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Abstract

Indian National Centre for Ocean Information Services (INCOIS) collaborated with Indian Coast Guard(ICG) and conducted Surface Velocity Program (SVP) drifter experiment at Mumbai High region for evaluating the operational oil spill trajectory model. INCOIS adopted General National Oceanic and Atmospheric Administration(NOAA) Operational Modelling Environment(GNOME) from NOAA and customised it in diagnostic mode for Indian ocean. GNOME was operationalised during May 2014. The objective of this experiment is to compare the drift pattern obtained from an oil spill trajectory model with the observed drifter track. SVP drifter was procured from M/s. Pacific Gyre, USA. It gives the Lagrangian trajectory path over the ocean. It was deployed by officials of Indian Coast Guard at Mumbai High region on 20 November 2016,12.45 hrs at 72.2295º E, 18.91035º N off Mumbai. It gave its drifted path along the west coast of India for ten days, before it beached near Diu on 3 December 2016.This observed track was considered for comparing the simulated positions obtained from GNOME when forced with currents of different ocean general circulation models. The results show that the positions of the drifter obtained, while forced with analysed currents of GODAS -MOM4p1 (GM4p1) and Hybrid Co-ordinate Ocean Model (HYCOM) are found to be in better agreement with the actual position of the drifter.

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Title of the report: EVALUATION OF OIL SPILL TRAJECTORY MODEL WITH THE OBSERVED SVP DRIFTER TRACK.

by

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1. INTRODUCTION

Coastal regions of Indian main land are very rich in biodiversity. It includes estuaries, lagoons, mangroves, backwaters, salt marshes, mudflats, rocky shores and sandy structures.[1-3].The marine habitats of Indian coast are being affected by 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. INCOIS established an oil spill trajectory prediction system with GNOME[6]. It is an oil spill trajectory model developed by NOAA and adopted at INCOIS for issuing the operational oil spill advisory on real time through web application. The trajectory model is operationalised in diagnostic mode of operation. In this system the user need to give the necessary details of the spilled pollutant such as location, date & time, type of oil spilled and its quantity. The forcing fields such as wind drift and surface currents are obtained from state of the art Ocean State Forecast (OSF) models are used to force the oil spill trajectory model. The user can trigger the trajectory model online and get the results without any technical support of the modeling community. The online system can be accessed through the INCOIS web link (http://www.incois.gov.in/portal/osf/oosa.jsp)

1.1 NEED FOR THE STUDY

INCOIS launched its online beta version of oil spill trajectory prediction system in May 2014 followed by their upgradation as version 2.0 in April 2015 & version 3.0 in August 2016 respectively.

Figure 1. Launch of OOSA Ver 3.0 by Chairman, NOSDCP

Version 2.0 included the high resolution ocean currents and the version 3.0 has the facility to treat different types of oil spill and posting the trajectory with the geomorphological features in a open layers webmap. Figure 1 shows the inauguration of version 3.0 by Director General, Rajendra Singh Chairman, National Oil Spill Disaster Contingency Plan (NOSDCP), Indian Coast Guard on 05 August 2016. The snap shot of the online oil spill advisory system in INCOIS web site is also shown in the right panel of Figure 1. The purpose of this drifter experiment is to periodically validate the drift pattern obtained from oil spill trajectory prediction system established at INCOIS. As a part of research, this exercise was held on 20.11.2016 at Mumbai high.ICG officials from Marine Rescue Coordination Centre(MRCC), Mumbai have deployed the SVP drifter at 72.2295º E, 18.91035º N on the same date. In the present study, the drift pattern of the SVP drifter is obtained by forcing 15 m depth averaged ocean surface currents.

