Chapter

The Risk of Potential Cross Border Transport of Oil Spills in the Semi-Enclosed Eastern Mediterranean Sea

Steve Brenner

Abstract

Environmental risks posed by oil spills in semi-enclosed basins are more pronounced than those in the open ocean due to potential deposition along long segments of the coastlines. As a semi-enclosed sea, the Mediterranean is highly vulnerable to pollution events. Recent discoveries of major oil and natural gas reserves in the eastern Levantine basin have led to accelerated drilling, with several countries at various stages of exploration and production and others having mapped blocks for licensing, thereby significantly increasing the risks of a potential spill. Due to drilling by multiple, adjacent countries, any spills from deep water wells will be prone to cross border transport due to the highly variable winds and ocean currents. This risk is assessed through a series of simulations with an oil spill model forced with high resolution ocean currents and winds. The scenarios considered are well blowouts of several weeks duration, located within the drilling zones of each of various countries. Models such as this provide the basis for further environmental assessment and risk analysis. They also emphasize the importance of multinational cooperation to respond to and mitigate the environmental impacts which would result from a potential oil spill from any of the countries involved.

Keywords: oil spill modeling, oil slick dispersion, cross border pollution transport, ocean model downscaling, eastern Mediterranean Sea gas and oil exploration

1. Introduction

Environmental risks posed by oil spills in semi-enclosed basins are more pronounced than those in the open ocean due to potential deposition along long segments of the coastlines. As a prototype semi-enclosed sea, the Mediterranean is sensitive and vulnerable to pollution events in general, and specifically to potential oil spills from ships, offloading terminals, pipelines, or wells. As a semi-enclosed sub-basin of the Mediterranean Sea, the eastern Mediterranean can be expected to be even more vulnerable to pollution. During the past 10–15 years significant reserves of oil and natural gas have been discovered in the eastern Mediterranean Sea. The US Geological Survey [1] estimates that there are more than 3.45×10^{12} m^3 of recoverable natural gas and 1.7×10^9 barrels of recoverable oil in these reserves, most of which is located beneath the seafloor of the eastern Levantine Basin. These reserves are located within the territorial waters and/or the exclusive economic zones (EEZ) of five countries—Egypt, Israel, Cyprus, Lebanon, and Syria. In principle each of the countries of the region has the rights to explore and drill within its EEZ. However due to the relatively small size of the eastern Levantine Basin, the different exploration zones sometimes abut one another, as shown in **Figure 1**. The conflicting claims of neighboring countries often lead to partial overlap of adjacent EEZs [2]. These disputes are further exacerbated by the ongoing political conflicts in the region. The small size of this semi-enclosed basin also leads to increased environmental vulnerability in the case of an accidental oil spill with a high potential risk for cross border pollution transport due to the prevailing winds and the near surface ocean currents [3, 4].

Studies of oil slick dispersion in other semi-enclosed basins and seas [5–8] have demonstrated the risk of widespread oil deposition from the slick along large segments of the coastlines. However in many cases cross border transport was not a consideration since the particular sea or basin was contained mostly within the territory of only one country [6–8]. Nevertheless, concerns regarding the attribution of responsibility and legal accountability for cross border or transboundary transport of marine pollution and its detrimental effects have been increasing over the past 20–30 years [9, 10].

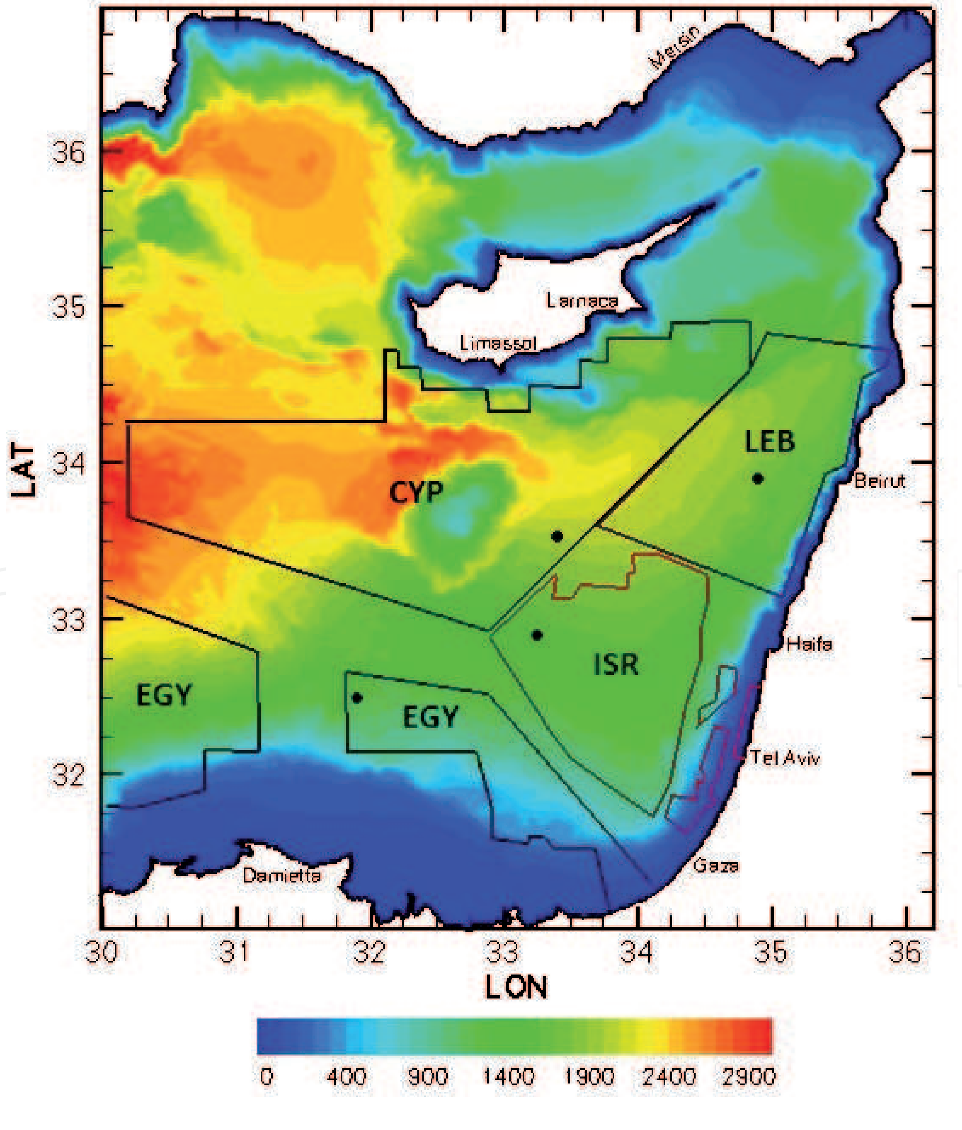

Figure 1.
Bathymetric map of the eastern Levantine basin showing the approximate boundaries of the oil and natural gas exploration zones of Cyprus (CYP), Lebanon (LEB), Israel (ISR), and Egypt (EGY). Black dots indicate locations of the hypothetical discharge points.

