EXTENDED ABSTRACT

1. Introduction

Oil spills are considered to be one of the major environmental issues for all marine and coastal environments. An oil spill in the sea has many impacts on many different aspects such as the environment, health and society as well as plenty of financial activities including tourism, one of the most important sources of the economy especially for Greece. Over the last decades, the oil spill incidents have significantly decreased, which is a very positive and optimistic fact. This is attributed to the increasing safety of shipping routes worldwide, the leakage control from satellite systems and the legislation and sanctions.

The existence of an emergency plan including the necessary response actions and methods is of paramount importance in the case of a leakage incident. The ability to predict the possible trajectory of the oil spill is significant for the development of this plan. This can be achieved via the oil spill simulation models, which consider the weathering processes of the oil and the environmental conditions in order to simulate oil spill trajectories. There are several oil spill models, including oil weathering, deterministic, stochastic and hind cast models.

This study is focused on the incident of the tanker "Agia Zoni II" on September 10th 2017 at 01:45. Under unknown circumstances, the tanker wrecked at the East waterside of Salamina Island. The vessel in total carried approximately 2732 metric tons of oil cargo, bunkers and chemicals. After the incident, approximately 600 meters of floating oil boom and sorbents were deployed. Despite the considerable resources and efforts, approximately 4 km of the coastline of Salamina Island and 20–25 kilometers of the heavily-populated coastline south of Piraeus port and Athens were contaminated, including the oiling of some 300 small pleasure craft berthed in various marinas along the respective coasts. In this study, the oil spill behavior of this incident is simulated and compared against observations and other oil spill simulation models.

The leakage incident of "Agia Zoni II" is simulated using the GNOME (Tsiatsiou, 2018) oil spill model with satisfactory results. For our analysis, this incident is simulated using the oil spill model MEDSLIK (R.W. Lardner B.A., Ph.D., Sc.D., 2004,2011), in order to reproduce the trace of the oil spill and compare the results with the calculations of Tsiatsiou (2018). In addition, a sensitivity analysis is made by modifying various parameters as diffusion coefficient and the number of parcels. It is assumed that the response effort (skimming, burning, and dispersant application) did not alter the spatial distribution of the oil reaching the shoreline but only reduced the amount of oil reaching the shorelines. This assumption is made because GNOME does not take into consideration the treatment mechanisms. The comparison of the results of those two models, reveals that the oil spill trajectories are very similar. However, there are discrepancies in the simulation of the weathering processes and the oil mass balance.

2. Materials and methods

2.1 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, as shown in Fig. 1.

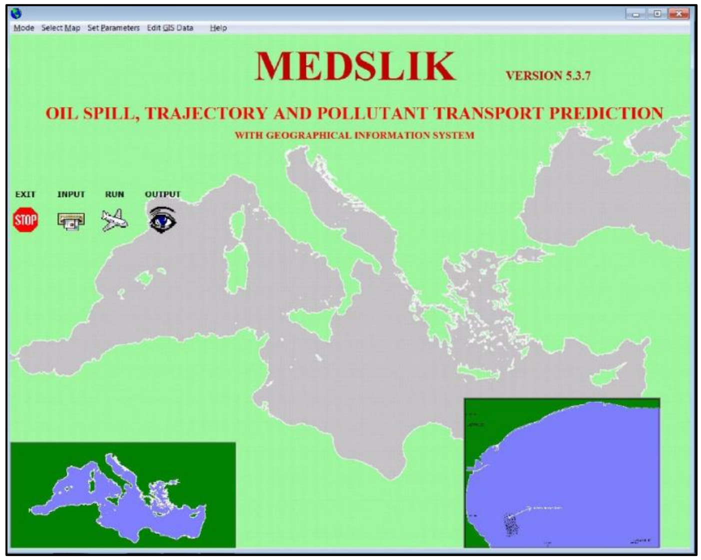


Figure 1 MEDSLIK interface *(R.W. Lardner B.A., Ph.D., Sc.D., 2004,2011)*

2.2 Input data

In order to be able to compare the GNOME results, the input data are the same as in the simulation by Tsiatsiou (2018). Firstly, as the Table 1 indicates, the problem and the oil spill characteristics are defined based on the incident. The study area is Saronikos Gulf, as shown in Fig. 2. The wind and the current data are inserted in the model with a 3-hour step, in accordance with the study of Tsiatsiou (2018).

Table 1 Characteristics of Oil Spill

Simulation start Date	10 September 2017
Leakage Time	01:45
Simulation Time	2:00 (1)[1]
Duration of Simulation (hours)	213
Time step (/hour)	2
Oil Spill Name	Agia Zoni II
Type of Oil	Generic Type : API: 16
Quantity of leakage (metric tons)	137
Location of Leakage	Lat 37.93, Long 23.56
End date of oil spill	12 September 2017
End Time of oil spill	9:10
Number of parcels	10000
Wind Factor	0.031
Diffusion Coefficient (cm^2/s)	20.000

The overall oil spill assessment is modeled as follows: In the simulation, there are 10000 parcels released at the water surface of the location, with Latitude: 37.93 and Longitude: 23.56, daily, until the tanker was sealed. These parcels represent the average amount of oil released to the water surface without depicting

[1] *Even though the leakage was started at 01:45, MEDSLIK could not accept the value "45" for minutes, because it can recognize values until "24".*

any oil volume. The parcels represent 137 metric tons of Fuel with API number 16 as it is estimated from the Ministry of Maritime and Island Policy. The model run period is taken equal to 213 hours of oil spill trajectory, from September 10th until September 18th, with a computational time step equal to 30 minutes.

The study area consists of the whole Saronikos Gulf, including the islands. The Latitude of the study area varies from 37˚24’’ to 38˚6’’, and the Longitude from 23˚ 8’’ to 24˚4’’. In this particular area, there is the anchorage and the port of Piraeus, which is the biggest and the most important port of Greece. As a result, the location is of paramount importance; most of the financial and social activities of Greece occur there. Thus, the oil spill in Saronikos Gulf creates a significant increased risk.

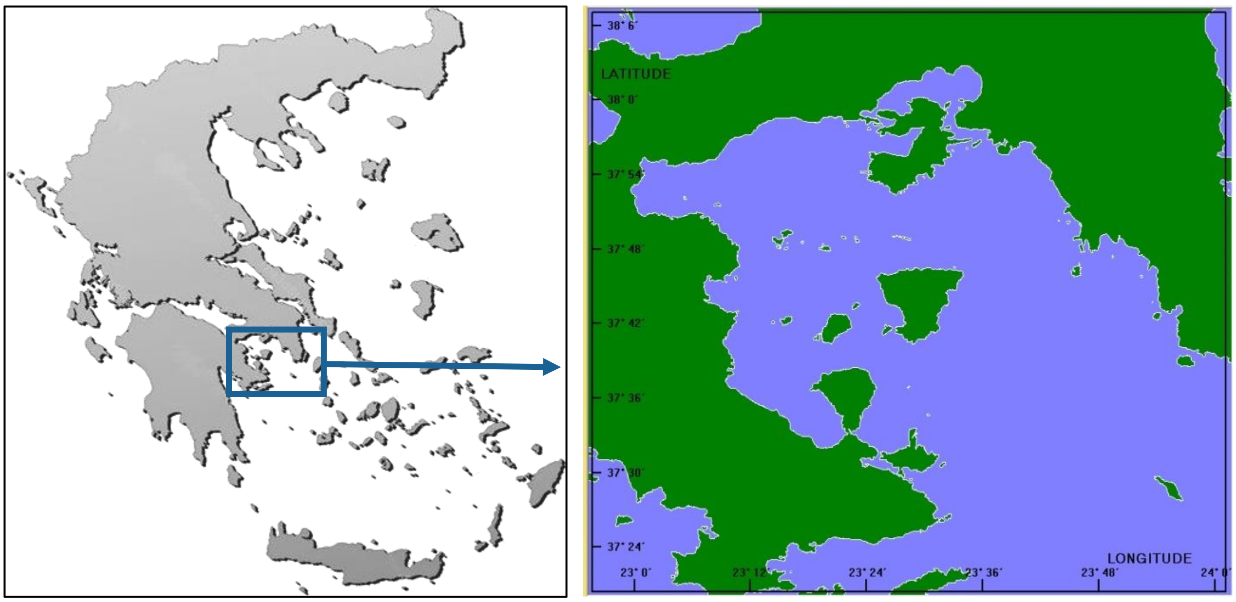


Figure 2 The area of study

The simulation in this study is made using the same wind data of the simulation of GNOME (Tsiatsiou, 2018).

