Mathematical Modeling and Forecasting the Spread of an Oil Spill using Python

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Abstract: This is a comprehensive paper on the oil spill phenomenon on what mechanisms change the oil spill displacement, what Computational Fluid Dynamic (CFD) applications of Finite Volume and Eulerian/Lagragian equations are used to solve oil-spill simulations and to provide a brief analysis of the models used. An oil spill is defined as a form of pollution caused by human activity and as the discharge of liquid petroleum hydrocarbons into the environment, mainly in the marine eco-system. This description is commonly used for marine oil spills, where the hydrocarbons are discharged into the ocean or coastal waters, but they can also occur inland. Oil spills occur because of discharges of hydrocarbons from platforms, rigs, wells, tankers and from refined petroleum products along with their by-products, also from heavier fuels. Thus, oil spill simulation is used to predict transport and weathering processes. State-of-the-art tools such as OILMAP, TRANSAS, OILFLOW2D, OSCAR and ANSYS, work by simulating the processes mentioned prior. In contrary to these tools, the aim of this paper is to provide a comparison of the weathering models used and propose a mathematical model using python to predict the spreading phenomenon of an oil spill.

Key-Words: Fate/Weathering Processes, Oil Spill, Simulation/Modeling

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1 Introduction

The proposed mathematical model used for the purpose of this experiment and paper only tackles the spreading aspect of a spill without taking into account wind/wave parameters using python programming language, but it also enables a future use of CUDA GPU (graphics processing unit) which will greatly increase processing speed.

Oil spills are a matter of serious concern due to their damaging nature. Due to the constantly changing conditions in the sea/ocean, the physical processes acting on a spill change. There are a number of ways to counter the negative impact of an oil spill in the sea, such as: skimmers, booms and chemical dispersants. One way of tracking oil spills is the use of numerical models [1]-[4]. The forecast of the oil slick movement relies upon the availability of dependable ocean estimates. Oil slicks are carried away by two systems correlated with mass. The initial spread of the slick is due to the force of gravity. The effects of gravitational forces tend to fade an hour after the start of the spill, (increase of viscosity, and decrease in thickness); it is then that diffusion starts to be the dominant mechanism in the oil spill movement [1], [2].

Crucial environmental data for oil spill modelling are: the wind, the sea currents, waves (Stoke' drift) and sea surface temperature. The water density is used in 3D oil spill models when the spill is below the sea [3]. Accessible data at all times for any occasion/circumstance that may be needed for oil spill models is now available for the requirements of the Oceanographic predicting systems (CMEMS, NOAA) [4]. It is fundamental to have admission to an adequate estimation of ocean conditions and information crucial to modelling, in order to provide response to oil spill crises [2].

Social, economic and environmental consequences of an oil spill are detrimental. As an outcome, the responsibility of governments was raised by the acute media coverage and political commotion, leading to a political attempt to engage reactions to oil spills and provide prevention methods [5], [6]. Oil related disasters can have economic impacts on tourism and in the marine industry, such as the Deepwater Horizon incident. The flora and fauna of the area are also affected. This is done either directly from the response or during the cleanup. Oil can impair the ability of animals to fly, use their scent, or it can even cause blindness. Oil bacteria; Sulphate-reducing bacteria, acid-producing bacteria and general aerobic bacteria consumption play the role of natural ecosystem oil removals. But due to the amount of oil present their mass will replace other biomasses in the food chain [1], [8]. Clean-up and recovery can prove to be a difficult task. However, the process depends on some factors: such as type of oil, temperature and or shoreline topography. Oil spill recovery is often an expensive procedure [9], [10]. Notable methods include the use of micro-organisms, dispersants, control burning, dredging, skimming, solidifying, vacuuming, beach raking and just waiting for natural attenuation [10], [27].

The remainder of this paper is structured as follows. Section 2 describes the related work in the form of a literature review and the models that have been utilized. While in Section 3 the oil weathering process is being introduced and analyzed. Afterwards, Section 4 presents the experimental results and the visualization approach that was followed to demonstrate the oil spilling through the utilization of machine learning and time series analysis techniques. Moreover, Section 5 discusses the experimental results. Finally, Section 6 concludes the paper and outlines some directions for future works and further enhancements on the proposed methodology.

