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Oil spill contamination probability in the southeastern Levantine basin

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ABSTRACT

Recent gas discoveries in the eastern Mediterranean Sea led to multiple operations with substantial economic interest, and with them there is a risk of oil spills and their potential environmental impacts. To examine the potential spatial distribution of this threat, we created seasonal maps of the probability of oil spill pollution reaching an area in the Israeli coastal and exclusive economic zones, given knowledge of its initial sources. We performed simulations of virtual oil spills using realistic atmospheric and oceanic conditions. The resulting maps show dominance of the alongshore northerly current, which causes the high probability areas to be stretched parallel to the coast, increasing contamination probability downstream of source points. The seasonal westerly wind forcing determines how wide the high probability areas are, and may also restrict these to a small coastal region near source points. Seasonal variability in probability distribution, oil state, and pollution time is also discussed.

1. Introduction

The infamous BP/Deepwater Horizon Oil and Gas Disaster in the Gulf of Mexico in 2010 (Norse and Amos, 2010) provides a notorious example for environmental damages that might result from oil and natural gas exploration and drilling activities. Oil and gas exploration and production have been established in several areas of the Mediterranean Sea for several decades (Belopolsky et al., 2012; Stocker, 2012). Exploration in the Nile Delta has moved from onshore to offshore areas in the 1980s, and technological advances have since enabled exploration and drilling to be used in deep waters, greatly enhancing the proven reserves of natural gas in the area. Given the unique biodiversity of the Mediterranean Sea, and the intensity of human activities in the Mediterranean, it is highly important to better understand the possible impacts of oil and natural gas activities.

As defined in the 1982 UN Convention on the Law of the Sea (UNCLOS), a coastal state has sovereign rights to explore and exploit, conserve and manage the natural resources in its exclusive economic zone (EEZ) (Kwiatkowska, 1991). Under UNCLOS, the EEZ can extend to a maximum distance of 200 nautical miles from the country's baseline.

Following the discoveries of very large gas fields during 2009–2010 in the Israeli EEZ (Fig. 1) there has been an increase in oil and gas exploration and gas production activities (Shaffer, 2011; Ratner, 2011). This increase in offshore exploration and production activities brings new challenges to decision makers with regards to conservation efforts, marine safety, and environmental protection. With increased oil and gas operational activity there is also an obvious increase in the risk for oil or other hydrocarbon pollution. Modelling tools enable us to create high resolution probability estimates for regions that might be affected by oil pollution. The resulting probability maps are therefore extremely important to decision makers when forming plans for marine protected areas, placing new infrastructures, or enacting protocols on handling marine pollutions.

The use of numerical models to estimate the wind and ocean currents, which determine oil slick trajectories, has been growing in recent years: Some individual oil spill events that have occurred in the Mediterranean Sea have been simulated (e.g. the Lebanon crisis oil spill in 2006 (Coppini et al., 2011)) and operational systems such as the Mediterranean Decision Support System for Marine Safety (MEDESS-4MS) (Zodiatis et al., 2012) make use of high resolution ocean forecast models to simulate new spills as they are reported. It is also common to simulate worst case oil spill scenarios for risk assessment.

The aims of this study are: (1) to estimate the location of regions in Israel's EEZ that have a high probability of being contaminated by an oil slick. (2) To relate the spatial distribution of these regions to

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the initial position of the spill and to the synoptic state (atmospheric and oceanic conditions), so as to improve Israel's preparedness for the event of an oil spill. For this end, we produce statistical estimates of probability based on the simulation of a large number of virtual oil spills which are transported by realistic wind and ocean currents. In that, we follow techniques similar to the ones which have been used in the gulf of Mexico by OSRA (Price et al., 2003), or in archipelago of La Maddalena, located in the northern extremity of Sardinia Island by Olita et al. (2012). Our work is also related to the work of Ferraro et al. (2009) who used radar based remote sensing of possible oil slicks to estimate the density of oil spills in the Mediterranean, as well as in other European seas. However, their work was based on actual observations which were mapped over a much coarser resolution (1°) than the one used in our work.

The manuscript is ordered in the following way: in Section 2 we review the main characteristics of the regional atmospheric and oceanographic circulations. In Section 3 we briefly describe the numerical models used in simulating the oil spills and the calculation of oil pollution probabilities. In Section 4 we present and discuss the probability estimates, their seasonality, and their relation to the weather and ocean circulation patterns. We conclude in Section 5.

2. Regional atmospheric and oceanic systems

2.1. Regional meteorology

In our analysis of the results, we consider the following regional atmospheric and oceanic circulation patterns. The weather in the south eastern Mediterranean is characterized by 6 major synoptic systems (Alpert et al., 2004).

