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Combining Contingency Planning with oil Spill Simulation Modeling in the Australian Bight (Gab) Field

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***Abstract**: An accurate oil spill prediction model is essential to minimizing coastal damages because spilled oil can cause serious harm to the marine environment when it disperses in open waters. An oil spill is typically considered a catastrophe that results in both catastrophic losses to marine life and enormous repair costs. This study used ADIOS and GNOME to model the oil spill trajectory for both the summer and the winter based on variables such as wind, and the current velocity of the Australia Bight Gab field. To derive the GNOME MODEL with a 32 knot westerly constant velocity, the Gab field was generated using the global custom map generator with the following parameters: wind and current data. Similarly, because of the uncertainty in the HYCOM, the GNOME was run with an uncertainty error value of 50% along current and 25% cross current using 455,000 liters of medium-light crude oil spilled over five days of transportation at the production platform were used in the simulation. On the other hand, ADIOS was utilized to weather oil spills under the presumption that the oil had an API of 27.5. The temperature, wind speed, wave height, salinity, and sediment load were among the input parameters because the ADIOS simulation model was calculated to simulate the weathering process over a period of time. About 33% of the slick oil was able to evaporate during the five days, and according to the trajectory's overall results, which showed that oil does not reach the beach during that time. Furthermore, since the oil does not reach the beach within the allotted five days, a chemical dispersant and sea containment recovery may be used to deal with the spill within that time frame.*

INTRODUCTION

The International Energy Agency (IEA 2001) states that an increase in energy demand has led to a growing trend in the international trade of oil products. Crude oil is a complex mixture primarily composed of molecules with molecular weight that contain hydrocarbons, sulfur, nitrogen, and oxygen. The Great Australian Bight (GAB) is distinguished by a length of more than 2400 km of zonal coastline and a width of 20 to 220 km of continental shelf. Strong seasonal variability dominates ocean recirculation in the GAB, and wind is primarily responsible for circulation over the continental shelf (Oke et al., 2018). Approximately 85% of the many different species of aquatic life that call this GAB home can be found in this isolated stretch of rocky coastline, which is relatively rare anywhere else in the world (Wright & Duffy 2019). This study as presume an exploration at the GAB field in Australia, where drilling is planned, hydrocarbon production is anticipated to start at a water depth of 1000 to 2,500 meters (m). However, the intended production location lacks storage facilities; the only way to move this product is by shipping it twice a month, with a daily production capacity of 445,000 barrels of medium-light crude oil anticipated. However, there is a greater chance of an oil spill with this mode of transportation, which will severely impact the local economy and ecology in the (GAB) field (li et al., 2016). The most common cause of oil spills is an unexpected accident that might happen on an exploration or production platform and result in catastrophic harm, particularly to the ocean environment where strong winds are present (Cho et al., 2012). In a similar vein, oil spills can contaminate people and harm the habitats of marine mammals (ITOPF 2003). According to Cho et al. (2012), accurate prediction behaviors of the spilled oil become crucial to maintaining the safety of the coastal environment for the resident species. Australian fishing takes place in the Great Australian Bight, directly supporting over 3,900 jobs in the region. But in Southern Australia alone, over 9,000 jobs would probably be in jeopardy in the event of an oil spill (Wright & Duffy 2019). The Marine Park, sea lions, dolphins, marine aquaculture, state marine park facilities, and the remaining biodiversities, including fish, are among the vulnerable structures within this axis of the Australian Bight that are prone to spills (Pidcock et al., 2003). An oil spill accident is typically considered as disaster that results in both catastrophic costs for damage compensation and disaster prevention, in addition to the death of marine life (Cho et al., 2012).Therefore, in order for the proposed oil exploration platform on the GAB field to start full-time production, an efficient prediction model of spilled oil and its response will be a crucial guide. Preparing a plan to foresee any necessary actions to be taken prior to, during, and following such accidents is the main goal of this simulation. It is possible to carry out this predetermined plan to determine where, when, and how the spill will occur (Wilson et al., 2017). Since seasonal variation dominates this GAB field, it is imperative that the trajectories of oil spill fate modeling be considered in order to respond to this incident effectively. Some clean-up options were evaluated for mitigation techniques in the coastal environment, such as the GAB field, and oil spill trajectory model for both the summer and winter seasons using ADIOS and GNOME is considered in this research work.

Model and Data/Method

Based on winter and summer conditions for the GAB field, two theoretical oil scenarios were taken into consideration in this study. Software from NOAA called ADIOS and GNOME were used to simulate oil movements. High temporal and spatial resolution data on the current state, wave, sea surface temperature, and wind were used in the compilation of this model table (1, and 2)

Table 1.the summary of the input data in ADIOS

ADIOS input data	Unit	Winter	Summer
Wind speed	Knots	32	32
Wave height	M	2	2
Temperature	^{0}C	25	14
Salinity	Ppt	35	35
Wind speed uncertainty	Knots	2	2
Oil spilled	Bbl	455,000	455,000
Duration	Days	5	5

Table 2 the summary table of the data sets, and source utilized in this study

Data	Source	The Methodological strategy
Coastline morphology	GNOME online Oceanographic data (GOODS) Database: Global self consistent Hierarchical, high resolution shoreline	Oil Spill Trajectory modeling
Current	HYCOM(Hybrid coordinate Ocean model)	Oil Spill Trajectory modeling
Oil type	ADIOS oil database	Oil spill weathering and fate modeling
Wind direction Wind speed,	Marine institute	Oil Trajectory modeling
Wave height salinity ocean temperature Wind direction		Oil spill weathering and fate modeling