The primary goal of this study is to demonstrate the potential for cross border transport of an oil slick discharged from several hypothetical, offshore, deep water, drilling platforms located within the exploration zones in the EEZs of each of the adjacent countries that are actively exploring or exploiting the hydrocarbon energy reserves in the region. This is accomplished by running an oil spill dispersion model for a series of worst case scenarios consisting of a 30 day continuous discharge from a well blowout during various periods of representative meteorological and oceanographic conditions. These hypothetical simulations are not intended to represent any specific existing or planned well, but are designed to assess what could potentially occur in the regions of interest. Furthermore, the focus here is on deep water sites since shallow water wells in this region will be much closer to the coast (~10–20 km or less) and slicks from the latter will most likely reach the coast in close proximity to the well within a few days and will therefore be less prone to cross border transport [4, 11]. While blowouts may be rare events, they tend to contribute a disproportionately large percentage of the total spill volume from all sources. For example, over a 39 year period (1969–2007), well blowouts accounted for less than 1.5% of the offshore oil spill incidents in the United States but contributed nearly 85% of the total volume spilled [12]. The results of this study are qualitative in the sense that the level of risk is not numerically ranked or scored, but rather it is considered sufficient to show that a slick enters the EEZ or reaches the shores of a country other than the one responsible for the spill. In this respect, for the scenarios considered there is a very high probability of cross border transport of the slick. This emphasizes the shared multinational responsibility to control and prevent catastrophic pollution events in this environmentally sensitive and vulnerable region.

2. The atmospheric and oceanographic setting

The Mediterranean Sea is often considered the prototype semi-enclosed basin driven by net evaporation and therefore producing relatively dense, saline water which flows out into the adjacent ocean where it quickly sinks. It is connected to the North Atlantic Ocean through the narrow and relatively shallow (~270 m) Straits of Gibraltar. It is divided into the western and eastern sub-basins at the Straits of Sicily with the eastern basin accounting for nearly 2/3 of the surface area of the Mediterranean. The residence time is on the order of 100 years which makes this basin sensitive and vulnerable to major pollution events. The sea is located between the mid-latitude Westerlies to the north and the hot, dry subtropical deserts to the south and is characterized by the unique Mediterranean type climate consisting of cool, wet winters and hot, dry summers. During winter the weather over the Levantine basin is affected mainly by migratory cyclones, many of which originate in the Gulf of Genoa, near Crete or near Cyprus [13]. During summer the eastern Mediterranean is mostly under the influence of a westward extension of the Asian thermal low, leading to a strongly persistent pattern referred to as the Persian Trough [14]. Consequently the predominant winds over the Levantine basin throughout most of the year have a strong westerly component and blow mostly from the northwesterly to southwesterly sector. Monthly mean winds for December 2010 and September 2007 are shown in **Figures 2** and **3**, respectively.

The apparently larger mean wind vector in September, as compared to December, is due to the strong persistence of the wind direction in this season. However, in December the mean wind speeds over the sea are typically 20–40% stronger than in September, while the standard deviations are 50–100% larger in December as compared to September. This is due to the relatively stronger and

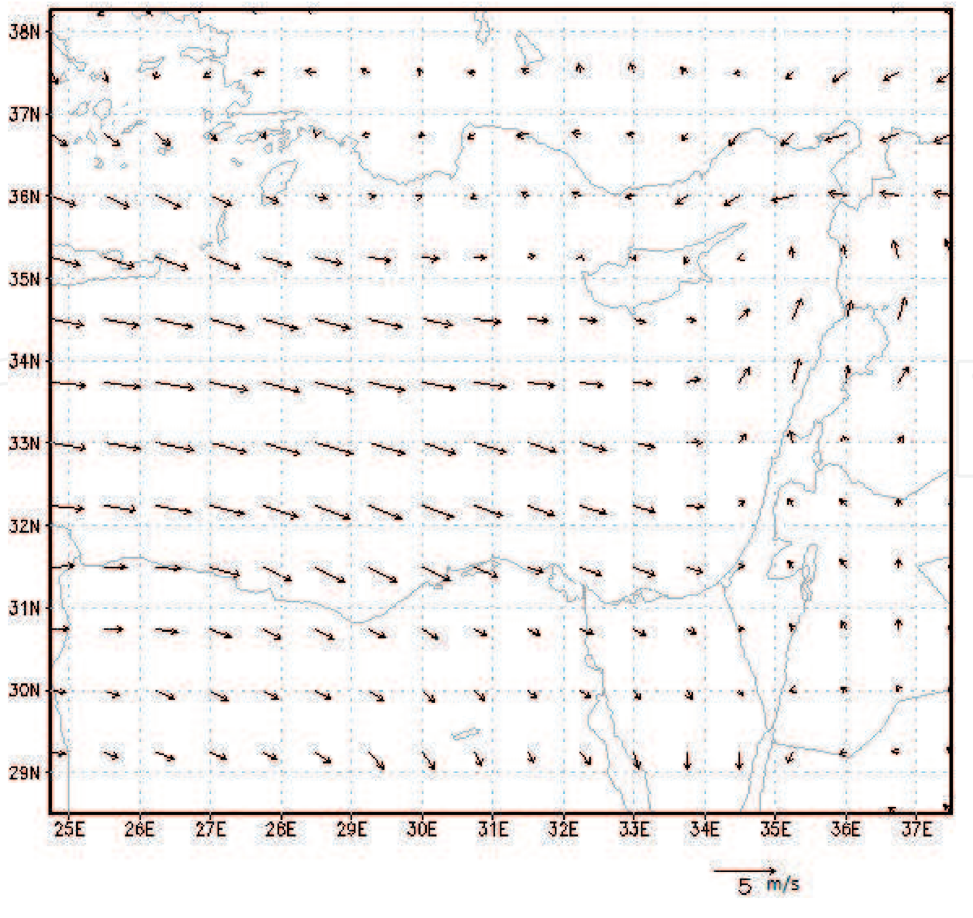

Figure 2.
Monthly mean 10 m winds for Dec 2010.

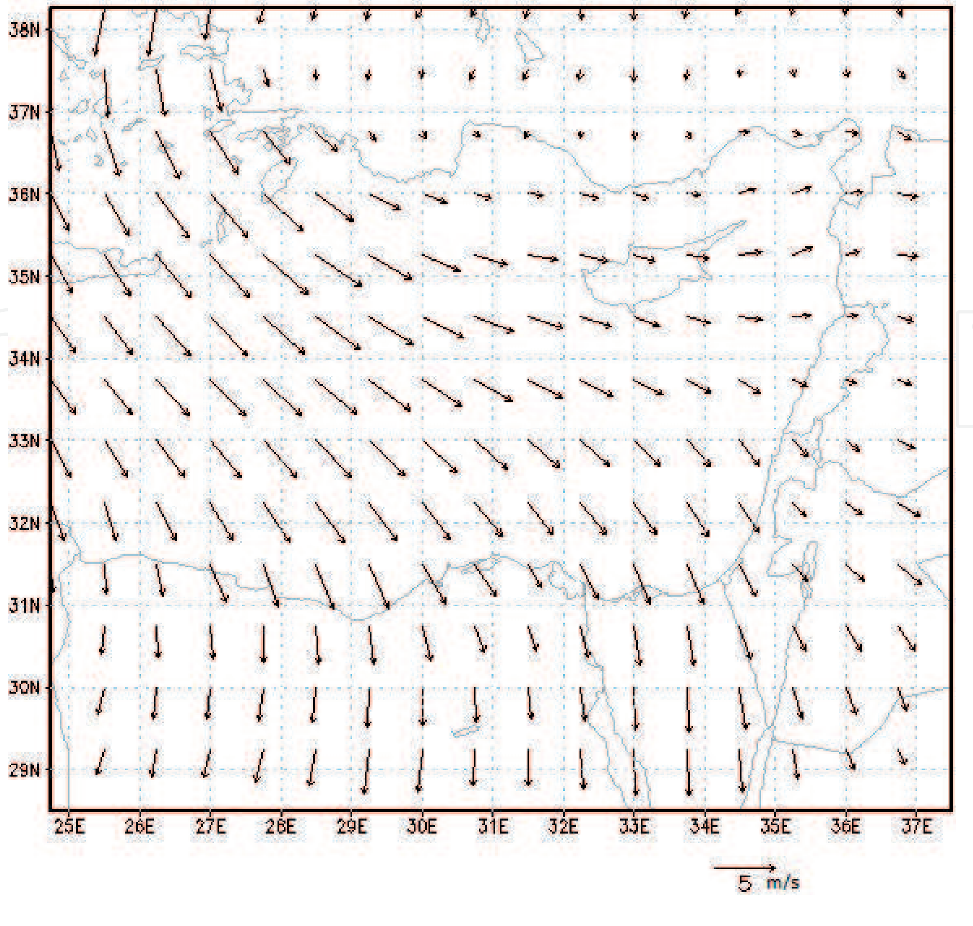

Figure 3.
Monthly mean 10 m winds for Sep 2007.

variable direction winds in the winter associated with the migratory cyclones that pass through this region. These seasonal wind characteristics have important implications for the spreading of oil slicks as will be seen below in Section 4.