2.SVP DRIFTER TESTING AND DEPLOYMENT

Surface Velocity Program (SVP) drifters, are the drifters that drift with the surface currents and reports its position along with environmental parameter such as Sea Surface Temperature, Sea Surface Salinity and wind velocity through Advanced Research and Global Observation Satellite (ARGOS) telemetry. However the drifter used in this study, has the facility to report its geographical position and sea surface temperature. The technical details of the SVP drifter are explained at https://www.pacificgyre.com/files/svp_datasheet.pdf. The drifter has a surface float of diameter 35 cm, made of Acrylonitrile butadiene styrene (ABS) Plastic material with White Anti-Fouling Paint Changing the Lower Hemisphere Color to blue. It has got a protected SST Probe. The transmission is switched on by a Magnet. A holey stock drogue (with tether) of 15 m has the diameter of 61 cm, is connected to the surface float. Figure 2 shows the schematic diagram of the SVP drifter.

Figure 2. SVP DRIFTER

2.1 SVP DRIFTER TESTING

Figure 3. SVP drifters during transmission test

Drifters were tested for their geographical positions, reported at INCOIS. Figure 3 shows the testing site at INCOIS. The geographical location of the drifter, the surface temperature of the submerged water were recorded through ARGOS telemetry. Parameters were obtained through the Argos web portal (https://argos-system.cls.fr/argos-cwi2/login.html). INCOIS maintains an active account in accessing the ARGOS data. After the successful testing, one of the drifter (ID 145819) was shipped to Marine Rescue Coordination Centre (MRCC), Mumbai for deployment.

2.2 .DETAILS OF THE DEPLOYMENT

SVP drifter was deployed by ICG officials from Indian Coast Guard ship, C-154, at 72.2295º E, 18.91035º N on 20 Nov 2016, 1245 hrs IST (Figure 4).The deployment was made at Mumbai Offshore Development Area. This site was considered for the deployment due to the lesser disturbance. Figure 5 shows the SVP drifter after deployment.

