Prediction of Marine Oil Spill Trajectory Using Lagrangian Approach

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ABSTRACT--- *Crude oil production is the largest and most profitable business in the world. From its development phase to production phase, many disasters have occurred in oil industries. Marine Oil spill is one of the most common types of environmental disaster which usually occurs due to the release of crude oil from tanker ships, offshore platform and drilling mines into the sea or ocean. This in turn has a huge impact on the marine ecosystem resulting in the loss or even extinction of aquatic species. We propose an approach to predict the range over which the oil spill will spread, the model is based on Lagrangian approach and the main model is a combination of several major sub-models that predict the oil slick transport on the sea surface, oil losses due to natural weathering processes and oil dispersion in water column. The coastal forecast is done using vector approach over the range of values available from various sources. All these constraints are considered together to predict the range over which the oil spill will spread so that relevant remedial measures can be taken accordingly to minimize the extent of damage in the marine environment. This prediction will be very useful in establishing an effective recover plan to prevent further spreading of oil in the ocean.*

Keywords - Oil Spill, Lagrangian model, Vector approach, prediction.

INTRODUCTION

Marine Oil Spill is a commonly occurring phenomenon which results in the release of liquid petroleum hydrocarbon into the ocean or sea. One of the growing combat methods being used in parallel with the traditional methods is to develop models to map or predict the position of the oil spill as time passes. About 3 million metric tons of marine oil contaminates the sea every year which is hazardous and causes damage to the aquatic ecosystem and the environment. By predicting the range covered by the oil spill, immediate recovery measuresto clear the affected environment can be adopted as soon as possible. This has proven to be useful in helping to determine the most appropriate methods to employ whether it be; the use of dispersants, oil booms or simply to leave to naturally dissipate.

One of the largest tanker oil spills occurred on the 19th July, 1979 approximately 10 miles of the North-East coast of Trinidad and Tobago. This involved the collision of two VLCC (Very Large Crude Carriers) the Atlantic Empress and the Aegean Captain. A total of 2,76,000 tonnes of crude was spilt into the Caribbean Sea and 26 sailors lost their lives. The spill spanned the course of 15 days from the time of collision to the time when the Atlantic Empress sank. The government spent a lot of money in the recovery process and it took almost months to sweep the entire coastal region from the oil spread. This situation could have been handled in a much better manner if there was a model which estimated the spread range and provided with a suitable remedial measure to be taken.

When crude oil is released into the sea a number of physical and chemical changes occur: The oil initially floats in a layer up to several inches thick at the water surface which is spread and moved by wind and water currents. Immediately, more volatile components begin to separate and disperse into the atmosphere and water soluble components (called polycyclic aromatic hydrocarbons, PAHs) leach into the surrounding water. Lighter insoluble components form thin films that spread and move more extensively than the thicker oil. The warmer the sea and air temperature, the more rapidly these components separate. Wave action separates the mass into smaller areas and patches, and eventually into smaller globules, some of which emulsify ('mix') with seawater. Oil-water emulsion has the characteristic tan- yellow colour often seen in floating oil slicks. Dispersants (detergent like substances) distributed to break up the oil slick facilitate the formation of emulsions, distributing the oil as droplets of oil and emulsion throughout the water column. As the lighter components dissolve, the remaining oil develops a thick gooey consistency, and breaks.

In the recent decades, many researchers have studied the transport and fate processes of oil spills based on the trajectory method and mass balance approach, i.e. (Yapa et al., 1994; 2002; ASCE Task Committee, 1996; Reed et al., 1999) as reported by Chao et al. 2003. Among these oil spill models, many focus on the surface transport. In our approach we are using vector model to determine the coastal forecast and by applying the Lagrangian approach we are calculating the trajectory of the oil spill. We are using various modelling approach and theoretical equations to determine the numerical values of parameters like evaporation, viscosity, dispersion and emulsification.

All these numerical values are incorporated together to arrive at a prediction so that the best suitable remedial measures can be applied, thus saving a huge amount of time and money spent in the recovery process.

LITERATURE SURVEY

Over the years, different methodologies have been studied widely and are divided into different categories according to the approach being used.