As such, this work employs the two primary methodological approaches: weathering and fate modeling for oil spills and oil trajectory modeling. Together, these strategies will address critical issues that may come up during oil spill incidents, such as where the spill will end up, when it will arrive, and what harm it will cause. Thus, ADIOS and GNOME models for known met-ocean scenarios are presented in this study along with a coastline environmental sensitivity map for fictitious oil spill scenarios along the GAB field's coasts figure 1.0

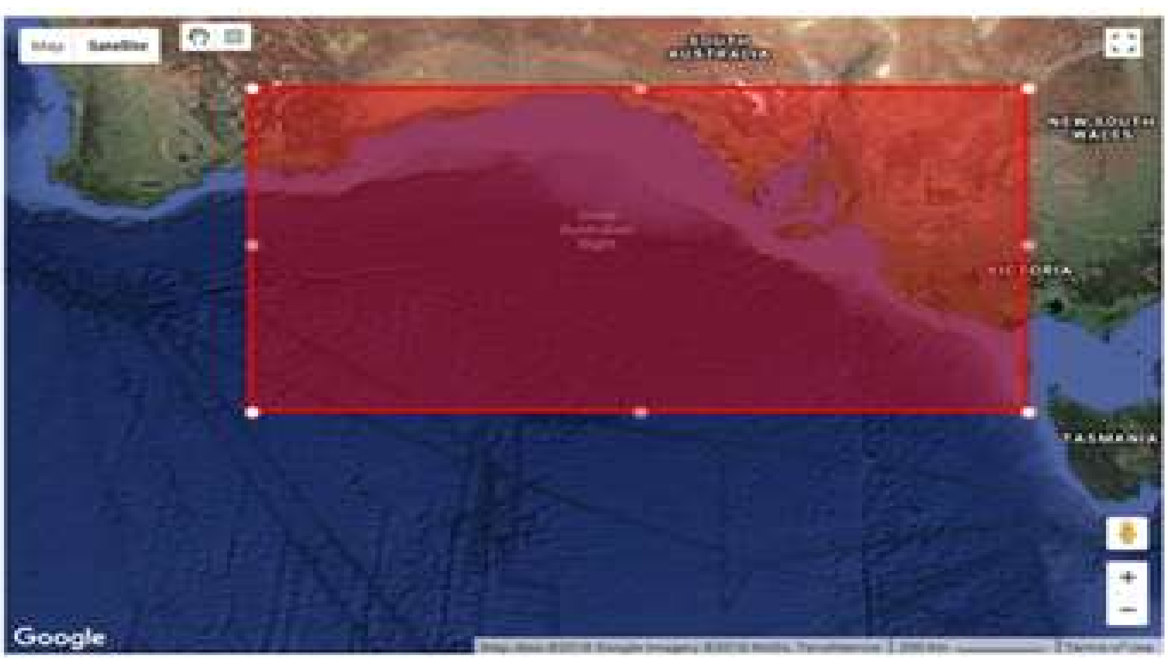


Fig1.0 the map of Austrian GAB field

GNOME Oil Spill Simulation

This study uses the GNOME (General NOAA Operational Modeling Environment) simulation, and because of its high prediction accuracy, for the trajectory model was therefore selected

(Xu et al., 2013). But numerous studies have shown that it's a cheap and useful tool for managing the risk of oil spills (Cheng et al., 2011; Marta-Almeida et al., 2013; Toz et al., 2016).

The maps, spills, and movers are the main working mechanisms of GNOME as a modeling tool. The vector seashore maps for a particular location can be obtained from the Oceanographic Data Server (GOODS) via the Map file in GNOME (Zelenke et al., 2012).

In addition, movers are the actual physical factors such wind and currents that cause oil to move through water. To illustrate the overall movement of the oil in this study, movers were added at each time step (Beegle-Krause, 2001). This study used medium-light crude oil, which falls into one of the five (5) characteristic categories of crude oils according to GNOME. In the GNOME models the oil spill's splotches as a continuous flow from the fields, resulting in an oil spill animation movie that shows the expected movement of the spilled oil over an adjustable hour. The splotts have a known starting point for each step time, and they query each mover to determine its direction and distance traveled in that time step. The new splott location is then determined by adding the steps in a vector sum (Beegle-Krause, 2001). The study involves taking snapshots of the oil spill trajectories at different time steps.

GNOME Simulations

Oil spill simulations using "GNOME" are shown in this section. The model's best guess estimate of the location of the oil slick (small black dots) and its uncertainty (red dots) are displayed for the two oil spill scenarios using GNOME results using medium crude oil type while Fig 4 shows the oil movement results from GNOME modeling in the northern gab field bay. The large black dots in each image represent the spill sites, and the red dots represent the least amount of regret a) 24 hours, b), 48 hours c) 72 hours d) 96 hours, and e) 120 hours, GNOME simulation results for the GAB Bay.

