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Modelling of oil spills in confined maritime basins: The case for early response in the Eastern Mediterranean Sea

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A B S T R A C T

Oil spill models are combined with bathymetric, meteorological, oceanographic, and geomorphological data to model a series of oil spill accidents in the Eastern Mediterranean Sea. A total of 104 oil spill simulations, computed for 11 different locations in the Levantine Basin, show that oil slicks will reach the coast of Cyprus in four (4) to seven (7) days in summer conditions. Oil slick trajectories are controlled by prevailing winds and current eddies. Based on these results, we support the use of chemical dispersants in the very few hours after large accidental oil spills. As a corollary, we show shoreline susceptibility to vary depending on: a) differences in coastline morphology and exposure to wave action, b) the existence of uplifted wave-cut platforms, coastal lagoons and pools, and c) the presence of tourist and protected environmental areas. Mitigation work should take into account the relatively high susceptibility of parts of the Eastern Mediterranean.

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1. Introduction

Oil spills in remote offshore regions are of difficult management due to their relative distance to the shore, where civil protection teams and clean-up equipment are located. In addition, a strong influence of seasonal oceanographic and weather conditions is usually recorded offshore (Doerffer, 1992; Anderson and LaBelle, 2000; Burgherr, 2007). Key examples of this influence have been witnessed during the M/V Exxon Valdez (1989) and M/V Prestige (2002) accidents. Both accidents recorded the scattering and beaching of oil by strong currents and winds through a vast area (Petterson et al., 2003; González et al., 2006). Recent data on the Gulf of Mexico, Baltic and West Mediterranean Seas confirmed the crucial effect variable weather and oceanographic conditions have on oil slick movement and biodegradation (e.g., Cucco et al., 2012; Soomere et al., 2014; Prince, 2015).

Important re-circulation and scattering of oil by natural processes occurred during the Deepwater Horizon spill of 2010 (Atlas and Hazen, 2011; Thibodeaux et al., 2011). During its mitigation, real-time modelling of chemically dispersed oil under variable weather and oceanic conditions was paramount to the monitoring of ensuing environmental impact(s). For instance, the anionic surfactant DOSS (dioctyl sodium sulfosuccinate) included in chemical dispersants was found to be sequestered in deepwater hydrocarbon plumes at 1000–1200 m water depth. DOSS recorded a conservative transport and dilution (<1 ppm of oil) at depth, but persisted up to 300 km from the Deepwater Horizon platform some 64 days after dispersant applications ceased into the flow of oil near the seafloor (Kujawinski et al., 2011). Importantly, DOSS was selectively associated with the oil and gas phases in the deepwater plume, but recorded negligible (or slow) rates of biodegradation in the affected waters. DOSS concentrations and dispersant-to-oil ratios were lower than those tested in published toxicology data, but hint at significant movement of other hydrocarbon solvents in the water column after major oil spills (Kujawinski et al., 2011).

In the Baltic and Western Mediterranean Seas, statistical analyses of oil spill trajectories allowed the identification of areas

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where the impact of spilt oil is more significant (Chrastansky and Calles, 2009; Soomere et al., 2010; Lu et al., 2012; Olita et al., 2012; Soomere et al., 2014). These same statistical analyses confirmed the unpredictability of oil spill movement in extreme weather conditions, and the sensitivity of deterministic circulation models to small variations in the initial and forcing conditions (Griffa et al., 2004; Ciappa and Costabile, 2014). The understanding of small variations in circulation models was recognised by the latter authors as being paramount in the management of civil protection teams, often with limited resources and equipment, during the mitigation of large oil spill accidents.

As with the Gulf of Mexico, Baltic and Western Mediterranean regions, the variable weather conditions known to the Eastern Mediterranean Sea make the real-time prediction of oil spill movement crucial to prevent and mitigate major pollution events. Comprising one of the busiest shipping corridors in the world (REMPEC, 2002), weather and sea current patterns in the Eastern Mediterranean can vary significantly from summer to winter, and during storms, at times hindering mitigation procedures from civil protection authorities (POEM Group, 1992; Pinardi et al., 2006; Zodiatis et al., 2005, 2010; 2013; Menna et al., 2012). Challenging weather conditions can also be recorded during summer, as shown recently in the Ammochostos Bay. The northern part of Ammochostos Bay in Cyprus experienced a spill of 100 tonnes of heavy oil with 26° API, on 15 July 2013, during the upload of crude oil from a tanker in strong breeze (Beaufort 6) conditions (https://weatherspark.com/history/32006/2013/Larnaca-Cyprus). Large oil spills in challenging weather conditions were also recorded offshore Greece in the Bay of Pylos (1980), in Lefkandi and Kythira (2000) and in smaller, but rather common, accidents in the Aegean Sea (Giziakis et al., 2013). The largest platform accident in the Eastern Mediterranean was the 2004 Adriatic IV jack-up rig explosion, in which no oil spill ensued (Vinnem, 2014). In contrast, the bombing of the Jiyeh power station in Lebanon in 2006 resulted in the release of 15,000–20,000 tonnes of oil (Coppini et al., 2011). In the Eastern Mediterranean region, the importance of oil spills is enhanced when considering acute pollution events such as the Lebanon 2006 oil spill, or potential collision accidents in what is a major route for oil and gas tankers from the Middle East to Europe and North America (UNEP/MAP, 2012).