2 Related Work - Background

Taking into account the points mentioned above, engineering software is used to model oil spill by simulating the oil processes. Quoting Spaulding ML. “Current fields are generally considered to be the vectoral sum of wind, tidal density, and pressure gradient induced currents. Of these various components, the wind-induced drift is often the most important factor determining surface oil slick trajectories over time scales greater than 1 day. The extremely simple empirical approach, which assumes surface drift current is approximately 3-4% of the wind speed, has been used by most existing models and continues to be the most widely accepted methodology. Samuels et al. suggest a variable drift angle depending on wind speed, although a constant angle between 0 and 20 °, typically 10-17 °, is more common. This simplistic approach gives acceptable results if the study area does not include conditions in which coastal or bathymetric effects are dominant; in these cases wind-driven currents become much more complex (e.g. Spaulding et al.)” [1], [11].

Drifting occurs when materials are carried in the sea. The process relies on the sea status, such as wind, current and waves. Oil properties will change as it spreads when it is spilled. The time it takes for the spill to adapt to these changes that occur (to the spill) being chemical or physical, depends on the initial amount of oil spilled, as well as the oceanic conditions present and the characteristics of the oil. Thus, it is important for all the facet of the oil recovery process to know how the synergy of the physical and chemical processes change the balance and presence of oil.

Langrangian or Eulerian models are usually applied when modelling oil movement. Conservation of mass and momentum equations are utilized on the oil spill for the Eulerian method, or convection diffusion, where the spreading of the oil is presented by the diffusive part while the advection is the convective term [1], [2].

$$\frac{\partial C}{\partial t} = -u\frac{\partial C}{\partial x} + D_x\frac{\partial^2 C}{\partial x^2} - v\frac{\partial C}{\partial y} + D_y\frac{\partial^2 C}{\partial y^2} - w\frac{\partial C}{\partial z} + D_z\frac{\partial^2 C}{\partial z^2} \quad (1)$$

The time rate of concentration change is ∂C/∂t, x, y, z are the changes in the respective axis, current components u, v, w are the current components and D is the diffusive displacement.

On the other hand, a large number of particles advected due to the united effect of sea phenomena (such as wind, wave, currents, etc.) and diffusion are depicted by the Lagrangian models. By being more straightforward, more potent and requiring less computational processing power during a spill emergency, Lagragian models are commonly favoured over Eulerian ones due to rapid simulations.

Since the early 80s a lot of Lagrangian models have been developed featuring from 2D (two dimensional) particle tracking to 3D (three dimensional) advection diffusion models. Some notable mentions include: OSCAR2000 [12], OILMAP [11], GNOME [13], OILTRANS [13]-[14]. Oil-spill models are defined as scientific means, suitable of estimating the path of an oil spill (1), the time it takes to reach certain modelled points (2), and the state in which it will be once it reaches the said points (3). Points one (1) and two (2) call for precise data on winds, currents and waves in the wider vicinity of the oil spill incident, while the third (3) one needs knowledge and algorithms of oil-weathering-processes [14].

Precise forecasting of transport fate and weathering processes of the oil spill pose a challenge due to the complexity of the oil interaction with the marine environment. In this review they are categorized in Operational Response Models and Deep-Sea Blowout/Buoyant [14].

Operational Response Models can compute all of the essential transport, fate/weathering processes. The aim of the operational response models is to provide support in case of an oil spill by predicting the transport/fate of the oil spill [14]. Deep-Sea Blowout/Buoyant Models can compute simulations of spills originating from the sea bed or other depths and they rely on complicated physio-chemical processes [14], [25].

Below is a table, Table 1, illustrating the aforementioned software packages and their respective modelling capabilities (features and processes) categorized in Operational Response and Deep-sea Blowout [14].

