to the availability of the SAR data on 15.08.2010, 19.00 hrs, the trajectory obtained during this particular time step was considered for the comparison. The points of the predicted trajectory and the observed oil slicks from the radar data were plotted in the same scale which is shown in figure-7.
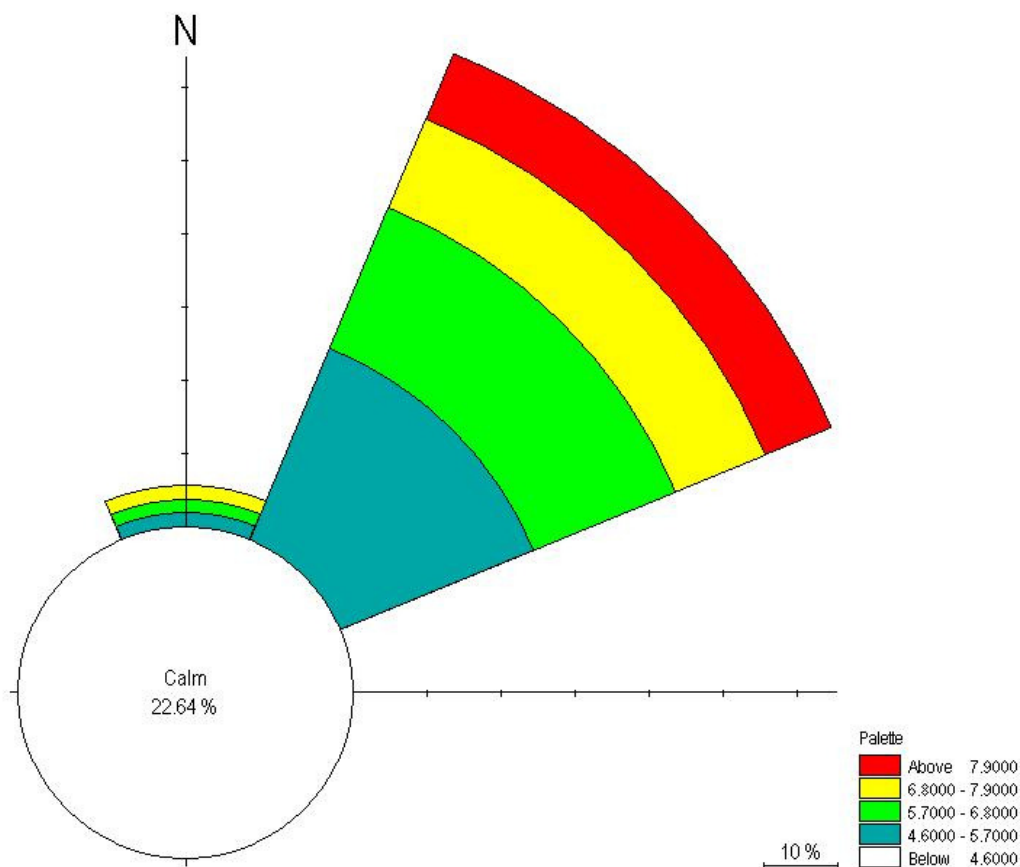