Figure 4. SVP drifter during deployment

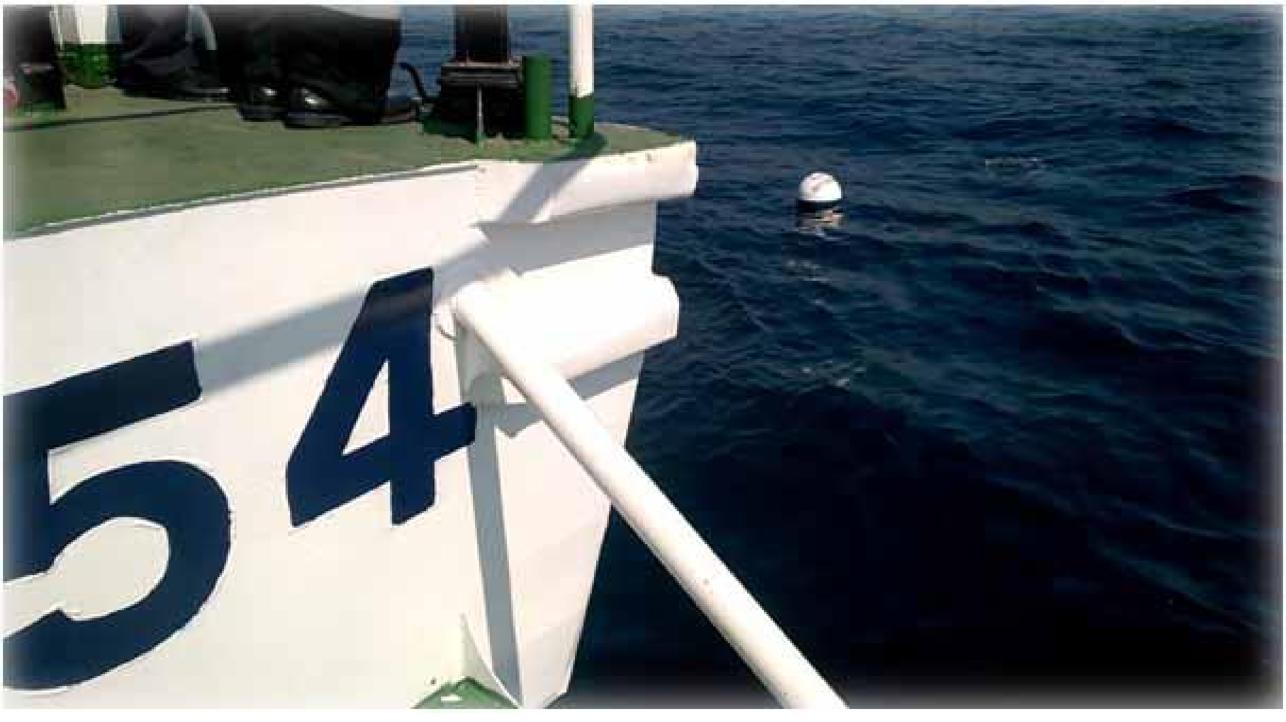

Figure 5. SVP drifter after deployment

3. DATA COLLECTION

After the deployment, the geographical position, sea surface temperature and battery voltage were obtained through ARGOS telemetry on real time. ARGOS is a pioneer satellite-based system which has been operating since 1978. The ARGOS system collects data from Platform Terminal Transmitters (PTT), and distributes sensor and location data to the final users. ARGOS helps the scientific community to monitor better and understand our environment, but also enables industry to comply with environmental protection regulations implemented by various governments. To meet system use requirements, all programs using ARGOS have to be related in some way or other to environmental protection, awareness or study, or to protecting human life. Applications for which there is a clear governmental interest are also approved.(http://www.argos-system.org). The SVP drifter deployed on 20.11.2016,12.45 hrs drifted by the surface currents untill 27.11.2016, 07.00 hrs. Afterwards, it was subjected to external disturbances, which caused it to beach near Diu island on 3.12.2016,12.43 hrs. The drifter was tracked during the exercise through ARGOS telemetry. The deployed location, the recovered location and the trajectory of the drifter during 20.11.2016,12.45 hrs to 3.12.2016,12.43 hrs are shown in Figure 6.The blue dots in the Figure 6 represents the reported geographical locations by drifter (ID:145819).