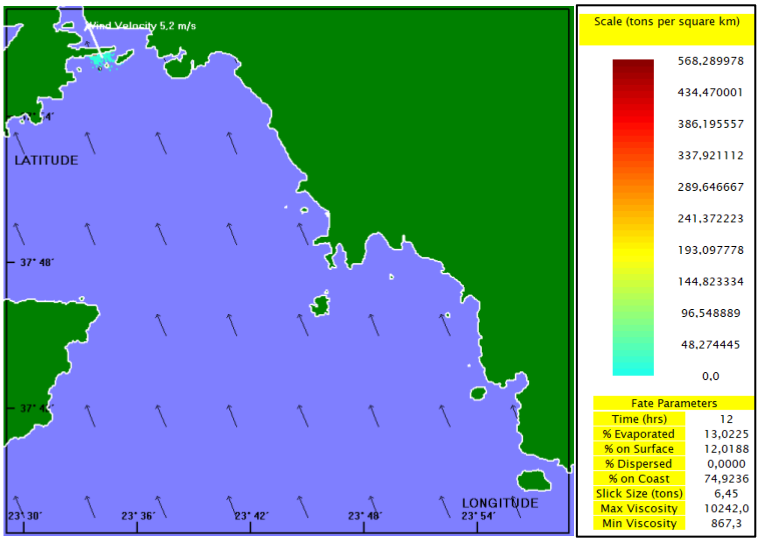
The diffusion coefficient is selected as equal to 20000 cm^2s^{-1} and the “wind factor” is 3.1 % (R.W. Lardner B.A., Ph.D., Sc.D., 2004,2011). Oil is expected to be vanished from the surface because of the various physical and chemical mechanisms. Some of these are the dispersion through entrainment into the water column, the droplets because of the waves, as well as the evaporation, the photo oxidation, the dissolution, the emulsification and the biodegradation. All these mechanisms, including the beaching of oil, contribute to the oil weathering. In addition, based on these assumptions and the final computations, a sensitivity analysis (SA) is performed by altering certain parameters and reaching to variant results and conclusions. Furthermore, there is a comparison between the final computations and the SA scenarios.

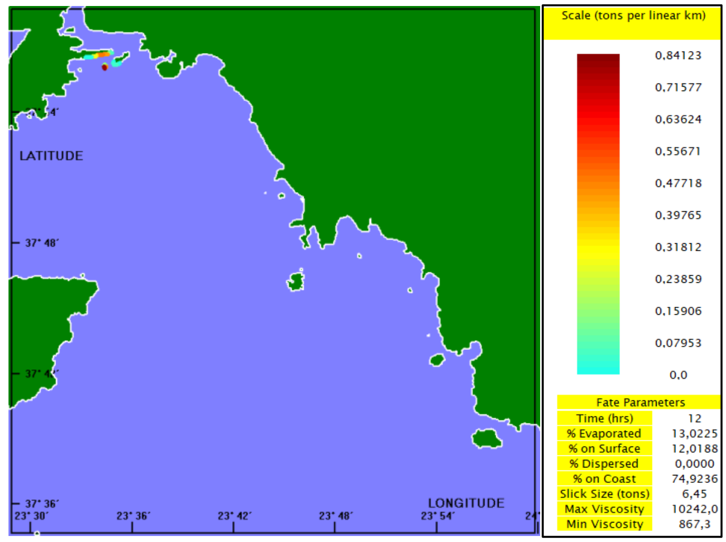
3. Results and discussion

3.1 Results from MEDSLIK simulation

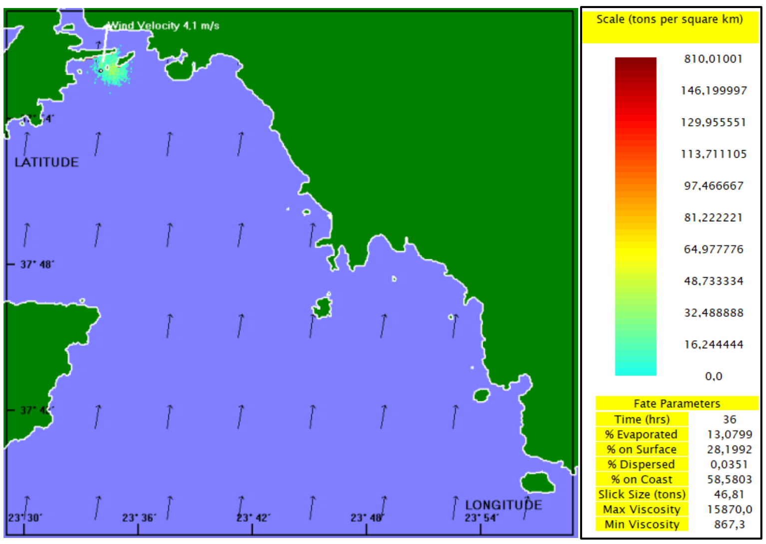
The simulation results are shown in Fig. 3 for all days of simulation at 14:00.

