Numerical Simulation of Oil Spill in Nanri Island Channel Based on the MIKE Spill Analysis Model

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Abstract: Based on the MIKE spill analysis model, the oil spill model was built in the sea area around Nanri Island, and then the drift path and the influence of oil film were simulated under the dominant wind conditions (the northeast wind). Ten tons of fuel oil was set as the initial spill to model the oil-spill diffusion process over 48 hours. The results showed that the oil spill drift in the sea was mainly influenced by tide and wind, while the tide played a dominant role. The migration trend of the oil film was different under different wind conditions. The total area after oil spill was 190.81km^2, 142.95km^2 and 11.71km^2 under the dominant wind conditions with oil concentration exceeded 0.05mg/L, 0.3mg/L and 0.5mg/L, respectively. In general, the oil film covered largest area when oil spill happened at high tide moment under the dominant wind. The predicted results could provide technical support for the oil spill emergency decision-making and its damage assessment.

1 INTRODUCTION

Over the past few decades, with the rapid development of the global marine economy, many oil spill accidents have frequently occurred in the sea. Marine oil spill can significantly impact the coastal and estuarine environment, which cause damage to the ecosystem, beaches, coastal wetlands, fisheries and water supplies(Wang et al., 2008; Griggs, 2011). Recently, scientific studies on marine oil spill prediction techniques play a key role to ensure the emergency plans can be implement successfully (Li et al., 2017). In the past two decades, some oil spill simulation models have been developed and the technology in oil spill model has been reviewed by researchers(Wang and Shen, 2010; Liu and Sun, 2009). Some mature oil spill models such as OILMAP, OSIS, OSCAR, MOTHY have been widely adopted in the oil spill prediction and response for the coastal areas (Zhou and He, 2018; Reed et al., 1999). The study on simulation of oil spill in China began in the 1980s, which was successfully applied in Pearl River Estuary(Xiong et al., 2005), Yangtze River Estuary(Yang et al., 2013), Bohai Bay(Zhang and Wu, 1998), Jiaozhou Bay(Lou et al., 2001) and Meizhou Bay(Zhao et al., 2011). There are many numerical studies on oil spill behavior in the offshore and estuary waters, but there are only a few reports on numerical simulations of oil spills in the sea near islands. The MIKE spill analysis (MIKE SA) module in this study was used to simulate oil spills and applied to the sea areas around Nanri Island to predict the impact of oil spills under different weather conditions. The predicted results could provide technical support for the oil spill emergency decision-making and its damage assessment, which may reduce the impact of the oil spill accident on the marine environment and improve the emergency capacity for environmental risk management.

2 THE MIKE SA MODEL

The MIKE SA module uses the "oil particle" approach to simulate the spatiotemporal behavior of oil spills in the sea. Based on the Lagrangian theory(Chao et al., 2001), the model predicts the weathing of oil particles over time by predicting drift, diffusion, turbulent diffusion (fluid and wind field effects), evaporation, emulsification, and

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dissolution of oil particles in the sea, simulates location, degree and scope of influence, thickness of oil film. In addition, the model has a complete pre- and post-processing module that can quickly process the results file to service decision-making system. The model has had many successful application cases (Xu, 2011; Jiang, 2007) around the world.

The oil spill processes of MIKE SA module, mainly includes advection, horizontal turbulent diffusion and expansion processes.

2.1 Advection Process

Flow and wind stress are the main forces that lead to the drift of oil particles. The advection velocity of each grid point (U_t)can be computed as:

$$U_t = C_w \cdot U_w + U_s$$

Where, U_w is the wind velocity at 10 m above the water surface (m/s); C_w is the wind drift factor, usually abopted as 0.03~0.04; U_s is the surface water current velocity, which can be obtained from the 3-D turbulence tidal model (Chao, 1999).

2.2 Horizontal Turbulent Diffusion

The turbulent diffusive transport is normally calculated by a random walk procedure. Based on Al-Rabeh et al.'s study (Al-Rabeh et al., 1989), the distance that any oil particle travels by horizontal diffusion is:

$$S_\alpha = [R]_{-1}^{1}\sqrt{6D_\alpha \cdot \nabla t_p}$$

where $[R]_{-1}^{1}$ is the random number in the interval [-1,1]; D_α is the horizontal diffusion cofficient and ∇t_p is the time step (s).

