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Research Article

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Research and Development for Oil Spill Simulation Backward in Time at East Vietnam Sea

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Abstract

The paper is presented the evaluation of the oil spill simulation backward in time with some input data conditions such as the environment factors (from simple to complex conditions) and oil spill data (from one to multifarious). The scientific basis is used the hypothesis of the mathematical basis forward in time, the physical phenomena backward in time (reverse phase) and non-negative requirements. The oil spill process is calculated with important components involved in the simulation such as physical, weathering and oil properties change. The East Vietnam Sea was chosen to apply the study that oil spill incident data was used in the past and especially in 2007 and 2008. The simulation results are considered and determined with concentration and layer thickness of oil spill on sea that they always appear in small areas. This area has a peak concentration value that jumps over nearby surroundings for a short period of time. This time interval depends on the environmental factors that make the input data condition. Hence, the surrounding higher concentrations are predicted oil streaks that could have survived in the past. Finally, the peak concentration area is predicted for the possibility of an oil spill emission source in the past. Besides, this study may still not be optimized so they will continue to be solved in the future.

Keywords: Oil spill; East Vietnam Sea; Concentration; Oil streaks; Backward in time

Highlights

- Research and development for the prediction method of the possibility of finding an emission oil spill source backward in time has been proposed.
- The Euler approach was used in this study.
- This methodology allows prediction of the search area that is likely to occur in the past.
- The simulation backward in time with inputs data from simple to complex have been made to conform to the laws of physics.
- Other factors affecting simulation results have not been specifically addressed in various respects.

Introduction

Marine economy in which oil and gas contribute important to the country development. In side, oil pollution at sea has become one of the most important goals in marine science. For example, the oil spill phenomenon drift and unknown origin on the sea and coast in the East Vietnam Sea. The oil collected over 5000 tons at coastline of Vietnam [1]. In the past, over 50 oil spills happened in the period from 1990 to 2015. Currently, maritime traffic is still active and accidents resulting from oil spill incident occur frequently to the marine environment [2,3]. As a result, the risk of future oil spills in the East Vietnam Sea will increase due to some reasons: (1) The seaports system is increasing; (2) From oil depots, oil pipelines, oil rigs and drilling rigs; (3) From maritime traffic density is the 2nd largest in the world after the Mediterranean region.

In the past, research on the possibility of tracing the spillway has existed several methods, but they still have many difficulties. Historically modeled development to trace the pollution source, the meteorological sector first pioneered the ocean. Models are usually constructed in the Euler and Lagrange approaches.

Oceanography, studies of the plankton movement in the sea by the Lagrange approach to solve the Lagrangian Particle-Tracking Models (LPTMs) by Batchelder et al. [4]. LPTMs are an integrated model of the forward-in-time-trajectory (FITT) and the backward-in-time-trajectory (BITT) that without considering the diffusion process. Studies of the drift objects on the sea have also been used to track the origin of the accident area with empirical evaluations by Breivik et al. [5,6]. Lectures on branching studies using the Lagrangian Coherent Structures (LCSs) by Thomas Peacock [7]. (LCSs) are distinguished surfaces of trajectories in a dynamical system that exert a major influence on nearby trajectories over a time interval of interest.

For the oil spill approach, Thang [8] researched in various respects such as chemical isotopic comparison of oil to determine origin; Ca et al. [9] presented a using the method of time-tested modeling with the Euler approach; Thai et al. [10] applicated the MIKE model according to Lagrange approach; Nhan [11] developed to solve the approach by reversing the time with the Lagrange approach.

Thus, based on the results of research in the world, the author has synthesized, researched and developed simulation of oil spill transmission and transformation backward in time in the East Vietnam Sea. This simulation approach is applied the Euler approach with the involvement of physical processes, weathering and oil properties change of the oil spill into the marine environment will be presented.

Theoretically the Oil Spill backward in Time

The approach of the oil spill backward in time is solved by based on the following hypotheses:

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- According to Newton's law [12] shows that the force (F) impact to move the distance (L) with forward in time, the force with opposite direction (-F) will have impact to move the distance (L) to be original location with backward in time;
- According to Fick's law [13], if forward in time, the diffusion process movies from high to low of concentrations. Backward in time, back diffusion process is gone back with the diffusion direction from low to high of concentration.
- According to the law of matter conservation show that part of the matter is dissipated with forward in time, they will become part of the matter is accumulates with backward in time;
- Conditions for solving non-negative test. This means that the oil spill is a non-negative scalar.

