Battlespace on Demand for Maritime Threats: Mine/IED Drift in the Strait of Hormuz and near Iraqi Oil Terminals

Peter C. Chu[1], C.L. Williams[1], T. Clem[1], S.D. Haeger[2] & M. Ward[3]
[1)] *Naval Ocean Analysis and Prediction Laboratory, Naval Postgraduate School, Monterey, California, USA*
[2)] *Naval Oceanographic Office, Stennis Space Center, Mississippi, USA*
[3)] *Applied Science Associates, Inc., Narragansett, Rhode Island, USA*

Abstract

An attack by drifting mines and or improvised explosion devices (IEDs) in the Strait of Hormuz or near Iraqi Oil Terminals in the northern Persian Gulf has disastrous effects on global economy and military operations. Such impacts are highly dependent upon environmental conditions. The Strait of Hormuz is narrow and has turbulent currents that change in intensity and direction due to the reverse estuarine flow of the Persian Gulf. On the border between extratropical and monsoonal atmospheric synoptic influences, the wind direction and intensity are dependent on time of year, which side of the strait due to terrain, and time of day due to land/sea breeze cycles. Mine/IED drift trajectory is analyzed utilizing a Lagrangian drift model with inputs of surface winds and currents from the Naval Oceanographic Office and the Fleet Numerical Meteorology and Oceanography Center, followed by comparative analysis with climatology inputs. The results show that the variable nature of the wind/current direction and speed through the strait and in the Gulf is impossible to capture using climatology inputs. Therefore, using operational, near real-time environmental data is necessary for information superiority.

Keywords: Battlespace on Demand, Mine/IED Drift Prediction, COMPS, NCOM, Persian Gulf, Strait of Hormuz

1. Introduction

The Persian Gulf, also known as the Arabian Gulf, is a semi-enclosed marginal sea connected to the Indian Ocean through the Strait of Hormuz with the major axis tending in the NW-SE direction (Fig. 1). The Persian Gulf is approximately 990 km long; the maximum width is about 338 km. The estimated surface area and volume of the gulf are around 239,000 km^2 and 8,630 km^3, respectively, which correspond to a mean depth of close to 36 m. The maximum depth is around 100m near the Strait of Hormuz, with the Gulf of Oman (GOO) being much deeper. The major axis of the basin separates a relatively deeper channel near Iranian coast from the shallow Persian shelf that slops gently towards the axis.

In the current threat environment, a mine or improvised explosion device (IED) attack on the economic lifeline of Iraq is anything but impossible. Since this study is unclassified, it is not permitted to use elements, which would be used in the case of an actual attack; however using a simple drifter can give a good impression of the vulnerabilities to a drifting mine/IED attack. Understanding the oceanographic effects on drift mining could mean the difference for a faster recovery from an incident at this choke point. The faster the mine clearing, the faster shipping and maritime patrol can resume. Numerical models of drift tracks for mines and oil spill dispersion are currently available. The environmental inputs of current and wind speed that are vital to the performance of those models. Thus, the better the environmental data and models, the more accurate predictions are for dealing with mine/IED drifting.