Fig 4.a spill after 24 hours with minimum regret

Fig 4.b spill after 48 hours with minimum regret

Fig 4.c spill at 72 hours with minimum regret

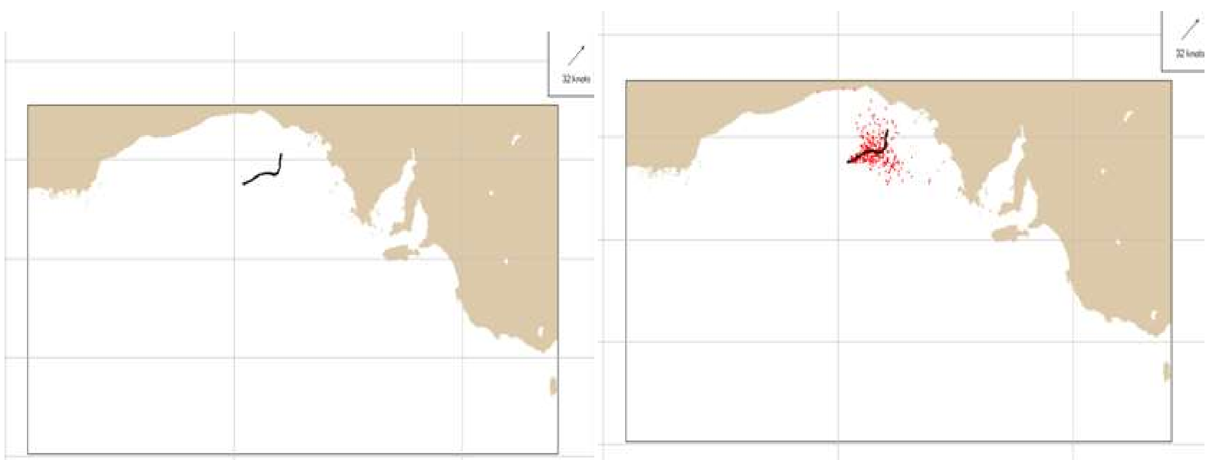


Fig 4.d spill at 96 hours with minimum regret

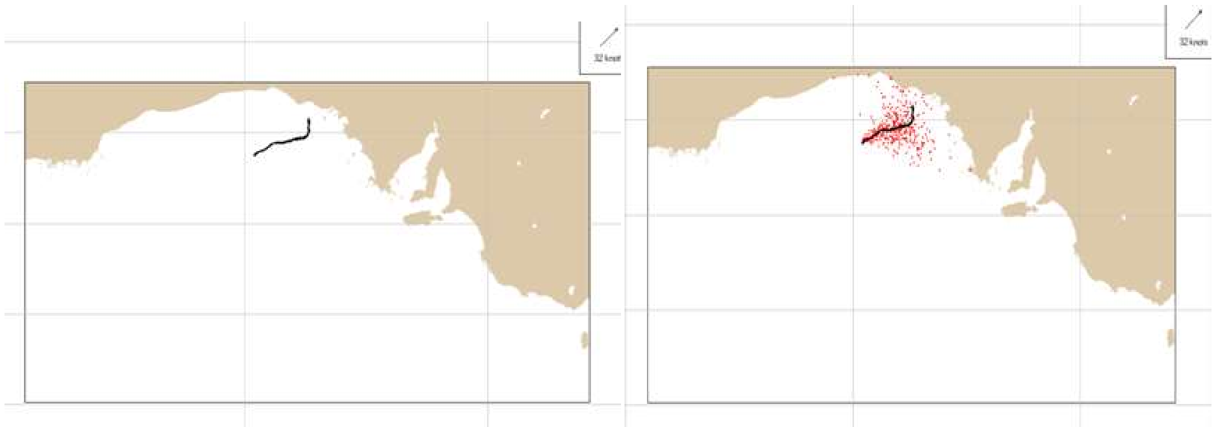


Fig 4.e spill at 120 hours with minimum regret

GAB Bay

The winds blowing from the south play an important role in the movement of the spilled oil, especially within the 72 hours of the spill (Fig. 4b). Ocean currents turn out to be more of an influence as the spilled oil drifts farther from GAB Bay to the shoreline fig 4(C& D). After 120 hours, the oil released at bay does not reach the shoreline in the north part of the shoreline fig (4E). However, the drift rate of the crude oil released was appreciably slower as wind speeds remained constant. In addition, different current velocities manipulate the drift rate as time progresses from 24 hours to 120 hours. The results show that oil released from the field follows predominantly the wind direction in the first instance, wind speed, and direction are major factors influencing the trajectory of oil at this point in this model. The movement of oil released in 3 days becomes influenced by ocean currents after 72 hours, slowing in speed and drifting slightly towards the north fig (4E). This shows that at greater wind speeds the direction of the oil spill trajectory is less influenced by ocean currents. Therefore, ocean currents turn out to be more of an influence as the spilled oil drifts farther from the GAB field to the shoreline after 120 hours. The Spill oil is leaving the bay and is moving toward the shore in the north direction due to advection factors. The overall results indicate that spilled oil does not reach the seashore in the first 5 days as shown in fig (4E). Thus, the results further indicate that the interaction; the influence of gravity, surface tension, wind and pour point of the crude oil facilitated the slick movement of the crude oil (Alofs & Reisbig 1972). Similarly, after spilled, gravity tends to spread oil slick immediately as reported by Fay 1969. The slick thins then breaks up and conversely disperses on the water column as small droplets that could be easily transported for a long distance away from the location of the spill, the movement of the slick will be influenced by tidal and wind current (Lynagh, 1985).

The oil weathering and fate modeling (ADIOS)

ADIOS ''Automated Data Inquiry for Oil Spills'' is a driving tool in oil spill weathering and fate modeling used in the analysis of this work. It is used collectively with GNOME to furnish more accurate estimates of the crude oil behavior in the marine environment (Zelenke et al., 2012).