Figure-3
Predicted wind speed (m/s) and to direction at the spill point
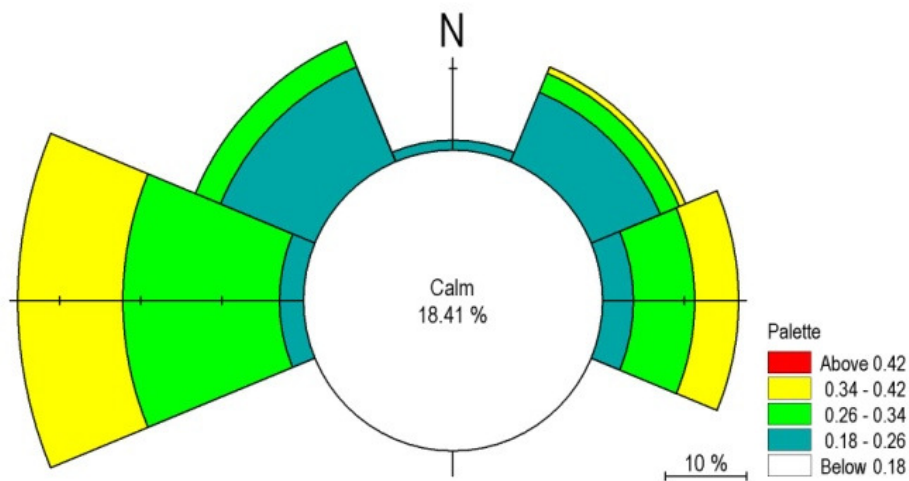
Figure-4
Predicted Tidal current (magnitude in m/s and direction) at the spill point
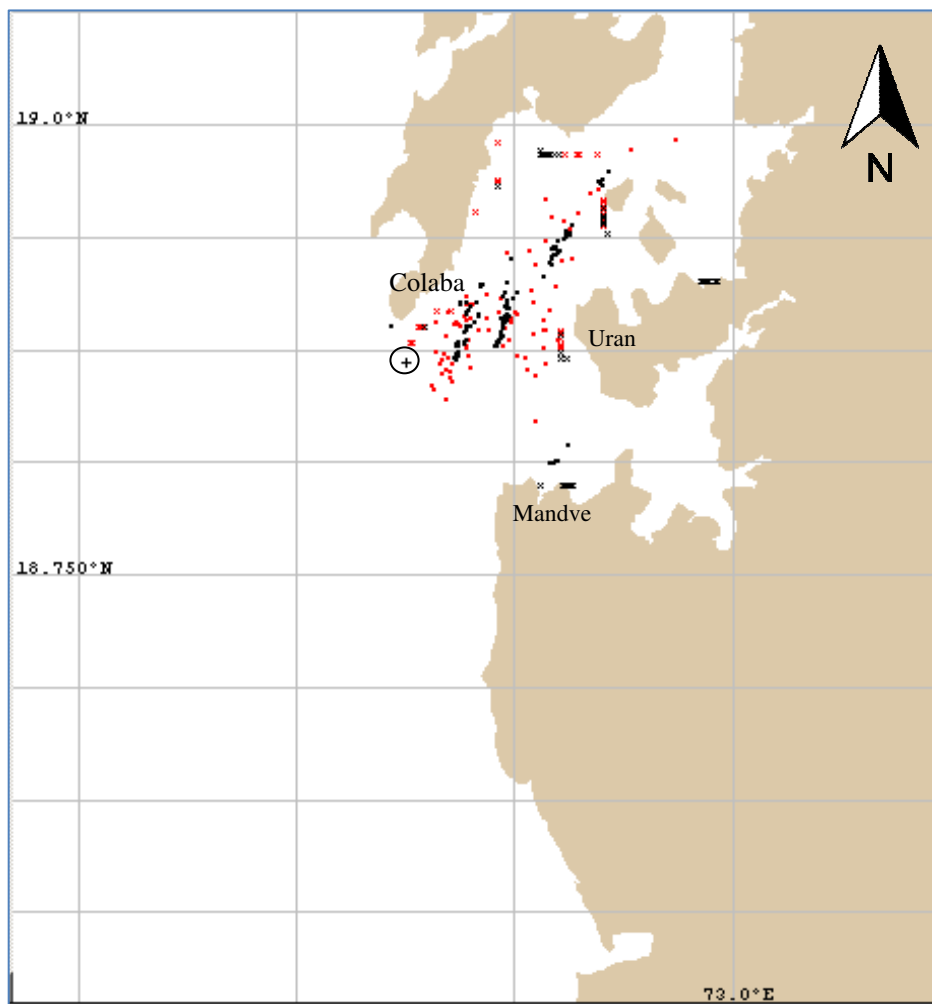
Figure-5
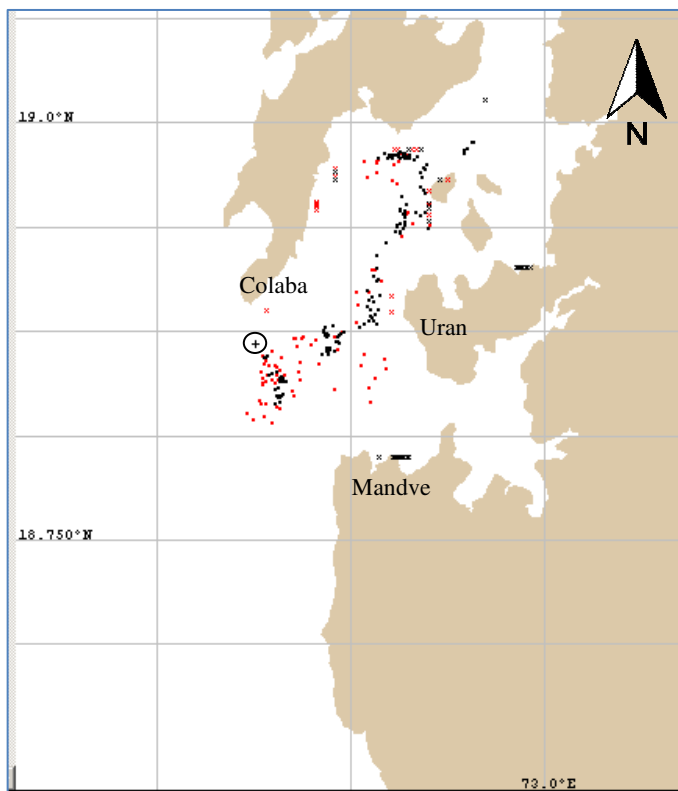**Spill trajectory on 12.08.2010, 10.00hrs**