2.3 Spreading on the Water Surface

Spreading is the horizontal expansion of oil slick due to gravity, inertia, viscous and surface tension forces. A modified Fay-type spreading equation is as follow:

$$\frac{dA}{dt} = K_a \cdot A^{\frac{1}{3}}\left(\frac{V}{A}\right)^{\frac{4}{3}} \qquad (1)$$

Where A is the area of the oil slick (m^2); K_a is a coefficient; V is the oil volumn; t is time in seconds.

3 HYDRODYNAMIC MODEL AND MODEL VALIDATION

3.1 Hydrodynamic Model

In this paper, MIKE model was selected as the hydrodynamic forecast component around Nanri Island area. The simulated area include Meizhou Bay, Pinghai Bay and Xinghua Bay, with the south boundary reaching N24°52'and the east boundary up to E119° 36' (Figure 1). In this model, an unstructured triangular was created (Figure 2). The grid resolution in most of computing, such as coastal areas, and harbors was refined to 50m, while the grid resolution was set to 1.5km in the open boundary. The tide forcing at open boundaries consisted of tidal elevations and barotropic velocities for 8 major tide constituents, which are obtained from the Oregon State University Tidal Data Inversion software.

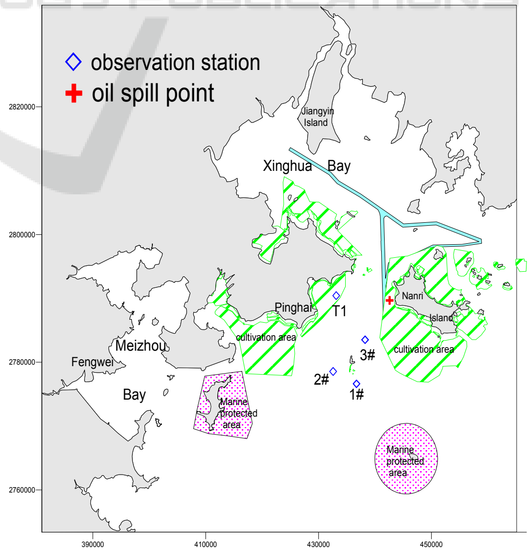


Figure 1: Locations of oil spill and sensitive objects in the sea area around Nanri island.

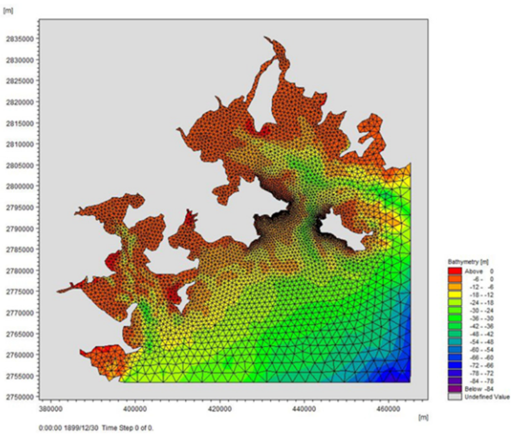


Figure 2: The grid configuration and the bathymetry of the simulated area.

3.2 Validation of Hydrodynamic Model

In this study, observation from one tidal station as tidal elevations and three current stations including the surface current velocities and directions were adopted to validate the model results (Figure 1). The tidal elevation comparison between observation and the model simulated outputs was shown in Figure 3. The tidal elevations from the model were in good agreement with the observed data. The tidal elevations were thus well predicted.

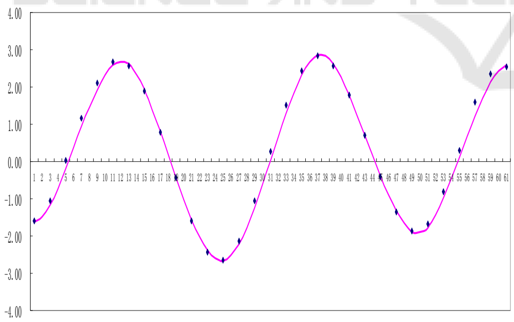


Figure 3: The tidal elevation comparison (point: observation; line: model outputs).

As shown in Figure 4, the surface current velocities and direction from the numerical model were in good agreement at different stations, which showed that the model could produce reliable prediction of the current velocity and direction.