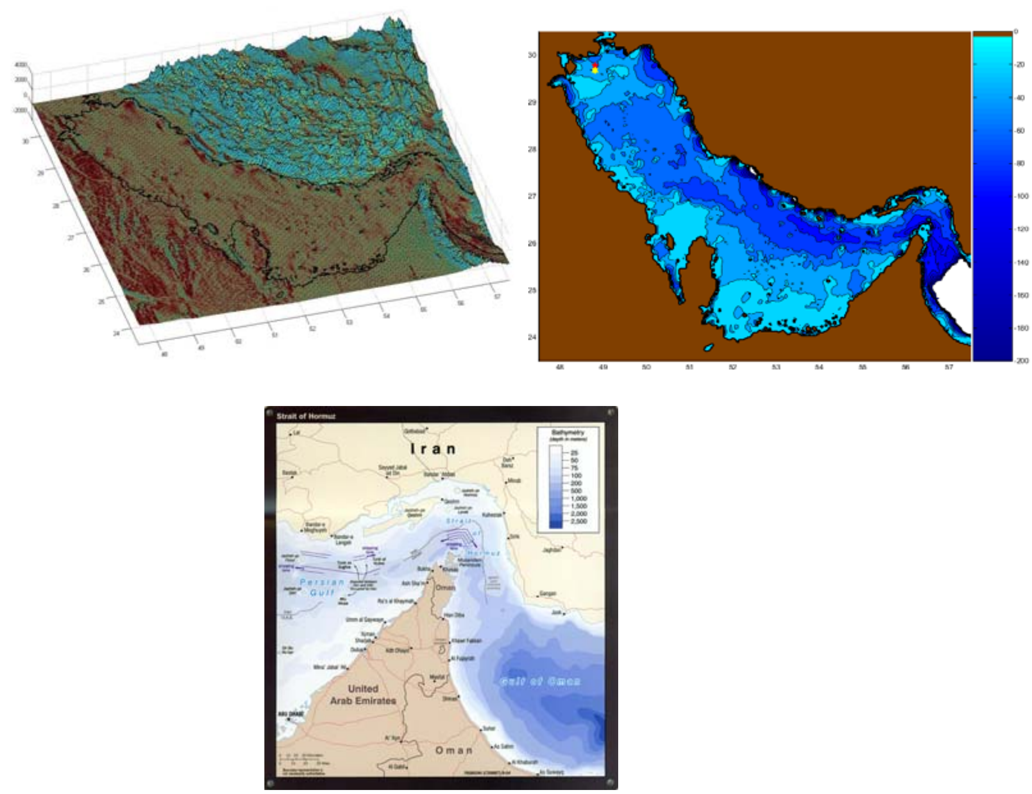

Figure 1: Topography and bathymetry in Persian Gulf.

Recently RAML Titley at the Commander Naval Meteorology and Oceanography Command (CNMOC) propose the concept of “Battlespace on Demand” (Fig. 2), which effectively supplies combatant commanders with information superiority over the entire area of operation. This concept contains three tiers, which include: (1) Environment Layer, (2) Performance Layer, and (3) Decision Layer. This study utilized this concept in the analysis of the data with respect to the mine/IED drift scenarios. The ability to add value by using real-time or climatological data was of interest when analyzing the scenarios.

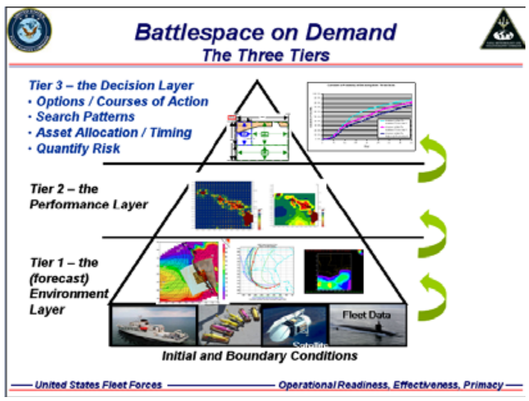

Figure 2. Three Tiers of Battlespace on Demand (From RAML David Titley, USN, 2008).

2. Ocean-Atmospheric Nowcast/Forecast System

This study utilizes ocean-atmospheric model to predict mine drifting. This system contains: (1) the atmospheric part of the Navy's Coupled Ocean Atmospheric Mesoscale Prediction System (COAMPS), and (2) the Navy's Coastal Ocean Model (NCOM).

2.1. COAMPS

The atmospheric part of COAMPS (Hodur, 1997[3]) is comprised of the nonhydrostatic, fully compressible equations of atmospheric motion, thermodynamics, and continuity. The transformation of the vertical coordinate is applied to map the lowest coordinate surface to an irregular lower boundary

$$\sigma = z_{top}\left(\frac{z - z_{sfc}}{z_{top} - z_{sfc}}\right), \quad (1)$$

where z_{top} is the depth of the model domain and z_{sfc} is the height of the topography. Both the horizontal and vertical grids in the forecast model are staggered. The horizontal grid uses the Arakawa-Lamb C-staggering scheme. COAMPS uses a level 2.5 scheme (Mellor and Yamada 1982[4]) that solves both a prognostic equation for turbulent kinetic energy (TKE) and diagnostic equations for second-moment quantities such as primarily fluxes of heat, moisture, and momentum. The surface layer parameterization follows the Louis (1979) scheme, which uses polynomial functions of the bulk Richardson number to directly compute surface sensible heat flux, surface latent heat flux, and surface drag.

Although the equations are solved on a staggered C-grid, the atmospheric data assimilation using COAMPS is performed on the Arakawa-Lamb A-grid (i.e., no grid staggering). The bicubic spline interpolation is used to interpolate the analyzed fields to the C-grid within the forecast model code. The COAMPS analysis is based on the multivariate optimum interpolation (MVOI) analysis scheme. Observational data include the following data types: (1) Radiosonde, (2) Pibal, (3) Surface land, (4) Surface marine, (5) Aircraft, and (6) Satellites (including SSM/I, Scatterometer, Sea Surface Temperature, and QUIKScat).