1. DIMENSIONAL-OIL SPILL MODELLING:

The latest approach in the oil spill prediction process is the 3- Dimensional projection of the path of the spill (Wang et al. 2010; Papadimitrakis et al. 2006; Tkalich et al. 2002). Wang (2010) used Ocean Wave model[5] to predict the range of oil spread in the marine environment, one of the advantage of his model is that the oil dispersion rate problem in the previous approaches was solved using particle tracking method. However before Wang's approach Papadimitrakis (2006)[6] used hybrid turbulence model for simulating the fate of oil spills in various water bodies, this model combined three parameters namely the Navier-Stokes equations for two-phase flows, following an Eulerian approach, the RNG (Renormalization Group Theory) turbulence sub-model, and parameterized expressions of the basic processes affecting the fate of oil spills to predict the range over which the spill will spread. Oil spilled on a sea surface will be dispersed by a variety of natural processes, Tkalich's (2002) ultimate goal of the research was to parameterise influence of breaking waves[7] on vertical mixing of oil droplets to be used in a general 3-Dimensional oil spill model and he formulated an algorithm for this approach that considers advection and turbulent diffusion as its constraints to achieve it.

2. 2DIMENSIONAL-OIL SPILL MODELLING:

The oil spill trajectory prediction was also projected in 2-Dimensional approach (Aghajanloo et al. 2011; Nagheeby et al. 2010; Tkalich et al. 2006; Fay et al. 1971). Aghajanloo (2011) used the Hydrodynamic model[8] for computing the marine situation and surface current velocities. The 2 Dimensional current velocities were solved using Finite Volume Method (FVM) on a structured grid system and the resulted algebraic expressions were solved using Alternative Direction Implicit (ADI) technique. This model has been implemented in Visual Fortran language. Nagheeby and Kolahdoozan (2010)[9] estimated the rate of oil slick carried on sea surface and projected in a graphical model. The prediction was based on Oil Weathering model and in order to increase the compatibility of this model Eulerian approach has been used. However before Nagheeby's approach Tkalich (2006) used Time- Splitting Technique[10] in order to predict the effective process of oil weathering in spillage which includes evaporation, vertical dispersion, and water in oil emulsification. These processes were time dependent but it can be seen that the relative contribution of each process varies during the spill period. The modelling of this process has some complexities about

formulization and collection of the input data, thus there is a significant lack of data on predicting the accurate trajectory of the spill. In order to increase its accuracy we can use the Oil Slick Dynamic model[11] addressed Fay (1971), he establish a classical spreading equation for formulization with the use of Navier-Stokes technique.

3. IMAGE PROCESSING OF OIL SPILL:

One of the most commonly used approach in oil spill prediction is by processing the images of oil spill region and predicting its further path (Solberg et al. 2007; Karantzalos et al. 2006; Kavzoglu et al. 2003; Frate et al. 2000). Solberg (2007)[12] used Statistical Classifier with rule based modification of prior probabilities in order to predict the oil spills in the SAR Images. The Statistical classifier involves segmentation which extracts the oil spills from SAR and avoids complexities. Karantzalos and Argialas (2006) used pre-processing technique[13] which involves Anisotropic Diffusion Filtering (ADF) and Morphological

Filtering (MF). Anisotropic diffusion is a non linear operators aiming at to reduce the image noise without removing significant parts of image content. The concept of Morphology which relates to the shape of features in the image such as boundaries, skeleton etc is also used. The process has been implemented in Matlab to predict the range. However, Kavzoglu and Mather (2003)[14] deployed neural networks to process the remote sensing image and improved in accuracy when compared to traditional statistical methods. Here a single neuron can be compared with a multi-variance linear regression model, which works without any priori assumptions concerning the statistical nature of the data set. The massive parallel work of several neurons gives further capabilities for solving complex problems in the remote sensing area. Frate (2000) on the other hand used dark area detection methods[15] which are based upon pixel-basis processing. When dark areas are detected, statistical classification methods are applied to characterize the dark areas as oil spills or 'lookalike' objects. For this purpose, estimation of a number of spectral and spatial features of the dark areas (geometric, surrounding, backscattering, etc.) was pre-required.