On the other hand, ADIOS was used by many researchers to estimate swiftly the oil spill weathering and fate, with the use of mathematical equations to predict changes in oil properties such as water content, density, and viscosity (Lehr et al., 2002; Zhao et al., 2015; Toz et al., 2016). In addition, ADIOS can estimate dispersion in the water column, spill oil evaporation rates from the sea surface, and the formation of oil droplets that become emulsified/suspended in water from the oil and property changes (NOAA, 2022).
However, ADIOS can provide best-guess predictions for crude oil processes such as; dispersion, evaporation, and emulsification. The software used a pseudo-component evaporation model in the case of evaporation (Jones, 1997). Similarly, ADIOS uses an asphaltene fraction while estimating the emulsification, according to Fingas et al.'s (1996) study. In addition, Delvigne & Sweeney (1988) developed a hydraulic model used for the estimation of dispersion, and this technique measures the breaking wave size/number of distribution of the oil droplets dispersed into the water column (Lehr et al., 2002).
ADIOS requires input data such as the environmental conditions, oil spill, and oil spill information, ranging from the type of oil, the spilled quantity of the oil, the rate, and duration of the release, all are considered for the two different scenarios in this study. However, in the case of oil type, the ADIOS library contains over a thousand of numerous oil types data that were also used (ADIOS, 2022). Wind speed, wave heights, water temperature, water salinity, and direction, are environmental conditions provided. Finally, clean-up options were considered based on the oil spill scenarios, which include the uses of dispersants, and skimming (Lehr et al., 2002).
The data output information of the ADIOS is represented by a collection of graphs, which includes, the oil budget, dispersed, remaining, viscosity, and benzene graphs respectively. This helps to visually the understanding of how long the spilled oil should remain in the GAB field for two different scenarios incidents. In addition, the output information such as the quantity of oil dispersed, evaporated, and remaining within the marine environment was collated for this work. The graphs of the oil budget were gathered based on those data. The oil behaviors were predicted for a period of 5 days because of ADIOS's limitation of predicting oil behavior for a maximum of 5 days.

ADIOS weathering and fate results

Following the GNOME modeling concerning oil-spill movement below is given an account of oil weathering and fate for the two modeled scenarios fig 5. Oil budget graphs showing ADIOS results for fig 5 A,) C),E) G), I) ,K),M) and O) crude oil under summer, and winter conditions, b) fig 5 D) F) H) J) l) N) and P), the dotted black represents the formation of stable 'water-in-oil emulsions'.
In all models, the oil does not reach the shoreline and beach within the period of the simulation and those near the shoreline are also considered as the constituting part of naturally dispersed oil, as shown in fig 4(A, B, C, D, and E). Figures 4(e) and (f) demonstrate that oil does not reach the beach and is regarded as a component of the oil that is still at the surface. This oil is not naturally distributed; rather, it is a result of evaporation, the slick remaining phase, and fig. 5 C),D) & M) & N). A typical medium light crude oil will lose up to about 40% of the spillages due to evaporation within the first few days of plot, as shown in Table 1 (a & b), which agrees with Wilson et al., (2017) study and is also consistent with Fingas's (1997) study. During the 5-day period, about 33% of this slick oil was able to evaporate or disperse.