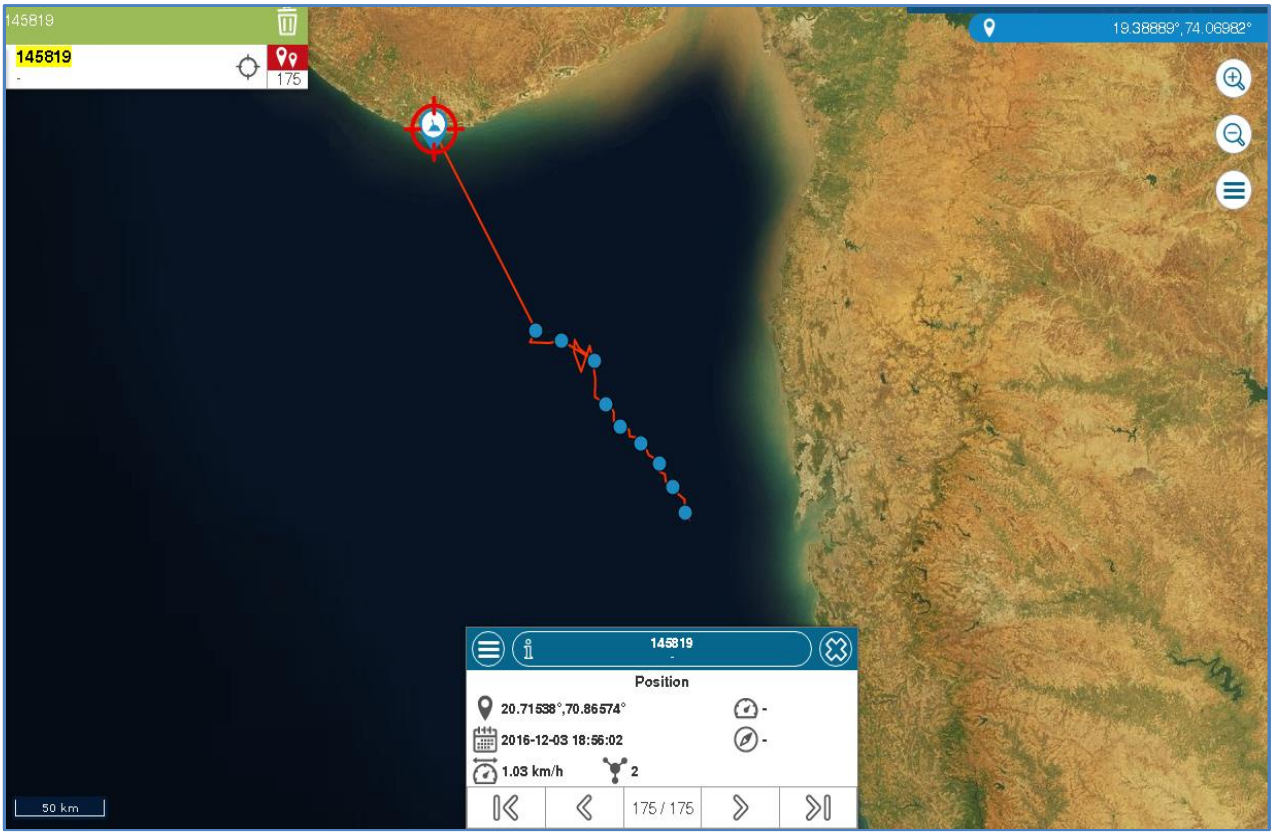

Figure 6.Drifter tracking through ARGOS during the exercise

4. EXPERIMENTS WITH TRAJECTORY MODEL

The trajectory model GNOME was run with the 15 m depth averaged ocean currents from operational High-resolution Operational Ocean Forecast and reanalysis System (HOOFS) (http://www.incois.gov.in/portal/HOOFS#HOOFS), experimental, research and development models at INCOIS

4.1 Trajectory model forced with operational WC-HOOFS (West Coast HOOFS)

The domain of the High-resolution Operational Ocean Forecast and reanalysis System (HOOFS) setup for the West Coast of India (WC-HOOFS), which is based on the Regional Ocean Modeling System (ROMS) version 3.7 extends from 60° E to 78° E in the east-west direction and from 8° N to 26.5° N in the north-south direction. The horizontal resolution of the HOOFS is 0.021° (1/48^o or approximately 2.25 km) and it has 40 sigma levels in the vertical. The vertical stretching parameters are chosen in such a way that the vertical resolution is highest in the upper part of the ocean. The lateral boundaries in the west and south are treated as open, where the tracer and momentum fields are nudge to daily fields derived from the Indian Ocean setup of ROMS model with horizontal resolution of 0.0833^o. The eastern and northern boundaries are solid walls with no slip conditions. The model uses the KPP mixing scheme(Large et al 1996[7]) to parameterize the vertical mixing. Smagorinsky type viscosity and diffusion schemes (Muschinski,1996[8]) are chosen for horizontal mixing and a bulk parameterization scheme (Fairall et al 1994[9]) is chosen for the computation of airï sea fluxes of heat. Sea surface salinity is relaxed to the monthly climatological values derived from WOA 2009. Ten constituents of tide are used to represent the realistic tides in the model. The model is initialized with realistic ocean state of 1 July 2010 derived from the basin-scale setup of ROMS (same as the one used to derive the lateral boundary conditions). The model is integrated with atmospheric forcing obtained from the National Centre for Medium Range Weather Forecast (NCMRWF), New Delhi (http://www.ncmrwf.gov.in/t254-model/t254_des.pdf). The atmospheric forcing to integrate the model in the forecast mode is also taken from six-hourly forecasts issued by the NCMRWF. Each atmospheric forcing dataset obtained from NCMRWF consists of forecasts for the succeeding five-days (20 time-steps). Every day after, the ocean model is forced by the analysed atmospheric data to obtain the best estimate of the state of the ocean (initial condition for the forecasts), the model is forced by the atmospheric forecast data for the next five-days. At the end of each forecast cycle, it generates a six-hour averaged ocean analysis for the previous day and an ocean forecast for the next 120 h.