The annual evaporation from the Mediterranean exceeds the fresh water input by precipitation and runoff with a net loss of ~0.64 m y^{-1} [15]. This leads to a long term, mean anti-estuarine thermohaline circulation pattern in which less saline water flows in from the ocean in the upper layer and is nearly balanced by the subsurface outflow of saline water produced in the basin. Most of this saline outflow consists of Levantine Intermediate Water (LIW) which is formed at various locations in the Levantine Basin [16]. A variety of dynamical circulation features, covering a range of temporal and spatial scales, is superimposed on this thermohaline cell, including convective deep water formation, sub-basin scale gyres, meandering jets, and a highly energetic mesoscale eddy field [17]. One of the most prominent features in the Levantine Basin is the meandering Mid-Mediterranean Jet (MMJ) which flows eastward through the center of the basin where it flanks various quasi-permanent or recurrent sub-basin scale features such as the cyclonic Rhodes gyre and the anticyclonic Mersah Matruh and Shikmona gyres [16, 18]. The MMJ bifurcates off the coast of Egypt where it splits with a southern branch that forms the cyclonic shelf break jet which then turns northward flowing along the coasts of Israel, Lebanon, and Syria [19], followed by a turn to the west flowing along the coast of Turkey. Examples of the winter and summer upper layer (30 m), monthly mean currents for the eastern Levantine Basin are shown for Dec 2010 in **Figure 4** and for Aug 2008 in **Figure 5**. These current patterns together with the prevailing

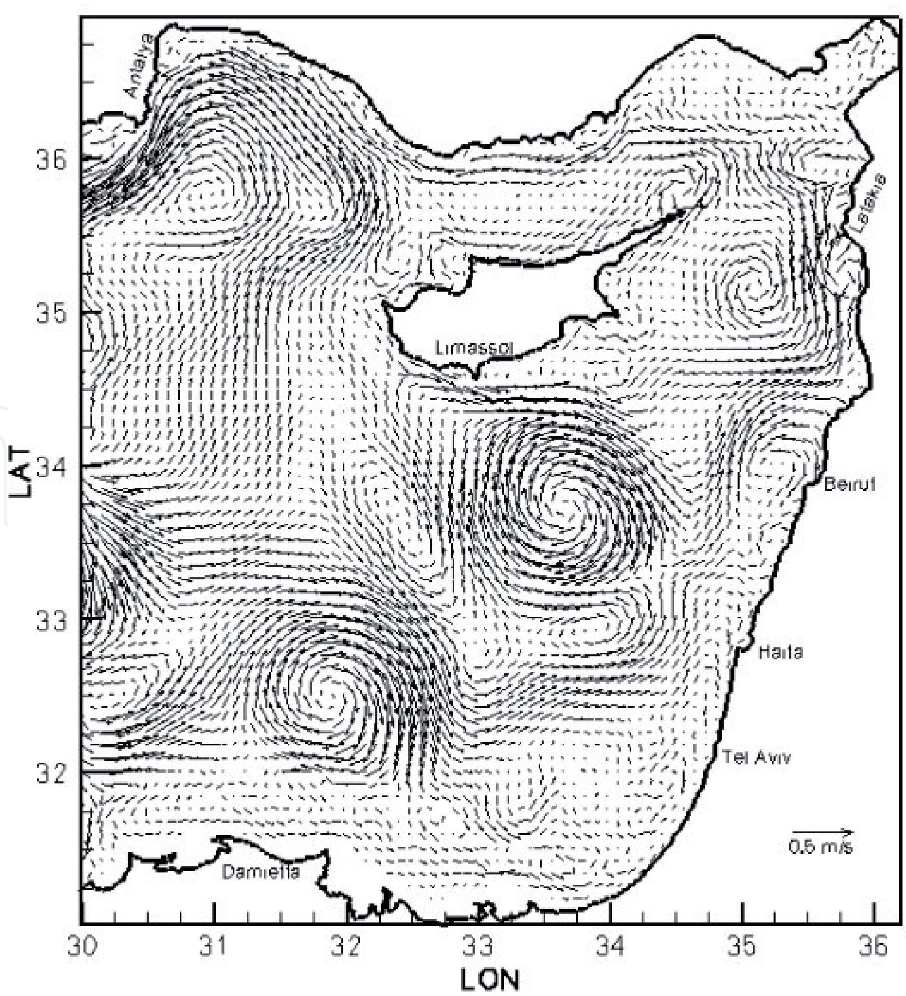

Figure 4.
Upper layer (30 m) monthly mean currents for Dec 2010.

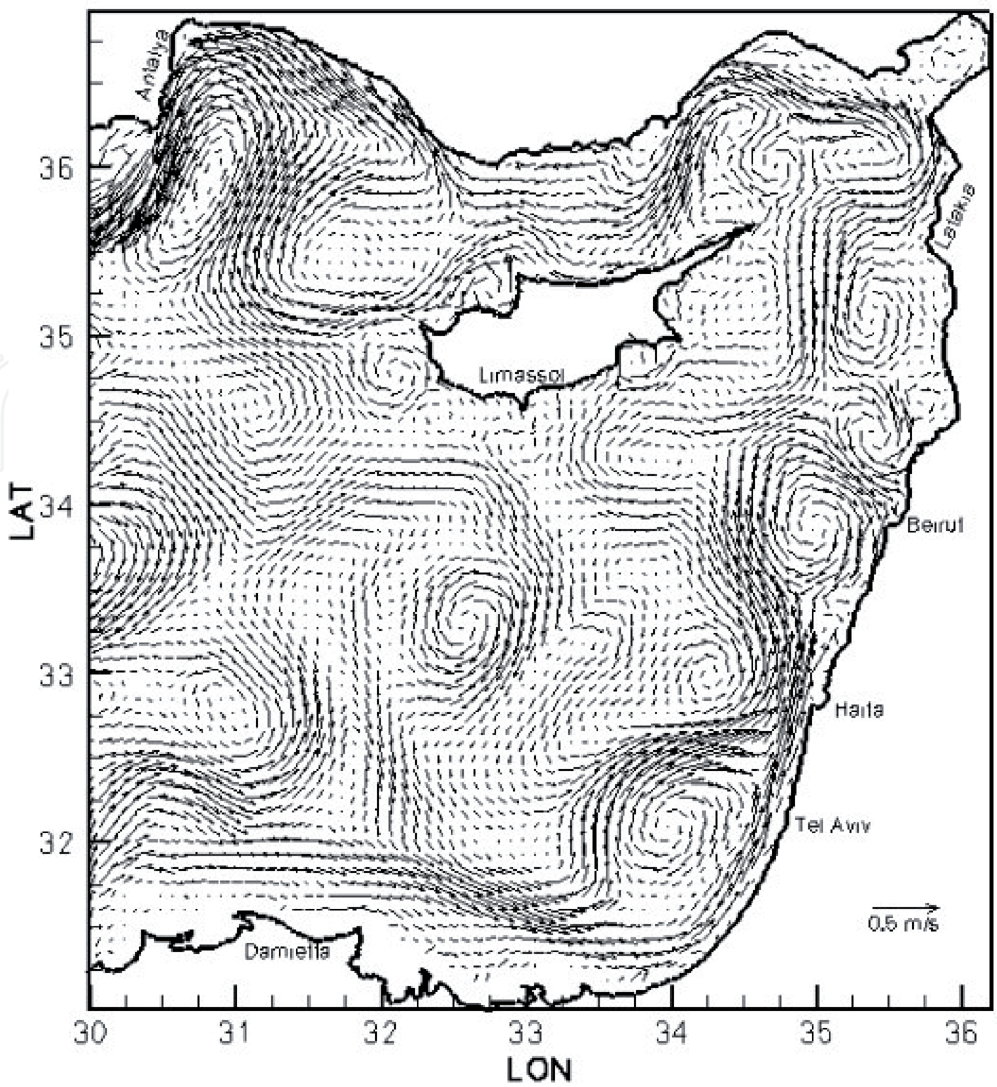

Figure 5.
Upper layer (30 m) monthly mean currents for Aug 2008.

winds are expected have a major impact on the dispersion of near surface oil slicks released from offshore locations in this region.