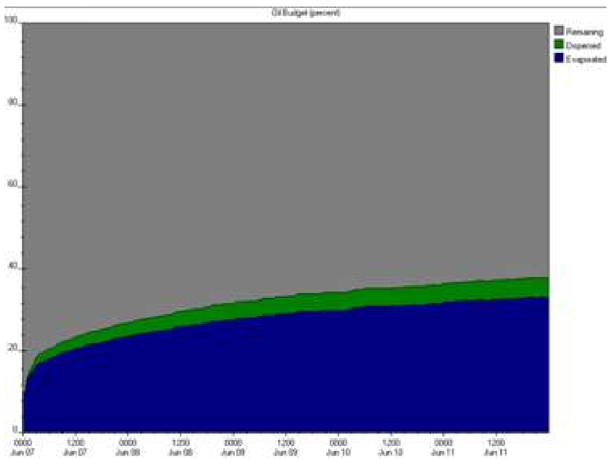


Fig 5A Oil budget during summer

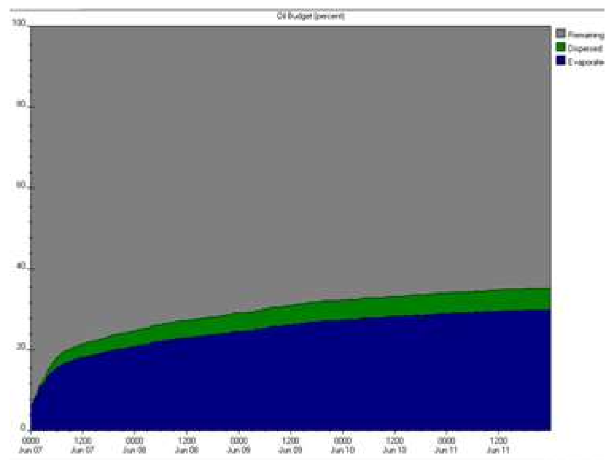


Fig 5.B Oil budget during winter

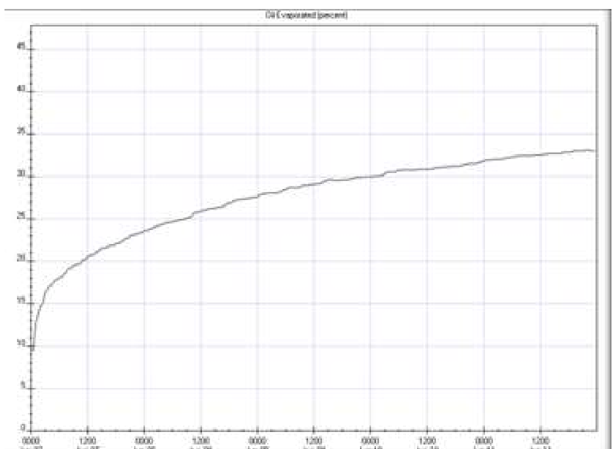


Fig 5c Oil evaporated during summer

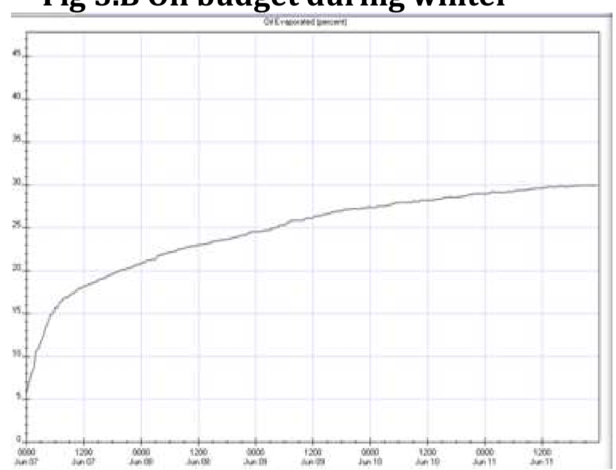


Fig 5d Oil evaporated during winter

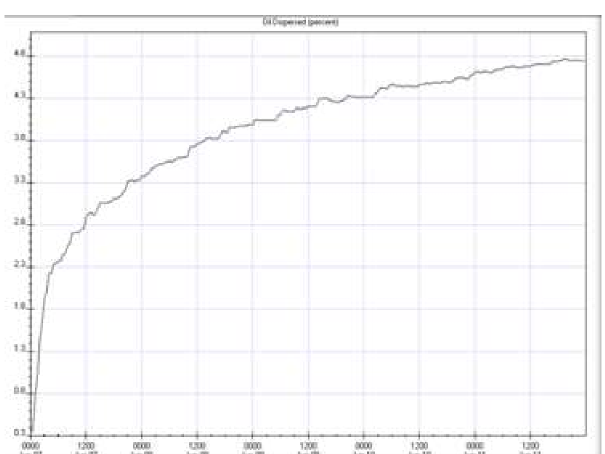


Fig 5.E Percentage of Dispersed during summer winter

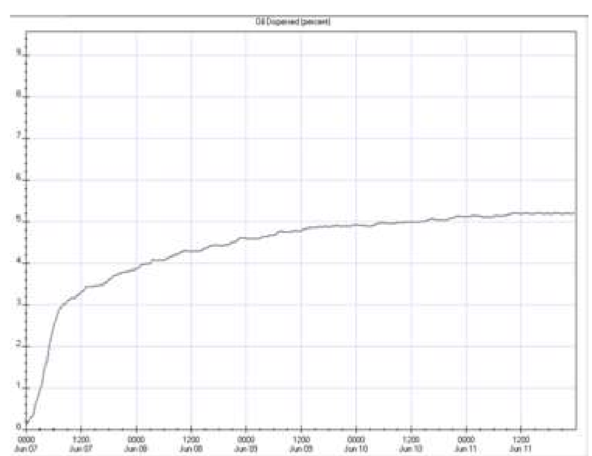


Fig 5.F Percentage of Dispersed during winter

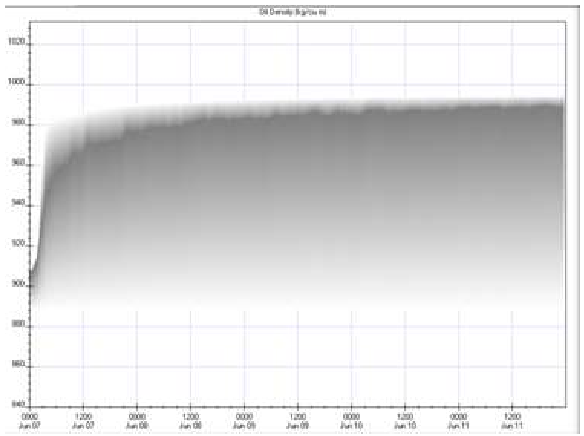