The trajectory model was forced with analysed currents(2.25 km) of WC_HOOFS. The trajectory obtained while forcing with this analysed currents of WC-HOOFS is shown in brown colour in Figure 7.It can be seen that this simulated trajectory is almost opposite to that of the observed SVP trajectory.

4.2 Trajectory model forced with operational IO-HOOFS (The Indian Ocean setup of HOOFS)

The domain of the Indian Ocean model based on ROMS extends from 30°E to 120°E in the east-west direction and from 30°S to 30°N in the north-south direction. The horizontal resolution of the Indian Ocean model is 1/12° (approximately 9 km) and it has 40 sigma levels in the vertical. The vertical stretching parameters are chosen in such a way that the vertical resolution is highest in the upper part of the ocean. There are approximately 26 levels in the top 200 m of the water column. The number of levels in the given depth of water column is more in the shallower regions. The lateral boundaries in the east and south are treated as open where the tracer and momentum fields are relaxed to INCOIS-GODAS using clamp boundary condition. The western and northern boundaries are solid walls with no-slip and no-normal flow conditions. The model uses the KPP mixing scheme (Large et al., 1994) to parameterize the vertical mixing. A combination of harmonic and bi-harmonic viscosity and diffusion schemes are chosen for horizontal mixing. Bulk parameterization scheme is used for the computation of airï sea fluxes of heat. Sea surface salinity is relaxed to the monthly climatological values derived from WOA 2009 (Antonov et al., 2010[10]; Locarnini et al., 2010[11]). The model is initialized on 1 January 2010 using solutions derived from INCOIS-GODAS. Then model is run from January 2010 to August 2013 forced by six-hourly analysed atmospheric fields.

In an another experiment, the trajectory model was forced with analysed currents(9 km) of IO_HOOFS. The trajectory obtained while forcing with analysed currents of Indian ocean is shown with dark navy blue colour in Figure 7. It can be seen that, although, the simulated trajectory is improved when compared to simulated trajectory forced with WC-HOOFS analysed currents, it is way off the observed trajectory from SVP drifter.

4.3 Trajectory model forced with GODAS based on MOM4p1

Global Ocean Data Assimilation System (GODAS) based on MOM4p0d adopted from NOAA/NCEP was operationalised at Indian National Centre for Ocean Information Services (INCOIS) in 2013. This system uses state of the art ocean general circulation model called Modular Ocean Model(MOM) version-4p0d and 3D VAR assimilation techniques. Temperature and salinity profiles from all the in-situ observations over global ocean are assimilated to produce best analysis products (Ravichandran et al. 2013[12],Sivareddy et al., 2015[13]). More recent improved version MOM4p1 was released in late 2009 and many operational and research centers around the world are using this version. Recently Rahaman et al., (2016) upgraded the GODAS with MOM4p1 and have shown the improved ocean analysis with this upgradation[14]. The trajectory model was executed with the analysed fields of GODAS with MOM4p1 (GM4p1). In Figure 7, the red line is the trajectory obtained while forced with analysed GM4p1 currents. The trajectory was found to be closer to the observed SVP drifter track.