From the above assumptions, the theoretical basis will be chosen as follows:

Forward in time, Lehr [14] applicated the process of changing the oil concentration under the influence of environmental factors that is written as:

$$\frac{\partial C}{\partial t}=-\left(V_{ax}\frac{\partial C}{\partial x}+V_{ay}\frac{\partial C}{\partial y}\right)+\left(D_{hx}\frac{\partial^2 C}{\partial x^2}+D_{hy}\frac{\partial^2 C}{\partial y^2}\right)\pm\sum_m S_m \quad (1)$$

In the approach backward in time, according to the above hypothesis then the equation (1) is written as:

$$\frac{\partial C}{\partial t}=-\left((-V_{ax})\frac{\partial C}{\partial x}+(-V_{ay})\frac{\partial C}{\partial y}\right)-\left(D_{hx}\frac{\partial^2 C}{\partial x^2}+D_{hy}\frac{\partial^2 C}{\partial y^2}\right)\pm\sum_m S_m \quad (2)$$

where: C is the oil concentration per unit surface area (kg.m^{-2}); V_{ax} and V_{ay} are the velocity parameters of horizontal components in x and y axes (m.s^{-1}) that is determined by Trinh et al. [15]; D_{hx} and D_{hy} are the diffusion parameters of horizontal components in x and y axes (m^2.s^{-1}) that is determined by Trinh et al. [15]; S_m is the source of the spill (kg.m^{-2}s^{-1}); t is time (s).

The equation for the oil thickness simulation by Warluzel and Benque [16] and Tkalich et al. [17] in parallel with the oil concentration is also shown in reverse:

$$\frac{\partial h}{\partial t}=-\left((-V_{ax})\frac{\partial h}{\partial x}+(-V_{ay})\frac{\partial h}{\partial y}\right)-\left(D_{hx}\frac{\partial^2 h}{\partial x^2}+D_{hy}\frac{\partial^2 h}{\partial y^2}\right)\pm\sum_m \frac{S_m}{\rho} \quad (3)$$

where: h is the oil thickness (m); Δ is the oil density (kg.m^{-3})

The relationship of oil spill on the surface between oil concentration, oil thickness and oil density is determined by the following expression:

$$\rho_0=\frac{C}{h} \quad (4)$$

Studies show that the oil density varies depending on evaporation rate, oil temperature, emulsion rate and initial oil density, for example Lehr [14], Mooney [18], Mackay [19], Buchanan and Hurford [20]. Formula to determine the backward in time of oil density used:

$$\rho=\frac{\rho_O-F_W\rho_W}{(1+F_W)\left[1+C_1(T-T_e)(1-C_2F_e)\right]} \quad (5)$$

The close relationship between the thickness, area and volume of the oil spill was determined:

$$V_o=h*A \quad (6)$$

The oil spill process on the sea is affected from the variation of weathering processes by Wang et al. [21], and Ehsan Sarhadi Zadeh and Kourosh Hejazi [22]. The oil spill volume backward in time is depended on the oil weathering process, which is defined as:

$$V=V_o\frac{(1+F_e+F_d+F_{disc}+F_{sed}+F_{coats}+F_{oxy}+F_{bio})}{(1+F_W)} \quad (7)$$

where: V_0 and V are the pre and post-weathering oil volumes (m^3); ρ0 and ρ are the pre and post-weathering oil densities (kg.m^{-3}); ρw is the water density (kg.m^{-3}); C1 and C2 are experimental constants; T and Te are the oil and environmental temperatures (K) that is determined by Trinh et al. [23]; F_w, F_e, F_d, F_{disc}, F_{sed}, F_{coats}, F_{oxy} and Fbio are the proportions of the respective emulsion, evaporation, dispersion, dissolution, sedimentation, shore line, oxidation and biological processes (%) that is determined by Trinh et al. [23].