Fig 5.G Oil density after spill during summer

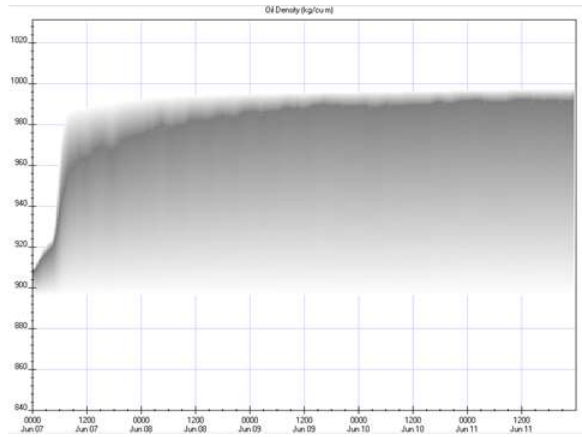


Fig 5 H Oil density after spill during winter

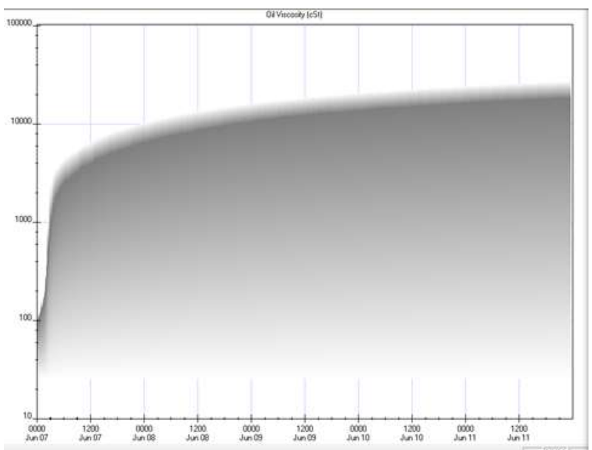


Fig 5. I oil viscosity during winter

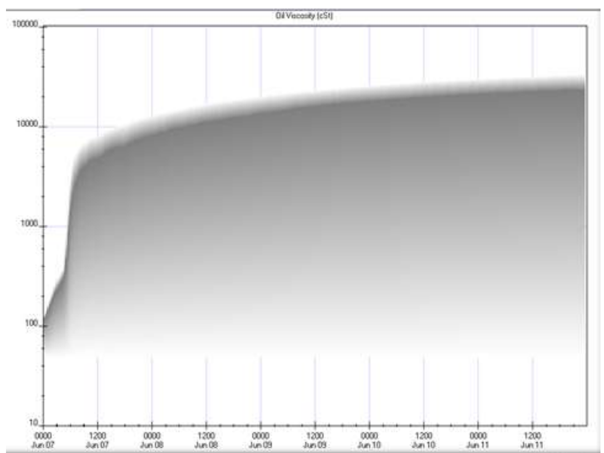


fig 5.J oil viscosity during winter

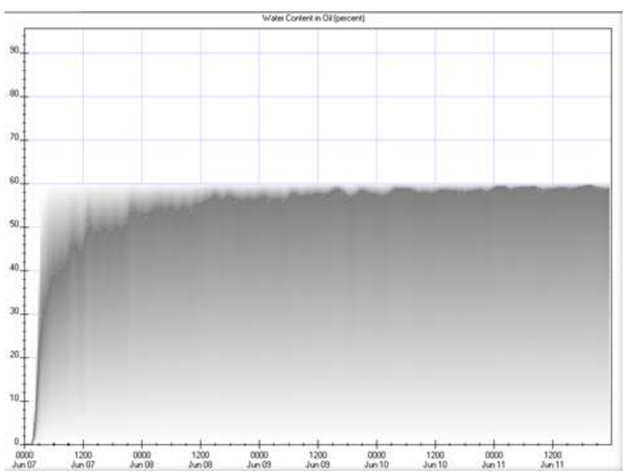


Fig 5. K Water content during summer

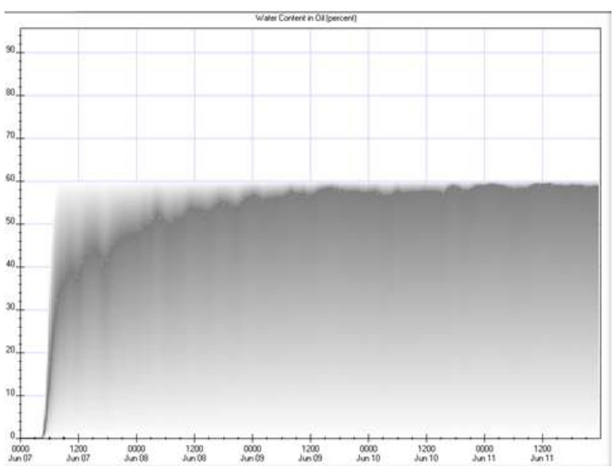
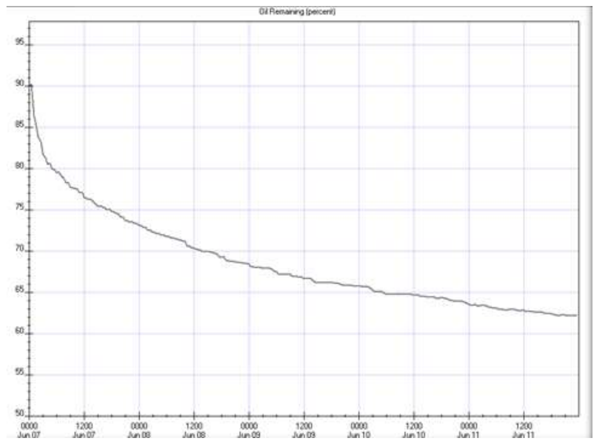


Fig 5.L Water content during winter



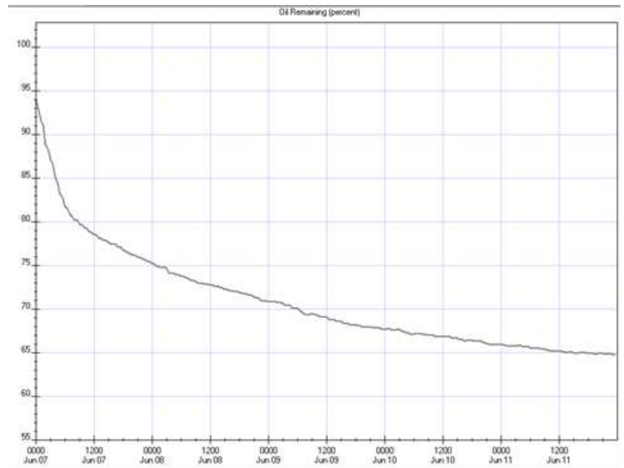
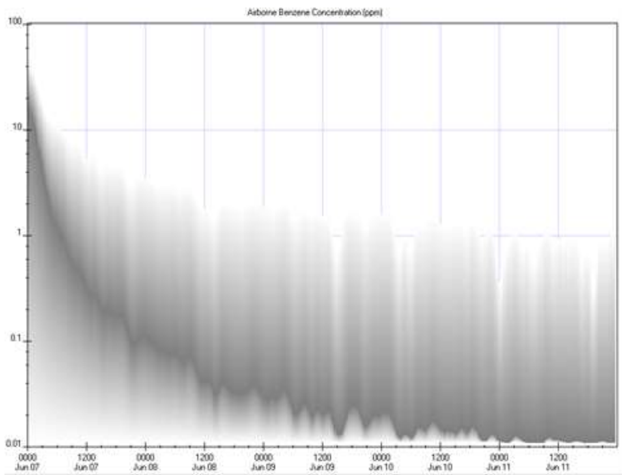