4. RECENT APPROACHES ON OIL SPILL TRAJECTORY PREDICTION :

Current methods have seen an increase in accuracy to the previous prediction methods. One such method was introduced by Olmo Zavala et al. (2018). They used Lagrangian method for particle tracking with a second-order Runge-Kutta scheme. This model uses ocean currents from the Hybrid Coordinate Ocean Model (HYCOM)[3] and winds from the Weather Research and Forecasting Model (WRF) and it also considers multiple oil components according to their density, and includes multiple types of oil decay like evaporation, burning, gathering and exponential degradation.

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The consideration of all these parameters is what makes this model more precise. Avin Hardeo (2016) developed a simple mapping model to predict spill position taking wind and ocean currents as the main influences on the movement. Spreadsheet (Microsoft excel)[1] was used to develop the plots. His historical spill data showed that the amount of spills originating from ships is on the decline and it was hypothesized that the number of spill occurring from drilling and production could increase tremendously. The mapping model's response was as anticipated to the input data but this mapping requires some real

data to test its accuracy and improve in the presence of the wind and ocean currents. It can be seen that during the same time Zhen Li et al. (2016) also introduced a mapping model[4] which was based on OSRA model. This model uses hindcast surface winds and ocean currents to calculate hundreds of thousands of trajectories initiated from hypothetical oil spill locations and estimates contact probability of these trajectories with resources that are of biological, social and economic importance. It can be seen that the results of this model shows that a strong seasonal and annual variability exists in the contact probability estimates for the time period considered, and the effects of hindcast surface winds and ocean currents on the contact probability can be quantified.

PROPOSED MODEL & RESULTS

Our methodology works utilizing both vector model and Lagrangian method to deal with the prediction of trajectory of the oil slick. When an accident happens and due to this if the oil is the ship is discharged into the sea the corresponding latitude and longitude of the spill area is fed into our application. Our system first checks the area for any false positive esteem. The rate at which the oil is spilled into the marine environment and the type of oil that is spilled is also specified by the user. The end product is deployed in the form of a web application where the user will provide the co-ordinate of the spill and the spill trajectory will be exhibited on the screen. The forecast will be displayed in the form of an animation and a plot in which the oil is depicted as a swarm of dots, which we are calling it as "Seeds" (each seed equals to 1 liters of oil spilled into the ocean) each representing a portion of the volume of oil spilled Our application uses live data to anticipate the trajectory which ensures the accuracy of our approach. We have used datasets from AROME and NOAA for efficient numerical prediction.

VARIOUS PARAMETERS CONSIDERED

The following are the various parameters considered for the forecast of trajectory of the oil spill in a particular location with respect to time. Each parameter has a specific use and a specific formula to determines its value.

Vector Model :

Oceanic regional forecast values like Wind speed, Wind direction, Current speed and Current direction from various live sources are given as input for this vector model. It is determined from the survey that wind affects 3% of its speed in its direction within specific time and the current

affects 100% of speed in its direction within the same specific time.

*Oil spill speed = (wind speed * 0.03) + current speed*
*Oil spill direction = (wind direction * 0.03) + current direction*

The output of this system will help us determine the speed and direction of the oil spill which will be later used for the trajectory prediction process.

Viscosity:

The viscosity of the oil is one of the most crucial factors which determines the dispersion of oil slick. It is the most significant parameter as it increases from a few hundred cSt to approximately 50,000 cSt. The viscosity of various types of oil at different temperature is previously stored in the system, so based on the type of oil and the temperature of the marine environment we can determine the effective measure.

Viscosity	Less than 2,000cSt	2,000cSt - 10,000cSt	Greater than 10,000cSt
Effectiveness	Probably dispersible	Good Dispersion	Difficult to Disperse

Evaporation:

It is an important process for most oil spills. In a few days, typical crude oils can lose up to 45% of their volume. The Macondo oil lost up to 60% in a short time when released under water at high pressure. Almost all oil spill models include evaporation as a process and output of the model. In our model we are considering 45% as a standard value for evaporation of crude oil over a time span of 52 hours.