3. Methodology

In order to assess the risk of cross border transport of an oil slick discharged from hypothetical offshore, deep water wells located in the EEZs of each the four countries actively involved in exploration or production, a widely used oil spill dispersion model has been run for a variety of discharge scenarios during different, representative meteo-oceanographic conditions. As noted in the introduction, all of these scenarios assume a continuous 30 day discharge of oil from an uncontrolled well blowout with no preventative or mitigating measures such as deployment of booms or dispersants implemented. In this respect the simulation conducted can be considered worst case scenarios. A 30 day period also ensures that the slick will spread significantly and will be subjected to a wide range of winds and currents. The oil spill model requires winds and near surface ocean currents to compute the trajectory and dispersion of the slick. It is therefore run in two steps. First a high resolution, ocean circulation model is run to downscale the currents from an ocean reanalysis data set. In the second step, these currents and the winds are used as input to the oil spill fate model which computes the trajectory of the slick as well as various weathering processes.

3.1 Ocean circulation model

The currents used to drive the oil spill model are generated using an expanded domain and higher resolution version of the model developed as part of an operational ocean forecasting system for the southeastern Mediterranean Sea [20]. It is based on the Princeton Ocean Model (POM) [21] which is a three dimensional, free surface, time dependent primitive equations model. POM uses an Arakawa-C grid in the horizontal and a terrain following, sigma coordinate in the vertical. It contains full thermodynamics and includes a higher order turbulence closure scheme to account for sub-grid scale vertical mixing. It is forced at the surface with climatological heat and fresh water fluxes [15] corrected with a Newtonian relaxation or nudging to the daily varying surface temperature and salinity extracted from the Mediterranean Sea reanalysis [22]. Six hourly winds were extracted from the ECMWF Interim Reanalysis [23]. Initial conditions and lateral boundary conditions at the open western boundary are derived from the daily varying, three dimensional Mediterranean Sea reanalysis [22]. The horizontal resolution of the model is 1/60° in latitude and longitude (1.85 × 1.55 km) and there are 30 unevenly spaced sigma levels in the vertical. The domain and bathymetry used in the model are shown in **Figure 1**. The examples of the near surface currents shown in **Figures 2** and **3** were produced by this model.

3.2 Oil spill model

The oil spill fate model used to assess the dispersion of slicks discharged from the hypothetical deep water wells is MEDLSIK [24, 25]. In the model, the surface oil slick is advected and dispersed by the direct action of the near surface currents and the wind forcing. The slick is assumed to be composed of a very large number (tens or hundreds of thousands) of particles which are transported following a Lagrangian trajectory determined by the incremental displacement due to the currents, the winds, and small scale, horizontal turbulent diffusion based on the random walk hypothesis. The model computes the total oil budget with a full accounting of oil that remains on the surface, oil that is mixed in the water column, and oil that is beached. It also accounts for weathering of the oil through physio-chemical processes such as evaporation, emulsification, and small scale, vertical turbulent mixing [24, 25]. MEDSLIK has been tested extensively and widely used in many locations around the Mediterranean [3, 4, 11, 26, 27] as well as in other regions of the world [6].

3.3 Scenarios

As noted above, the goal of this study is to demonstrate the vulnerability of this semi-enclosed basin to the risk of cross border transport of an oil slick originating from spills at hypothetical, yet representative, offshore, deep water wells potentially operated by four different countries in the region. To this end, worst case oil spill scenarios are considered, consisting of uncontrolled discharges from continuous, 30 day well blowouts at each of the four locations indicated by the black dots in **Figure 1**, with no preventative or mitigating measures implemented. Selection of the meteo-oceanographic conditions for the simulations was done following the guidelines of the Israel Ministry of Environmental Protection for conducting environmental impact studies of offshore gas exploration or production. They have specified four representative 30-day periods including: (1) at least one extreme winter storm (Dec 2010–Jan 2011), (2) a winter period with at least two typical storms (Jan–Feb 2008), (3) a typical summer period with persistent northwesterly winds (Jul–Aug 2008), and (4) a transition season (late summer—autumn) period with several episodes of strong easterly winds (Sep–Oct 2007). The oil from each blowout is assumed to be medium grade with an API gravity of 33° (within the range of exploratory discoveries in this region [3]) and discharged at a rate of 2000 barrels per day (total of 60,000 barrels from each blowout).

4. Results and discussion

An overview of the results of all 16 simulations is presented in **Table 1** where the oil budget at the end of 30 days is broken down by percentages of the total discharged, into the amounts evaporated, remaining on the surface, dispersed (vertically mixed) in the water column, and amount deposited on the coast. The next to last column of the table lists the coasts of the countries affected, while the last column gives the time (in days) until the first beaching of oil.

Perhaps the most important result from **Table 1** is that in 88% of the cases (14 out of 16) cases, the coastlines of two or more countries will be affected, while in 25% of the cases the coasts of four or more countries will be impacted. In two cases the impact is limited to the coast of only one country. In one of those cases

Period	Source	Evap	Surf	Disp	Depo	Coasts affected	Beaching (days)
12/10–01/11	C	42.1	43.2	14.0	0.7	**C**, I, **L**, S	21
	L	42.1	36.9	12.3	8.6	C, I, **L**, **S**, T	4
	I	42.06	41.4	16.5	0.04	C	26
	E	42.1	38.4	16.8	2.5	**E**, I	21
01/08–02/08	C	42.1	34.6	17.1	6.1	**I**, L	19
	L	42.1	32.2	15.3	10.0	C, L, **S**	17
	I	42.1	31.0	16.4	10.1	E, **I**, L	16
	E	42.1	30.6	15.9	11.0	**E**, I	11
07/08–08/08	C	42.1	35.8	14.5	7.6	C, L, **S**, T	18
	L	42.1	15.1	7.1	35.6	**L**, **S**	6
	I	42.1	35.0	14.9	8.0	L, **S**	16
	E	42.1	34.6	14.4	9.0	**I**, L	19
09/07–10/07	C	42.1	40.3	14.2	3.4	E, **I**	18
	L	42.0	27.0	6.3	24.5	C, **L**, I, S	13
	I	42.1	22.1	11.5	24.1	E, **I**	14
	E	42.1	23.1	12.3	22.0	**E**	19

Coastlines affected are also listed according to C, Cyprus; E, Egypt; I, Israel; L, Lebanon; S, Syria; T, Turkey. The most severely impacted coastlines are indicated by bold letters. The last column gives the number of days until first beaching of the oil.