Fig 5. M Percentage oil remaining during summer **Fig 5. N Percentage oil remaining during winter**



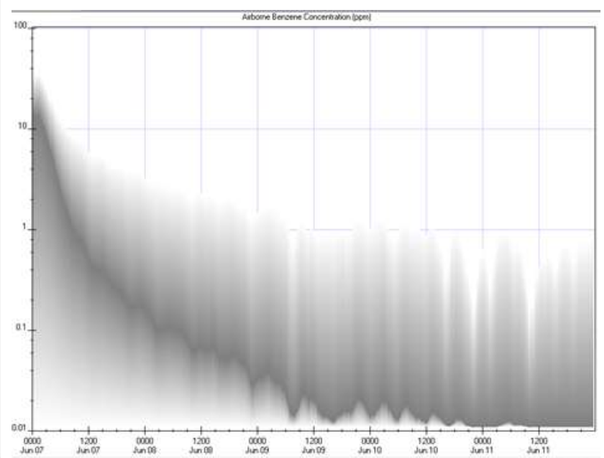


Fig 5. O Benzene concentration in ppm summer **Fig 5. P Benzene concentration winter**

Oil Name = MISSISSIPPI CANYON BLOCK 807
API = 27.5 Pour Point = -34 deg C
Wind Speed = constant at 32 knots Wave Height = 5 meters
Water temperature = 14 deg C
Time of Initial Release = June 07, 0000 hours
Total amount of Oil Released = 455000 bbl

Hours Into Spill	Released bbl	Evaporated percent	Dispersed percent	Remaining percent
1	3,792	7	0	93
6	22,750	15	2	83
12	45,500	18	3	79
18	68,250	19	4	77
24	91,000	21	4	75
30	113,750	22	4	74
36	136,500	23	4	73
42	159,250	24	4	72
48	182,000	24	5	71
54	204,750	25	5	70
60	227,500	26	5	69
66	250,250	27	5	68
72	273,000	27	5	68
78	295,750	28	5	67
84	318,500	28	5	67
90	341,250	29	5	66
96	364,000	29	5	66
102	386,750	29	5	66
108	409,500	30	5	65
114	432,250	30	5	65
120	455,000	30	5	65

Table 1a Budget for winter

Oil Name = MISSISSIPPI CANYON BLOCK 807
API = 27.5 Pour Point = -34 deg C
Wind Speed = constant at 32 knots Wave Height = 5 meters
Water temperature = 25 deg C
Time of Initial Release = June 07, 0000 hours
Total amount of Oil Released = 455000 bbl

Hours Into Spill	Released bbl	Evaporated percent	Dispersed percent	Remaining percent
1	3,792	9	0	91
6	22,750	17	2	81
12	45,500	20	3	78
18	68,250	21	3	76
24	91,000	23	3	74
30	113,750	24	3	73
36	136,500	25	3	72
42	159,250	26	4	70
48	182,000	27	4	70
54	204,750	28	4	68
60	227,500	29	4	67
66	250,250	29	4	67
72	273,000	30	4	66
78	295,750	30	4	65
84	318,500	31	4	65
90	341,250	31	4	64
96	364,000	32	5	64
102	386,750	32	5	63
108	409,500	32	5	63
114	432,250	33	5	62
120	455,000	33	5	62

Table 1b Budget table for summer

Oil spill fate and Response

Since there is currently no proven basic cleanup technique, prevention is one of the most crucial aspects of oil spill risk management (Othumpangat & Castranova, 2014). On the other hand, there are numerous actions that can be taken in the event of a spill, the most common being the application of dispersant spraying, mechanical countermeasures, in-situ burning techniques, and skimming, among others. Fig. 1 depicts the map of the Gab field; however, the shorelines around the spill area taken into consideration for these works are rocky shorelines and beaches. According to some assessments, oil spills in coastal environments tend to adhere quickly to intertidal vegetation that has a very low capacity for self-cleaning.

In the event of an oil spill, even if the oil does not reach the beach for five days, protecting species such as fish, dolphins, and the other animals that live with them should be given top priority. Furthermore, the response and recovery plans should give priority to fishing operations that employ thousands of locals. Many different species that needed to be protected were able to breed in the gab field. According to the shifting rules of oil spill weathering for evaporation, dispersion, and emulsification processes, the ADIOS results for two distinct summer and winter scenarios with medium-light oil are consistent (ITOPF, 2002). For example, evaporation, which is also taken into account in this study table 1(a & b), has the largest role in the natural removal of oil from the surface of water for all oil types.

