EXTENDED ABSTRACT

1. INTRODUCTION

Oil spill formation affect both the natural environment and human activity (economic, social, recreational) that develops in open and coastal waters. Recently, permits for research and exploitation of undersea hydrocarbons have been increasingly available in Greece (Ionian, Patraikos Gulf, West Crete). This implies, in the near future, an increased risk of causing an oil spill accident in the marine environment and it is for this reason that it is imperative to create strategic plans to deal with such accidents at both a preventive and early response level. Accidents can be caused by various factors and at different stages of the process of researching and exploiting the underwater hydrocarbon deposits.

- In the process of researching or exploiting drilling (on the oil rig, on the drilling rig)
- During the process of transshipment of oil to and from its storage tanks
- Due to a maritime accident involving one or more ships
- Due to war operations with drilling or oil tankers

For this reason, oil spill behavior models have been developed to help predict the trajectory and its evolution, that is, the temporal variation of its properties which is a key element in dealing with such incidents.

This paper compares three oil spill behavior models (commercial and open source) (OSCAR, MEDSLIK, TELEMAC2D-oilspill) in different applications. First in the Gulf of Patras by comparing OSCAR-MEDSLIK to a scenario of oil spill and then to the south of Zakynthos in a scenario of a marine accident. The selection of the above models as well as the specific areas of application is done in order to better compare them and draw conclusions about their potential for a more accurate description of the phenomenon.

For the application and comparison of the OSCAR and MEDSLIK models, the Gulf of Patras area is selected as it is an area of increased interest in research and exploitation of proven oil fields. Also, since OSCAR is a commercial program, it is only possible to compare it with existing simulation results made by MAKATONIS.

For the application and comparison of the TELEMAC2D-Oilspill and MEDSLIK results, an application area should be selected for which a qualitative hydrodynamic model could be built on which to base the oil spill behavior model. The formation of a qualitative hydrodynamic field in the Gulf of Patras was not possible during the postgraduate work, so the thought of comparing all 3 oil spill behavior models simultaneously was abandoned. For this reason, a different, simplified case was sought that could serve as a model for the application of this model, for which the creation of the hydrodynamic field would be easier, the computational time reduced and would be within the wider study area. This area is Laganas Bay in Zakynthos and the selection criteria of the area were its geometry, with the gulf coastline and the two small islands within it as well as the existence of the protected area of Zakynthos National Marine Park which makes the area particularly sensitive.

2. COMPARISON BETWEEN OSCAR AND MEDSLIK (APPLICATION IN THE GULF OF PATRAS)

2.1 MEDSLIK OIL SPILL MODEL

MEDSLIK (R.W. Lardner B.A., Ph.D., Sc.D., 2004,2011) is a user-friendly software package which is designed to predict the fate and the transport of an oil spill in sub-regions of the Mediterranean Sea. The particles of oil move mostly because of the water currents and the wind. The weathering processes that MEDSLIK simulates are: diffusion, evaporation, emulsification, dispersion, the spreading and the beaching of oil (R.W. Lardner B.A., Ph.D., Sc.D., 2004,2011). MEDSLIK consists of three parts; (a) a graphical input interface through which the user is able to enter the data concerning the spill and environmental conditions, (b) a run module that performs the computations that simulate the spill behavior and (c) a graphical output interface through which the user can examine the predictions of the model.

2.2 MEDSLIK OIL SPILL MODEL

In order to be able to compare the two models, the input data entered in MESLIK should be as similar as possible to those entered in OSCAR for the particular leakage scenario under consideration. The leak date was set 20/11/2015 at 15:00 hrs Greece (13:00 UTC) with a duration of 5 days until 25/11/2015 15:00 hrs Greece (13:00 UTC).

The simulation duration is 10 days in total. The oil leakage rate is 10000m3 / day with a total leakage of 50,000m3 / day. The location of the leak is the point C in the Gulf of Patras, as shown in the figure 2-1 with coordinates (Lat: 38.10, Long: 28.05). While the type of oil used is Oseberg Blend [a low viscosity (5 cP at 40 C), light paraffinic oil with API equal to 37.2 and specific gravity equal to 0.839.]

The wind is variable in time and constant throughout the field as only in this form is introduced into the model, while the point chosen to derive its values is the point of leakage. As for currents, they are variable in time but constant in space throughout the field, again with reference point the point of leakage. Finally, the anemological and hydrodynamic data were entered in a MEDSLIK 3-hour time step.

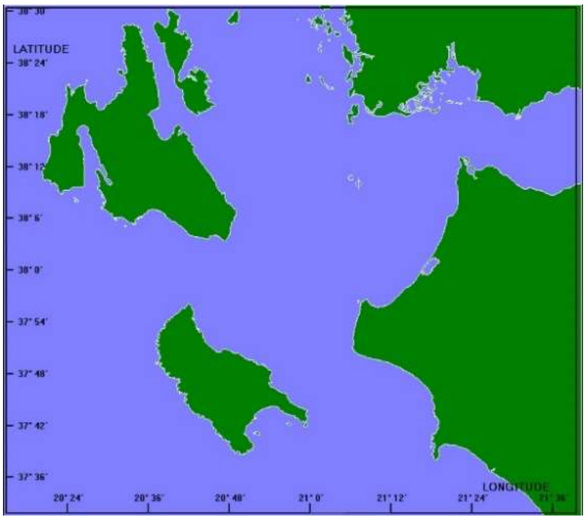

Figure 2-1 The point of leakage and the study area as presented in MEDLSIK

Date start oil leakage	20 November 2015
Time start oil leakage	15:00 (13:00 UTC)
Time start of model	15:00 (13:00 UTC)
Duration of model simulation (hours)	237
Time step of calculations	30min
Name of oil spill	Patraikos
Oil type	Generic Type : API: 37.2
Quantity of oil spill (cubic meters)	50.000
Oil spill location	Lat 38.10 , Long 21.05
Date finish oil leakage	25 November 2015
Time finish oil leakage	15:00
Number of particles	10000
Wind factor	0.031
Diffusion factior (cm^2/s)	20.000

Figure 2-2 Elements of leakage and calculations in MEDSLIK

2.3 RESULTS COMPARISON BETWEEN OSCAR AND MEDSLIK

The qualitative comparison is made on the following axes:

- When does the oil reach the shore and in what area?
- In what part of the coastline does the oil spread?
- What track does the oil spill follow?
- How does the oil spill evolve over time, that is, at each time point, what are the properties of the oil?