4.4 Trajectory model forced with HYCOM

The general circulation pattern (ocean currents) is also obtained from HYCOM model with the spatial resolution of 0.25 x0.25 degrees(http://www.incois.gov.in/Incois/HYCOM.jsp). (http://www.incois.gov.in/documents/hycom/hycom_0.25x0.25_tech_rep.pdf). HYCOM is a primitive equation general circulation model which is isopycnal in the open, stratified ocean, but uses the layered continuity equation to make a dynamically smooth transition to a terrain following coordinate in shallow coastal regions, and to z-level coordinates in the mixed layer and/or un-stratified seas. It maintains the significant advantages of an isopycnal model in stratified regions while allowing more vertical resolution near the surface and in shallow coastal areas, hence providing a better representation of the upper ocean physics. In the current setup which is used in this experiment, the HYCOM is forced with GFS atmospheric fluxes and winds. The model assimilates SST, and SLA from satellites and vertical profiles of Temperature and Salinity from ARGO program. The trajectory obtained while forced with hindcasted HYCOM currents is shown in black colour in Figure 7.

4.5 Intercomparison between the simulated and observed trajectory

The simulated trajectory from GNOME model is compared with observed SVP trajectory during 12.45 hrs of 20.11.2016 to 07.00 hrs of 27.11.2016. The plot of comparison is shown in Figure 7. The simulated trajectory by GNOME model when forced with operational currents (HOOFS), moves way off the observed SVP drifter trajectory. It even goes opposite to the observed trajectory. Simulated trajectory is improved slightly when forced with IO-HOOFS analyzed currents. The end point of simulated position is 73 km away from the end position of the observed SVP trajectory. The simulated trajectory is also deviated by ~ 43 km when compared to the observed trajectory. The simulated GNOME trajectory obtained by GM4p1 forced currents is very close to the observed trajectory shown in red colour in Figure 7. Eventhough, the simulated trajectory from GM4p1 currents travelled closer to observed SVP drifter's track, it has not reached the end point, as that of the drifter. This could be due to the underestimation in the magnitude of analysed currents, when compared to observation. The distance between the simulated and observed end point is 50 km. The deviation of ~12 km is seen between observed and simulated trajectory. It is to be noted that GM4p1, a global model and the resolution is ~ 50 km. The simulated trajectory obtained from 9 km resolution HYCOM forced currents is most closest to observed SVP trajectory (Figure 7). It almost follows the observed trajectory. Like GM4p1 simulated trajectory, HYCOM simulated trajectory also underestimates the distance. The HYCOM simulated and observed, end points of the drifter were noticed 32 km apart.