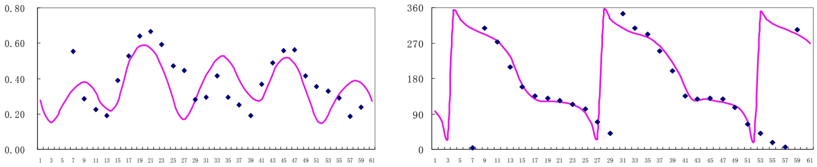
3.3 Surface Water Currents

The simulated surface water current near Nanri Island at different times was showed in Figure 5. The essential formation of water current was reversing currents, and the direction changes of water current occurred at the time of high or low tide. The maximum current velocity rapidly generated when the rate of tidal level rise or ebb reached maximum. The tidal currents in calculated area were typical reciprocation currents in a tidal cycle and the tidal flats changed obviously along the tidal cycle.

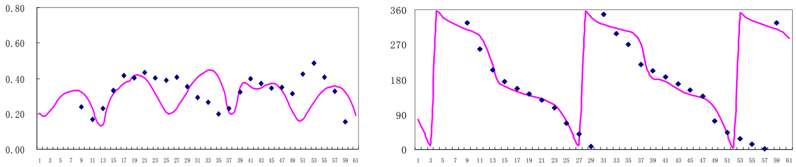
4 ACCIDENTAL OIL SPILL IMPACT PREDICTION IN THE SEA AREA AROUND NANRI ISLAND

4.1 Oil Spill Parameter

The assumed location of oil spill in this study is 24.47°N, 118.09°E (Figure 1), which was the intersection of the Nanri Island channel and the fishermen's route, where oil spills occured frequently in the past. The type of oil spilled was fuel oil with a specific gravity of 920 kg/m^3. The designed oil spill volume was 10 tons (transient oil spill), which was represented by 1000 "oil particles" in the model. The wind speed was 4.5m/s and the perennial dominant wind direction was northeast for the model. For the time of oil spill, 4 kinds of situations were selected: high tide moment, low tide moment, ebb tide moment and flood tide moment.



(a)1#



(b)2#

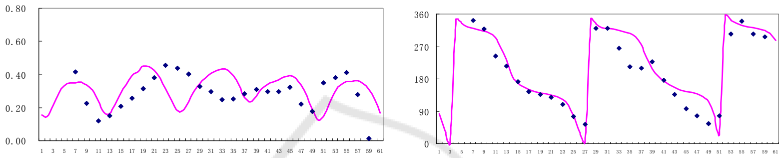


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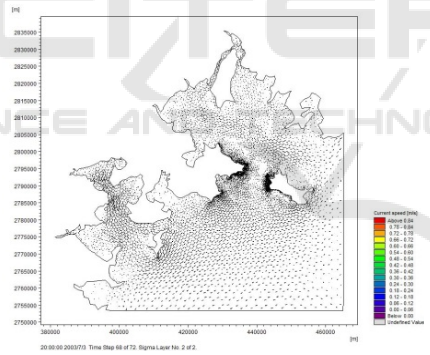
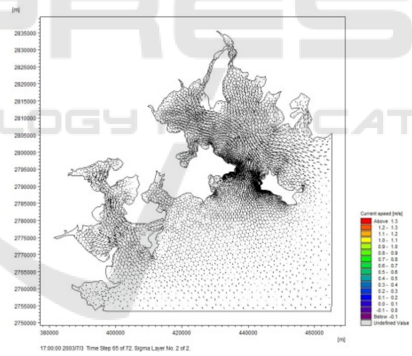
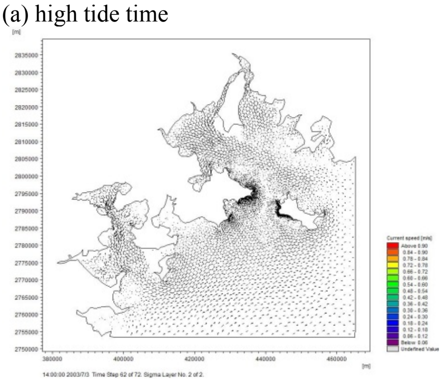
Figure 4: The current velocities (left) and direction (right) comparison form the model and observations at different station (point: observation; line: model outputs).



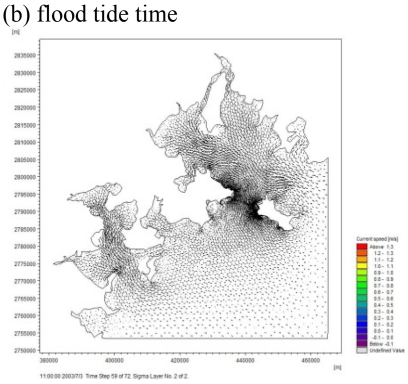
(a) high tide time



(b) flood tide time



(c) low tide time



(d) ebb tide time

Figure 5: The simulated surface water currents near Nanri Island at different times.