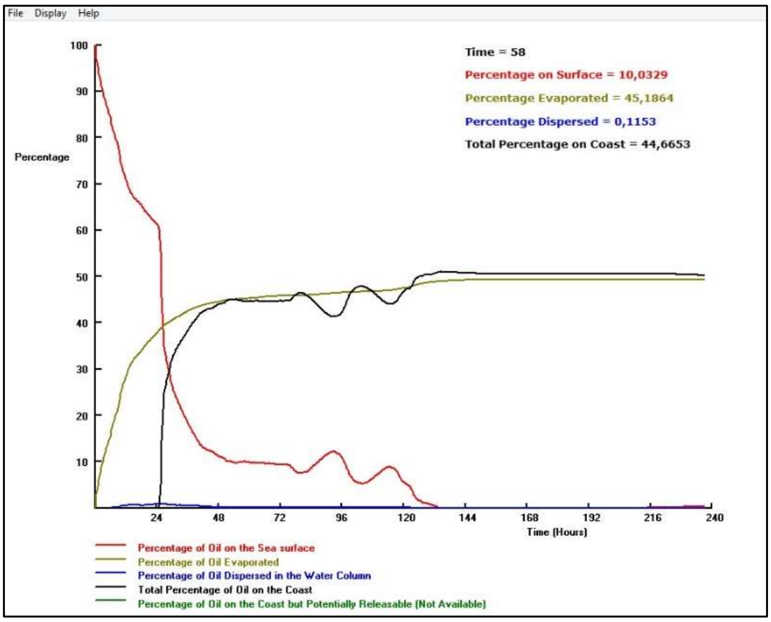

Figure 2-3 The percentage of oil on the surface, evaporated, dispersed and the percentage that has reached the shore

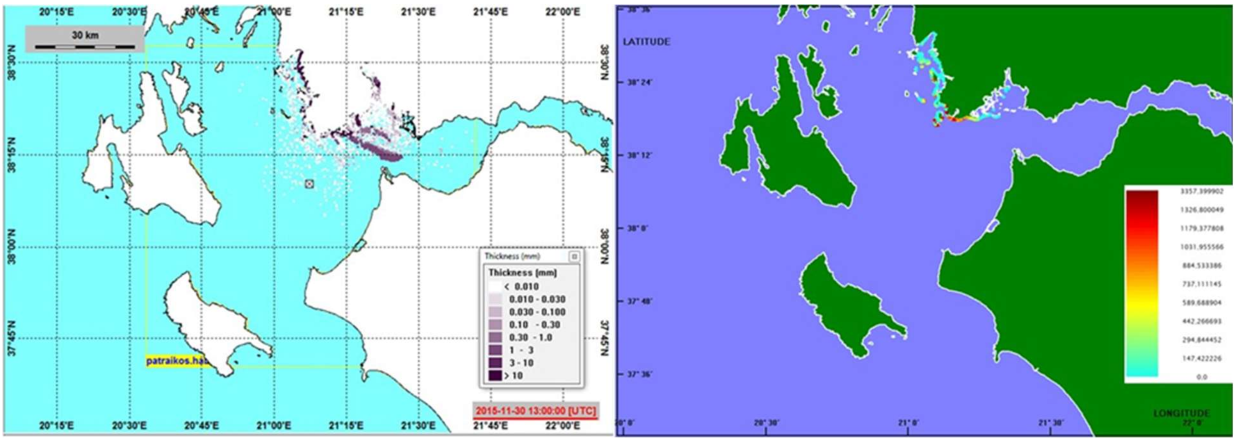

Figure 2-4 Time of oil arrival on shore approximately 24 hours after the leak (21/11/2015 15:00))

The results of the two models for the first three questions posed are almost completely identical, which are essential for timely treatment of the oil spill by developing an appropriate response plan. Arrival of oil in both models approximately 24 hours after the leak (figure 2-4), similar in trajectory as shown in the figures 2-5 and 2-6 but also in the same area where the oil was spread throughout.

Subsequently, the two models for mass balance differ in both the quantities and the information on the results of the simulated processes (figures 2-7 and 2-8). MEDSLIK does not take into account processes such as sedimentation, biodegradation and dissolution. They also have a major difference in the surface oil and the oil that ends up on the shore. While the maximum amount of oil on the surface in MEDSLIK is observed 24 hours after the leak (5000 tons), at OSCAR the corresponding maximum is 114 hours after the leak was initiated (19000 tons). This is mainly due to the difference between the two models in the corresponding amount that ends up on the shore (1/10 at OSCAR, 1/2 at MEDSLIK). This large discrepancy between the oil on the shore and the oil on the sea surface may be due to:

- the type of shore that is defined in each model, OSCAR is defined as shingle, while in MEDSLIK it is defined as sandy (by default)
- the density of the mesh used in both models

Whereas in terms of the amount of evaporation the two models show less variation as they reach their maximum value, at MEDSLIK about 1/2 of the total quantity (21000 tonnes), while at OSCAR about 2/5 (16000 tonnes) the same timing (120 hours after the leak).