Table 1.
Components of oil budget (in%) after 30 days—evaporated, remaining on surface, vertically dispersed, and deposited on the coast.

practically no oil reaches any cost (only a negligible amount on the southern coast of Cyprus) while in the other case, the coastline affected belongs to the same country in whose domain the spill originated (Egypt). Once again it should be noted that in this study a coastline is considered to be affected as long as some oil is deposited. This measure is strictly qualitative with no numerical ranking or risk factor computed. The distribution of the oil on the coast is not uniform and can be very patchy. In many cases the most severely impacted zones (i.e., highest concentrations) are limited to one or several relatively short stretches of coastline. In all of the cases considered, slightly more than 42% of the discharged oil evaporates. This is due primarily to the API gravity of the oil. As a general rule of thumb, for heavier oil, a smaller portion would evaporate while for lighter oil more of the oil will evaporate. For example, several scenarios were rerun with 40° API (a value that is representative of condensate that could potentially leak from a natural gas well). In these cases slightly more than 53% of the oil evaporated with the other components of the oil budget reduced accordingly, but the spatial distributions of the oil remaining on the surface and deposited on the coast were similar to the original simulations with 33° API gravity.

In 14 of the 16 cases, the second leading term in the oil budget, after evaporation, is the oil remaining on the surface. The percentage ranges between 23.1 and 43.2% with an average of 32.6%. In the remaining two case, the amounts are 15.1–22.1%. The next term in the budget, in order of magnitude, is oil dispersed (vertically mixed) in the water column with an average of 13.7%. These two components of the budget, which represent the portion of oil that remains in the water, account for most of the oil that remains after evaporation. The last term in the oil budget is the amount deposited on the coast, which ranges from 0.04 to 35.6% with an average of 11.5% of the total amount discharged. In two of the cases (both in Dec 2010), the amount deposited on the coast was less than 1%. In four of the cases more than 22% of the oil is deposited on the coast. Three of these four cases occurred in Sep 2007 and can be attributed to the persistent northwesterly winds in the southeastern part of the basin and westerly winds in the northeastern part of the basin (**Figure 3**).

The last column in **Table 1** shows the time in days until the first oil is deposited on the coast. This time ranges from 4 to 26 days with an average of 16 days. From the table it is noticeable that the hypothetical slick originating from the EEZ of Lebanon will tend to reach the coast faster than the slicks originating from other EEZs. This is due to the closer proximity of this well to the coast and the relatively confined domain, as compared to the others, combined with the predominant westerly component of the winds in this region. The other interesting point to note in the table is that the amount of oil reaching the coast is consistently lowest in the Dec 2010 simulations. The strong near surface currents, dominated by two large and intense anticyclonic features (see **Figure 4**), combined with the relatively strong and variable winds during this period lead to widespread dispersion of the slicks across the basin with most of the unevaporated oil remaining in the sea as shown in **Figure 6**.

To better appreciate the important roles of near surface currents and winds in spreading the slick, the next four figures present the spatial distribution of the oil remaining on the surface and the oil deposited on the coast at the end of the simulations from Dec 2010 and Sep 2007. **Figure 6** shows the oil remaining on the sea surface at the end of the four hypothetical well blowouts in Dec 2010. This period was chosen since the amount of oil that was deposited on the coast was minimal while the dispersion of the surface oil was most widespread. This period was characterized by an extreme winter storm towards the beginning and strong, but highly variable direction, winds throughout the period. The general tendency for

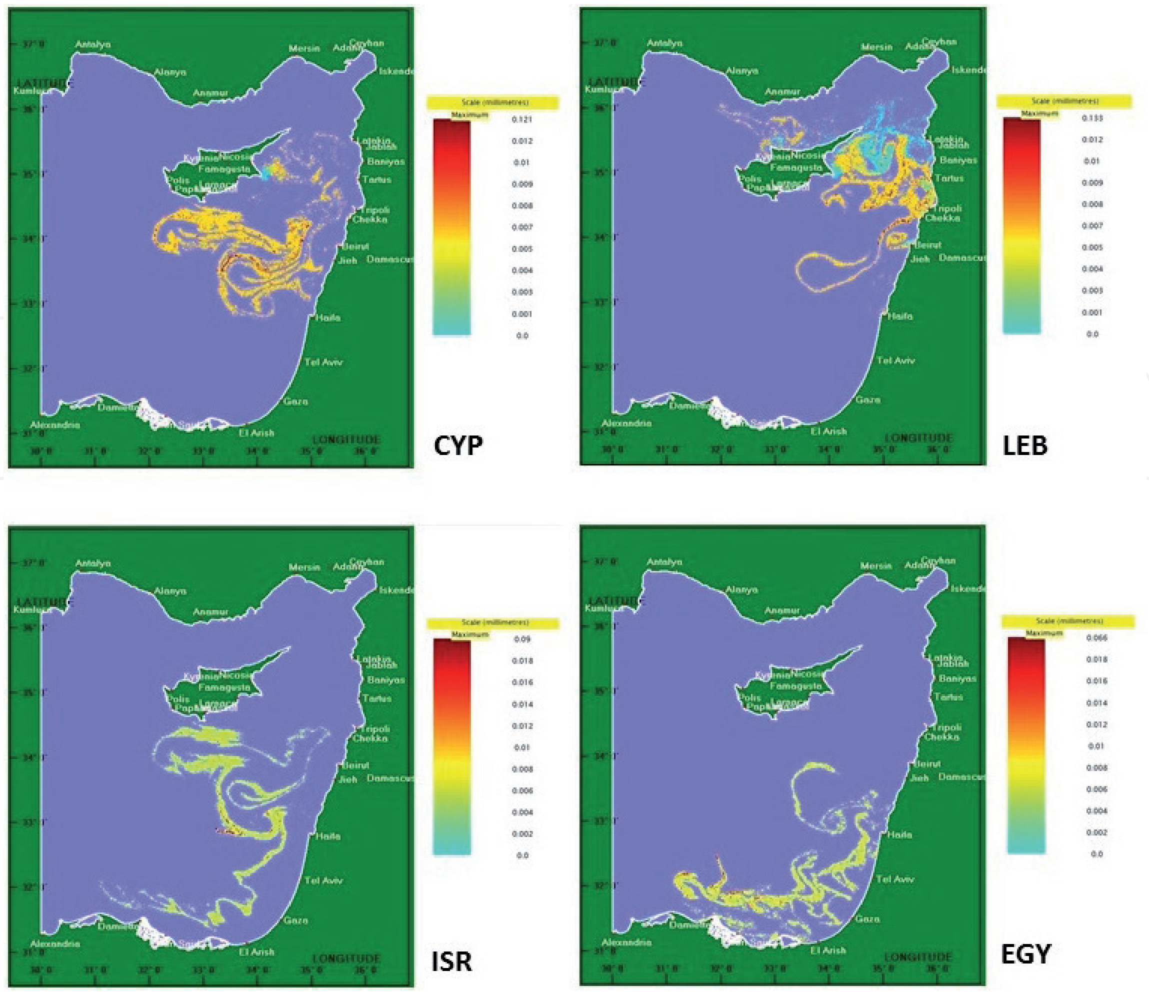

Figure 6.
Oil remaining on the surface at the end of the four hypothetical 30 day well blowout simulations in Dec 2010.

widespread dispersion in these cases can be explained by the relatively strong and variable winds. However the details of the spreading in streamers and filaments are clearly a result of the mesoscale variability of the near surface currents.

Figure 7 shows the oil deposited on the coast for the Dec 2010 simulations. The slick originating from the Cyprus and Lebanon EEZs are the most likely to result in cross border transport and lead to deposition on the coastline of four different countries. The slick originating from the Egyptian EEZ will also reach the coast but almost exclusively affecting the Egyptian coast. The exception here is the slick originating in the EEZ of Israel which almost completely remains at sea, with a negligible amount of oil (only 0.04%) deposited on the southern coast of Cyprus.