Figure-6
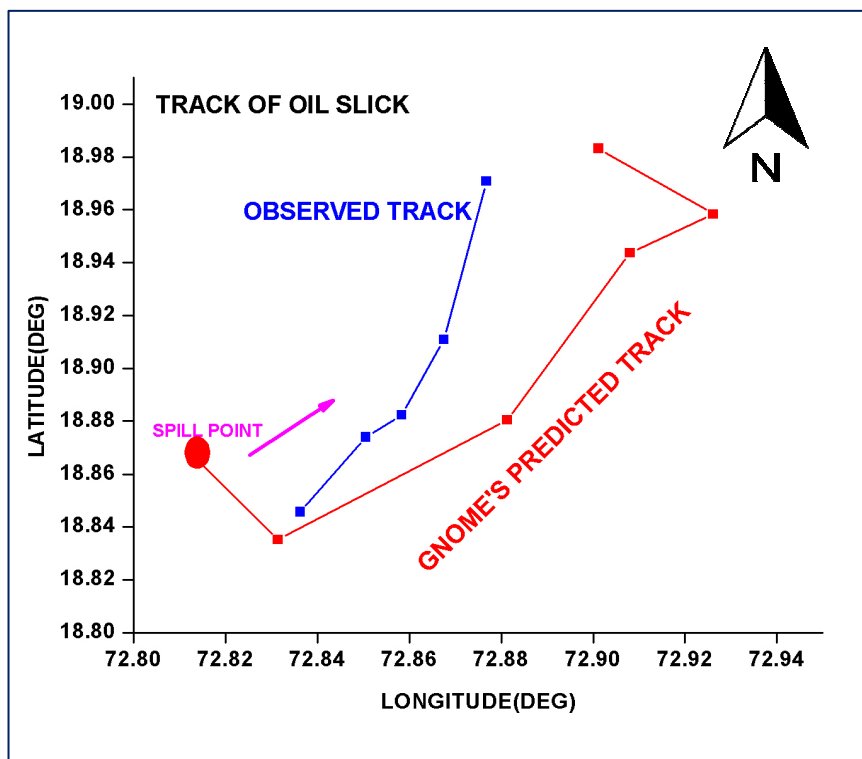**Spill trajectory on 15.08.2010, 19.00hrs**