Final conclusions from comparing OSCAR and MEDSLIK models

1. The two models have a similar identity in describing the development and behavior of an oil spill in terms of its trajectory, the time and position that the oil will end up on the coastline.
2. OSCAR excels in the quality characteristics of oil spill evolution and aging, both because it takes into account a large number of processes that MEDSLIK ignores and because it enables coupling with models describing various environmental impact indicators.
3. A major disadvantage is the fact that MEDSLIK is only supported by older software (windows XP and earlier)
4. However, MEDSLIK as a free distributed model (version used) is sufficient to describe the phenomenon, compared to OSCAR, in the key aspects that are qualitatively compared above.

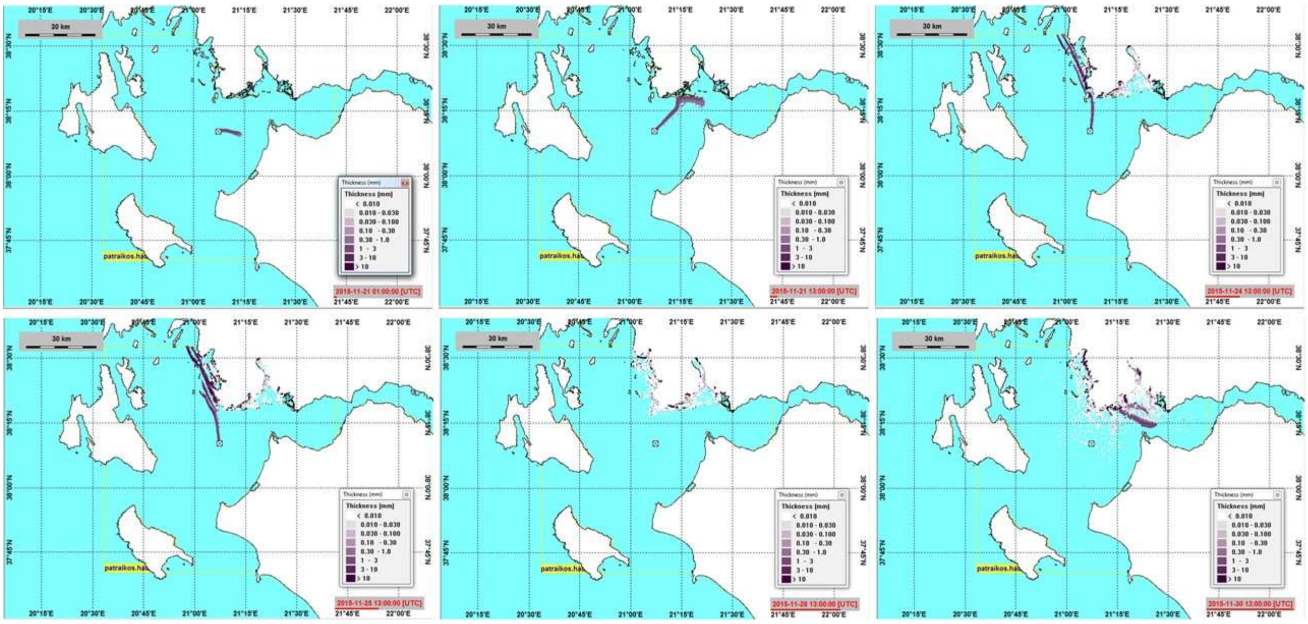

Figure 2-5 Indicative snapshots describing the oil spill track according to OSCAR results

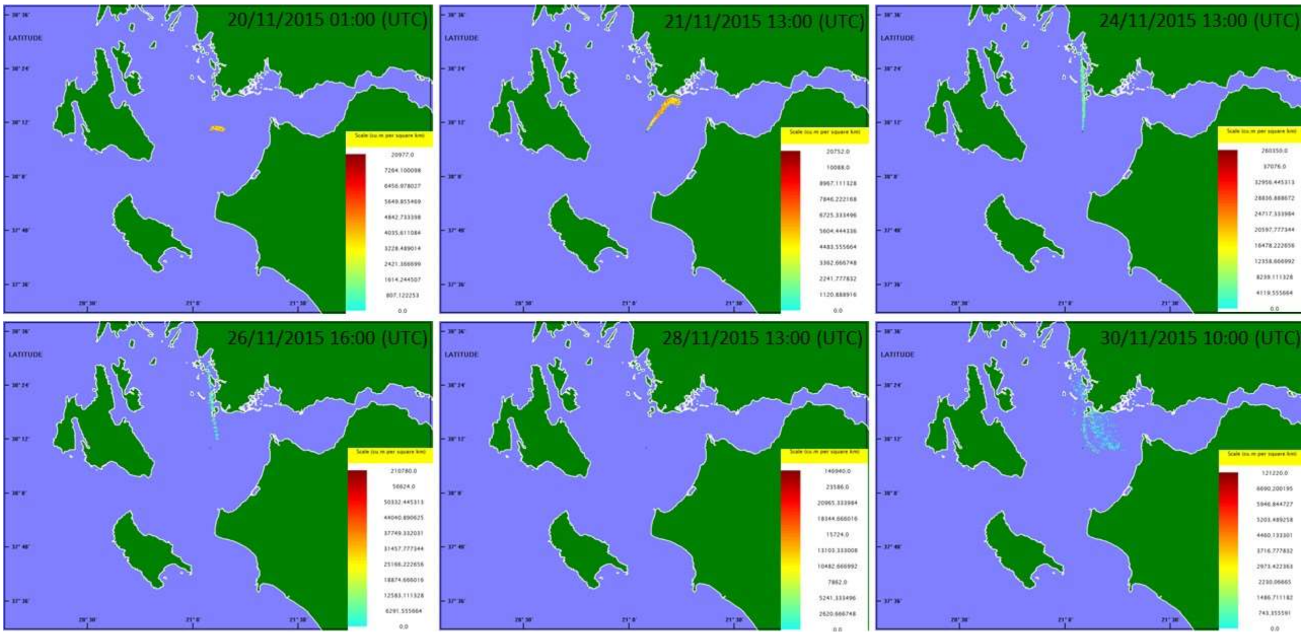

Figure 2-6 Indicative snapshots describing the oil spill track according to MEDSLIK results