For comparison, **Figures 8** and **9** show the results for the Sep 2007 simulations. This period was chosen to contrast with Dec 2010 since on average here the percentage of coastal deposition was significantly larger than for the other cases. In this case the transport of the slick was strongly controlled by the combined effects of the persistent winds and the mesoscale features of the currents. The slicks originating from the EEZs of Cyprus, Egypt, and Israel are all transported southward in the open sea by the strong northwesterly winds. It is interesting to note that the transport is highly focused in thin filaments following the near surface currents. When the slick reaches the continental shelf it is transported alongshore by the cyclonic, shore parallel current system [19]. The behavior of the slick originating the EEZ of Lebanon is somewhat different. In this region the winds have a stronger westerly component which transports the slick rapidly towards the coast. Upon reaching the continental margin, the oil is then transported northward by the combined action of the shore parallel jet and a series of energetic, northward moving mesoscale

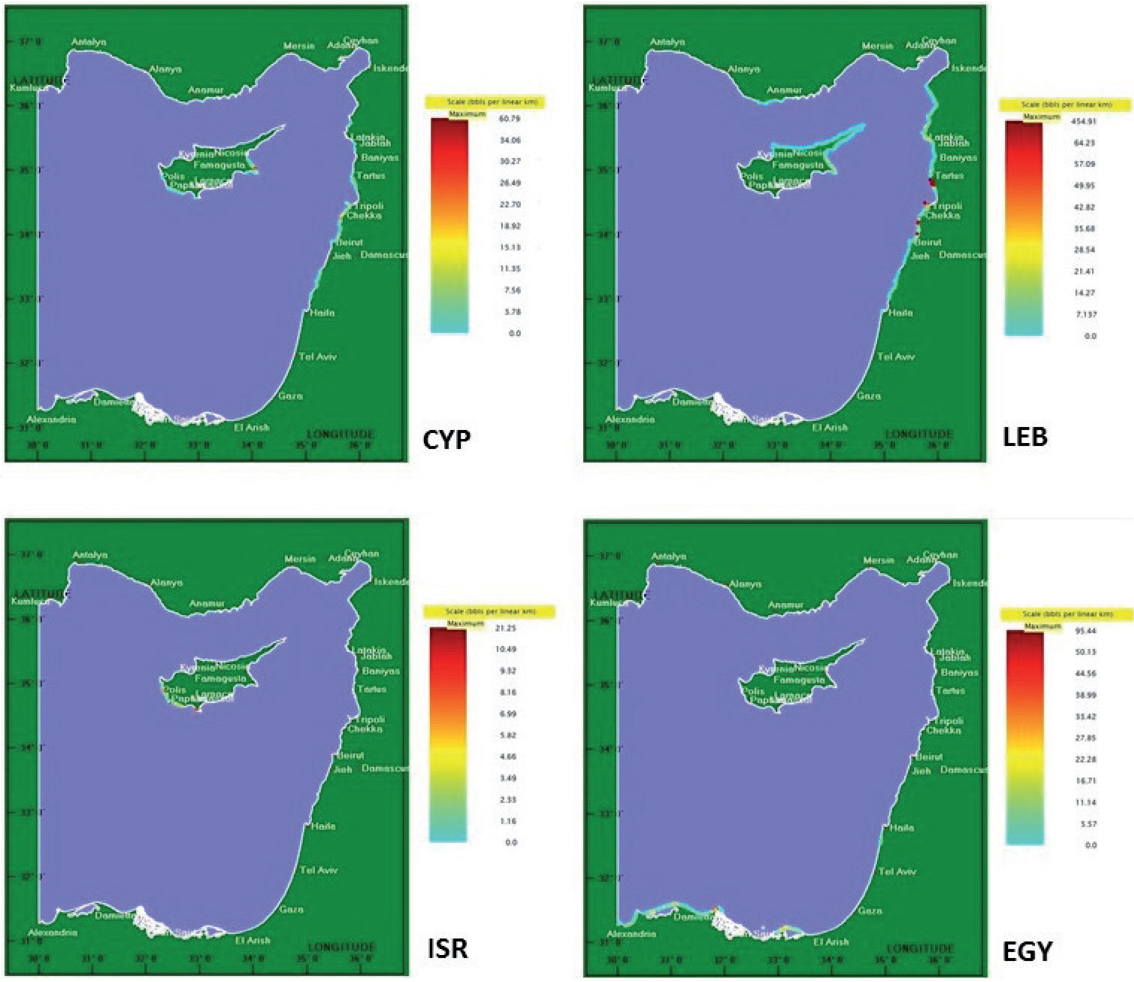

Figure 7.
Oil deposited on the coast at the end of the four hypothetical 30 day well blowout simulations in Dec 2010.

eddies. Consequently the shape of the slick is more diffuse and less focused than the other three slicks.

The oil deposited on the coast from the four slicks in Sep 2007 is shown in **Figure 9**. In all four cases it is clear that the pattern of coastal deposition is strongly controlled by the shore parallel current that flows over the continental shelf [19]. Consequently the oil primarily affects the coasts of Egypt, Israel, Lebanon and Syria. Only a small amount of oil from the Lebanon slick reaches the north coast of Cyprus.

The main goal of this study has been to provide a broad overview of the potential risk from hypothetical oil spills originating in the EEZ's of four different countries in the region that are at various stages of exploration and production of natural gas and oil. Other modeling studies of oil spills in this region [3, 4, 11] have focused on spills originating from the EEZs of only a single country. This study also differs from the others in terms of the longer duration of the spills and simulations, as well as the focus on spills originating from deep water platforms which tend to be further from the coast. Nevertheless, even in those studies there was often a tendency to see some cross border transport of the slicks, at least to the coasts of the immediately adjacent countries. Based studies like this it is clear that this region, in which gas and oil exploration and production has proceeded at an accelerated rate, is highly susceptible and vulnerable to cross border transport of oil slicks and the resulting environmental damage. None of countries of this region are immune to the risk. They all share the vulnerability and must also accept and share the responsibility. The need for action and cooperation to control and respond to cross border marine pollution events was already recognized more than 2 decades

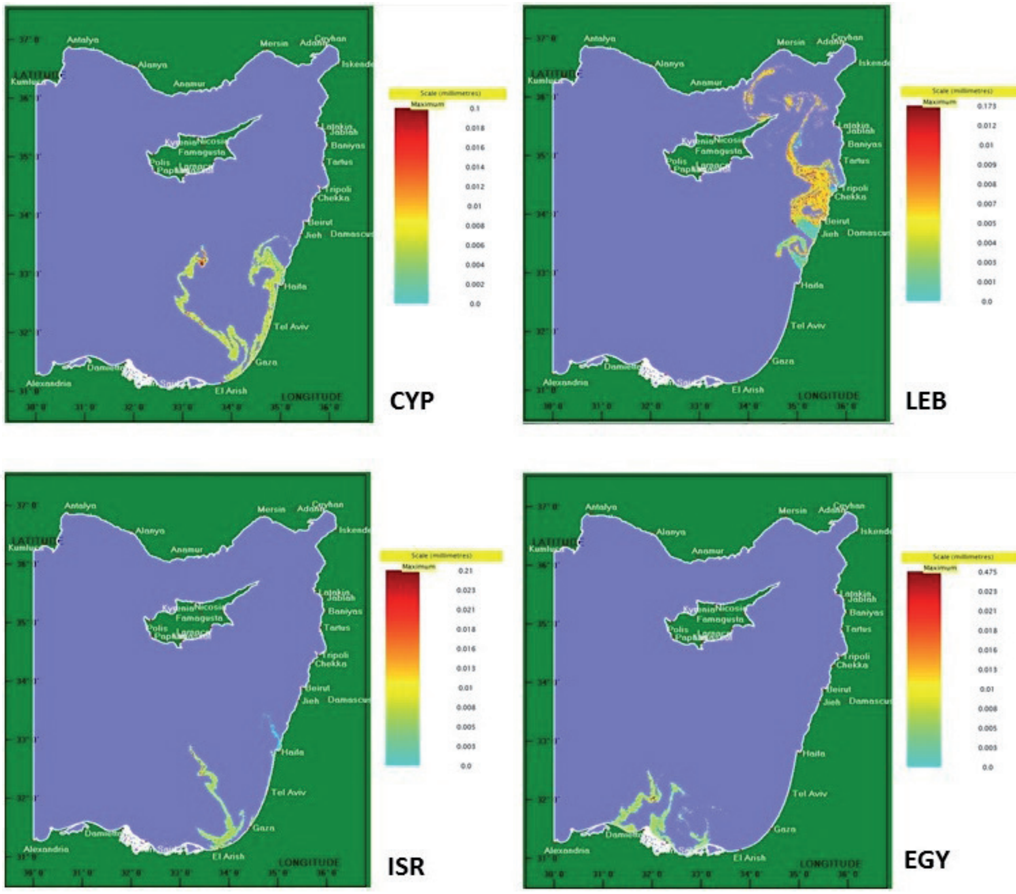

Figure 8.
Oil remaining on the surface at the end of the four hypothetical 30 day well blowout simulations in Sep 2007.