Table 1. - Weathering Models – Features and Processes Quoting Zodiatis G, Lardner R, Alves TM, Krestenitis Y, Perivoliotis L, Sofianos S, et al. *Oil spill forecasting (prediction)*. Journal of Marine Research. 2017;75:923-53. [28-29]

		OPERATIONAL RESPONSE MODELS														**DEEP SEA BLOWOUT/BUOYANT**			
	Features/Processes	GNOME	MOTHY	POSEIDON-OSM	MEDSLIK	MEDSLIK-2	OpenOil	OSCAR	SIMAP	OILMAP	MOHID	OILTRANS	OSERIT	OILTOX	DELFT3D-PART	CDOG	OILMAPDEEP	TAMOC	BLOSOM
General Features/Application	Open source coding	×				×	×		×		×	×						×	
	Weathering/Fate model	×	×	×	×	×	×	×	×	×	×	×	×	×	×		×	×	×
	Lagrangian model	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
	Transport model	×	×	×	×	×	×	×	×	×	×	×	×	×	×		×	×	×
	Near-field plume	×						×	×							×	×	×	×
	Far-field transition	×						×	×	×						×	×		×
	Surface-oil model	×	×	×	×	×	×	×	×	×	×	×	×	×	×				×
	Blowout/buoyant plume model	×			×			×	×							×	×	×	×
	Back-tracking	×	×		×	×	×		×	×	×		×						×
	Stochastic element	×	×		×	×	×	×	×	×	×	×	×	×	×				×
	Random-walk scheme	×	×		×	×	×	×	×	×	×	×	×	×	×	×			×
	Oil data-base	×			×	×	×				×	×	×						×
	Bathymetric data	×	×	×	×	×	×	×	×	×	×	×	×	×	×		×	×	×
	Response assistance	×	×		×	×	×	×	×	×	×	×	×				×		×
	Environmental impact							×	×		×		×					×	
	Injury assessment							×	×				×		×				
	Research			×	×	×	×	×	×	×	×		×		×	×			
/Weathering	Advection	×	×	×	×	×	×	×	×	×	×	×	×	×	×		×	×	×
	Spreading	×	×	×	×	×	×	×	×	×	×	×	×	×	×		×	×	×
	Diffusion	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
	Beaching	×	×	×	×	×	×	×	×	×	×	×	×	×					×

Dispersion/Entrainment	×	×	×	×	×	×	×	×	×	×	×	×	×		×	×	×
Evaporation	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×		×
Emulsification	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×		×
Dissolution	×						×	×		×	×				×	×	
Sedimentation		×	×	×	×		×	×	×	×			×	×	×		
Bio-degradation							×	×								×	×
Wind drift	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×		×
Vertical turbulent mix		×	×	×	×	×		×	×	×	×	×	×	×			
Resurfacing				×	×	×		×			×		×				
Stokes drift		×	×	×	×	×	×			×	×	×					×
Photo-oxidation														×			

Oil Spill Contingency and Response or **OSCAR2000**, is a state of the art three (3) dimensional dynamic oil simulation package. It predicts the fate, recovery and processes of oil or gas. The processes at the surface i.e., wind, diffusion, currents and wind are expressed as algorithms i.e. spreading, evaporation, dispersion. As a decaying first order processes the degradation and sedimentation are described. OSCAR2000 has been widely used as a response (planning and operation) as well as a spill rick estimate package [12], [14].

OILMAP is a three (3) dimensional modelling package that can predict oil movement. It can predict surface and sub-surface oil discharges, while its modelling package is used for spreading, evaporation, emulfication ,entrainment etc.[11], [14]

General NOAA Operational Modelling Environment or **GNOME** is an oil spill model that predicts the fate and transport due to wind, current, tide and spreading. GNOME is capable of supporting three-dimensional molecule transits; ability to process any hydro-dynamic model and data; grow wind surface transfer; it has open-source coding capabilities; and many more. Furthermore, it is very adjustable, able to apply any oil-field environment and can be compelled by an abundance of data such as: evaluated point data, models, and meshes [13], [14].