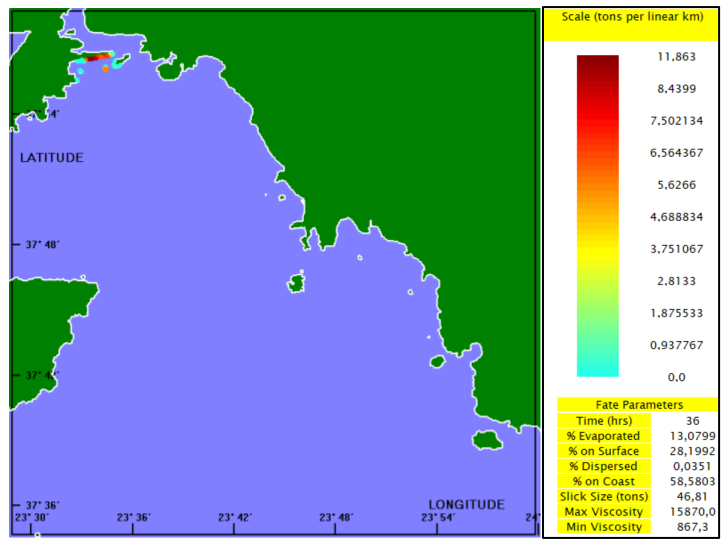
10/09/2017 Time: 14:00



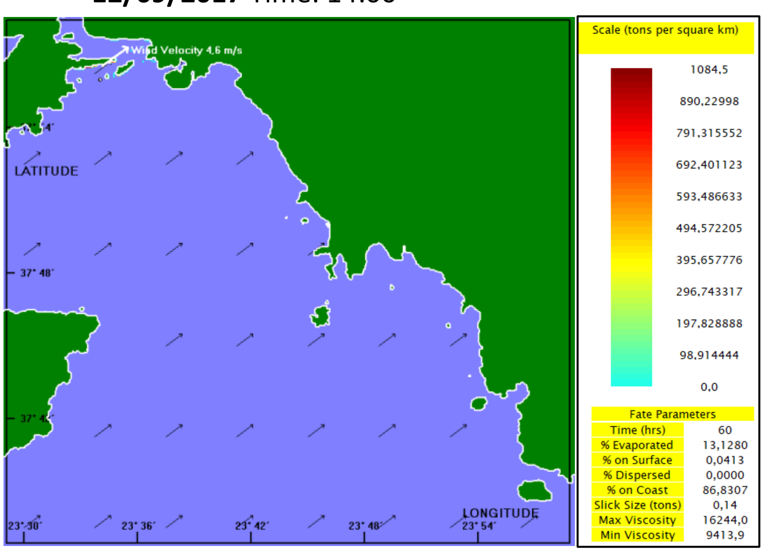


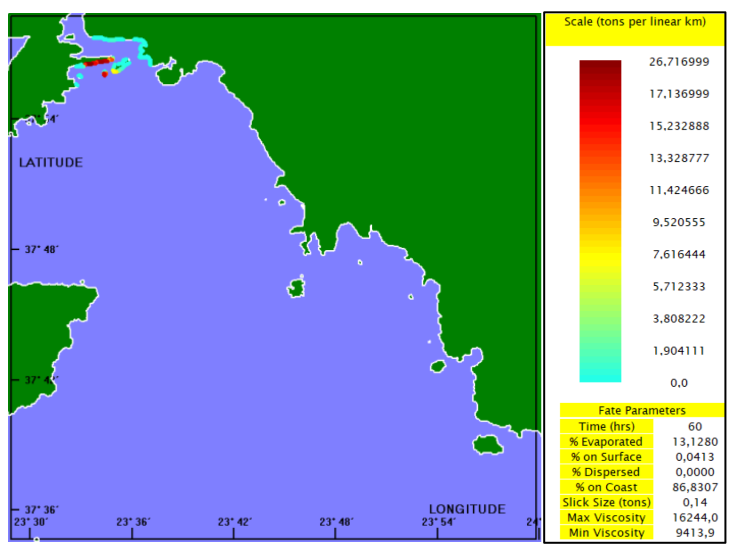
11/09/2017 Time: 14:00



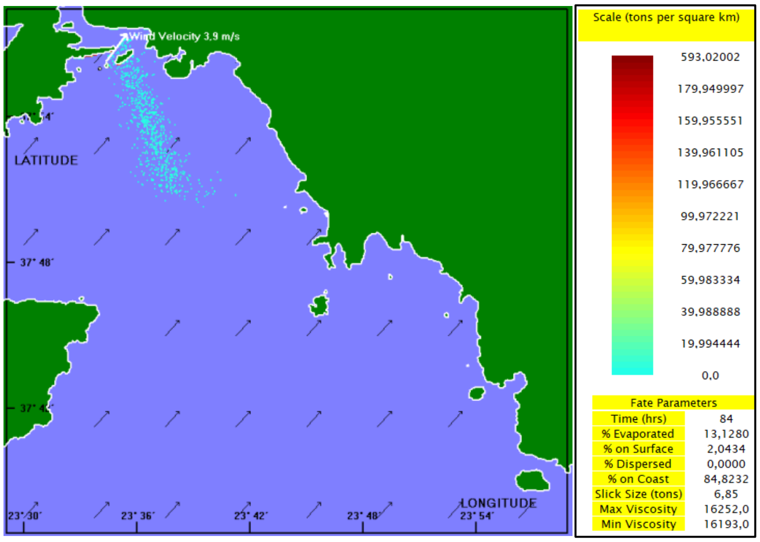


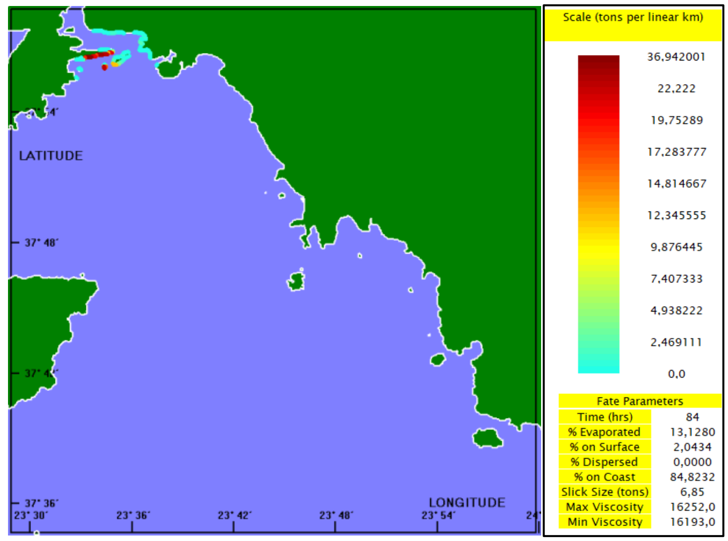
12/09/2017 Time: 14:00



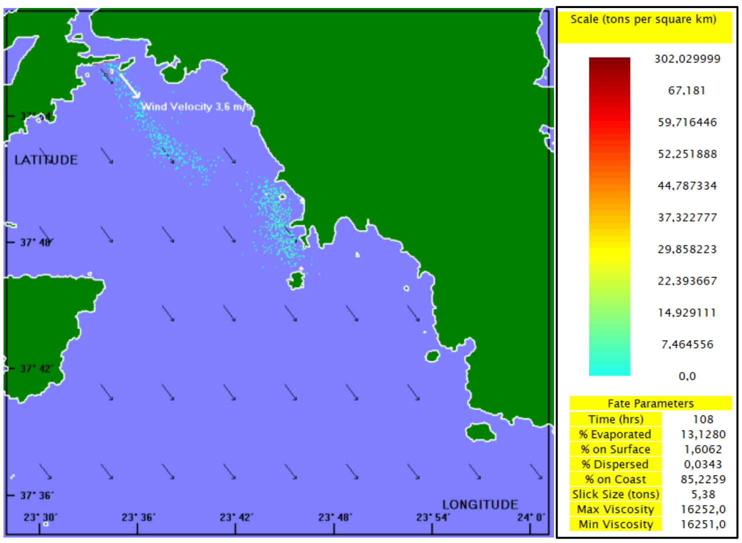


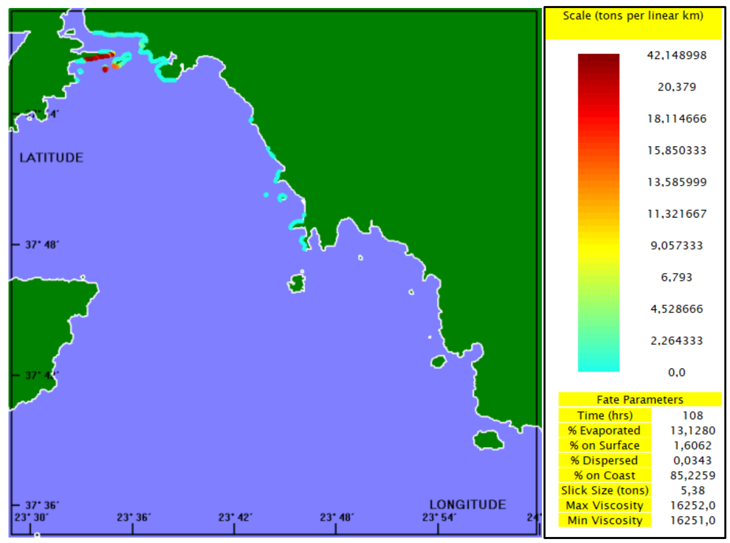
13/09/2017 Time: 14:00



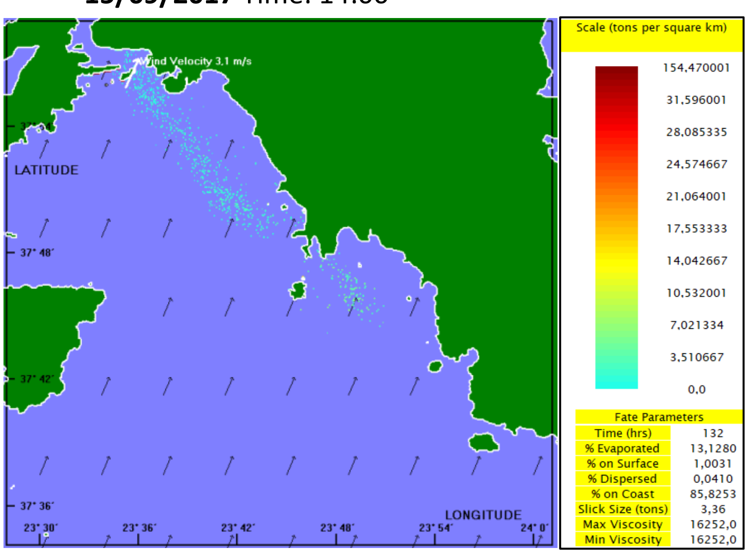


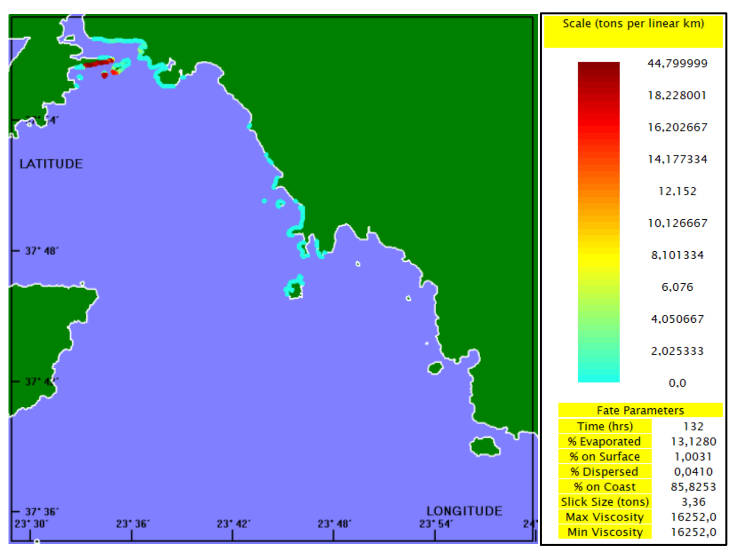
14/09/2017 Time: 14:00



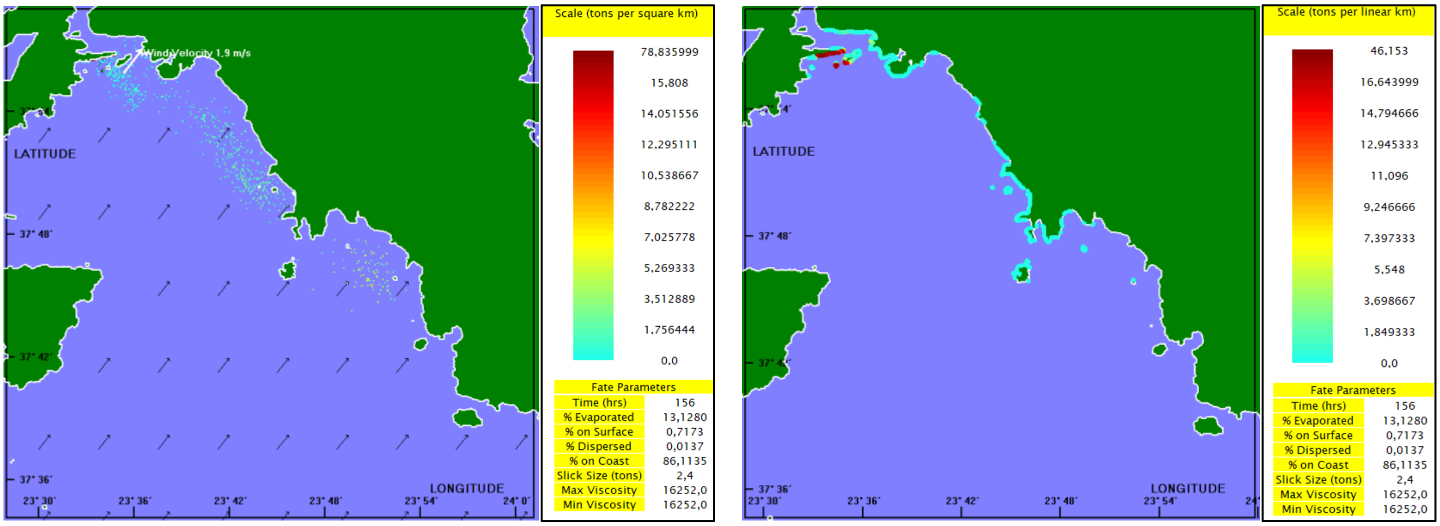


15/09/2017 Time: 14:00

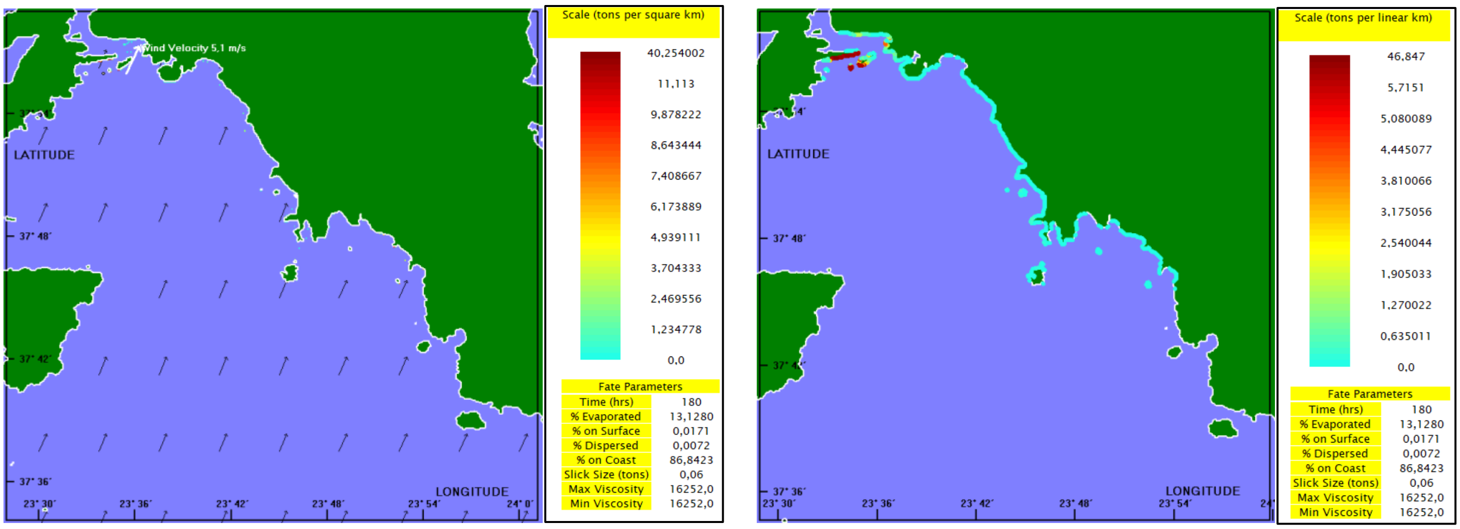




16/09/2017 Time: 14:00



17/09/2017 Time: 14:00



18/09/2017 Time: 14:00