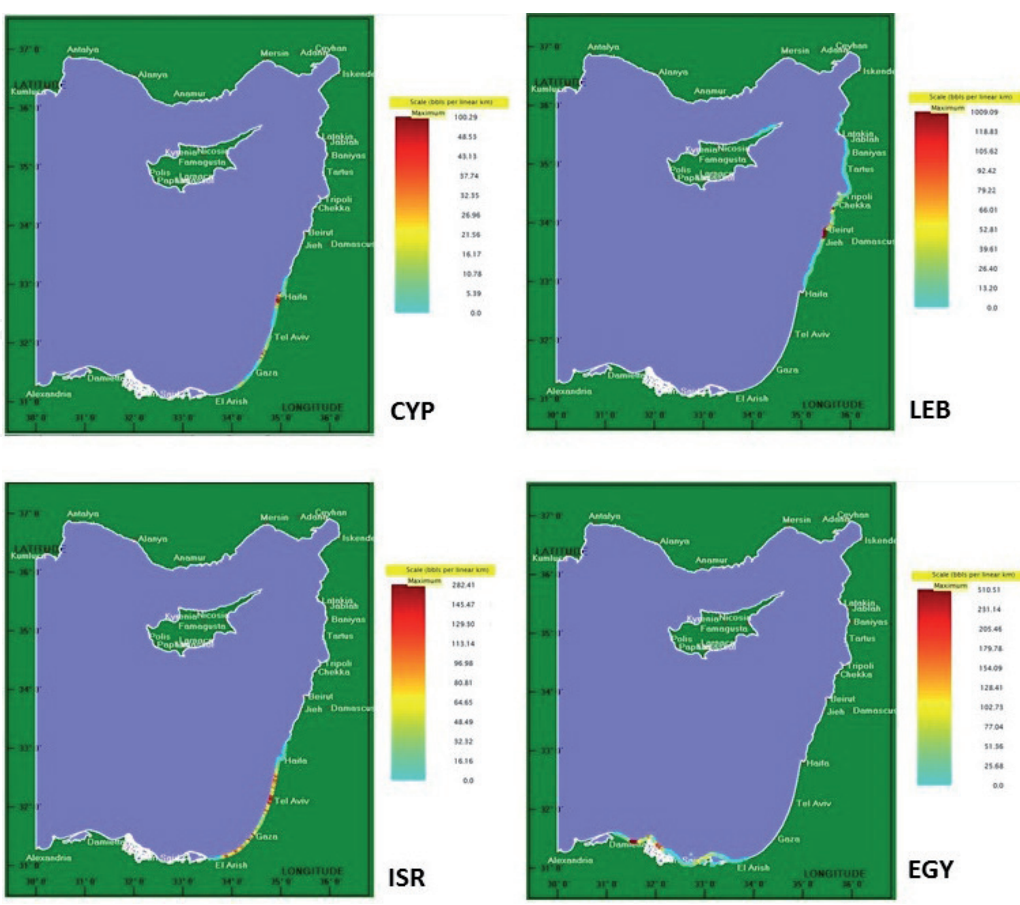

Figure 9.
Oil deposited on the coast at the end of the four hypothetical 30 day well blowout simulations in Sep 2007.

ago when a trilateral agreement establishing a sub-regional contingency plan was signed between Cyprus, Egypt, and Israel in 1995 [28]. More recently, an additional sub-regional contingency plan agreement was signed between Cyprus, Greece, and Israel last year [29]. Both of these agreements are important and encouraging and hopefully additional sub-agreements or parallel (bilateral) agreements will be signed that will allow for crucial cooperation in response to major oil spills despite the ongoing political tensions in the region.

5. Conclusions

In general, the environmental risks posed by oil spills in semi-enclosed sea, basins or bays are more pronounced than those in the open ocean due to potential deposition along long segments of the coastlines. As a prototype semi-enclosed sea, the Mediterranean is sensitive and vulnerable to pollution events in general, and specifically to potential oil spills from ships, offloading terminals, pipelines, or wells. As a semi-enclosed sub-basin of the Mediterranean Sea, the eastern Mediterranean can be expected to be even more vulnerable to pollution and therefore serve as a test case for investigating the risks associated with widespread dispersion and beaching of oil slicks. Recent discoveries of extensive hydrocarbon energy reserves beneath the seafloor of the eastern part of the Levantine basin have led to accelerated gas and oil exploration by four countries in the region—Cyprus, Egypt, Israel, and Lebanon. Two countries, Cyprus and Israel, have already begun production. In addition to the general risks posed by an oil spill in a restricted sea due to the patterns of the prevailing winds and sea surface currents, the active exploration and exploitation by multiple, adjacent countries make this region potentially sensitive and vulnerable to significant cross border transport. The risk of cross border transport is especially acute from spills originating in deep water platforms located in the open sea due the time required to reach the coast. Previous modeling studies of hypothetical oil spills in this region have generally focused on spills originating from the EEZ of only a single country. The goal of this study was to highlight the vulnerability of the eastern Levantine basin to the pronounced environmental risks of an oil spill in a semi-enclosed sea or basin combined with the unique situation of multiple, adjacent countries actively exploring and exploiting oil and natural gas reserves, thereby adding the consideration of risks of cross border transport. Thus a comparative overview is provided considering potential spills originating from deep water wells in the EEZs of four different countries. Due to the relatively large distance of these wells from the coast (tens of to more than 100 km) the oil can spread across large areas and will typically take 2–3 weeks to reach a coast. Consequently the risk for cross border transport of a slick originating from any of the EEZs is very real. Simulations were conducted for hypothetical 30 day, continuous, uncontrolled spills from four deep water platforms in different seasons. In 88% of the cases considered (14 out of 16) oil was deposited on the coast of at least one country other than the country responsible for the spill. On the other hand, the relatively long period until the oil reaches the coast is in principle important for allocating and deploying resources to contain the slick and to mitigate the damage. This emphasizes the importance of multinational cooperation in developing contingency and response plans and procedures in regions where several countries in close proximity are simultaneously producing oil or natural gas. It also highlights the importance of mutual responsibility to protect the marine environment since no country will be immune from potentially causing and subsequently suffering from the damaging effects of cross border pollution transport.

Acknowledgements

We would like to thank Dr. George Zodiatis of the Cyprus Oceanographic Center for providing the oil spill model, MEDSLIK. Wind data were provided by the ECMWF and the oceanographic data were provided by the EU COPERNICUS Marine Environment Monitoring Service. This work was conducted as a downstream application and follow-on to several EU funded projects that supported the development of the Mediterranean Ocean Forecasting System (MFS).

Conflict of interest

There are no known conflicts of interest related to this work.