OILTRANS model is established on the LTRANS molecule transference model. OILTRANS is a state-of-the-art model that replicates the fate, transport and oil weathering processes [14], [15].

OpenDrift and **OpenOil**. OpenOil is a python open-source transport and fate module (drift) build on OpenDrift.

Blowout and spill occurrence or **BLOSOM**, is a java model and is used to model the fate and transport of surface and subsurface oil spills. BLOSOM is also capable of anticipating off-shore oil-spills emerging from deep water (>150m and >1500m) blowouts. BLOSOM reproduces oil spill incidents from the start of the spill to the fate and de-gradation point [14].

Delft3D-PART is a component of Delft3D, that predicts oil transport via a molecule tracking method. Delft3D-PART offers two components; a tracer one and the oil spill which focuses on transport and dispersion [14].

OSERIT is an evaluation and response component. It can forecast the drift and fate of the oil-spill and its dispersion into the water column. OSERIT can compile oil weathering processes such as: diffusion, dispersion, spreading and beaching amongst others [14].

Modele oceanique de transport d'hydrocarbures or **MOTHY**, is a 3D-Langrangian model, which forecasts the fate and transport of oil-slicks. It can simulate shallow water with wind, pressure and turbulent viscosity processes, along with turbulent diffusion.[14]

OILTOX is also a Lagrangian oil-spill model which can predict the following processes; transport and fate such as: spreading, advection, evaporation, emulsification, entrainment, sedimentation and diffusion [14].

Modelo Hidrodinamico or **MOHID**, is a Lagrangian oil-spill model that simulates the transport and fate processes of an oil spill such as: sedimentation, beaching, evaporation, dispersion, entrainment, sedimentation, dissolution, emulsification and dispersion respectively [14].

POSEIDON OSM is an oil spill model capable of simulating the following processes: transport, spreading, weathering, beaching, sedimentation, advection and dispersion [14].

SIMAP is a Lagrangian three-dimensional oil spill model. It can simulate fate and transport of an oil slick. Some of the processes it can model are:

dissolution, sedimentation, evaporation, dispersion, spreading, sedimentation and beaching [14].

TAMOC is an open-source oil spill model capable of processing dissolution, particle tracking, transport and plume dynamics of an oil slick [14].

OILMAPDEEP is capable of estimating the fate processes and transport of sub-surface spills [14].

Comprehensive Deepwater oil and gas model or **CDOG** is a three-dimensional oil spill model used for deep-water spills. Using hydro and thermos dynamics it can simulate disintegration, gas dissolution and partition. It can process ambient current, density stratification, salinity and water temperature [14].

Weathering, spreading, advection, and diffusion instead of dissolution, photo-oxidation and or decomposition are processes most models use, using experimental relationships [15]. Discrete physical mechanisms produce aside from advection caused by wind, currents, drift and displacements, time-susceptible variations. Gravity is the first force that acts on a slick after an incident occurs, making the slick spread over an area, with individual particles spreading. With the volume of oil being reduced due to the evaporation of lighter oil, the reminder is either absorbed or emulsified. Those changes are considered as oil spill property changes. By breaking down the main spill into various others instead of a whole one, for each time step, the computer models calculate the fate processes affecting the oil spill. These processes are autonomous for each sub spill. Mackay's adjusted model is the one commonly used for evaporation, dispersion and emulsification [16]. According to Makay, the oil slick is divided into a thick part near the middle and thin parts (sheen) around the edges. Quoting Zodiatis, Oil spill forecasting (prediction) "The sheen is very thin, generally of the order of 10 microns, whereas the thick slick may, in the case of a large spill, be initially several centimeters thick. Flow of oil from the thicker core feeds the thinner parts. Evaporation and dispersion both occur much more rapidly from the thin sheen than from the thick areas and these processes are modelled differently for two components of the s lick" [2].