Figure-7
Comparison of the predicted spill trajectory with the observation during 15.08.2010, 19.00 hrs

Mumbai uran trunk pipeline spill: The forcing parameters were tuned to unique resolution and the model was run. The wind rose plot of the forecasted wind is shown in figure -8. The predominated wind direction was predicted to be from N to S and the wind speed was in the range of 6.3 to 7.5 m/s. The magnitude and direction of the predicted currents is shown in the form of rose plot in figure -9.The magnitude of currents was estimated to be in the range of 0.007 to 0.1 m/s.
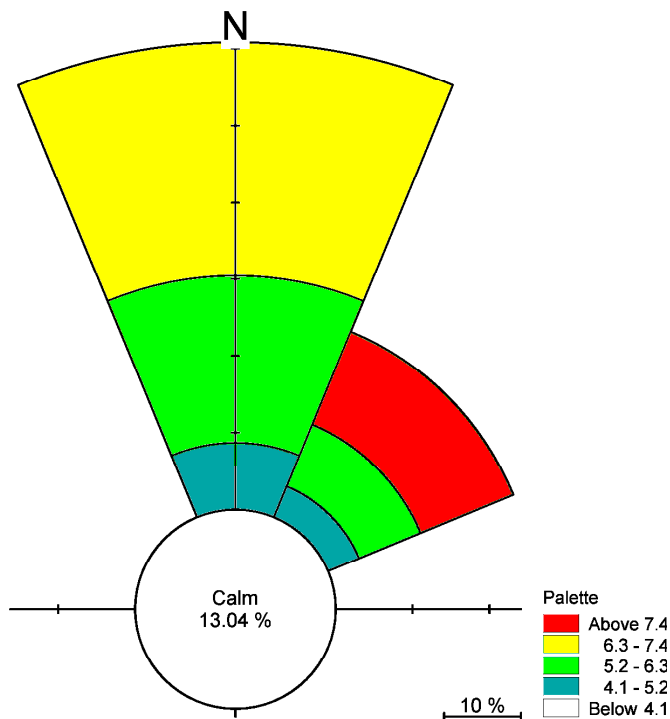
Figure-8
Predicted wind speed (m/s) and from direction at the spill point
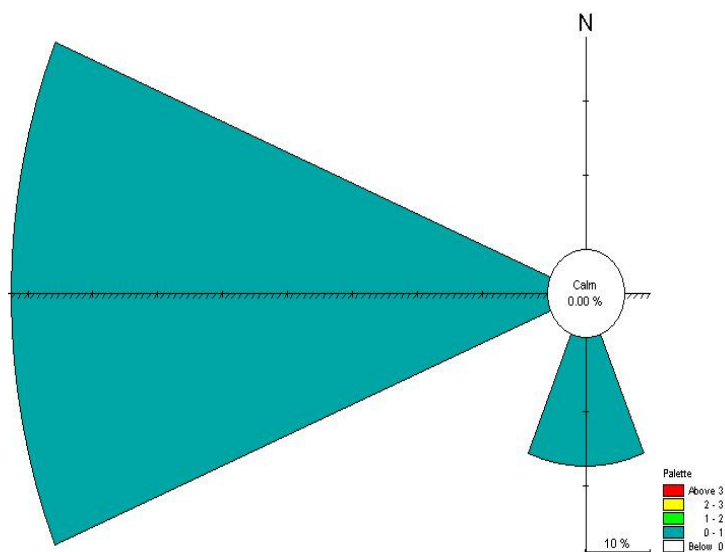
Figure-9
Predicted current (magnitude m/s and to direction) at the spill point
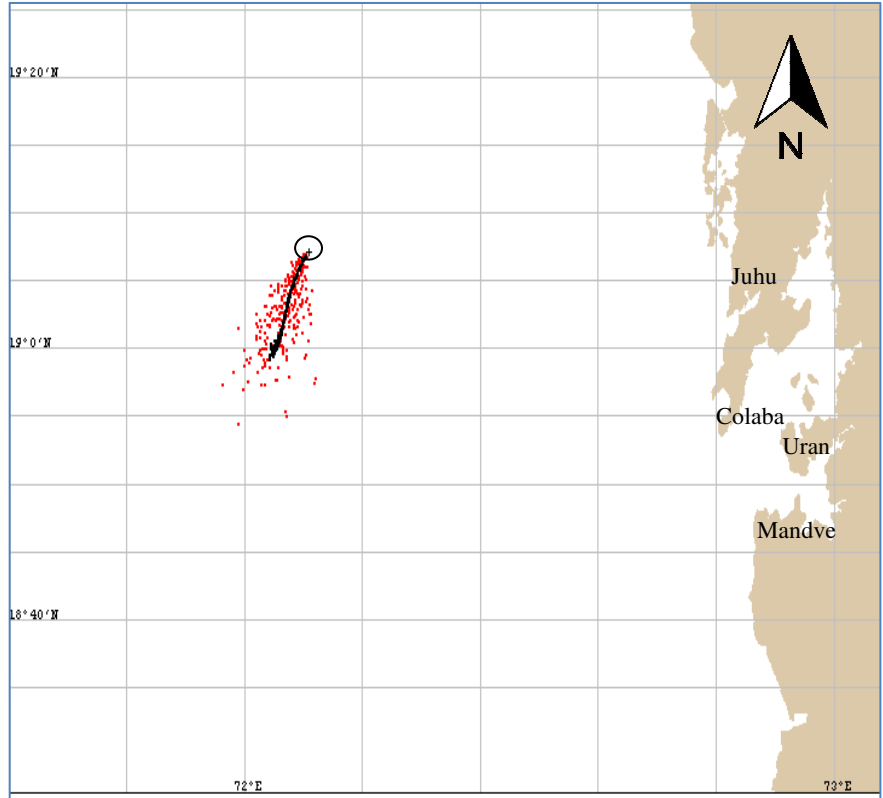
The predicted trajectory was found to move towards the southwest with respect to the spill point. The snapshots of various executions are shown in figure-10 and figure-11.