2.2. NCOM

NCOM is built based on the Princeton Ocean Model (POM, Blumberg and Mellor, 1987) with the main differences in data assimilation. The principal attributes of the model are as follows: (1) it contains an imbedded second moment turbulence closure sub-model to provide vertical mixing coefficients. (2) It is a sigma coordinate model in that the vertical coordinate is scaled on the water column depth. (3) The horizontal grid uses curvilinear orthogonal coordinates and C-grid. (4) The horizontal time differencing is explicit whereas the vertical differencing is implicit. The latter eliminates time constraints for the vertical coordinate and permits the use of fine vertical resolution in the surface and bottom boundary layers. (5) Complete thermodynamics have been implemented. The basic equations have been cast in a bottom following, sigma coordinate system,

$$x^* = x, \quad y^* = y \quad, \sigma = \frac{z-\eta}{H+\eta}, \quad t^* = t \,, \tag{3}$$

where (x, y, z) are the conventional Cartesian coordinates; where $H(x, y)$ is the bottom topography and $\eta(x, y, t)$ is the surface elevation. The reader is referred to Blumberg and Mellor (1987) for a derivation of the basic equations in sigma coordinate system.

3. Mine/IED Drift Modeling and Scenarios

Applied Science Associates (ASA) has been developed a numerical model (CHEMMAP^{TM}) to predict particle trajectory and fate of a wide variety of chemical products. For the mine/IED drift, the scenario started with a generic iron filings particle in CHEMMAP. To simulate an actual mine the diameter of the particle was enlarged to 1.0 m. Since iron is much denser than water, the density of the particle had to be modified as well. To allow the particle to float on the surface and simulate a possible generic floating mine the density was changed to the sea water density. The scenario also included inserting numerous mines running the scenario and then changing location and repeating the process. Times for the model runs were longer for Mine Warfare (MIW) scenarios than for the other scenarios. This was due to the fact that once a mine is placed in the water it does not degrade but remains until it is either hit, washed ashore, or sinks. As such scenarios length of the scenario was based more on operational planning than on anything else.

Greer and Bartholomew (1986) [5] declared that the most effective use of mines as a deterrent was overt mine laid and that if ship destruction was desired that covert mine was best. The scenario dealt with here is the second form. By causing destruction, terrorists feel they can get their needs addressed and the world attention they desire. This also gives plausible deniability to state actors; who may not want direct conflict with a world class military superpower such as the U.S., yet may want to damage an opponent's resolve. The mines/IEDs utilized are of the low-technology, contact-type, deployed from a civilian vessel or unobtrusive vessel that blends with normal SOH traffic. This could be a fishing vessel or high speed craft. Avery (1998) noted that "Practically any surface platform, including fishing boats, patrol craft and merchant vessels" could be easily modified to carry naval mines; hence, the choice of deployment. The usage of drift mines/IEDs is with the assumption of range and lack of discrimination for target. Any hit is a good hit in this case as the idea is for chaos to ensue. Couple this with the possible economic and political fallout and the message would be sure to be heard.

The scenarios are run for 48 hours since that is the longest forecast ability for currents immediately available and we are intending to compare to climatology. The "climatology" used was just the six month mean propagated over the six month term. In reality the climatology would not be available for currents. Four release times were picked for variety of current profiles for the "real" data runs. Only one run was required for the "climatology" portion since the output would be the same no matter the time started. Comparisons of the "real" to "climatology" were then compared.

4. Mines/IEDs Release Locations

The primary scenario was for a newly laid drifting mine, and could be examined in several different ways. Some of these could be: (1) if one mine was placed in the water, where is it likely to travel; (2) if a large amount of mines were placed in the water, where would they go and how much would they spread; and lastly (3) given that a mine is going to be placed in the water, where is the worst case scenario for Iraq's oil terminals, or is there a place that the oil terminals would be affected (Williams, 2007 [6]). Drifting mine scenarios were run using different locations around the northern Persian Gulf (Fig. 3a). When the mines/IEDs were released from locations south of the oil terminals the mines drifted away from them and never affected the oil terminal operations. For the climatological runs, no matter where the mines were placed, they followed the same pattern as will be discussed for the release near the oil terminals. This was primarily due to the nature of climatological forcing. When examining scenarios with COAMPS and NCOM inputs, the worst case scenarios involved mines/IEDs originating near the oil terminal.