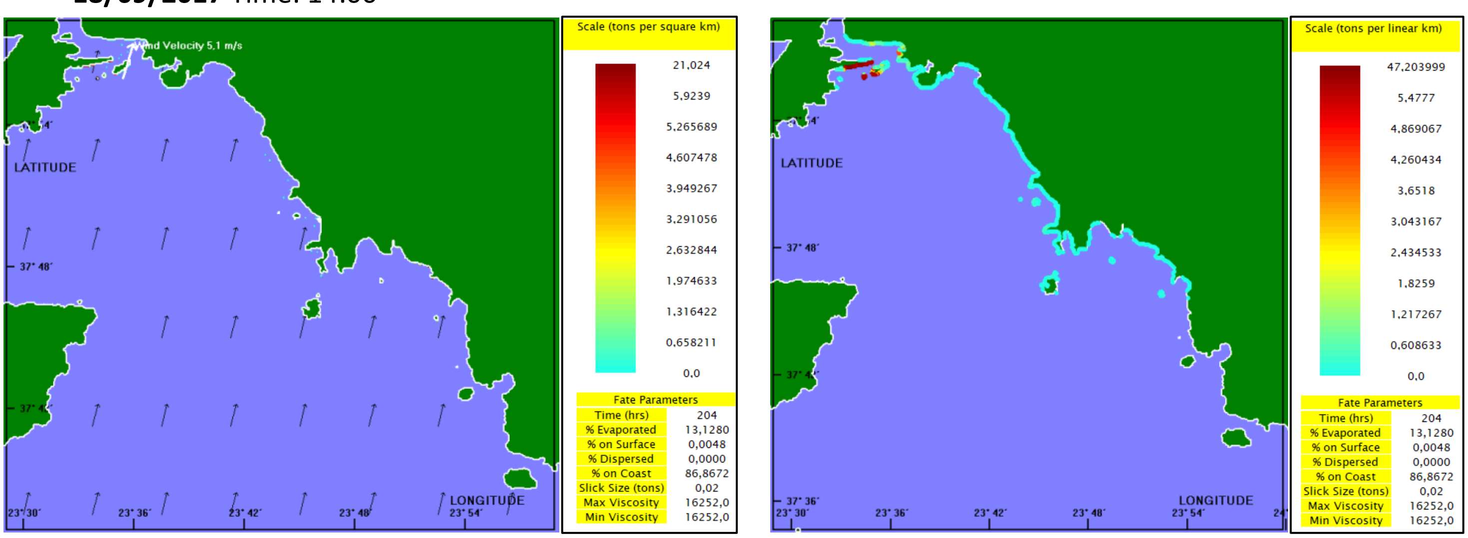


Figure 3 MEDSLIK results

In conclusion, it is obvious that the wind was the most important factor in obtaining a satisfactory prediction of the behavior of the oil spill. The current data, given from Copernicus, did not satisfy the prediction of the real incident, since they did not affect the movement of the oil spill (Tsiatsiou, 2018). Thus, in this study, the current data used are calculated as the wind induced currents with a simple approach (Huacan Fang & Meglan Duan, 2014). MEDSLIK reproduced satisfactorily the trajectory of the real oil spill.

3.2 Comparison between MEDSLIK and GNOME

Figures 4-9 show the comparison between the results of MEDSLIK and GNOME simulations.