Comparison with the SAR data: The model was executed for a period of two days (during 21.01.2011 09.00 hrs to 23.01.2011 23.00 hrs). Due to the availability of the SAR data on 23.01.2011 23.00 hrs, the trajectory obtained during this particular time was considered for the comparison. The points of the predicted trajectory and the observed oil slicks from the radar data were plotted in the same scale. Figure-12 shows the comparison between prediction and observation.

Deviation analysis: In MSC chitra spill case, the positions of the oil slick obtained from Radarsat data are compared with the predicted trajectory. Table-2 shows the deviation distance between the predicted trajectory and observed trajectory.

Table-2
Deviation between the prediction and observation during 15.08.2010, 19.00 hrs

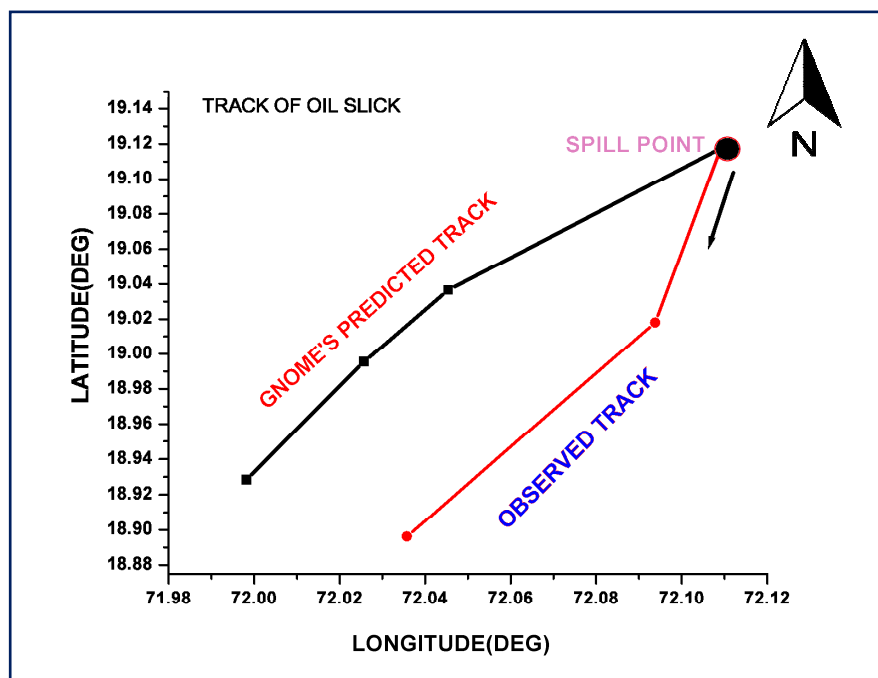|	Predicted positions of oil drift	SAR DATA Observation (Observed oil traces)	Deviation(km) from observation
1.	72.93º E,18.960º N	72.875º E,18.960º N	5.784
2.	72.92º E,18.95º N	72.872º E,18.95º N	5.048
3.	72.91º E,18.94º N	72.865º E,18.94º N	4.733
4.	72.90º E,18.92º N	72.865º E,18.92º N	3.682
5.	72.885º E,18.90º N	72.860º E,18.90º N	2.630
6.	72.880º E,18.89º N	72.860º E,18.89º N	2.104
7.	72.865º E,18.865º N	72.845º E,18.865º N	2.104
	Average deviation distance (km)		3.73