Oil spill variables needed for models include: type of oil, location, amount released etc. The tracer equation (seen below) is used for Lagrangian models [22], [23],

$$\frac{\partial C}{\partial t} = -U\nabla C_1 + \nabla\left(K\nabla C_1\right) + \sum_{j=1}^{M} r_j\left(C_1\right) \quad (2)$$

Where, the rate of time of oil concentration change, current U, turbulent effects K (diffusivity tensor), oil con transformation rate (M) due to processes (chemical, physical) [2]. The equation above (Lagrangian tracer equation), is split into two:

Advection/Diffusion equation:

$$\frac{\partial C}{\partial t} = -U\nabla C_1 + \nabla\left(K\nabla C_1\right) \quad (3)$$

Where currents, waves and other processes acting on the spill and transporting a number of particles are represented by.

Fate Weathering transformation:

$$\frac{\partial C_1}{\partial t} = \sum_{j=1}^{M} r_j\left(C_1\right) \quad (4)$$

where C1 is the oil concentration due to the changes occurring.

Drift flow, resistance due to wind and wave forces that cause a spill to drift on the surface are the major forces inflicted on oil spills. Wave movement causes the submersion of oil particles at the uppermost-sub surface, while the wind's magnitude preponderates the evaporation. In order for the response oil system models to be successful they require the feasibility of viable ocean data in order to anticipate oil slick movement.

Wind is a force moving currents in the water, as well as moving slicks on the surface of the sea, thus making it a sovereign element when predicting oil spill presence in the sea. The wind factor approach is what most oil spill models are based on, claiming that wind force will drive the oil spill at a specific fraction of the speed of the wind and at a specific angle to wind direction. Drift factor and angle are much disputed topics regarding oil modelling. For the drift factor the most common value used is 3 (three) % while for the angle, it is between 0-30 (zero – thirty) o. This method does have a flaw because in some cases the effect of currents is calculated twice. As mentioned by De Dominicis et al., drift caused by wind related actions has a variety of ways to be dealt with despite those models being convoluted. A first choice is to pick current velocity at an average depth. Another possible solution would be to reduce the drift factor. And finally one could use the values of wind to compute sea current flow to reduce effective wind data to compute drift [12], [17].

The most common walkthrough used in models is to completely ignore wind and rather use buoyancy. This way the current effects will not be counted twice, as the drift factor will be in relation to water. As mentioned beforehand, the force of wind also effects the movement of the oil slick as it pushes the slick with a fraction α of the speed at an angle β.

$$U_w = a\left(W_x \cos\beta + W_y \sin\beta\right), V_w = a\left(-W_x \sin\beta + W_y \cos\beta\right) \quad (5)$$

Where Wx and Wy are wind Velocity comp. α and β are the percentage of wind added to current velocity and the deviation angle respectively.

The local sea currents consist of smaller Lagrangian parcels, at which the impact of the wave-caused currents are considered by Stokes drift velocity. This is due to the fact that particles move slower going backwards at the "base" of a wave rather than going fast in an oblique movement at the top of a wave. The significant height (Hs), wave (0) traverse time (Tz) and water extent (z) are used to compute Stokes drift velocity (S) as shown below,

$$\left(S_x, S_y\right) = \frac{1}{8} H^2 k\omega d \quad (6)$$

Where k is the wave number, ω the angular frequency and d the direction [12].

As the wind speed increases, so do the wind drift, the Stokes drift as well as surface currents. Because all of them depend on the bathymetry and the coastal geography, a comparison cannot be made on what effects these have on the spills. If the spill occurs in the open, with a deepness of more than 200 meters (m), then the Stokes will be 10 to 20 % of the wind one, as all of them (the drifts) will move in the same direction.

3 Oil Weathering – Mathematical Analysis

Weathering is described as the process of spreading, evaporation, emulsification, dissolution, dispersion etc. of hydrocarbons mixed in water. All the above processes will occur at the same time.