Viscosity is a parameter that depends on temperature, evaporation and emulsification, for example Lehr [14], Mooney [18], Mackay [19], Buchanan and Hurford [20], Ehsan Sarhadi Zadeh and Kourosh Hejazi [22], Reed et al. [24] and Aghajanloo et al. [25]. Since then, the scientific work has been published, the author selected to determine the kinetic viscosity of the oil spill backward in time, which is defined as:

$$\upsilon=\upsilon_o\exp\left[C_6\left(\frac{1}{T}-\frac{1}{T_e}\right)-C_5F_e-\frac{C_3F_W}{1+C_4F_W}\right] \quad (8)$$

The relationship between kinematic and dynamics viscosity of the oil spill is:

$$\mu=\rho\upsilon \quad (9)$$

where: μ is the dynamics viscosity of oil spill (kg.m^{-1}.s^{-1}) or [cP]; V_0 and V are the pre and post-weathering oil kinetic viscosity (m^2.s^{-1}) or [cSt]; C3 and C4 are coefficients; C5 is a parameter that depends on the type of oil; C6 is a parameter that depends on the oil temperature (K^{-1}).

Surface tension is the gravitational attraction between molecules on the surface of a liquid by Lehr [14] and Mackay [19]. For backward in time, the surface tension is used:

$$\sigma_w=\frac{\sigma_{wo}}{(1-F_e)} \quad (10)$$

$$\sigma_A=\frac{\sigma_{Ao}}{(1-F_e)} \quad (11)$$

where: σw^0 and σw are the pre and post-weathering surface tension of the oil - water (N.m^{-1}); σA_0 and σA are the pre and post-weathering surface tension of the oil - air (N.m^{-1}).

Stability conditions

The approach of the oil spill substances using Peclet number and depending on stable conditions by Courant et al. [26] is:

$$\Delta t\le\min\left(\frac{\Delta x}{\left(\sqrt{2gh+V_{ax}}\right)_{\max}};\frac{(\Delta x)^2}{2D_{hx}};\frac{\Delta y}{\left(\sqrt{2gh+V_{ay}}\right)_{\max}};\frac{(\Delta y)^2}{2D_{hy}}\right) \quad (12)$$

where: V_{ax} and V_{ay} are the velocity parameters of horizontal components in x and y axes [m.s^{-1}] that is determined by Trinh et al. [15]; D_{hx} and D_{hy} are the diffusion parameters of horizontal components in x and y axes (m^2.s^{-1}) that is determined by Trinh et al. [15]; h is the oil thickness; Δt is time (s); Δx and Δy are the horizontal scales of the mesh in x and y (m); g is the gravitational acceleration (m.s^{-2}).

Calculation Conditions

Sea bottom terrain data information (background)

Terrain field is divided into a 1/64-degree square grid with boundaries in the South China Sea (longitude between 99 and 121 East degree and latitude between 1 and 24 North degree). Databases are collected from charts with different ratios and use the method of map integration to bring about the same national benchmark by Trinh et al. [27]. Grid domain specificity is determined by the interpolation function.

Environmental data information

Environmental data include meteorology (wind, air temperature), waves, and oceanography on the surface (currents, water temperature and salinity). Some options for using inputs for calculations include:

• For homogeneous schemes, the average annual data is used;

• For real-time alternatives using meteorological data (CFSR) [28] and marine data from the 3D model product (POM).

Oil spill data information

Spilled oil data is used on the basis of past oil spills that include as:

• For the option of an oil spill, the choice is 0.001 (ton), equivalent to the oil

concentration 1.0 e^{-5} (kg.m^{-2}), corresponding to the oil pollution limit in accordance with the national standard for Water quality [29,30];

The 2007 and 2008, oil spill real scenarios were obtained from remote sensing image analysis by source from the Environmental Monitoring Center under the Vietnam Environment Administration and the Remote Sensing Observation Center under the Vietnam Remote Sensing.