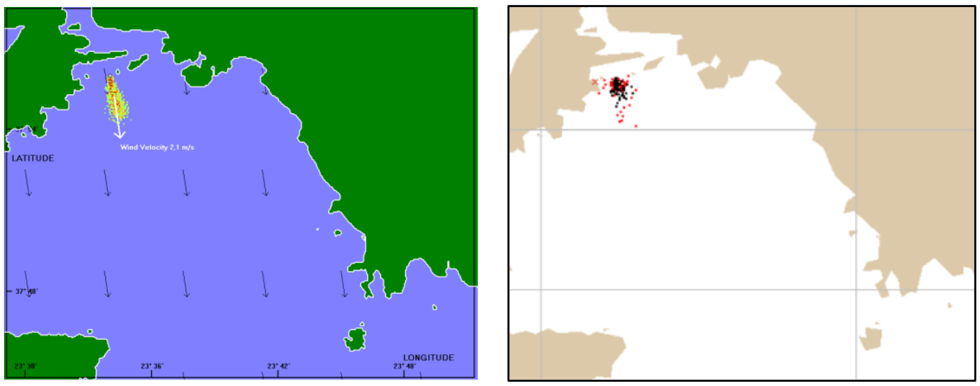


Figure 4 Comparison between MEDSLIK and GNOME at 10/09/2017 08:00

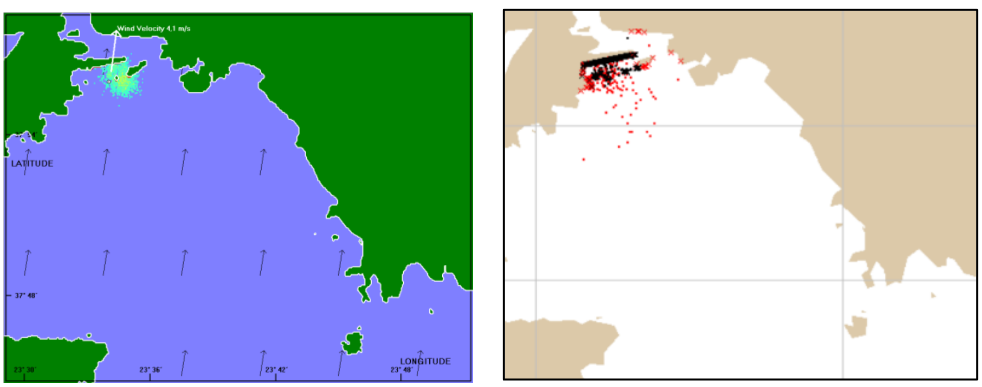


Figure 5 Comparison between MEDSLIK and GNOME at 11/09/2017 afternoon

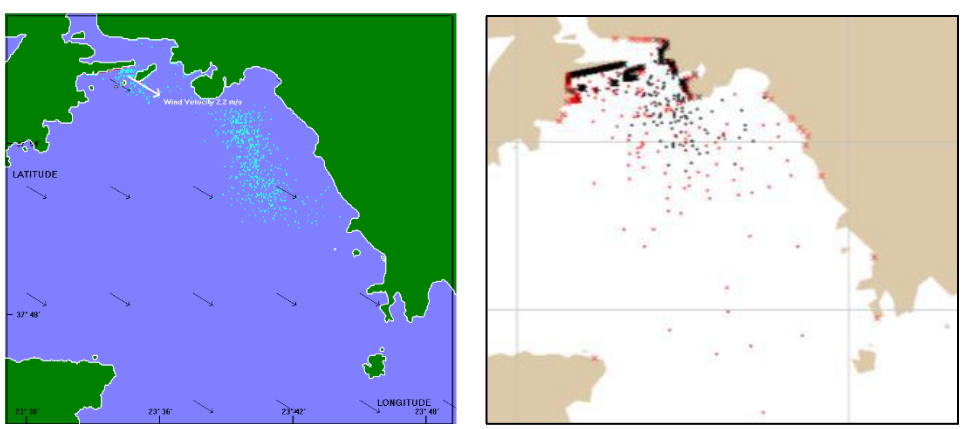


Figure 6 Comparison between MEDSLIK and GNOME at 13/09/2017

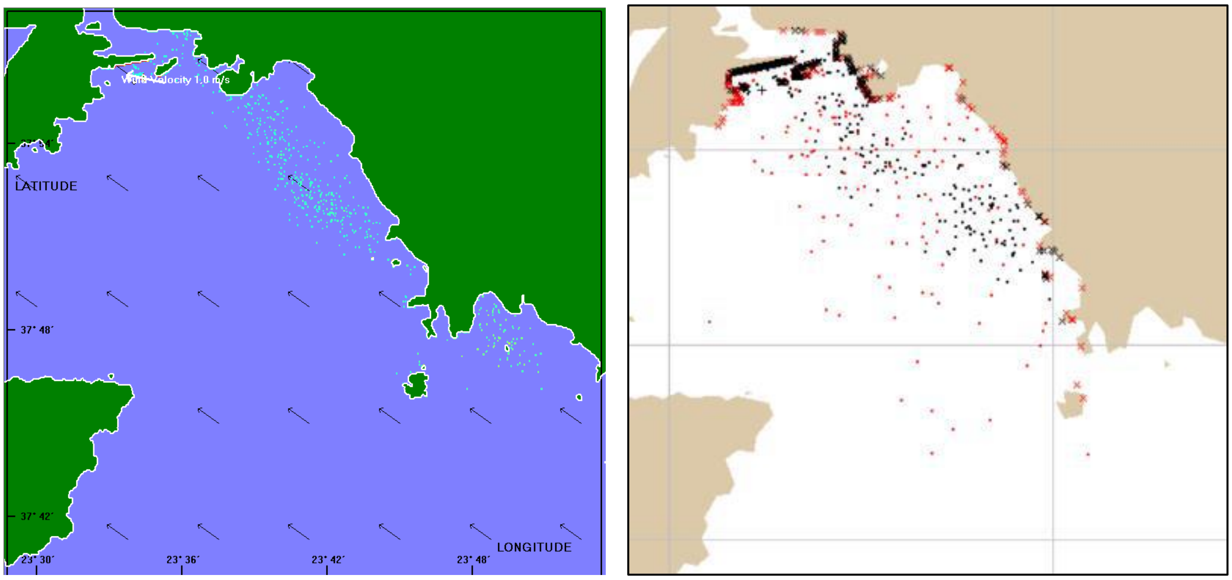


Figure 7 Comparison between MEDSLIK and GNOME at 15/09/2017

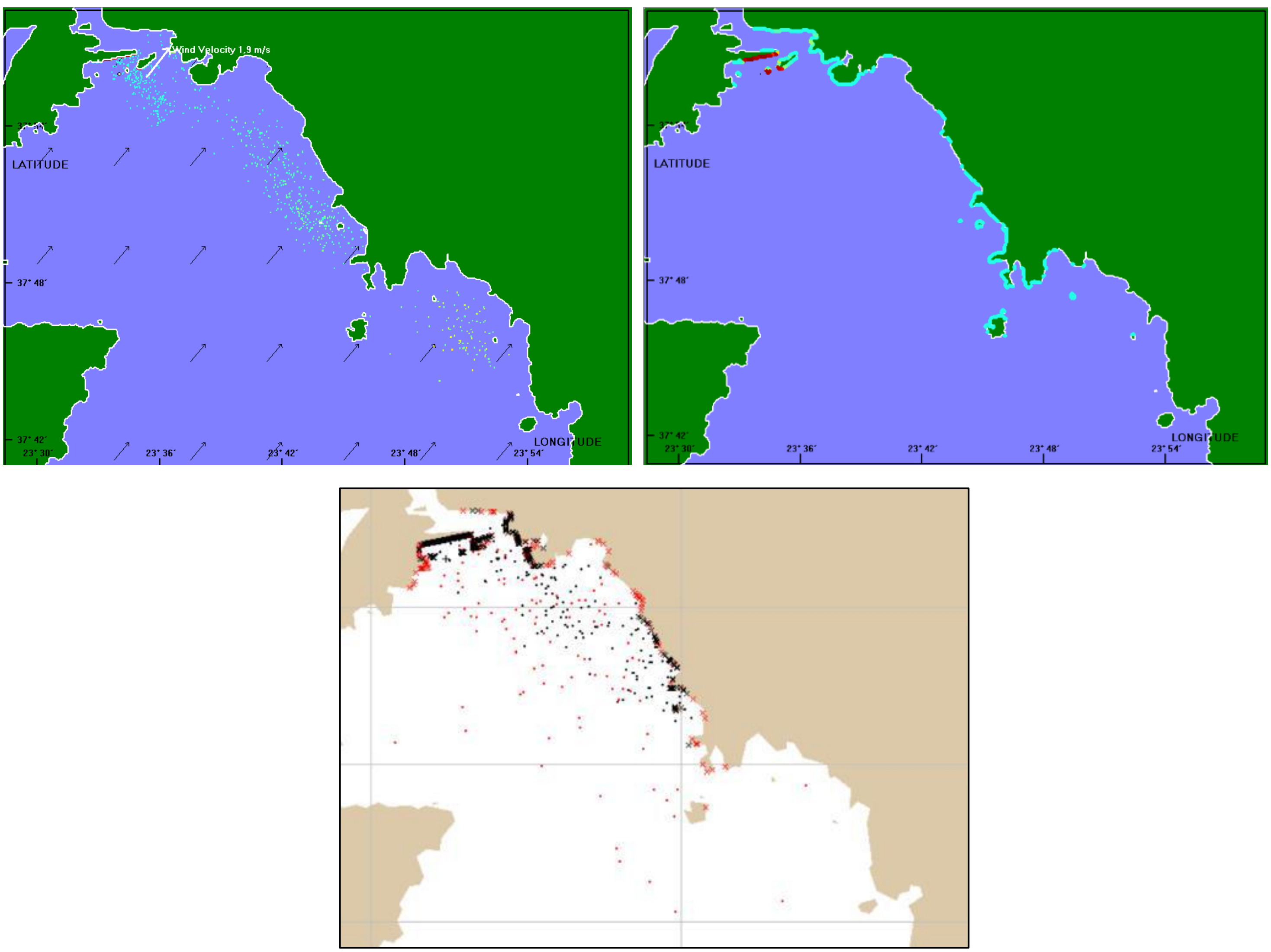


Figure 8 Comparison between MEDSLIK and GNOME at 16/09/2017

The results of the two models are very similar, despite the fact that GNOME shows the oil spill more scattered. In contrast, MEDSLIK shows the oil spill more concentrated near the shore. Both models coincide on the affected from oil coasts. The results are satisfactory taking into account the real incident and the observations.

MEDSLIK and GNOME have many differences as models, which justifies why their results also differ. MEDSLIK simulates the weathering processes of advection, diffusion, beaching, evaporation, emulsification and dispersion. On other hand, GNOME simulates the processes of advection, beaching, diffusion and evaporation. As a result, the two processes that MEDSLIK takes into account while GNOME does not, are the emulsification and the dispersion. The results indicate that the dispersion does not have a considerable impact on oil spill. However, the emulsification, especially the first hours of the oil leakage, has a significant influence on the volume of the oil slick, something that the GNOME model does not take into consideration. The following Table (Table 2) shows the differences of the oil spill models. Following this, in Fig. 9-10 there is the comparison of the mass balance of the two models.