Table 1: Influence area of oil concentration increment over 48 h under northeast wind conditions (km^2).

Concentration (mg/L)	High tide moments	Flood tide moments	Low tide moments	Ebb tide moments
≥0.05mg/L	190.81	176.49	104.83	159.55
≥0.3 mg/L	142.95	135.36	84.68	89.07
≥0.5 mg/L	117.71	109.63	75.28	67.12

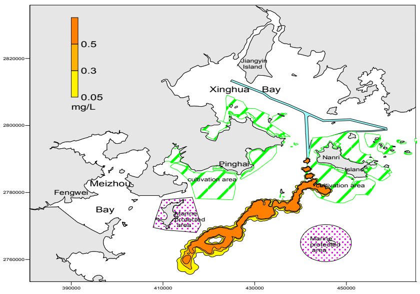


Figure 6a: Influence scope after oil spill over 48 h at high tide moments under northeast conditions.

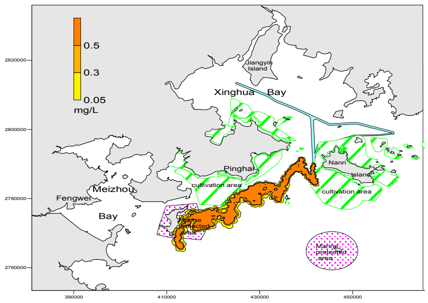


Figure 6b: Influence scope after oil spill over 48 h at flood tide moments under northeast conditions.

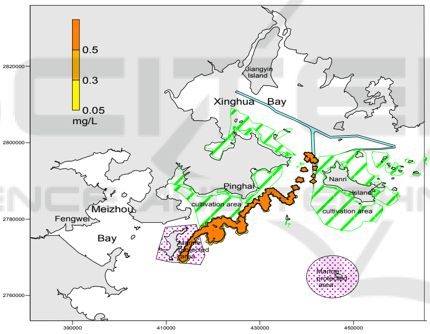


Figure 6c: Influence scope after oil spill over 48 h at low tide moments under perennial dominant wind.

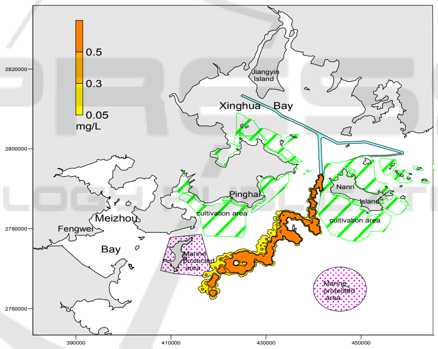


Figure 6d: Influence scope after oil spill over 48 h at ebb tide moments under northeast conditions.

4.2 Oil Spill Impact Prediction

After oil spills into the sea, advection, diffusion, evaporation and other processes take place under the combined effects of ocean hydrodynamic environment and atmospheric environment. In this study, the simulation time was 48h, and the oil spill risk prediction included four schemes. Under the conditions of northeast wind, the 48 hour impact scope of oil spill leakage at 4 different tides were shown in Figure 6 (≥0.05mg/L). The scope of impact under different concentration increments were shown in Table 1. The total impact areas of oil spills in four tidal were 190.81 km^2, 176.49 km^2, 104.83 km^2 and 159.55 km^2 respectively.

4 CONCLUSIONS

Based on the MIKE SA model, the oil spill prediction model for the sea area around Nanri Island was established. The drift path and impact degree of oil spills under the prevailing wind direction were well simulated.

The simulation results showed that the drifting process of oil spills was mainly affected by the tide and wind, and the tide played a leading role. Under the prevailing wind direction (Northeast wind) conditions, the oil film moves southwestwards under the influence of tide and wind. The impact of oil spillage at the time of high tide was the largest, and the sea areas that exceed one (or two), three and four water quality standards were 190.81, 142.95 and 11.71 km^2 respectively. Although the simulation model in this study adopted long-term statistical meteorological conditions, the prediction result still provided effective and referable oil spill behavior and technical support for the oil spill emergency decision-making to the marine environmental management department administration, which can reduce the impact of oil spill accidents on the marine environment and improve the emergency capacity construction of environmental risk management

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