*Evaporation = ∑ (Total amount of oil spilled * 0.0086)*

The value of Total amount of oil spilled * 0.0086 gives the evaporation rate for 1hour, if we want to find for a specific time we can perform the summation operation to determine the evaporation rate of a specific time period.

Dispersion:

Waves and turbulence at the sea surface can cause all or part of a slick to break up into fragments and droplets of varying sizes. These become mixed into the upper levels of the water column. Some of the smaller droplets will remain suspended in the sea water while the larger ones will tend to rise back to the surface. The dispersion percentage can be calculates as

*Dispersion (%) = Total Oil Dispersed x 100/Density of oil * volume of oil*

Emulsification:

Emulsion is the change of mixture of oil and water due to the breaking waves and water turbulence. The formation of emulsions can strongly change the oil properties. The density of the emulsion could be 1.03times denser than the initial oil density.

The first twelve hours of spilling is the most important time with regard to change in density (ASCE task committee, 1996). For the emulsion estimation, Mackay's relationship is used,

$$V = C[1-exp(-2*10\text{-}6/C \; x \; (1+Uw)2*t)]$$

Where V is the water content of the emulsion, Uw is the wind speed (m/s), C is the constant viscosity equal to 0.7 for heavy oil and 0.25 for light oil, and t is time (s).

Oil Film Thickness:

The thickness of the oil film plays a considerable role in determining the trajectory of the forecast. In correspondence to the crude oil type the maximum thickness of the oil is considered to be 0.01 (1 cm) to a minimum thickness of 1e-9 (1 nm).

Lagrangian approach:

The basis of the advective Lagrangian particle- tracking trajectory method is the following vector relationship:

$$\frac{dsi}{dt} = V_a \, (x_i \, , \, t)$$

Where x_i is the i th particle coordinate and V_a is the advective velocity due to wind and current at the particle coordinate.

IMPLEMENTATION :

The entire simulation process is done using OpenDrift framework which invokes openOil method for numerical simulation, data analysis and visualization.
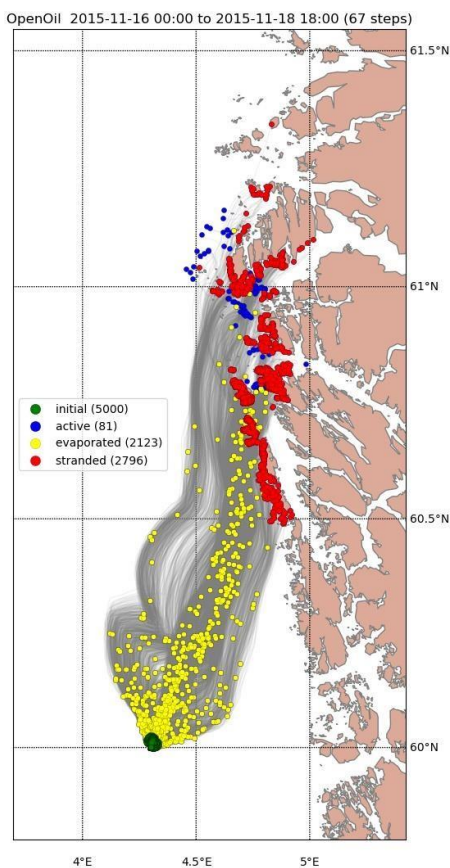

Fig : A sample plot

All these combined with mapping tool box will be useful in creating a basemap. In our approach we are going to simulate the trajectory of oil spill and visualizing how the oil particles will move in response to the external forces such as wind and ocean current and various other factors of oil like viscosity, evaporation, dispersion and emulsification to arrive at an accurate prediction. The data for prediction is accessed from NOAA archive during runtime and the forecast is displayed in the form of an animation and a plot both depicting the trajectory of the oil spill. The above image shows the plot of an oil spill along with the time duration specified at the top of the plot.

CONCLUSION:

Thus by using the vector model and Lagrangian method we were able to forecast the oil spill in any specified region. The use of live data from various sources like NOAA and AROME has further increased the accuracy of the oil spill trajectory. This forecast will be very useful in establishing an effective recovery play to prevent further spreading of oil in the marine domain.

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