Simulated time data information

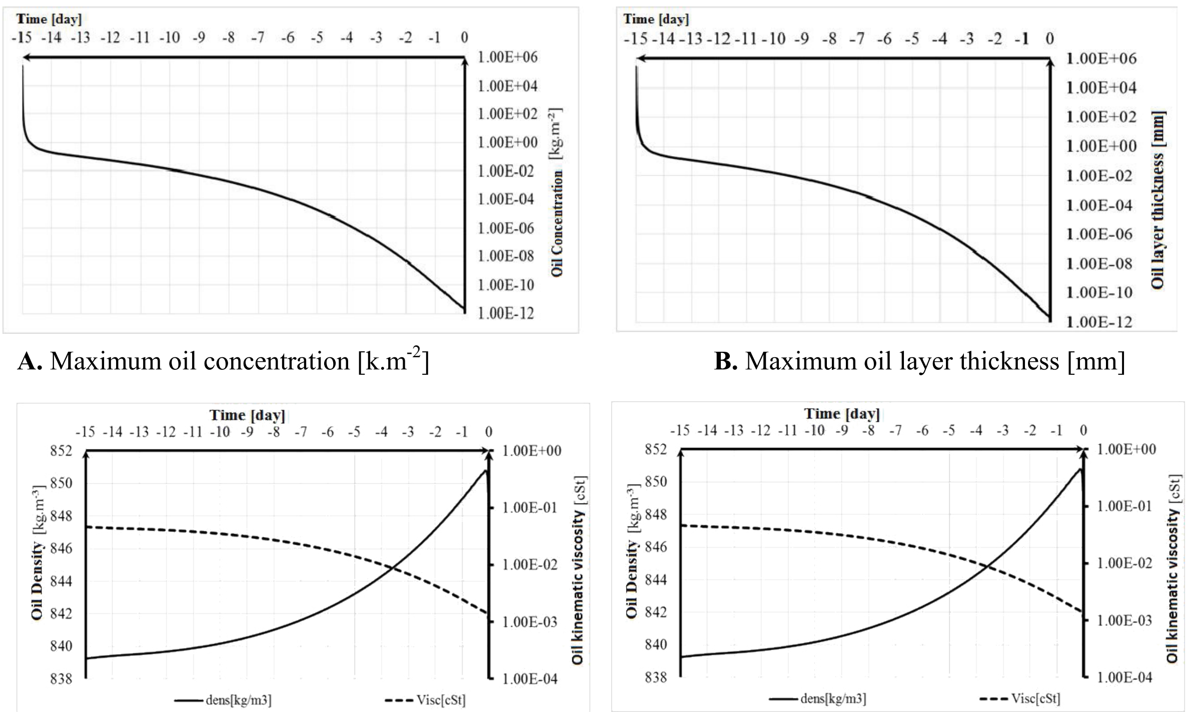
The calculation period is in about 15 days for the calculation options for an oil spill incident and in the month according to the real-time option.

Simulation Results and Discussion

Scenario for a consistent environmental input factor with an oil spill position

Simulating the process of tracing the oil spill source backward in time is calculated in accordance with the homogeneous input environment condition. The results of this simulation are presented as a reverse chronological order at the location of the maximum oil concentration (Figures 1a-1d) and the change of the oil concentration field in time (Figures 2a-2d).

Figure 1 demonstrates the result of computing simulation cases with environmental factors conditions uniform and stepped square grid (0.044 degree). This result showed that the process of the oil properties change element with the largest concentrations placements backward in time as the oil concentration, the oil layer thickness, oil density, oil viscosity, oil temperature and oil temperature gradient. Figures 1a and 1b indicate oil spill change consistent with rule variations in concentration and layer thickness of oil spill increases backward in



A. Maximum oil concentration [k.m^{-2}]

B. Maximum oil layer thickness [mm]

C. Oil Density (line) [kg m-3] and Oil Kinematic Viscosity (line break) [cSt]

D. Oil Temperature (line) [K] and Oil Temperature Gradient (line break) [K]

Figure 1: Transform some properties of oil spill backward in time with the consistent environmental input factor condition and computational grid step (Δx=Δy=0.044 deg.)