3.1 Spreading

The mechanical forces (gravity, inertia, viscous, and interfacial tension and turbulent diffusion) cause the horizontal expansion oil slick, this phenomenon is defined as spreading. Oil expands in an arrangement of a thin, constant layer with round mode, due to the forces of gravity and surface tension. Spreading coefficient is also known as surface tension, according to Petroleum Engineers Guide to Oil Field Chemicals and Fluids (2nd Edition), and the Hydraulic Fracturing Chemicals and Fluids Technology (2nd Edition). The spreading coefficient is described as the divergence of the surface tension foaming medium σf, the surface tension de-foamer σd and the interfacial tension σdf [26].

$$S = \sigma_f - \sigma_d - \sigma_{df} \quad (7)$$

The most commonly used equations/models for spreading were developed by Fay (in three phases). The second phase was adjusted by Wang et at.

$$A_2 = \pi 0.98^2 \left[\frac{\Delta\rho g V^2}{\rho_w \upsilon_w^{0.5}}\right]^{1/3} t^{0.5} \quad (8)$$

Where A2 is the area in m2, g is the gravity in ms-1, V is the volume in m3, t is the time in h, ρw is sea water density 997kgm-3, υw is the kinematic viscosity 0.0001 m2s-1.

Gravity is acting on the thick part of the slick, which is layered on top of water, and a more heave fluid is taken into consideration for spreading. Fay was the first to introduce the theory of "gravitational spreading against viscous resistance", which states that for a small amount of time when the spill is still "young", the impulse of the spill to expand is opposed by inertia, while the primary force resisting any spreading under gravity is the viscosity of the oil.

$$\Delta A_{tk}^{(s)} = -\frac{\Delta V_{tn}^{(s)}}{T_{tk}} + C_2^{(s)} A_{tK}^{1/3} T_{tK}^{4/3} dt \quad (9)$$

The equation implements the modification in the area of the thick slick at any time interval, and Fay's suggestion, mentioned above, where C2(s) is a constant, while the flow, flows from thick to thin ΔVtn(s). The surface thickness of the thick part of the surface oil slick volume is Ttk. The area of the thick part of the volume is Atk, while dt is the time step [2], [18].

$$\Delta V_{tn}^{(s)} = \Delta A_{tn}^{(s)} T_{tn} \quad (10)$$

The increase in the area of the area of the thin slick, is ΔAtn(s).

Spreading lasts for either a time frame of 48 hours after each sub spill happens, or until the thickness of the thin and thick slicks are equal. After the 48 hour period passes then wind currents etc. (advection forces) dominate the movement of the slick. The increase in the area of the thin slick ΔAtn(s) is calculated using an equation similar to Fay's (1971), equivalent to the third root of area times the timestep and the exponential function of the thickness.[2] When the slick becomes very thin it stops spreading, this is expressed by the last exponential:

$$\Delta A_{tn}^{(s)} = C_1^{(s)} A_{tn}^{1/3} dt \exp\left(-C_3^{(s)} \Big/ \left(T_{tk} + 0.00001\right) \right)$$

(11)

Where the model parameters are C1 and C3, the thickness of the thick part of the surface slick is Ttk and dt is the timestep.

Proposed by Lehr et al. was a stretched ellipse along the path of the wind model, to resolve the attended non-symmetrical expanding of slicks [19]:

$$Q = 1.13\left[\left(\rho_w - \rho_o\right)/\rho_o\right]^{1/3} V_o^{1/3} t^{1/4}$$

$$R = Q + 0.0034W^{4/3} t^{3/4} \qquad (12)$$

Where the length of the major and minor axis is R and Q respectively. 20]

While Lehr et al. composed an altered Fay spreading equation considering wind:

$$A = 2270\left(\frac{\Delta\rho}{\rho_o}\right)^{2/3} V^{2/3} t^{1/2} + 40\left(\frac{\Delta\rho}{\rho_o}\right)^{1/3} V^{1/3} U_{wind}^{4/3} t$$

(13)

Quoting Lehr et al.: “where A is the area of the oil slick (m2); _ρ=ρw_ρo; V is the total volume of the spilled oil in barrels; Uwind is the wind speed in knots; and t is the time in minutes” [21].