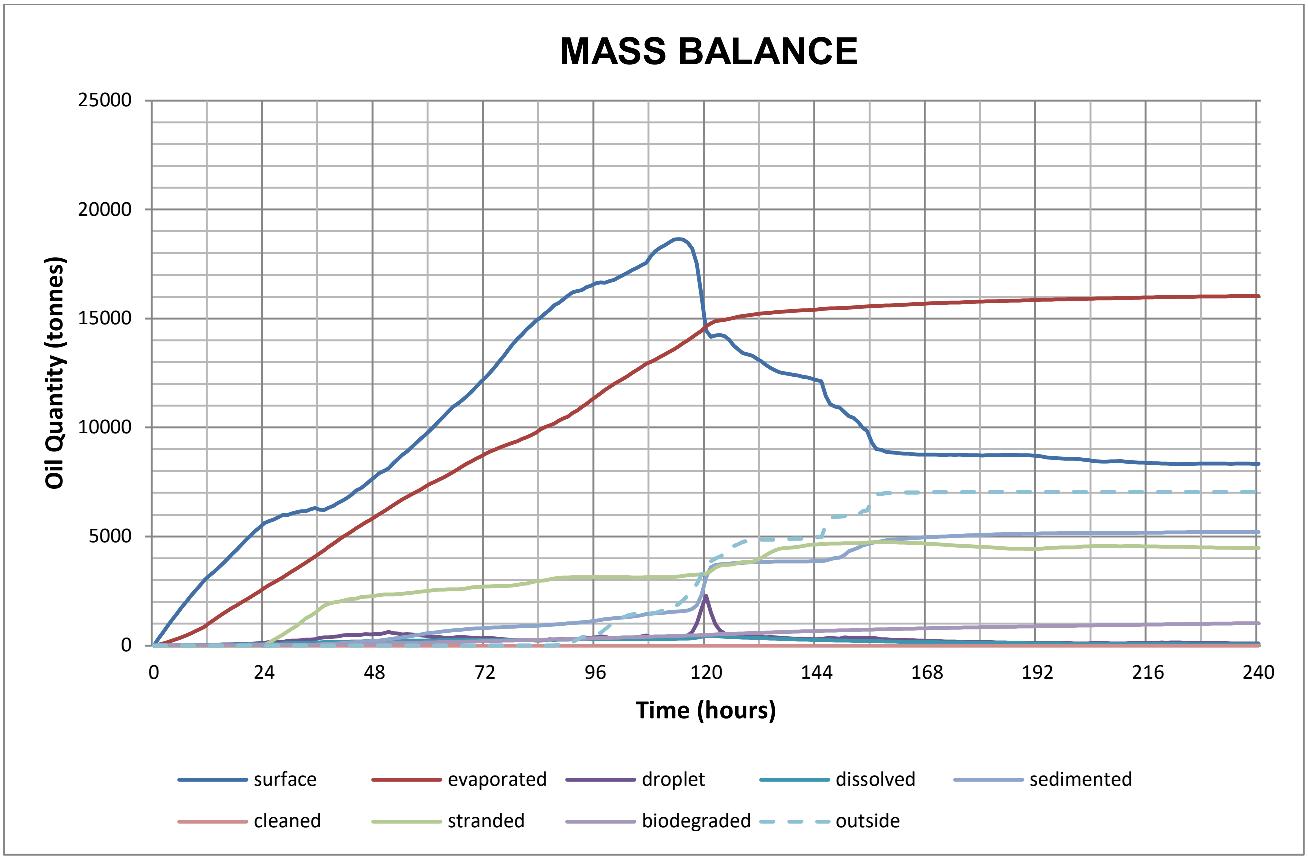

Figure 2-7 Oil mass change over time in OSCAR model

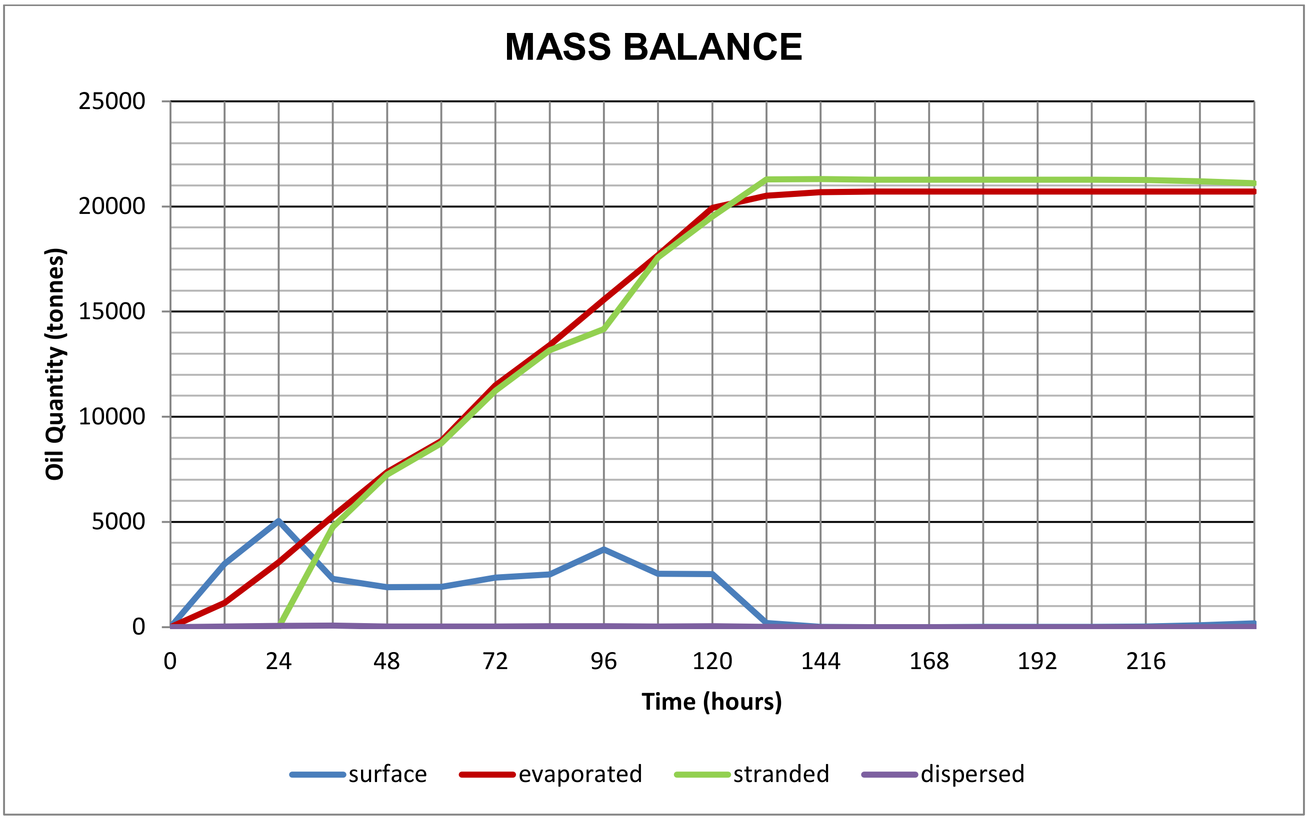

Figure 2-8 Oil mass change over time in the MEDSLIK model

3. COMPARISON BETWEEN OSCAR AND MEDSLIK (APPLICATION IN THE GULF OF PATRAS)

3.1 TELEMAC2D (OIL SPILL MODEL)

The Telemac-2D model is part of the Open-Telemac Mascaret software package and developed by the Laboratoire National d'Hydraulique et Environnement (LNHE), part of the R&D group of Electricité de France. Its basic function is to solve depth-averaged surface flow equations as first formulated by St.Venant in 1871 and their results at each point of the grid are the depth and velocity components in function over time.

Oil spill simulation is a relatively new feature that has been added to TELEMAC-2D and is based on the work of Goeury (Cédric Goeury Engineer-Researcher, 2014) In particular, a Lagrangian / Eulerian oil spill model has been incorporated into the TELEMAC system. A Lagrangian approach was used to predict the transport of oil spill to the sea surface and an Eulerian approach to simulate water quality, which must be coupled to the hydrodynamic model. This model aims to simulate the processes of horizontal advection, turbulent diffusion, evaporation, volatilization and dissolution.

3.2 INPUT DATA