(a) (b)

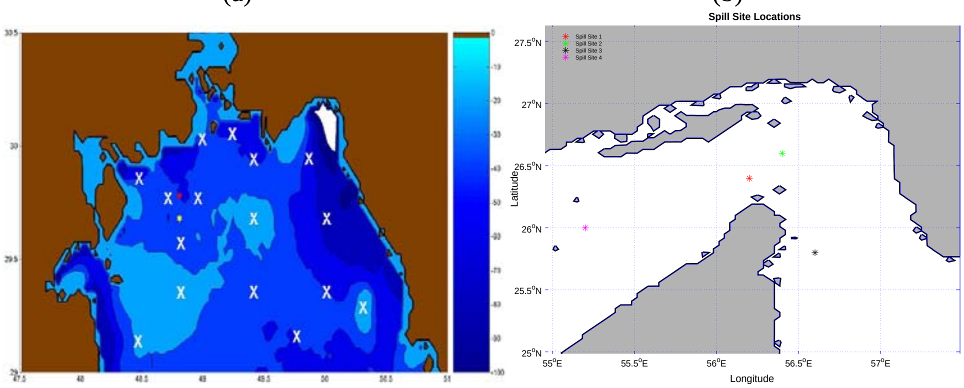

Figure 3. Mine/IED drop-off points utilized during the drift scenario model runs: (a) northern Persian Gulf with white X's mark mine/IED drop locations, while the two stars represent oil terminal locations (from Williams, 2007), and (b) Strait of Mormuz with circles indicating the mine/IED drop location (from Clem, 2007).

Either a terrorist from any number of organizations currently in play, or accidents on oil shipping through SOH (Clem, 2007 [7]), will cause severe oil spill and hamper the movement of shipping, civilian and military, through the SOH. We choose four particular locations on both the eastern and western legs of the SOH in or near the transit lanes. Additionally, two locations near the tip of the Musandam Peninsula as the shipping lanes are tightest through that area. This covered most of the region's flow regimes and gave a wide look to possible outcomes. Fig. 3b shows the locations of the four sites chosen. Sites 1 and 2 are at the tip of the peninsula, Site 3 is on the eastern leg towards the GOO, and Site 4 is on the western leg. These sites are close to the grid points of COAMPS and NCOM.

5. Ocean Environment

The ocean-atmospheric circulation models are running operationally in the Fleet Numerical Meteorology and Oceanography Center (for COAMPS) located in Monterey California and in the Naval Oceanographic Office (for NCOM) located at the Stennis Space Center in Mississippi with a 24 hr hindcast and 48 hr forecast. Data from the six month period (00UTC February 1 to 24UTC July 31, 2006) are selected for the analysis. In this study, temporally averaged fields over the whole six month period is taken as 'climatological' (Fig. 4).

(a) (b)

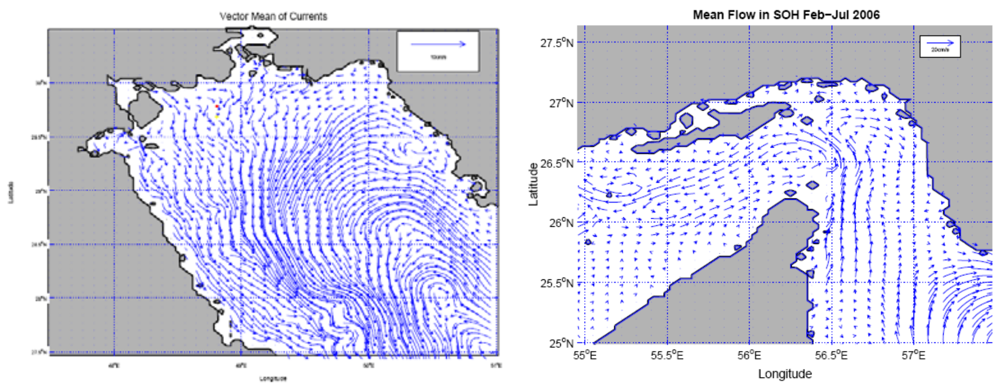

Figure 4. 'Climatological' mean (over 1 Feb to 31 July 2006) currents at 5 m depth: (a) northern Persian Gulf, and (b) Strait of Hormuz.