4 Fate Weathering – Visualization of Spreading

The issue of simulating and visualizing the spread of an oil slick based on the introduced equations was characterized and treated as a time series data and analysis problem. The data points, thus the radius and spreading of the oil spill were monitored and visualized to indicate the spatial coverage of detected oil spill over time in different experiments. Thus, machine learning and time series data exploratory analysis approaches, such as time-based indexing and multi-step forecasting, were utilized to depict the expansion of an oil spill through the time and based on the various iterations that were conducted. The latter can also be utilized to forecast the time-and-space-varying velocity of an oil spill. In this context, the visualization was based on laboratory experiments of an oil slick spread and was implemented tasks with the Python programming language and the utilization of Anaconda environment and IPython Notebook. Moreover, several tools and libraries of the Python language for the implementation of the abovementioned tasks were utilized. For instance, the “*matplotlib*” package was used to provide the final visualizations and plots for the demonstration of the experimental results [24]. Additionally, “*numpy*” was utilized to perform quick computations and mathematical equations, while the capabilities of the “*pandas*” package and its data structures and data frames were leveraged for working with time series data, as the examined data were characterized.

Furthermore, each record of the initial experiments acts as a different time series. Hence, dA is used as the step of the overall spill progress across time. Starting from the initial spill with radius A in time t=0 and reaching to A_2 that is the final condition of oil spill after *t*.

The utilization of the developed Python code on the simulations resulted in interesting plots that showcase the overall spreading of an oil spill through the various simulations and initial number of drops. More specifically, “Fig. 1” depicts a comparison between the spreading rate of the three examined simulations based on the initial drops of oils. The visual analysis of this figure indicates that there is a tremendous growth of the spread of the oil spill between an initial 1-Drop of oil and initial 5-Drops of oil. While, on the other hand there is a small difference between the spreading rates of 5-Drops as compared to initial 10-Drops of oil. Moreover, it showcases that the 5-Drop and 10-Drop simulations have almost the same high exponential growth in the radius of the oil spill across time. In contrary to the 1-Drop simulation where the growth of the radius of the oil spill follows a more linear increase.

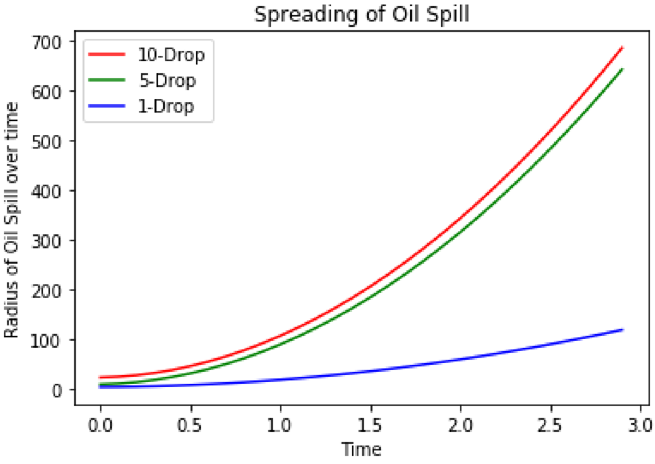

Fig. 1: Comparison between the spreading of an oil spill in the different experiments

What is more, Figure 1 above illustrates the graphical representation of the results obtained from the python model using the data from the laboratory experiment, the graph shows the increase of the rate of spread for one (1), five (5) and ten (10) droplets of oil, 0.0228gr each against the time. As it is clear from the illustration there is an exponential increase on the rate of spread of the oil slick in relation to time with the increase of the volume of oil being disposed.

Trying to provide a more depth analysis on this expansion and increasing rate of spreading between the three different simulations “Fig. 2”. The latter showcases the overall expansion in the covered area of an oil spill over time. In all three subplots that are presented in this figure the overall time for reaching to the final condition (A_2) is the same (t=3.0sec). From this figure it is easily understood that in the simulations of the 5-Drop and 10-Drop there is a great expansion in the final area that the oil spill covers as in comparison with the 1-Drop simulation.