The scenario of the leak is as follows: a marine accident occurs at a distance of 12.5 km or 6.75 nm southeast of Zakynthos, off the National Marine Park (Figure 3-1) resulting in an instantaneous leakage of 500 tonnes of heavy-duty fuel from a bunkering ship. The data entry and selection of the parameters of each model can be seen below (Figure 3-2).

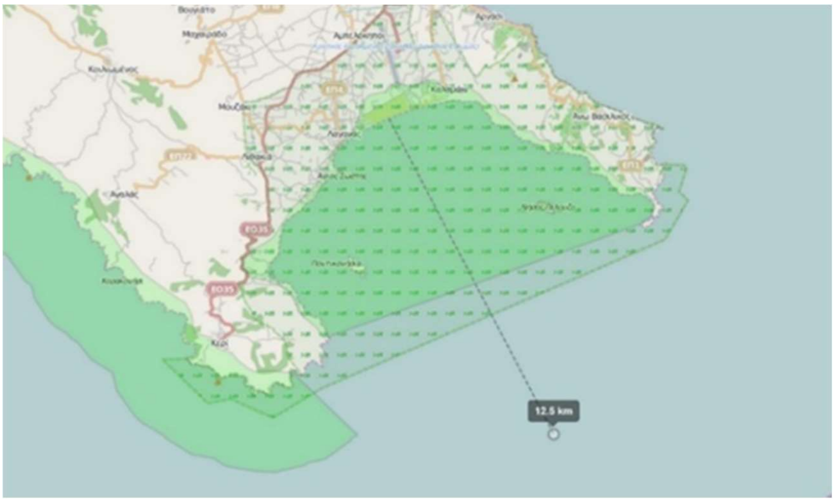

Figure 3-1 Protected area NATURA2000 National Maritime Park of Zakynthos- The point of the leakage is shown

	MEDSLIK	TELEMAC2D
Duration of leakage	Instant	
Accident location	12.5 km S. Lagana Coast Lat 37.38 Long 20.57	
Duration of oil spill simulation	48 hours	
Hydrodynamic field	Constant in space- Variable in time current	Based in boundary conditions / Variable in time and space
Wind field	Constant in space-Variable in time	
Oil (Quantity and type)	500 tonnes/ API 16 (heavy oil fuel)	500 tonnes /Fuel Oil #5 (heavy oil fuel)
Timestep/ Display timestep	30 mins/ 3 hours	1 sec/ 1 min
Number of particles	10000	500

Figure 3-2 A comparison between the input data of the two models

To form the hydrodynamic model of the application area, the finite element grid was created in the BLUE KENUE graphical environment. The mandatory files for TELEMAC are:

- Geometry File
- Boundary Conditions File

Visualized through the BLUE KENUE software as follows:

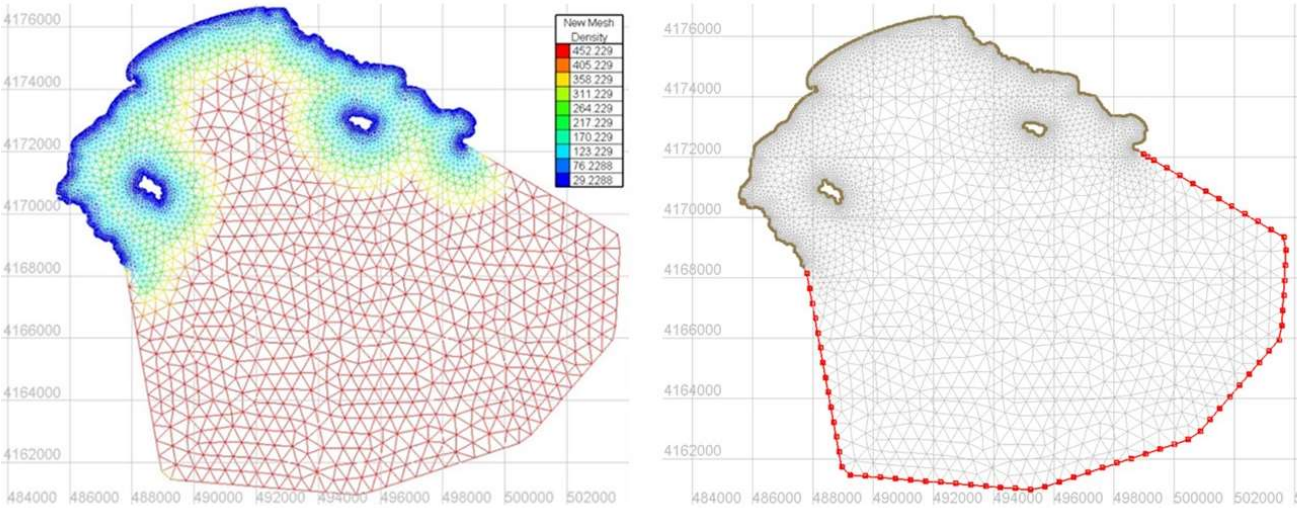

Figure 3-3 (Left) The final grid, the color represents the size of the triangular elements created (Right) Final image depicting the type of all boundaries in different colors, red for open boundary conditions with prescribed U, V, brown for closed boundaries (walls)

3.3 RESULTS COMPARISON BETWEEN OSCAR AND MEDSLIK

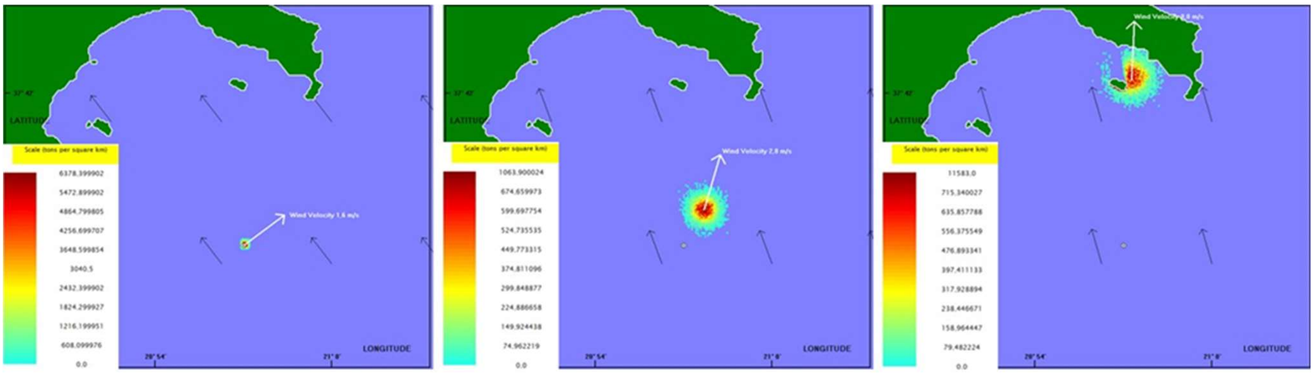

Figure 3-4 Oil spill track at times 0, 9 and 15 hours after the leak (MEDSLIK)

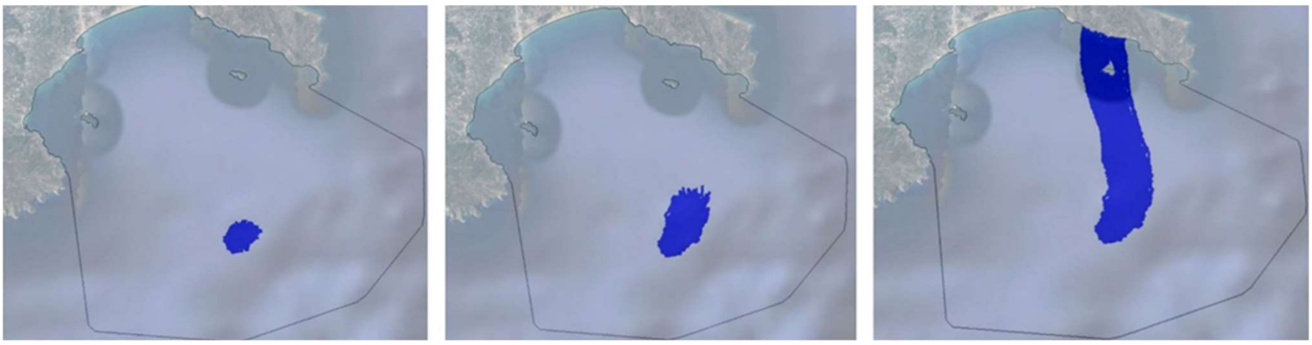

Figure 3-5 Oil spill track 4, 9 and 15 hours after the leak (TELEMAC2D)