Nevertheless, table 1(a & b) shows that the model's dispersion contributions to the oil spill's natural removal were minimal. Similar to this, evaporation is the physical process that removes the volatile components of spilled oil; as a result, it will quickly reduce a sizable portion of the slick's total mass, with the rate determined by the oil's composition, degree of emulsification, and ocean conditions at the time of the spill (Zodiatis et al., 2017). In addition, Fingas (1997) states that during the initial hours of the spill, evaporation eliminated majority of the volatile fractions found in crude oil. According to Table 1(a) and (b) of this study, evaporation allows the volatile components to escape, and between 21 and 24 percent of the slick evaporates in a day. This is consistent with a study by Hua (2018) that found that 25 percent of the oil in the slick evaporates in the first 24 hours following the spill. The rate at which evaporation occurs depends upon the volatility of the oil. For instance, light products such as gasoline will evaporate virtually complete in a few days and without emulsions. Hence, evaporation is the most essential weathering process for the analysis of this work, because it helps in removing about 33% of the volatile low-molecular-weight components from the spilled oil, components that are particularly important in light petroleum products (Mishra & Kumar, 2015). Furthermore, in line with the results of this investigation, Mishrah and Kumar's (2015) study found that medium-light crude lost an average of roughly 25% to evaporation.

ITOPF (2002), states that both atmospheric and sea temperatures affect the rate of evaporation; however, the findings of this study indicate that wind speed has a greater impact on evaporation rate in the GAB field than sea temperature. The composition of the spilled oil has a greater impact than evaporation or wind.

According to Zodiatis et al. (2017), dispersion is the process by which oil the size of droplets uptake into the water column decreases until it is no longer a part of the slick. The wave action that breaks up the oil into different-sized droplets and pushes them into the water column supports these processes and creates a cloud of droplets underneath the spill. According to Johansen et al. (2015), dispersion plays a significant role in determining how long oil spills on the ocean's surface should last. The primary influencing factors in oil dispersion, according to Elizaryev et al.'s (2018) study, are wind speed, wave height, and water temperature. It was also discovered in this study that dispersion was highly dependent on the sea state, increasing as wave height and wind speed increased. Similarly, the temperature of the sea and evaporation have not affected the rate of dispersion, the dispersion rate is lower during the summer scenarios, despite higher sea temperature. Due to the 'light' properties of crude oil, and the weather conditions during the spill, oil dispersed naturally with minimal impact on the shoreline (White & Molloy, 2003).

In general, lower viscosity oils will disperse more quickly (ITOPF, 2002). The ADIOS results, on the other hand, contradict this theory because the crude oil disperses slowly. Evaporation occurred first for all oils, removing most of the volatile components and leaving less oil to be dispersed this highlights that, the dispersion plays a less significant role than the evaporation in this study.

When water and oil in a slick combine to form an emulsion, this process is known as emulsification (Zodiatis et al., 2017). It does not begin until a certain percentage of the oil has evaporated according to the Australia Maritime Safety Authority (2014) report, but mousse began to form when 19% of the spilled oil had evaporated after the first two hours, as shown in figs. (a, b, c, and d). In a similar vein, windrows form at wind speeds higher than 10 knots. Singsaas et al.'s (2000) study revealed that the break wave will begin to rise and is the common factor that helps the oil slick break up when the wind speed is higher than 10 knots. As surface turbulence, these also aid in entraining the oil droplets in the water column.

Emulsion formations typically result in a considerable increase in the water content (Mishra & Kumar 2015). This slows down the rate of evaporation and raises the density and viscosity of the slick particles. Figure 5 (I, J, G, and H) demonstrates that the summertime has a higher initial viscosity and water content of the slick oil than the wintertime does. Comparably, fig. 5 (I & J) demonstrates that the oil slick had a high initial viscosity and low water content. But within 24 hours of the spill, the amount of water in the crude oil rises dramatically. This further suggests that the slick has the same density as seawater after this time. Refer to fig. 5 (g & h).

Thus, the initial oil viscosity and composition of an oil spill have an impact on the emulsification process (Mishra & Kumar, 2015). According to some research, oil's emulsification is largely dependent on the proportion of waxes, resins, and asphaltenes in it (Bobra, 1991). These substances, which are generally present in crude oils, have large molecular weights (Mansoori, 1996). Furthermore, according to Lehr et al. (2002), the majority of medium-light crude oils will not emulsify until a specific percentage of the oil has evaporated. The findings also imply that because medium light crude has a low proportion of high molecular weight compounds, it does not form a stable emulsion mousse at the sea surface.

Additionally, oil is typically removed from the sea surface by evaporation and dispersion; however, emulsification lengthens the spill's duration and volume (ITOPF, 2002). Furthermore, emulsification prevents other processes like evaporation and weathering strength (Fingas et al., 1993). Water-in-oil emulsions are more likely to form following storm conditions and can persist in the marine environment for longer than three months, as emulsification is highly dependent on water turbulence (Speight & Jauhari, 2012). Moreover, as the temperature drops, these emulsions' stability tends to rise. As seen in fig. 5(O & P), the concentration of benzene in the air decreases with time, suggesting that the lighter portion of the spilled oil was easily lost on the sea surface. The variation in Mississippi medium light crude's density with respect to its times was similarly displayed in Figure 5 (G & H). In addition, it is evident that as time passes following the spill, the crude oil's density rises. Due to variations in the rate of evaporation, which raise the concentration of heavy molecules, there is an increase in density in the winter as opposed to the summer (Mishra & Kumar 2015). Consequently, the slick's density increases.

CONCLUSION

The purpose of the study was to model ADIOS and GNOME for oil spill accidents while taking into account advection factors, seasonal variations, and the direction that influences the movement of oil slicks. The effect of advection and diffusion uncertainties is the fundamental factor that was taken into account when making decisions regarding responses.

The results of ADIOS show that the oil slick undergoes weathering after the spill and it evolved further after some time. Similarly, some smaller volumes of oil slick were evaporated and dispersed leaving behind the remaining. In addition, the Splot mass balance of both ADIOS and GNOME are in line to some certain extent. The most essential factors that influence the choice of any response are the location of the spill, the type of oil and fate, legislation, and the available resources.

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