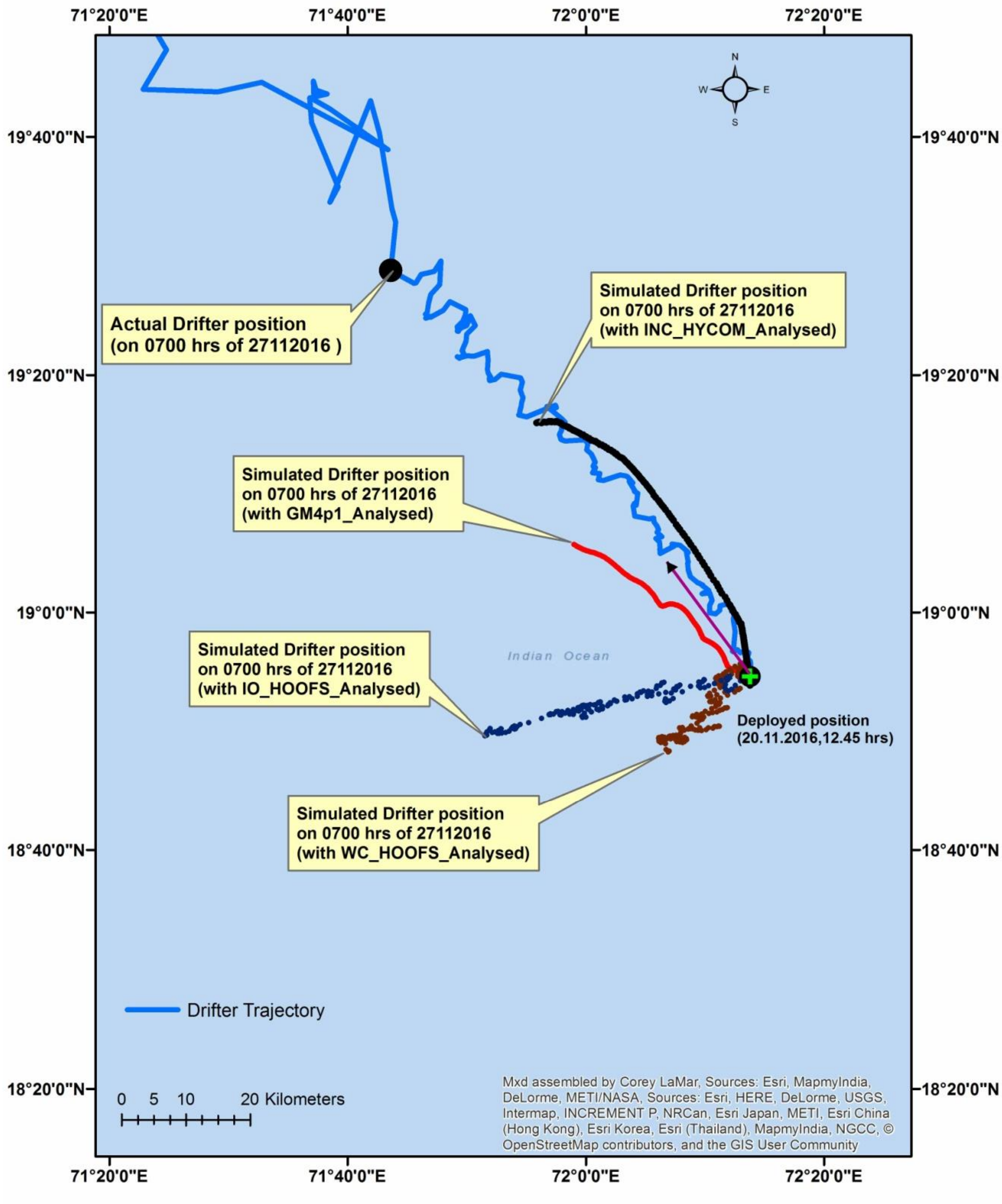

Figure 7. Intercomparison of the drift pattern- Plus sign encircled by black circle is the deployed location of the drifter. The thick blue line is the drifter's track. The brown curved line is the trajectory obtained while forced with analysed wc_hoofs currents. The dark navy curved line is the trajectory obtained while forced with analysed io_hoofs currents. The red line is the trajectory obtained while forced with analysed GM4p1 currents. The black plain line is the trajectory obtained while forced with Analysed HYCOM currents.

5. CONCLUSIONS

Oil spill trajectory advisory is being issued based on GNOME model by INCOIS on operational basis in case of any oil spill events in the Indian Ocean. This advisory is issued based on an online oil spill advisory system (OOSA). In order to evaluate this system an SVP drifter was deployed off Mumbai, by the Indian Coast Guard 20 November 2016. It drifted by the surface currents for about 10 days, before it beached off Diu coast on 03.12.2016. Different experiments were performed with this GNOME model forced with surface currents of INCOIS operational and R& D models during this period. The simulated trajectory was not performed well as compared to SVP observed trajectory when forced with operational currents of HOOFS. The simulation improved, when forced with Analysed GM4p1 currents and was very close to observed trajectory with Analysed HYCOM currents. However to further evaluate OOSA's performance many more drifter observations are required in Indian Ocean especially in the Bay of Bengal and Arabian Sea. An evolving program called COFOVEX (Coastal forecast Verification exercise) for validating the coastal forecast of various ocean general circulation models is proposed at INCOIS.

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