Figure-10
Spill trajectory on 22.01.2011, 10.00hrs
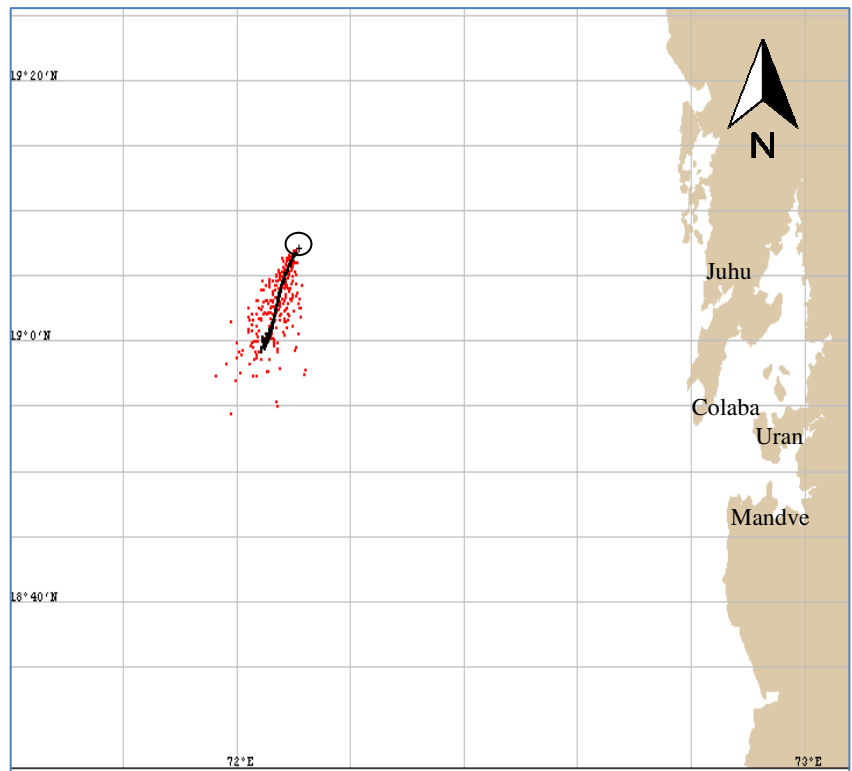
Figure-11
Spill trajectory on 22.01.2011, 23.00hrs

Figure-12
Comparison of the predicted spill trajectory with the observation during 22.01.2011, 23.00 hrs

Table-3
Deviation between the prediction and observation during 22.01.2011, 23.00 hrs

	Predicted positions of oil drift	SAR DATA Observation (Observed oil traces)	Deviation(km) from observation
1.	72.10º E,19.11º N	72.106º E,19.11º N	0.634
2.	72.079º E,19.07º N	72.102º E,19.07º N	2.417
3.	72.051º E,19.05º N	72.098º E,19.05º N	4.309
4.	72.037º E,19.02º N	72.089º E,19.02º N	5.466
5.	72.023º E,18.958º N	72.080º E,18.958º N	5.994
6.	72.019º E,18.951º N	72.066º E,18.951º N	4.943
7.	72.00º E,18.92º N	72.051º E,18.92º N	5.365
		Average deviation distance (km)	4.16

Table-2 represents that the predicted trajectory is deviated at an average distance of 3.73 km from the observed path of the oil spill. oil slicks were observed at a minimum distance of 2.104 km and a maximum distance of 5.784 km. The average deviation was found to be 3.73 km. This study shows that the trajectory prediction helps in identifying the likely areas which are to be affected.

In Mumbai Uran Trunk pipeline spill case, the positions of the oil slick obtained from Envisat -ASAR data are compared with the predicted trajectory.

Table-3 represents that, the predicted trajectory is deviated at an average distance of 4.16 km from the observed path of the oil spill. The oil slicks were observed at a minimum distance of 0.634 km and a maximum distance of 5.994 km.

The distance (deviation) between the predicted trajectory and the observed oil slick path is measured in both the cases. Resultant is estimated from the magnitude and direction of wind forcing and the current forcing. Wind has stronger effect on the upper layer of the water column, and near the coast the tide has effect over the entire water column[16]. In case of MSC chitra spill, the tidal currents in the creek are stronger and hence the oil has followed an up and down movement along the wind path. In case of Mumbai uran trunk pipeline spill, wind has stronger effect on the water surface and hence the oil is carried mainly by wind as weaker surface currents prevailed. This deviation between the prediction and observation can be reduced by the usage of the in situ wind and current forcings. Assimilated forcings from the high resolution forecasting system can also be fed to get closer results. The above said measures lay the foundation for the future scope of work.