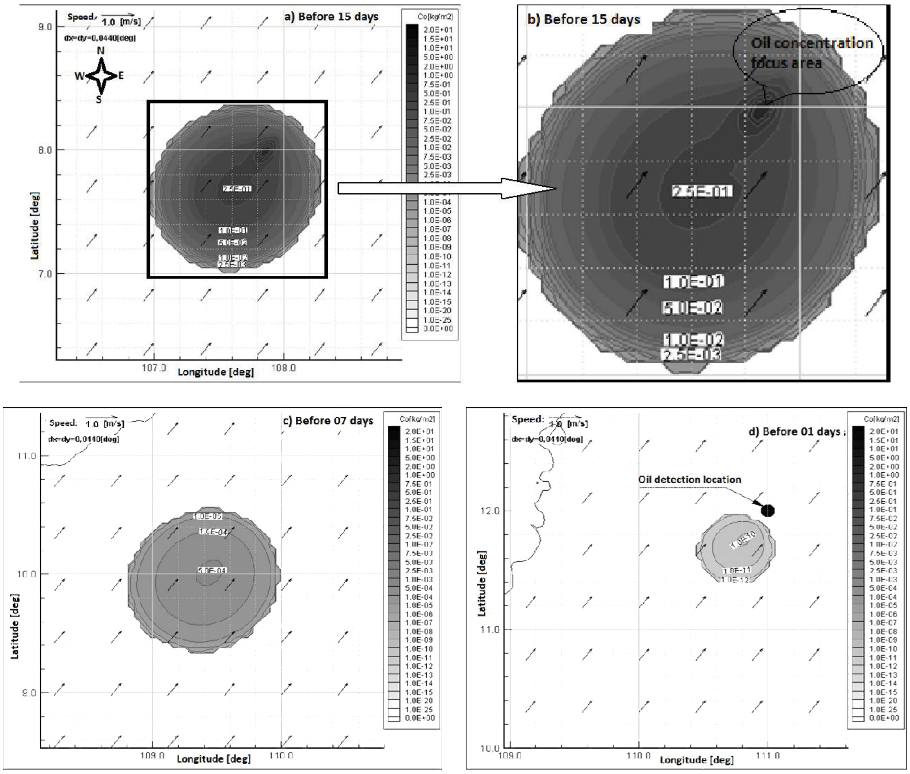


Figure 2: Results calculation of the oil spill concentration (kg m^{-2}) according to the different time.

time, especially given the time to jump on the oil spill magnitude. So, this simulation process has limited that they are showing the convergence focus of oil spilling in space and time of stopping in time. Besides, oil spills are reviewed according to the oil concentration field in the space under the cut time. Oil density variations in the space suit with the rule that means the movement direction of the oil streaks and magnitude of concentration due to the effects of weathering.

Figure 2 expresses the oil spill concentration field according to the different times on the same space rate (Figures 1a, 1c, 1d) but the area change by moving of the oil streaks. This present may indicate an area of oil streak change from time to time. Figure 1b is the zooming oil streaks from the Figure 1a to see clearly the oil concentration focus areas leap better. From this image shows the movement of the oil streaks is consistent with the hypothesis according to Newton's law means the oil streaks moving against the movement direction of the force; increased oil concentration according to Fick's law meant the large oil concentrations will increase sharply over the small oil concentration, around the point of concentration will probably appear the oil concentration in the previous time step. These processes combine to create the fit is next time calculate the area appears to have increased considerably higher concentrations.

In addition, in order to account for the unreasonable result of visualization, the oil spills are increasingly widespread backward in time, which is likely to be influenced by some reasons such as: (1) the initial oil data is a grid node, the grid computing will interact with the grid nodes around it after each step time. So, the possibility of the oil concentration at the nodes will be generated according to Euler approach. This phenomenon is often referred to as digital diffusion effect. If one or more points are maintained, the Euler approach is transformed into a Lagrange approach; (2) according to Fick's law, the mesh node has an oil concentration and the nodes around it will likely have higher oil concentrations after a calculated period; (3) the calculation process will be affected by many other processes such as approximation process, diffusion process...; (4) Especially this is the ability to search for oil spills in the past, so the search area will have to be scaled out backward in time that is consistent with the diagnosis and forecast approach.

But this result will orient the region's allowable concentration limits according to the oil concentration level, meaning that regions a superior oil concentration are likely to allow the possibility of the oil traces in the past, especially the timing and location of leaps in concentration allow the appearance of the oil source to be large. This is the advantage of the ability to limit the space and time to find oil spill sources.

Scenario for real input environment conditions in 2007 and 2008

From simple to complex simulations, the purpose is to test the stability of the approach. In this part, the author will verify the conditions of the environment variable in space and time as the actual. The above information has been included in the simulation of the oil spill in 2007 and 2008. The simulation results are shown below.