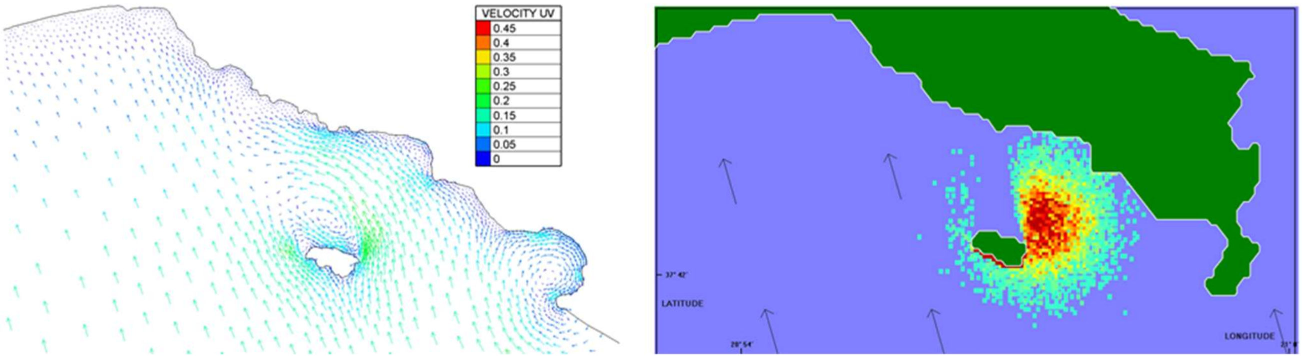

Figure 3-6 (Left) Hydrodynamic field for TELEMAC2D (Right) for MEDSLIK (focus on the area where oil meets the coast)

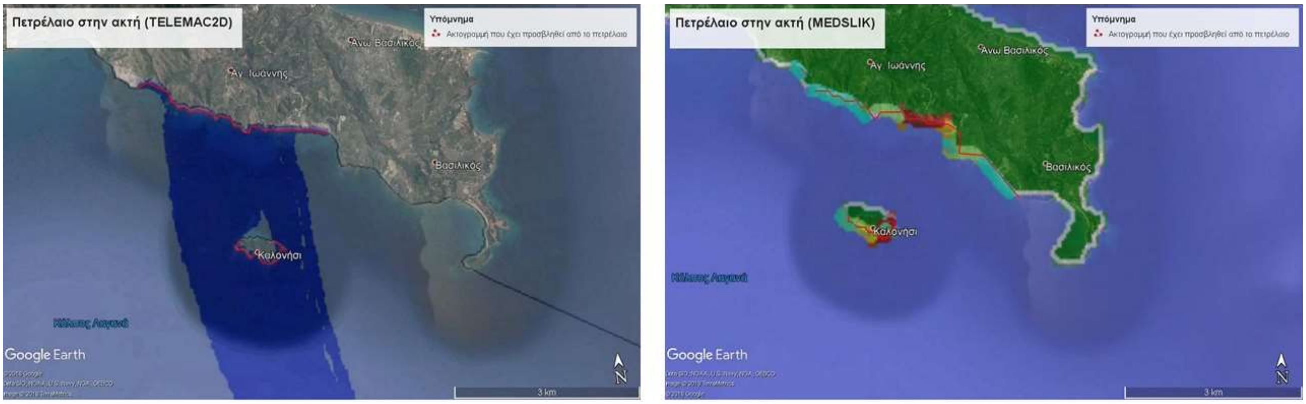

Figure 3-7 The oil-affected part of the coast (Left-TELEMAC2D, Right-MEDSLIK)

<u>Conclusions on the use of the TELEMAC2D (oilspill) model for simulating oil spill behavior</u>

The module OIL_FLOT.f (oilspill) embedded in the TELEMAC2D hydrodynamic model presents specific weaknesses in both its application and the results it can deliver. Analytically:

1. It offers satisfactory results, compared to MEDSLIK, in terms of overall oil displacement and oil spill displacement (similar time of oil arrival on shore) (figures 3-4 and 3-5)
2. It has the advantage over MEDSLIK that it can simulate the dissolution process of the individual oil components and record their concentration and evolution, which is extremely useful for studying the water quality characteristics (figure 3-8)
3. It is based on the TELEMAC2D hydrodynamic model that runs simultaneously and does not use current data that can be extracted from any available database. Therefore, its use requires a reliable and qualitative traffic model developed in TELEMAC2D (such as in figure 3-6 (Left)), resulting in both time-consuming field creation and increased computational time.
4. A continuous oil spill cannot be simulated without the intervention and modification of the code, only instant, in that it implies the ability to simulate leakage incidents.
5. There is a serious weakness in this application regarding the subroutine that controls the oil contact with the shore (subroutine oil_beaching) and the corresponding percentage of oil is not recorded. This is also the case with the application used to document the work (Cédric Goeury Engineer-Researcher, 2014) -Girondine Estuary, so there is a possibility that this part of the code may need improvement.
6. Also difficult is the configuration of the file with the characteristics of the oil (oil spill steering file) as it is not easy to obtain the data required for each soluble and insoluble component of a particular type of oil, free from the internet.