This paper presents the results of 104 new oil spill simulations, bathymetric analyses and shoreline susceptibility maps for the region spanning the Mediterranean coasts of Cyprus, Egypt, Israel, Lebanon, Syria and Turkey (Fig. 1a). The aim is to understand oil spill movement and scattering in offshore regions where exploration drilling has been equated, or has occurred in the past, so that the best practices are suggested to civil protection authorities in the Eastern Mediterranean (and other confined seas) to control, and clean, remote oil spills, either maritime or platform related. In summary, this work addresses the following questions:

a) How quickly spilt oil will reach the Eastern Mediterranean shores under known oceanographic and meteorological conditions?
b) In what direction(s) spilt oil will be dispersed before reaching the shore, and for how long it will remain at sea?
c) In light of the new model results what will be the best mitigation techniques to prevent large quantities of oil reaching the Eastern Mediterranean shores?

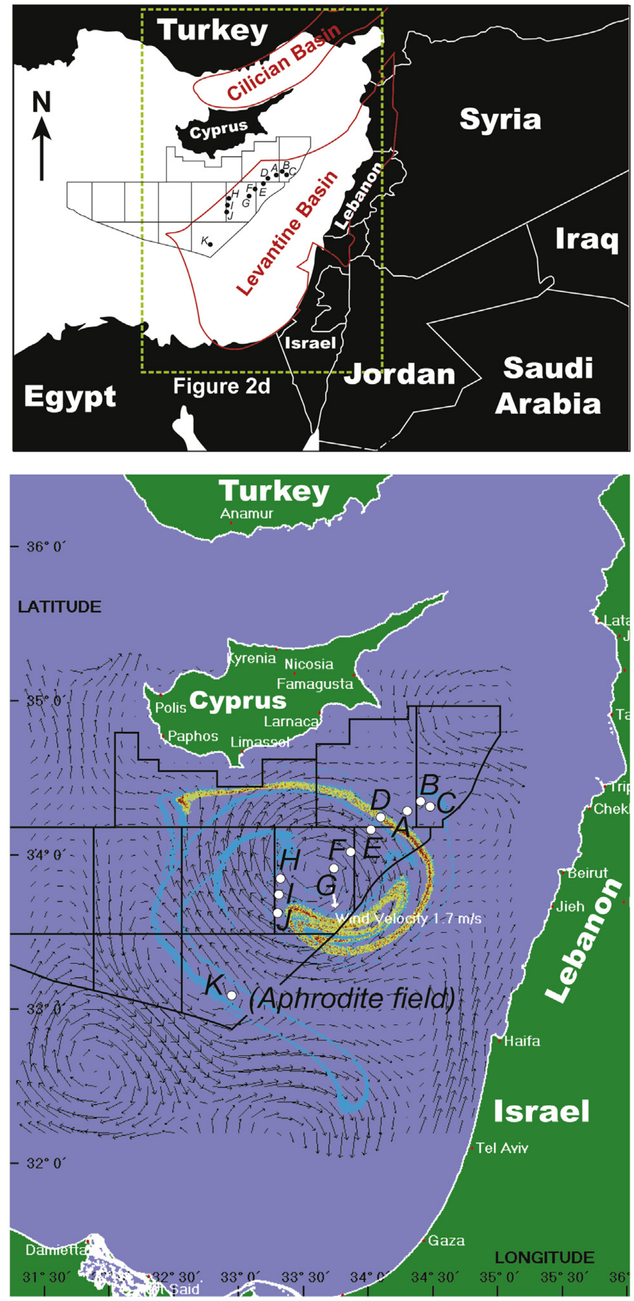

Figure 1

Fig. 1. (a) Location map showing the study area relative to the Cilician and Levantine Basins, Eastern Mediterranean Sea. The area analysed in this work is highlighted by the green box. The geometric areas south of the island of Cyprus highlight current hydrocarbon exploration blocks south of Cyprus. Locations A to K are also shown in the figure. (b) MEDSLIK model of slick diffusion under late spring conditions (01 June 2013 to 30 June 2013) for an oil spill accident originated at the Aphrodite field. The model considered a release of Belayim oil (API 23.5°) for 50 days, at a rate of 8000 m^3/day. Average wind velocities of 1.7 m/s blow in a northerly direction during the accident. The model shows that surface currents will cause widespread scattering of the oil slick by current eddies. Locations A to K, as well as hydrocarbon exploration blocks south of Cyprus, are highlighted in the figure. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

2. Datasets and methods

The data in this paper were analysed using the methodology in Lardner and Zodiatis (1998), which was updated to accommodate the processing of bathymetry data for the Eastern Mediterranean Sea (see Section 3). Physical parameters, such as wind direction, ocean circulation and wave direction were taken into account in the models compiled, as illustrated in Supplementary Fig. 1. In summary:

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