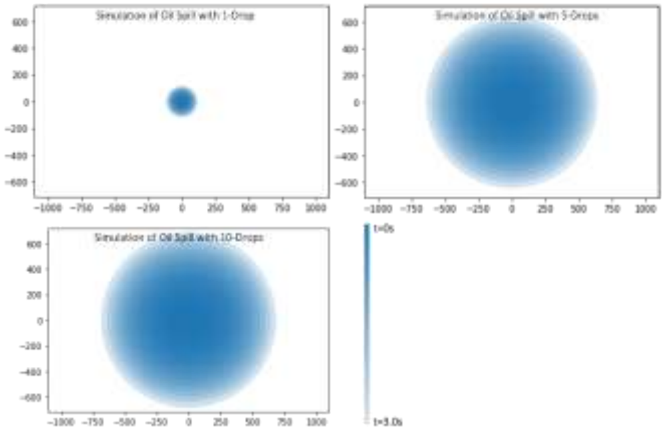

Fig. 2: Comparison between the rates of spreading between the three different simulations

The figure above, i.e, Fig. 2, illustrates the spreading affect of the oil spill using python in relation to the time. The x and y axis represent the dimensions of the laboratory tank used to replicate the spreading of the oil spill in centimeters (cm). While the different oil spill spreading variations over time are represented by the different color cycles as depicted in the time scale on the right bottom of the figure. In this respect, Fig. 2 provides a visual representation of the spreading weathering effect that occurs during an oil spill from the moment the droplet reaches the water surface until the spreading stops.

5 Discussion - Response System

Python simulations have been carried out based on results and data obtained from the laboratory experiments. The results of the python model representations as well as of the laboratory experiment oil spill feature a close resemblance. At this point, it should be noted that both the laboratory and the python model did not take into account the other weathering processes mentioned in table 1, apart from the spreading effect nor did the accumulate for wind or water wave effects.

Trustworthy real-time data is required regarding the movement and growth of the oil slick for the response department. Nowadays this information is provided by atmospheric and forecasting services like NCEP and NOAA respectively. The most important aspect in the response system is to identify the location in order to forecast the movement of the oil spill. The location as mentioned above plays the most critical role because in order to tackle the oil spill and create a response system there is first a need to create a trajectory map. This map potentially will show any boundaries (i.e., beaches) that might alter the direction trajectory of the spill or even cause beaching of the oil. It will also help decide which type of response system will be used to clean or control the oil spill.

There is a clear necessity for establishing a live-action event response system to counter the negative aftereffects of oil spill incidents on the environment and society. This statement is greatly justified by the fact that in recent years 30% and 25% of the yearly spills occur with an average spillage of 160.000 and 290.000 tons from platforms and tankers respectively.

6 Conclusion – Improvements Needed

The oil slick is depicted as a stream of individual molecules for the analytical formulation. Each individual molecule is depicting a body of oil exposed to weathering and drift due to oceanic conditions/forces acting on the slick. Relying upon the ocean circumstances the depicting of the molecules and the analytical formulation of the weathering models change. These circumstances that play a critical role include factors such as wind currents etc. State of the art oil forecast models use extrinsic data for currents, stokes drift, air water temperature etc. Some elements of the ocean models are replicated better than others, thus it is important to know which the prevailing factor is in order to choose the appropriate oil spill model.

The spill augur is done using a mathematical model of the weathering. Weathering involves evaporation dispersion emulsification, oil properties, chemical properties, environmental conditions etc. Most models typically do not take into account dissolution and degradation. But these two factors are vital in order to approximate the effect of the spill on the environment and society. Oil has the ability to dissolve from the surface of the slick in the column or disperse. According to Mackay (1977), dissolution is deliberated as a mass flux connected to solubrity and temperature. Degradation depends on the chemical properties of the oil of the spill, but there is a limited amount of models that take into account biodegradation. Taking into account the above statements there is a clear need for the oil spill modelling to make a distinction based on their physical, chemical and toxicological characteristics and trail their movement individually so that a higher accuracy is achieved. Thus, it is crucial in order to forecast the effect on the environment, to consider the fate in the water column.

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