For tidally dominated Persian Gulf, the (de-tided) mean flow (daily, monthly, or climatological) is much weaker than the instantaneous flow. The magnitude of 'climatological' currents is around 10 cm/s. To investigate the temporal and spatial variability of winds and currents, we analyze the data for the area from 23.5°N to 30.5° N and 47.5°E to 57.5°E from the COAMPS-NCOM. The horizontal resolution of the operational model is 2 km. The temporal resolution is 1 hr. Here, we take the SOH as an example for illustration. Four patterns of variability in winds and ocean currents are found. They are: (1) low winds/low currents, (2) low winds/high currents, (3) high winds/low currents, and (4) high winds/high currents.

Each combination sought to establish extremes encountered in the environment to highlight differences from climatology. Time series of wind and current at all four of the selected spill sites are constructed and then compared to come up with the combinations necessary for evaluation. Each combination of high and low for wind and current was sought at each spill site to cover a five day period optimally. We only show the environments for the site-1 (Fig. 5) in the Strait of Mormuz.

High current was defined as greater than or equal to 60 cm/s. Coinciding low wind and high current events were found in July for Sites 1, 3, and 4 covering the period 8 to 17 July. Site 2 had an acceptable event from 1 to 6 June. High wind (defined as wind greater than or equal to 10 m/s) and low current events were almost identical for the first three sites and covered the period of 21 to 27 March. Site 4 had a coinciding event during the period of 17 to 22 February.

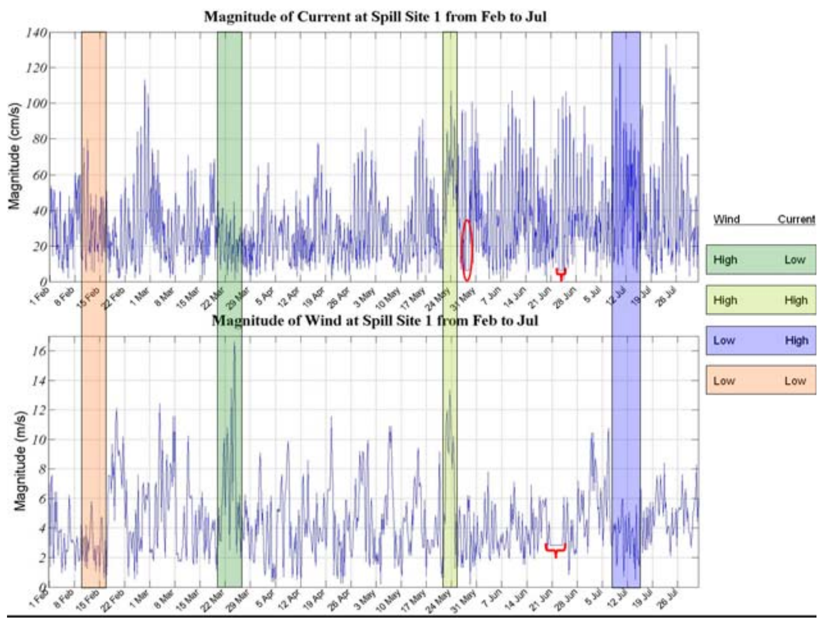

Figure 5: Time series of ocean surface current speed (upper panel) and wind speed (lower panel) at site-1 predicted by NCOM and COAMPS model. Four types (low High current winds/low currents, low winds/high currents, high winds/low currents, and high winds/high currents) are identified.

6. Environmental Impact on Mine/IED Drift

In the Persian Gulf, as with most of the world, sporadic current observations are usually accomplished during set research studies. Operationally, this presents a problem when in the planning phase. What would the planners' tactics be to account for currents in the Persian Gulf, when none are available? In all likelihood either a tidal model or a cyclic current would be used as inputs into the mine/IED drift models for planning purposes. With this concept in mind, several scenarios were used around the oil terminals in northern Persian Gulf, and Strait of Hormuz to simulate planning scenarios.

With the climatological scenario, regardless of where the mines/IEDs were placed they felt the same force. Under these conditions, little dispersion would be expected (Fig. 6a). For the minimum wind and weak current scenario, the mines felt different currents depending on where they were located. This meant if the starting point was shifted, mines/IEDs would experience different forcing, therefore could be disperse more. The fact the timeframe examined was a period of low currents, factored in to the amount of dispersion. As the other scenarios will illustrate, the low wind and weak current scenario had the least dispersion of all the scenarios. It also had the least movement, as would be expected (Fig. 6b).

High winds and low currents occur from July 3 to July 10. The mine/IED trajectories (Fig. 6d) are quite different from the climatological forcing (Fig. 6a) with larger mine/IED dispersion, but less traveling distances. The criterion for high currents combined with high winds was seen once from 9 until 16 June (Fig. 6c). This led to a shorter distance traveled with the same dispersion seen in the July scenario (Fig. 6d). This includes forming a line similar to the July event. The main difference is that the line would form, break apart and then reform.