<u>Overall it is considered that the oil spill behavior model OIL FLOT.f (oilspill) can be improved, so it is recommended that its further development be focused on the following:</u>

- Ability to simulate continuous oil spill
- Creation of a database of representative oil types with a description of the properties of their components
- Correction and improvement of subroutine that takes into account the oil's contact with the coastline
- Ability to visualize the evolution of the oil spill at any time chosen by the user

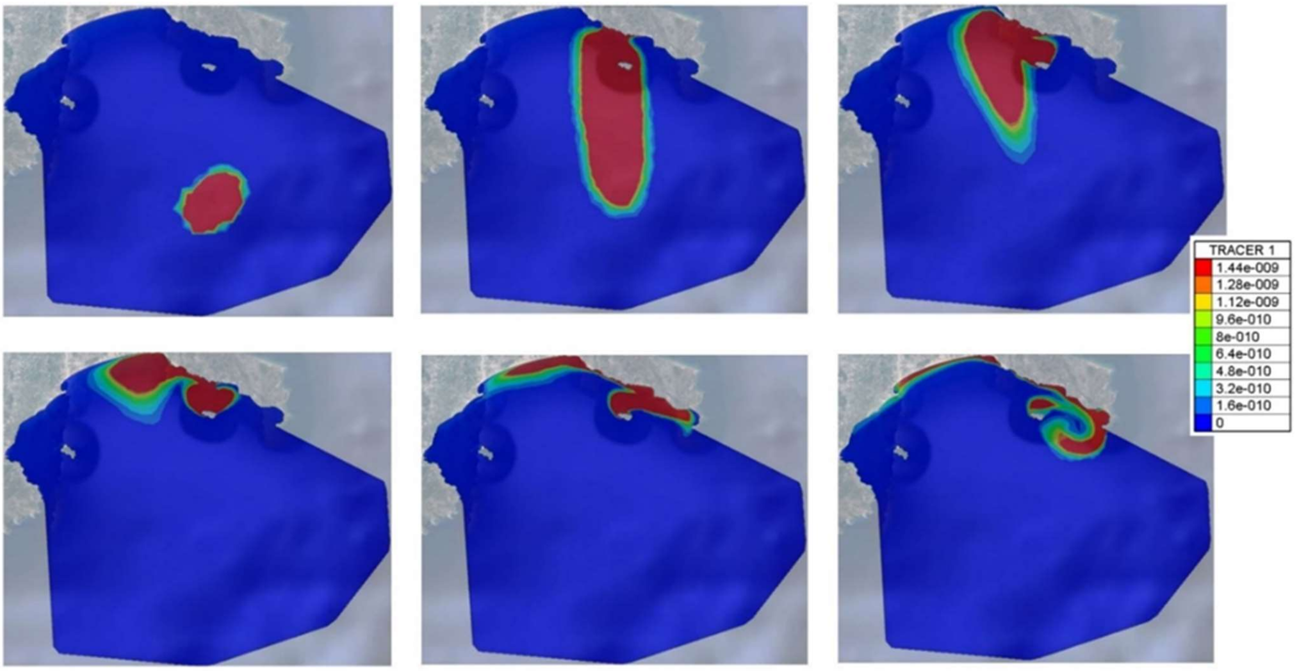

Figure 3-8 Evolution of component 1 concentration in kg / m3 every 8 hours, starting 8 hours after the leak (8,16,24,32,40 and 48 hours after the leak)

4. FINAL CONCLUSIONS

Initially, a comparison was made between the commercial model of the oil spill behavior OSCAR (based on his work (Panagiotis Makatounis, Jorgen Skancke, Evanthia Florou, Anastasios Stamou, Per Johan Brandnvik, 2017)) and the MEDSLIK model in the Gulf of Patras. An attempt was then made to simulate an oil leak accident using the open-source model TELEMAC2D and in particular the OIL_FLOT.f (oilspill) subroutine in a simple case (Laganas Bay, Zakynthos) and compare it with MEDSLIK. The conclusions from the model comparisons are given above, followed by the general conclusions regarding the use of the 3 models in the preceding applications:

1. The two OSCAR and MEDSLIK models can equally well describe the development and behavior of an oil spill in terms of its trajectory, the time and location of the oil on the coastline
2. OSCAR excels at quality characteristics of oil spill evolution and aging, both because it takes into account a large number of processes that MEDSLIK ignores and because it enables coupling with models describing various environmental impact indicators
3. The subroutine that simulates the behavior of the oil spill in TELEMAC2D, presents both difficulty in use and inability to properly describe the phenomenon, always compared to MEDSLIK. The difficulty in using it is that a quality hydrodynamic model of the area of interest created in TELEMAC2D is needed, as well as in other aspects related to the available oil data etc. Therefore, it is necessary to consider the suggestions in section 3.2 for improvement, in order to provide results that can be further exploited
4. It offers satisfactory results compared to MEDSLIK in terms of overall oil displacement and oil spill displacement. It also can take into account the process of dissolving the individual components of the oil and to record their concentration and evolution, which is extremely useful in studying the water quality characteristics. Finally, it has the potential to be coupled with the TOMAWAC wave model to take into account the interaction of currents and waves
5. Due to the use of the hydrodynamic field created through TELEMAC2D, the computational time is extremely increased both for its configuration and during the simulation. Of course, the use of this hydrodynamic field gives much more realistic results near the coast
6. The optimal model selection depends on the availability of resources by the user and the needs of each application. Obviously, the best option is the OSCAR commercial model and then MEDSLIK (though it has the disadvantage of running on old systems). Finally, with several improvements that need to be made to make it sufficient, TELEMAC2D can be applied mainly in cases involving the prediction of oil spill behavior and not during its development as it requires increased computational time.

	OSCAR	MEDSLIK	TELEMAC2D (OIL_FLOT.f)
Open Source Code			✓
Free Distributed		✓	✓
Advection	✓	✓	✓
Diffusion	✓	✓	✓
Wind Drift	✓	✓	✓
Stokes Drift	✓		✓
Backtracking		✓	
Beaching	✓	✓	✓
Spreading	✓	✓	✓
Evaporation	✓	✓	✓
Emulsification	✓	✓	
Natural Dispersion	✓	✓	
Vertical Movement	✓	✓	
Dissolution	✓		✓
Sedimentation	✓		
Biodegradation	✓		
Volatilization			✓

Figure 4-1 Comparison of the processes considered in the three models