Conclusion

The experimental hind casting of oil spill is executed using GNOME and the validation is done using the available SAR data. The observed oil traces were found within the average distance of 3.73 km and 4.16 km from the prediction for MSC chitra spill and Mumbai uran trunk pipeline spill respectively. However the present study has described a method to simulate the spill trajectory using GNOME and validating the results for a time period with the available SAR data. The prediction also determines the likely areas that are to be affected. This trajectory model can be used for making the contingency plans, conducting the mock drills and during oil spill response preparedness and operations.

Acknowledgement

References

1. Venkatraman, Coastal and Marine biodiversity in India, Indian Journal of marine science, **34(1)**, 57-75, **(2005)**

2. Ganguly Subha, Environmental and Ecological Importance of Coral Reefs: A Review, *Int. Res. J. Environment Sci.,* **2(7)**, 85-86, **(2013)**

3. Kumar Goutam and Ramanathan Al, Microbial Diversity in the Surface Sediments and its Interaction with Nutrients of Mangroves of Gulf of Kachchh, Gujarat, India, *Int. Res. J. Environment Sci.,* **2(1)**, 25-30, **(2013)**

4. Ladwani K.D. and Ramteke D.S., *Bulletin of Environmental Contamination and Toxicology,* **90(5)**, 1-6, **(2013)**

5. Parab S.R., Pandit R.A., Kadam A.N. and Indap M.M., Effect of Bombay high crude oil and its water-soluble fraction on growth and metabolism of diatom Thalassiosira sp, *Indian Journal of Marine Sciences,* **37**, 251-255, **(2008)**

6. Beegle-Krause C.J, General NOAA Oil Modeling Environment (GNOME) : A New Spill Trajectory Model. IOSC 2001 Proceedings, Tampa, FL, March 26-29, St. Louis, MO: Mira Digital Publishing, Inc, **2**, 865-871 **(2001)**

7. Brown C. and Fingas M., A review of current global oil spill surveillance, monitoring and remote sensing capabilities, In Proc. 28th Arctic and Marine Oil Spill Program (AMOP) Tech. Seminar Calgary, Canada, 7–9, 789-798, **(2005)**

8. Brekke C. and Solberg A., Oil spill detection by satellite remote sensing. Remote Sensing of Environment, **95**, 1–13 **(2005)**

9. Gade M. and Alpers. W., Using ERS-2 SAR images for routine observation of marine pollution in European coastal waters, *Sci. Total Environ.*, **237/238**, 441-448 **(1999)**

10. Alpers W. and H. Espedal, Oils and Surfactants, Chapter 11 in Synthetic Aperture Radar Marine User's Manual, National Oceanic and Atmospheric Administration, Center for Satellite Application and Research, NOAA/NESDIS, Ch.R. Jackson, J.R. Apel, editors, Washington, D.C., USA, ISBN 0-16-073214-X, 263-275 **(2004)**

11. Yu. Ivanov and V. V. Zatyagalova b a P. P., A GIS approach to mapping oil spills in a marine environment Shirshov Institute of Oceanology, Russian Academy of Sciences, Nakhimovsky prospect 36, Moscow 117997, Russia b Centre 'Almaz', NPO Mashinostroenia, Gagarina St. 33, Reutov, Moscow Region 143966, *Russia Version of record first published,* 23 Oct **(2008)**

12. Xu L., Li J., Brenning A., A comparative study of different classification techniques for marine oil spill identification using RADARSAT-1 imagery, *Remote Sensing of Environment,* **141**, 14-23 **(2014)**

13. Lee Jong-Sen, Speckle suppression and analysis for synthetic aperture radar images, *Optical Engineering,* **25 (5)**, 636-643 **(1986)**

14. Chang L.a, Cheng C.M.a and Tang Z.S.b, An automatic detection of oil spills in SAR images by using image segmentation approach, International Geoscience and Remote Sensing Symposium (IGARSS), Article number 1525287, **2,** 1021-1024 **(2005)**

15. Solberg A.H. and Volden E., Incorporation of Prior Knowledge in Automatic Classification of Oil Spill in ERS SAR Images*, IEEE Transactions on Geoscience and Remote Sensing,* 157- 159 **(1997)**

16. Sebastiao P. and Guedes Soares C., Uncertainty in predictions of oil spill trajectories in a coastal zone, *Journal of Marine Systems,* **63**, 257-269 **(2006)**