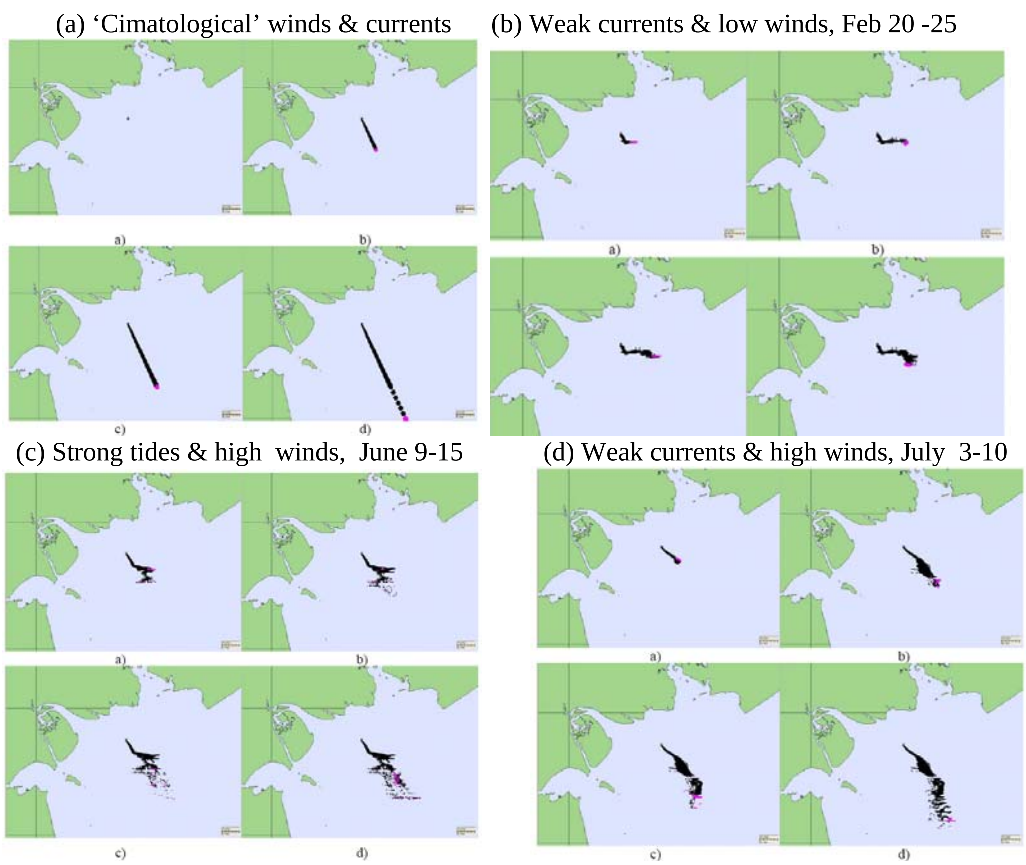

Fig. 6. Mine/IED trajectories under different scenarios: (a) climatological winds and currents, (b) weak currents and low winds (Feb 20-25), (c) strong tides and high winds (June 9-15), and (d) weak currents and high winds (July 3-10).

7. Conclusions

The Strait of Hormuz is a vital flow point for oil and natural gas which supplies the majority of the world with energy. Any halt to the flow of the resources exiting the Gulf via the SOH is tantamount to a world economic crisis. Once flow is stopped, criticality of the amount of time to transit recommencement can not be easily estimated. Through the use of sophisticated numerical modeling and data analysis methods, oceanographic and atmospheric models are among the best in the world.

Our study shows conclusively that the tidal forcing, along with variable winds are important for a better prediction of mine/IED trajectory. Without the tidal forcing the mine/IED is unidirectional and lacks the speed change associated with the inflow and outflow regime peaks. Essentially, the utilization of climatology currents is worse than a guess for oil slick prediction. In a reverse estuarine flow such as is found in the Strait of Hormuz, the tidal influence cannot be ignored. Realistic wind forcing is also a necessary feature.

From analyzing the movement oil under the influence of wind and currents we found that winds greater than 5 m/s can significantly alter the course of mine/IED. However, if the mean wind is an indication of the overall tendency of the strength of winds through the SOH (~ < 5 m/s), then it is the current that is the primary driving force for the course of oil spills in the SOH.

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