Author details

Steve Brenner
Department of Geography and Environment, Bar Ilan University, Ramat Gan, Israel

Address all correspondence to: sbrenner@mail.biu.ac.il

References

[1] US Geological Survey. Assessment of undiscovered oil and gas resources of the Levant basin province, eastern Mediterranean. US Geological Survey, US Department of the Interior Fact Sheet 2010-3014; 2010. 4 pp

[2] Stocker J. No EEZ solution: The politics of oil and gas in the eastern Mediterranean. Middle East Journal. 2012;**66**(4):579-597. DOI: 10.3751/66.4.11

[3] Alves TM, Kokinou E, Zodiatis G, Lardner R, Panagiotakis C, Radhakrishnan H. Modeling of oil spills in confined marine basins: The case for early response in the eastern Mediterranean Sea. Environmental Pollution. 2015;**206**:390-399. DOI: 10.1016/j.envpol.2015.07.042

[4] Brenner S. Oil spill modeling in the southeastern Mediterranean Sea in support of accelerated offshore oil and gas exploration. Ocean Dynamics. 2015;**65**:1685-1697. DOI: 10.1007/s10236-015-0902-2

[5] Amir-Heidari P, Raie M. Probabilistic risk assessment of oil spill from offshore oil wells in Persian gulf. Marine Pollution Bulletin. 2018;**136**:291-299. DOI: 10.1016/j.marpolbul.2018.07.068

[6] Yu F, Xue S, Zhao Y, Chen G. Risk assessment of oil spills in the Chinese Bohai Sea for prevention and readiness. Marine Pollution Bulletin. 2018;**135**:915-922. DOI: 10.1016/j.marpolbul.2018.07.029

[7] Ertürk Bozkurtoğlu SN. Modeling oil spill trajectory in Bosphorus for contingency planning. Marine Pollution Bulletin. 2017;**135**:57-72. DOI: 10.1016/j.marpolbul.2017.09.029

[8] French-McCay D, Crowley D, Rowe JJ, Bock M, Robinson H, Wenning R, et al. Comparative risk assessment of spill response options for a deepwater oil well blowout: Part 1. Oil spill modeling. Marine Pollution Bulletin. 2018;**133**:1001-1015. DOI: 10.1016/j.marpolbul.2018.05.042

[9] Kindt JW. International environmental law and policy: An overview of transboundary pollution. San Diego Law Review. 1986;**23**:583-609

[10] McCarthy EM. International regulation of transboundary pollutants: The emerging challenge of ocean noise. Ocean and Coastal Law Journal. 2001;**6**:257-292

[11] Goldman R, Biton E, Brokovich E, Kark S, Levin N. Oil spill contamination probability in the southeastern Levantine basin. Marine Pollution Bulletin. 2015;**91**:347-356. DOI: 10.1016/j.marpolbul.2014.10.050

[12] Etkin DS. Analysis of US Oil Spillage. Washington DC: API Publication 356, American Petroleum Institute; 2009. 71 pp

[13] Alpert P, Neeman BU, Shay-El Y. Climatological analysis of Mediterranean cyclones using ECMWF data. Tellus. 1990;**42A**:65-117

[14] Kostopoulou E, Jones PD. Comprehensive analysis of the climate variability in the eastern Mediterranean. Part I: Map-pattern classification. International Journal of Climatology. 2007;**27**:1189-1214

[15] Pettenuzzo D, Large WG, Pinardi N. On the correction of ERA-40 surface flux products consistent with the Mediterranean heat and water budgets and the connection between basin surface total heat flux and NAO. Journal of Geophysical Research. 2010;**115**(C06022):15. DOI: 10.1029/2009JC005631

[16] Robinson AR, Golnaraghi M. The physical and dynamical oceanography of the Mediterranean Sea. In: Malanotte-Rizzoli P, Robinson AR, editors. Ocean Processes in Climate Dynamics: Global and Mediterranean Examples. Dordrecht: Kluwer Academic Publishers; 1994. pp. 255-306

[17] Malanotte-Rizzoli P, Artale V, Borzelli-Eusebi GL, Brenner S, et al. Physical forcing and physical/biochemical variability of the Mediterranean Sea: A review of unresolved issues and directions for future research. Ocean Science. 2014;**10**(3):267-279. DOI: 10.5194/os-10-281-2014

[18] Menna M, Poulain P-M, Zodiatis G, Gertman I. On the surface circulation of the Levantine sub-basin derived from Lagrangian drifters and satellite altimetry data. Deep Sea Research Part I. 2012;**65**:46-58. DOI: 10.1016/j.dsr.2012.02.008

[19] Rosentraub Z, Brenner S. Circulation over the southeastern continental shelf and slope of the Mediterranean Sea: Direct current measurements, winds, and numerical model simulations. Journal of Geophysical Research. 2007;**112**(C11001):21. DOI: 10.1029/2006JC003775

[20] Brenner S, Gertman I, Murashkovsky A. Pre-Operational Ocean forecasting in the southeastern Mediterranean: Model implementation, evaluation, and the selection of atmospheric forcing. Journal of Marine Systems. 2007;**65**:268-287. DOI: 10.1016/j.jmarsys.2005.11.018

[21] Blumberg AF, Mellor GL. A three dimensional coastal ocean circulation model. In: Heaps N, editor. Three Dimensional Coastal Ocean Models. Washington DC: American Geophysical Union; 1987. pp. 1-16

[22] Simoncelli S, Fratianni C, Pinardi N, Grandi A, Drudi M, Oddo P, and Dobricic, S. Mediterranean Sea physical reanalysis (MEDREA 1987-2015) (version 1). [Data set]. Copernicus Monitoring Environment Marine Service (CMEMS). 2014. DOI: 10.25423/medsea_reanalysis_phys_006_004

[23] Dee DP, Uppala SM, Simmons A, Berrisford P, Poli P, Kobayashi S, et al. The ERA-interim reanalysis: Configuration and performance of the data assimilation system. Quarterly Journal of the Royal Meteorological Society. 2011;**137**:553-597. DOI: 10.1002/qj.828

[24] Lardner R, Zodiatis G. An operational oil spill model in the Levantine Basin (Eastern Mediterranean Sea). International Symposium on Marine Pollution. 1998;**10**:5-9

[25] De Dominicis M, Pinardi N, Zodiatis G, Lardner R. MEDSLIK-II, a Lagrangian marine surface oil spill model for short term forecasting—Part 1: Theory. Geoscience Model Development. 2013;**6**:1851-1869. DOI: 10.5194/gms-6-1851-2013

[26] Coppini G, De Dominicis M, Zodiatis G, Lardner R, Pinardi N, Santoleri R, et al. Hindcast of oil-spill pollution during the Lebanon crisis in the eastern Mediterranean, July-August 2006. Marine Pollution Bulletin. 2011;**62**:140-153. DOI: 10.1016/j.marpolbul.2010.08.021

[27] Zodiatis G, Lardner R, Solovyov D, Panayidou X, De Dominicis M. Predictions for oil slicks detected from satellite images using MyOcean forecasting data. Ocean Science. 2012;**8**:1105-1115. DOI: 10.5194/os-8-1105-2012

[28] REMPEC. Agreement on the sub-regional systems for preparedness and response to major marine pollution incidents in the Mediterranean

[Internet]. 1995. Available from: http://www.rempec.org/admin/store/wyswigImg/file/Information%20resources/Other%20Meetings-Activities/Contingency%20planning/Subregionals%20agreements%20and%20plans/Cont%20agreement-CEI.pdf [Accessed: 13 February 2019]

[29] UNEP. Implementation agreement on the sub-regional marine oil pollution contingency plan signed by Cyprus, Greece, and Israel [Internet]. 2018. Available from: http://web.unep.org/unepmap/implementation-agreement-sub-regional-marine-oil-pollution-contingency-plan-signed-cyprus-greece-and [Accessed: 13 February 2019]