Table 2: Overview of MEDSLIK and GNOME oil spill models,"√"means the model can simulate the process.

	MEDSLIK	**GNOME**
Open Source Code		√
Advection	√	√
Diffusion	√	√
Wind Drift	√	√
Stokes Drift		
Backtracking	√	
Beaching	√	√
Spreading	√	√
Evaporation	√	√
Emulsification	√	
Natural Dispersion	√	
Vertical Movement	√	
Dissolution		
Sedimentation		
Biodegration		

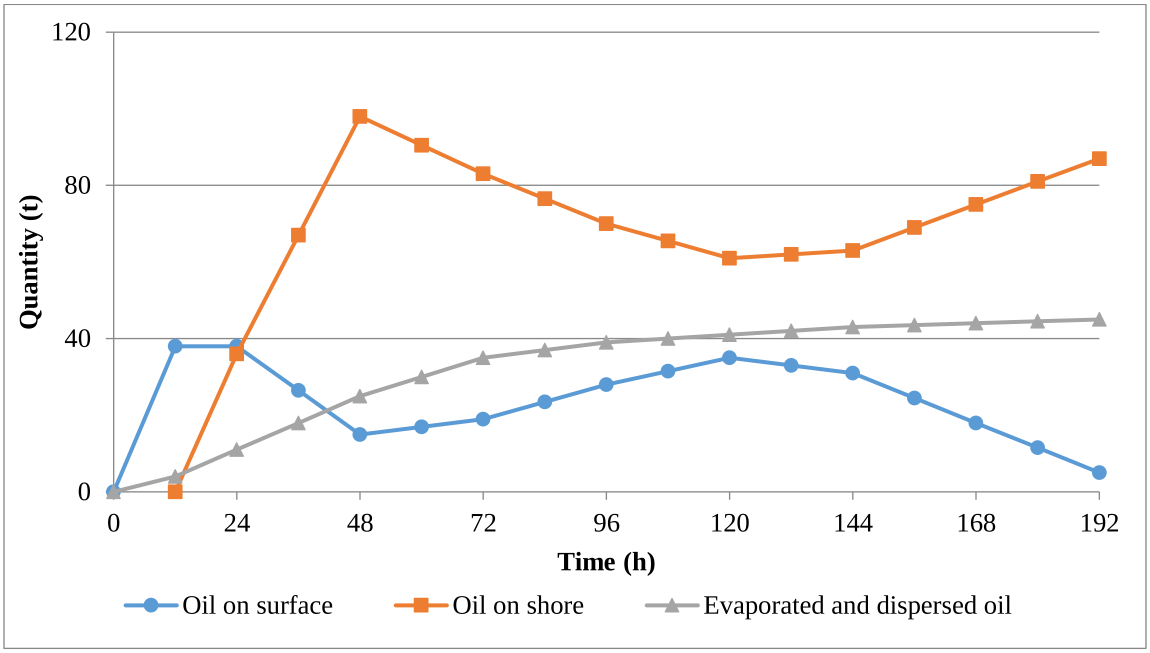


Figure 9 Mass balance of oil function of time in GNOME oil spill model (Tsiatsiou, 2018)

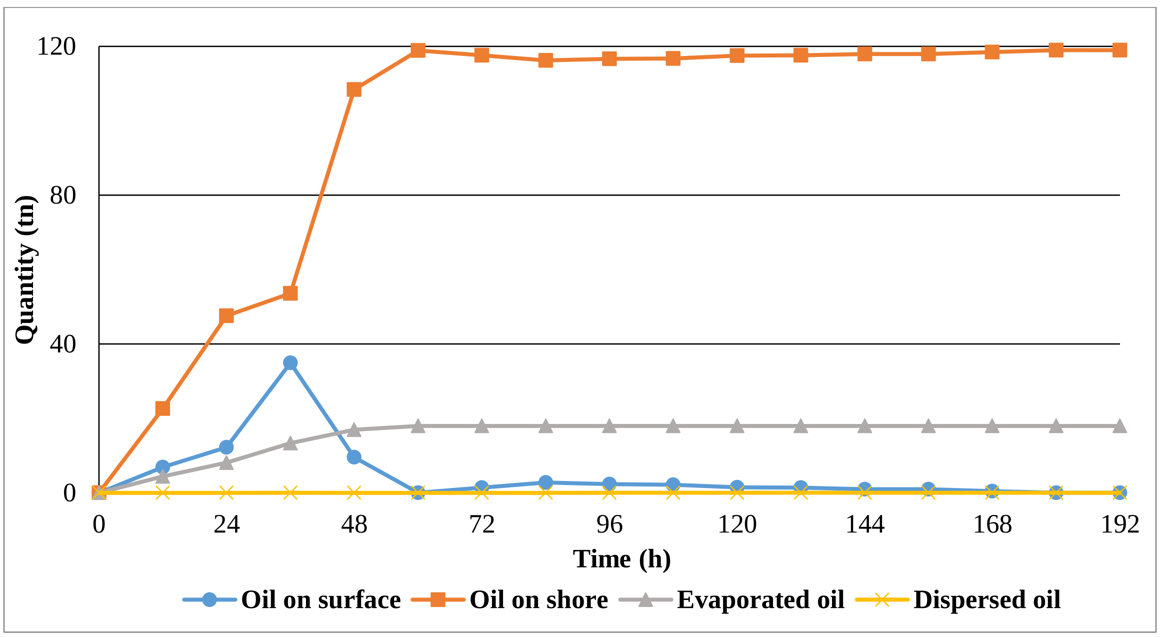


Figure 10 Mass balance of oil function of time in MEDSLIK oil spill model

The comparison of the mass balance of both models reveal that the models coincide in the evolution of the evaporation, which rises gradually and after the leakage, it remains stable. MEDSLIK calculates less evaporated oil than the GNOME. There are two reasons why this occurs. Firstly, MEDSLIK in order to calculate the evaporated oil takes in account the volume of oil slick. Secondly, MEDSLIK calculates the emulsification process which makes the evaporation of the oil difficult. Subsequently, it is obvious that MEDSLIK calculates bigger amounts of beaching oil than GNOME, but both show the peak value at 48 hours. GNOME calculates less quantity on coasts and more quantity on surface. This can be justified by the fact that GNOME shows the oil spill more scattered that the MEDSLIK model. This is happening because GNOME does not take into account the emulsification process, which affects the volume and the viscosity of oil slick. It is of paramount importance to note that both models are of the same size, for example surface oil in both cases do not exceed the 40 tons.

3.3 Sensitivity analysis investigation

Furthermore, the sensitivity analysis is constituted of 12 SA (Sensitivity Analysis) scenarios and each one resulted in different outcomes, depending on the changing parameters. These parameters are the diffusion coefficient, the number of the parcels and the time step of computations as it is described in the Table 3.

Table 3 Sensitivity analysis scenarios

Scenarios	Parameter	Value
Scenario 1	Diffusion Coefficient	1000 cm^2s^{-1}
Scenario 2	Diffusion Coefficient	5000 cm^2s^{-1}
Scenario 3	Diffusion Coefficient	10000 cm^2s^{-1}
Scenario 4	Diffusion Coefficient	50000 cm^2s^{-1}
Scenario 5	Diffusion Coefficient	100000 cm^2s^{-1}
Scenario 6	Number of Parcels	1000
Scenario 7	Number of Parcels	5000
Scenario 8	Number of Parcels	50000
Scenario 9	Number of Parcels	100000
Scenario 10	Time step of computations	1 per hour
Scenario 11	Time step of computations	3 per hour
Scenario 12	Time step of computations	6 per hour

At the Scenarios 1-5, where the diffusion coefficient changes, it is observed that the oil spill for small values is concentrated and for large values spreads more on surface.

At Scenarios 6-9, where the number of parcels changes, the surface oil is affected. The smaller number of parcels leads to scattered surface oil spill. After this, the surface is increased so as to the oil spill become more compact. This parameter also affects the computational time. For the Scenario 6, the run time is 0:42 minutes, for the Scenario 7 is 0:59 minutes, for the Scenario 8 is 03:59 minutes and finally, for the Scenario 9 is 07:14 minutes.

For the Scenarios 10-12, the parameter that changes, is the time step per hour. There are not obvious differences with the main scenario where the time step is 2 per hour. The main difference occurs in run time. At the Scenario 10, the run time is 0:55 minutes, at the Scenario 11 is 01:40 minutes and at the Scenario 12 is 03:07 minutes.

The results of the sensitivity analysis are given below on the left part (Sc. 1-9) at 11/09/2017 at 11:00 and the results of the main scenario are on the right part, to make the differences obvious and understandable.