1. Cyprus lows – winter low pressure storms whose center travels east in the northern part of the basin. The winds southeast of the center are southerly to easterly winds, whereas strong westerlies blow west of the cold front.
2. Persian trough is a persistent weather system occurring during summer. It is characterized by westerly wind.
3. Red Sea trough (RST also known as Sudan trough) – this trough extends north from the Red Sea during the cold season. The axis of the trough separates the easterly wind east of it from the northerly wind west of it. The position of this axis, east or west of the coastline, greatly determines the coastal weather.
4. Sharav lows or khamsin lows, which are common in spring, are thermal low pressure systems whose center travels east along the southern coast of the Mediterranean. They induce easterly winds over the sea east of their center and north-westerly wind west of their center.

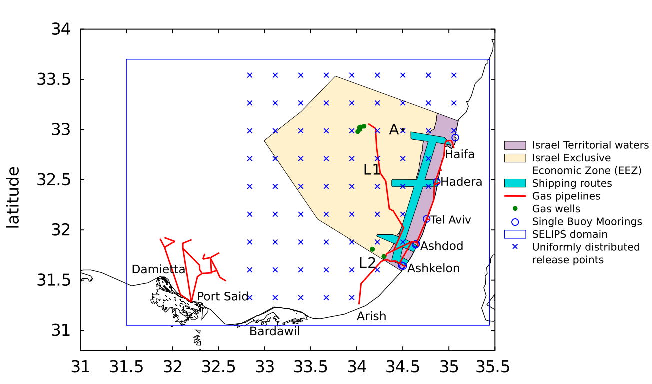

Fig. 1. Infrastructure in the south eastern corner of the Mediterranean near Israel's proposed exclusive economic zone. L1: Tamar gas pipeline. L2: Arish–Ashkelon pipeline.

5. Siberian high, is a system which is usually characterized by northerly winds along the Israeli coast.
6. Subtropical high, is a system which is usually characterized by calm weather.

2.2. Regional ocean circulation

A major feature in the circulation at the sea surface of the south-eastern Mediterranean Sea is a cyclonic along-slope current flowing over the shelf and slope areas (Rosentraub and Brenner, 2007). This current is persistent throughout most of the year, though it may be interrupted by episodes of southward flow. Suggested causes of such episodes include strong easterly and northerly winds typical to the RST, as well as the influence of off-shelf anticyclonic eddies (Rosentraub and Brenner, 2007). The maximal velocity is usually attained during summer or during storm events (values as high as 1 m/s have been observed during winter (Rosentraub et al., 2010)). The meandering of the along-slope current has been shown to be related to the exchange of coastal and deep water in either the detachment of the anticyclonic Shikmona eddy near Haifa bay (Gertman et al., 2010) or the formation of filaments of coastal waters intruding to deep waters (Efrati et al., 2013). Beyond the slope area, the flow is not characterized by a single permanent feature, but rather by an area populated with dynamic meso-scale eddies (Amitai et al., 2010). The circulation in this area, on average, is anticyclonic, but can be locally interrupted by cyclonic mesoscale patterns. Particularly, the area between latitudes 33° N and 35° N and east of 32° E, which includes the Eratostenes sea-mount, is a known location of recurring anticyclonic eddies (Shikmona/Cyprus eddies). As discussed by Menna et al. (2012), this area can contain one or two eddies.

3. Methods

In this study we performed numerical simulations of oil spill events in order to estimate the probability of different areas being polluted by oil. We treated different scenarios, each characterized by the spill event's proximity to different possible sources of pollution: shipping routes, pipelines, gas wells, single buoy moorings (SBM) and even distribution in space (Fig. 1). From each of these scenarios, a group of spill events was generated with either random or even distribution. Ideally, the scenarios should account for all the possible synoptic weather and ocean current patterns which influence the trajectory of the oil slick. In practice, we sampled the synoptic conditions by sampling the time of the initial spill from a year of atmospheric and ocean forecasts. Specifically, we used the SKIRON operational atmospheric forecasting system and the SELIPS circulation forecasts from September 2012 to August 2013 to provide wind and currents to the MEDSLIK oil spill model. Cutting off in August was motivated by the low variability in the atmospheric forcing during this time. We have not considered gas leaks, liquid natural gas spill or gas well blow-outs. We did this because the area affected by such events is expected to be relatively small (e.g., Hightower et al. (2004) recommend a hazard radius from liquid natural gas spill to be 2500 m) and the gas is expected to evaporate and disperse in the atmosphere quickly.

In Sections 3.1 and 3.2 we describe the atmospheric and oceanic models used. MEDSLIK is described in Section 3.3. Section 3.4 describes how oil spill events were sampled and analysed.

3.1. Atmospheric model – SKIRON

The SKIRON system has been developed by the Atmospheric Modeling and Weather Forecasting Group in the university of Athens (Kallos et al., 1997). SKIRON provides daily atmospheric