Simulation of the reversal of oil spill backward in time for the scenario of a oil spill incident location was calculated under conditions of actual environmental change in February 2007 and July 2008. The results are shown in terms of the distribution of oil concentrations field in February 2007 and July 2008 (Figures 3 and 4). Figures 3 and 4 show that the change in shape of oil traces backward in time is more complex than in the scenario of homogeneous environmental conditions (Figure 2). The oil streaks shape between the two seasons (February. and July) also varied over the same caculated period (Figures 3b and 4b).

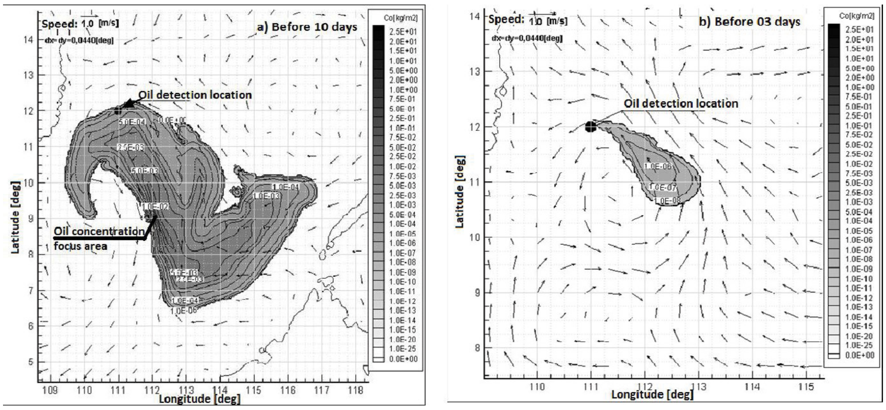


Figure 3: The concentration field (kg.m^{-2}) of the oil spill with the actual environmental conditions in February 2007 (CFSR and POM) and the mesh step (x=Δy=0.0440deg.) of an oil spill position accident detected.

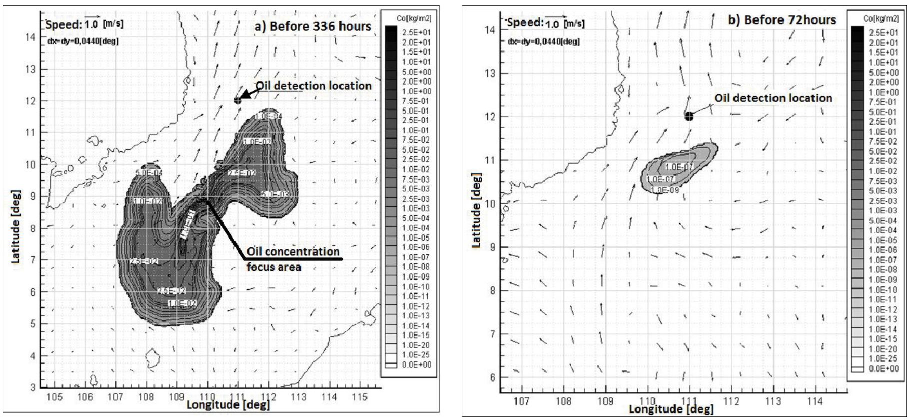


Figure 4: The concentration field (kg.m^{-2}) of the oil spill with the actual environmental conditions in July 2008 (CFSR and POM) and the mesh step (Δx=Δy=0.0440 deg.) of an oil spill position accident detected.

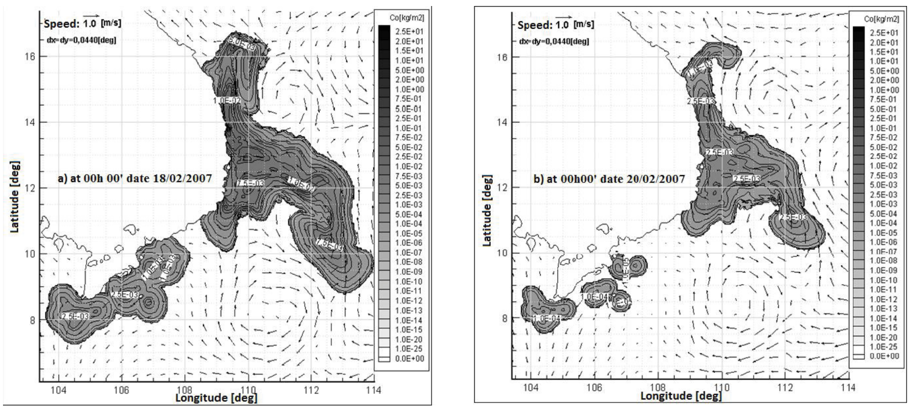


Figure 5: The concentration field (kg.m^{-2}) of the oil spill with the actual environmental conditions in February 2007 (CFSR and POM) and the mesh step (Δx=Δy=0.0440deg.) of many oil spill position accidents detected.