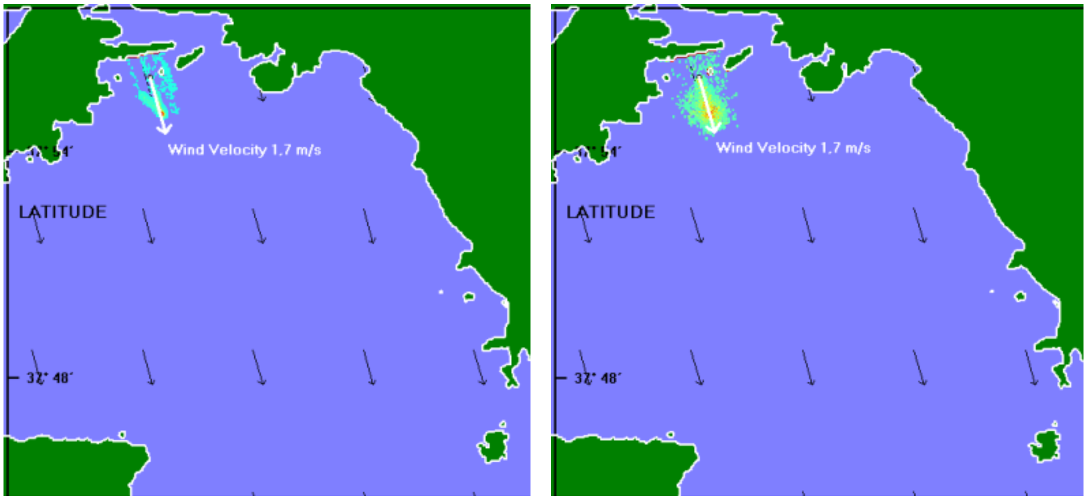


Figure 11 Scenario 1

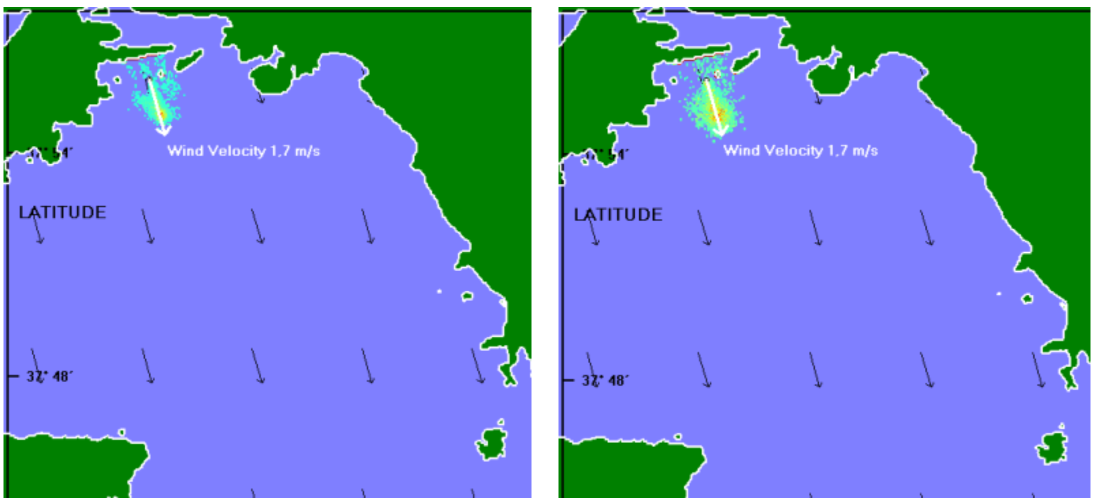


Figure 12 Scenario 2

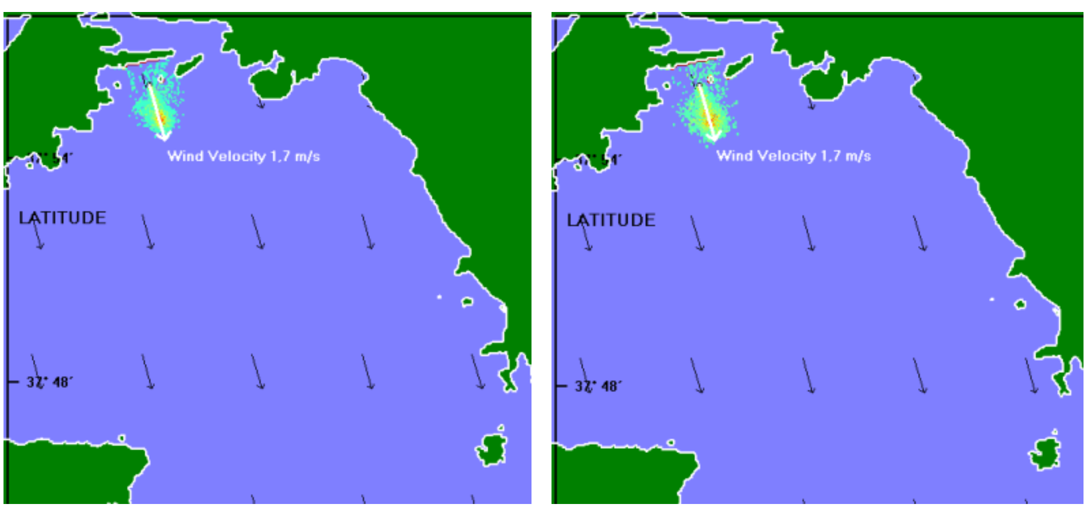


Figure 13 Scenario 3

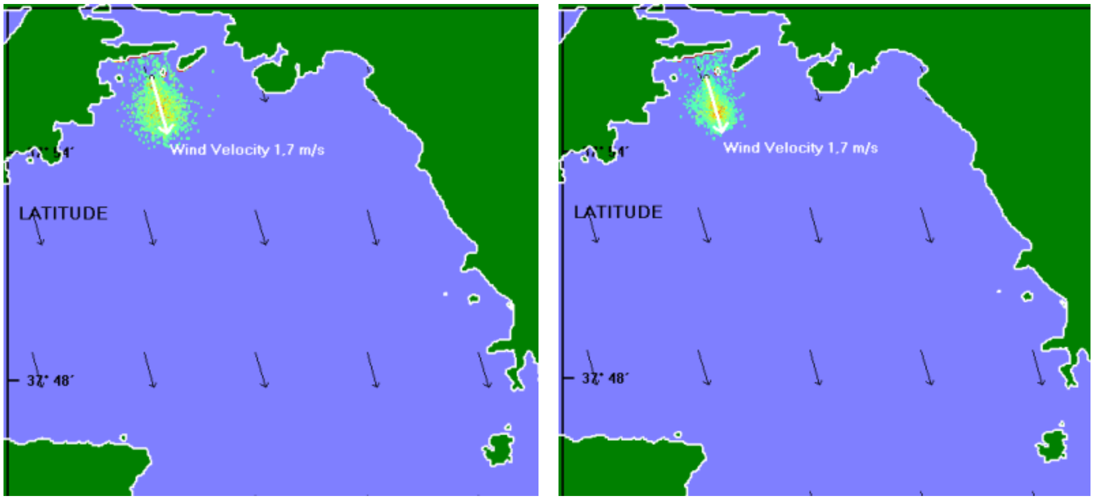


Figure 14 Scenario 4

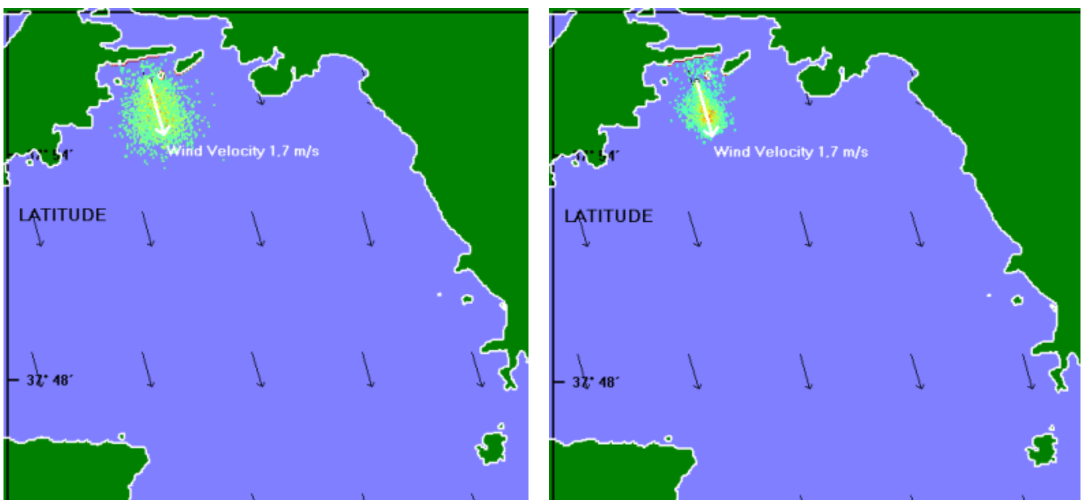


Figure 15 Scenario 5

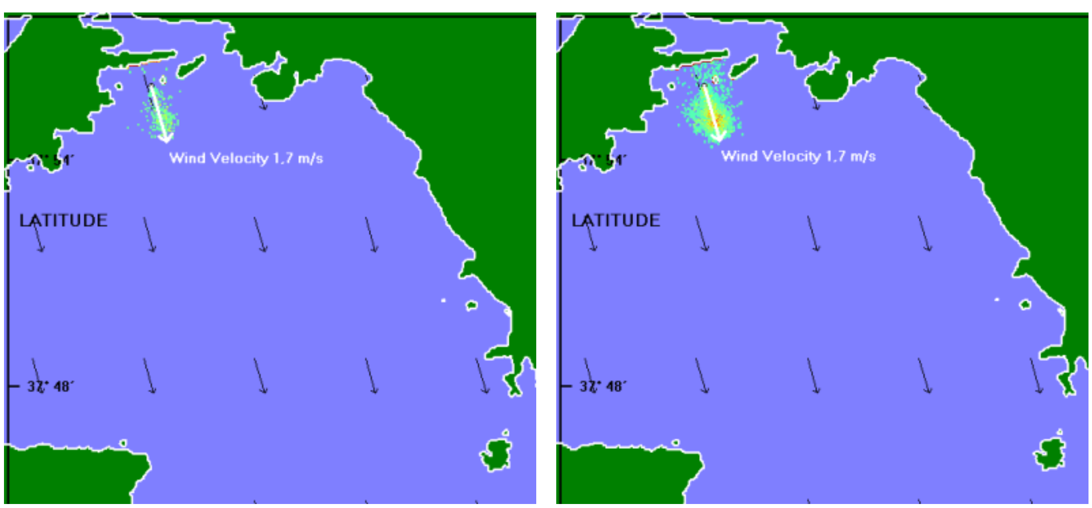


Figure 16 Scenario 6

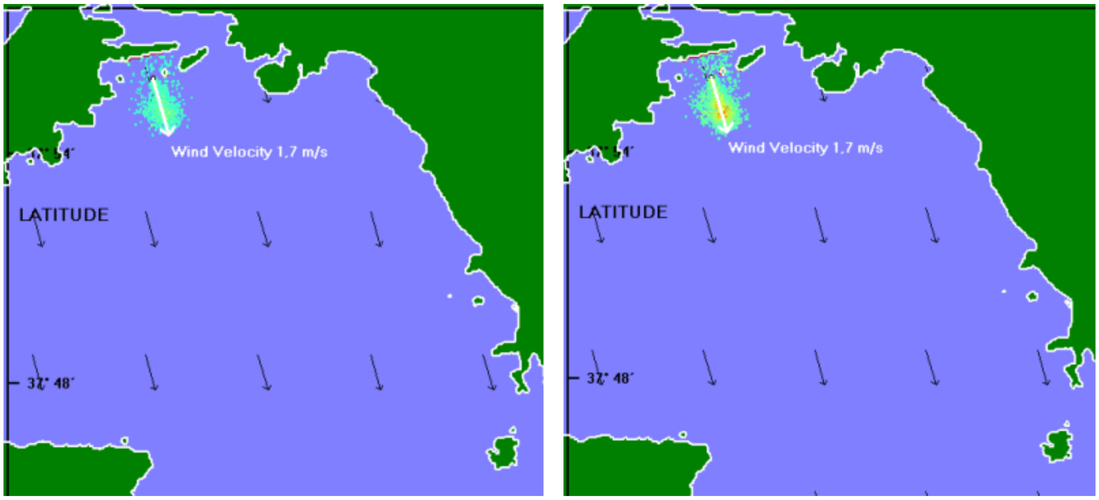


Figure 17 Scenario 7

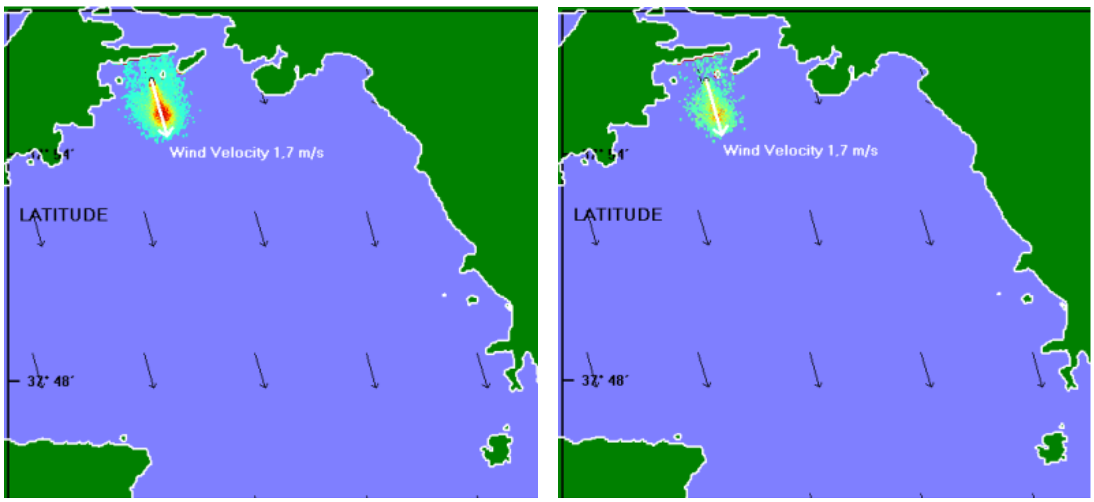


Figure 17 Scenario 8

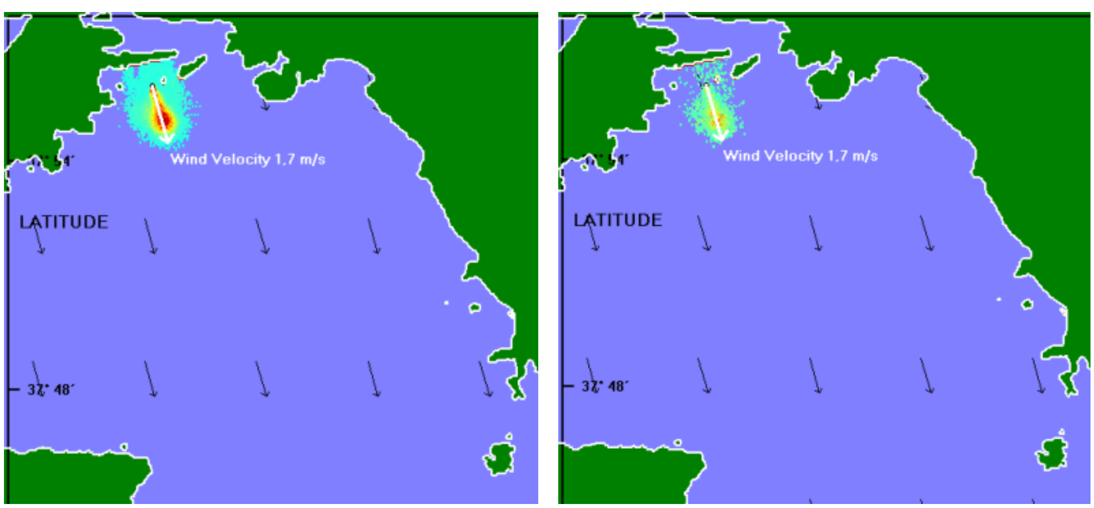


Figure 18 Scenario 9

4. Conclusion

This study uses the 3D mathematical oil spill model MEDSLIK in order to simulate the leakage of the oil spill from tanker "Agia Zoni II", which took place at Saronikos Gulf on the 10th of September 2017. The total leakage of the tanker was 137 tons and it affected the coastal area and the activities at the north side of the Gulf.

The calculations are compared with the results of Tsiatsiou (2018), who used the oil spill model GNOME in order to simulate this accident; the same input data were used for both models. By comparing the two programs the main conclusions can be summarized as follows:

1. The comparison with the real incident of "Agia Zoni II" is satisfactory for both models, despite the fact that there are many differences between them.
2. The main difference is that they do not simulate the same weathering processes as MEDSLIK simulates emulsification and dispersion whereas GNOME does not. Thus, GNOME presents bigger quantity of oil to evaporate.
3. GNOME presents the droplets of the oil spill, without any information while MEDSLIK shows the oil spill with a patch of colors, which represent the quantity of the oil per square kilometers; this is very helpful in order to assess the oil spill.
4. MEDSLIK is a user-friendly program that can be used at a business level, but only for the options the program provides. One of the main disadvantages of the model is that this version is backed by old software (Windows 95, 98, 2000 or XP) which is difficult to be found.

Moreover, an extensive sensitivity analysis is performed, by changing three parameters; the diffusion coefficient, the number of parcels and the time step of the computations, from which the following conclusions were drawn.

1. For small diffusion coefficients, the oil spill is very restricted, and it diffuses as the coefficient value rises. Here, it is very important to mention that the run time is affected a lot by this parameter.
2. The number of parcels has also the same effects, both at the oil spill and the run time of the model. The surface oil spill is presented based on this value. In case this value grows then the surface oil of spill also grows. This parameter should be used with caution, since the results may not represent the reality.
3. In terms of the time step, the sensitivity analysis only differs in the run time of the model.

To conclude with, the oil spill models are significantly affected by changing some parameters and in this way, their results and the run time are also differentiated.