Although the complex change of oil streaks varies, they appear to have areas that have jumped oil concentration at different times in the past (Figures 3a and 4a). These areas represent the spatial and temporal limits of the ability of different oil spill sources to depend on the environmental factor as the input to the calculational condition.

Complex input does not depend on space and time will be simulated. This simulation of oil spill at sea based on oil spill and sea drift data was analyzed from satellite imagery from reliable sources and transformed environmental conditions (CFRS and POM) in 2007 and 2008. Simulation results were presented in February 2007 and July 2008 (Figures 5 and 6). From these images, the complexity increases several times, but the areas of greater agitation around them also appear and move in as a dynamic mode as input.

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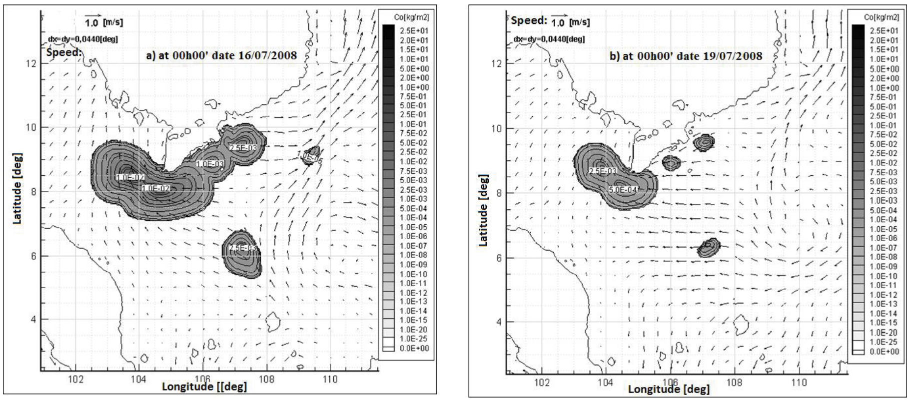

Figure 6: The concentration field (kg.m^{-2}) of the oil spill with the actual environmental conditions in July 2008 (CFSR and POM) and the mesh step (Δx=Δy=0.0440 deg.) of many oil spill position accident detected.

Conclusion

Through the study and development of the oil spill simulation backward in time at the East Vietnam Sea area, the author makes the following conclusion.

The approach for the ability to trace oil spill backward in time on the sea is a difficult and complex problem. But the theoretical basis chose mathematical assurances and the hypothesis of sticking to physical processes under the physics laws. The data used for computing has a clear origin and reliable reliability such as topography, surface meteorological factors (wind, air temperature), ocean waves and surface ocean elements (current, water temperature and saltiness). Oil spills data from past oil spills, particularly oil spills that floated and drifted offshore in 2007 and 2008 according to analysis from satellite data sources.

The results are reviewed, assessed and tested on the basis of the input environment factors from simple (space and time homogeneous) to complex (real change) and oil spills on the sea (one and multiple oil spill positions at different times) applies at the East Vietnam Sea area. The simulation results show hypothetical fluctuations and consistent with natural law. They also reflect the ability to look up emission oil source area or oil streaks backward in time under time slices term. Especially the simulation results always appear to be an area where the oil level jumps that much higher than the surrounding in space at a given time. Therefore, the probability of finding a emission oil source will be resolved in higher concentrations and spikes at specific times in the past.

So, in this study demonstrates the physical nature fit, specifically showing the possibility of being able to identify specific areas in space and over time with corresponding specific input conditions. To verify accuracy and minimize noise, experimental results are needed for specific comparisons. In addition, they still have limitations that exist, such as changes in large oil traces (numerical diffusion effect) or improved quantitative accuracy, which will be addressed in subsequent studies.

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