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Improving a prediction system for oil spills in the Yellow Sea: Effect of tides on subtidal flow

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ABSTRACT

A multi-nested prediction system for the Yellow Sea using drifter trajectory simulations was developed to predict the movements of an oil spill after the MV *Hebei Spirit* accident. The speeds of the oil spill trajectories predicted by the model without tidal forcing were substantially faster than the observations; however, predictions taking into account the tides, including both tidal cycle and subtidal periods, were satisfactorily improved. Subtidal flow in the simulation without tides was stronger than in that with tides because of reduced frictional effects. Friction induced by tidal stress decelerated the southward subtidal flows driven by northwesterly winter winds along the Korean coast of the Yellow Sea. These results strongly suggest that in order to produce accurate predictions of oil spill trajectories, simulations must include tidal effects, such as variations within a tidal cycle and advections over longer time scales in tide-dominated areas.

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1. Introduction

The MV *Hebei Spirit* accident that occurred on December 7, 2007, resulted in the largest oil spill ever recorded in the Yellow Sea (YS). The accident occurred when the crude oil tanker MV *Hebei Spirit* collided with a crane barge about 12 km offshore of the west coast of Korea (Kim et al., 2010).

Approximately 10,500 metric tons of crude oil were released into the sea from the MV *Hebei Spirit*; this is twice the amount of oil released in the MV *Sea Prince* accident, which was the largest oil spill in the south sea of Korea. For several days after the accident, weather conditions were poor, with maximum wave heights up to 4 m and strong (10–14 m s^{-1}) northwesterly winds. More than 70 km of coastline were impacted in areas where tourist attractions, habitats for migratory birds, and aquaculture farms are concentrated (Kim et al., 2010). Oil spills are a matter of constant concern from the viewpoints of environmental and social disasters in Korea as well as worldwide.

An exact prediction of oil spill dispersal could provide useful information for reducing the damage of future oil spills. A prediction system is a useful tool for predicting the movement of oil after a spill. In this work, a multi-nested prediction system for the YS that uses the Regional Ocean Modeling System (ROMS) was employed to reproduce the movements of the oil spilled from the MV *Hebei Spirit*. We adopt a one-way nested model with a domain that was implemented from large domain of the Northwest Pacific model (Cho et al. 2009). The ROMS has been widely used for oil spill models to predict oil spill dispersal (Berry et al., 2012; González et al., 2008; Sotillo et al., 2008).

The YS is a shallow semi-enclosed marginal sea located in the northwestern Pacific, surrounded by the west coast of the Korean Peninsula and the east coast of China. The mean water depth of the YS is about 45 m. Tidal ranges along the Korean coast are 4–8 m (Yanagi et al., 1997).

When we applied our prediction system to the MV *Hebei Spirit* oil spill, we observed an interesting frictional effect of the tides on subtidal flow. The subtidal flow has a period that is longer than the diurnal tide and is mainly driven by winter winds in the YS (Moon et al., 2009). The oil spill trajectories at the surface predicted by a 1-month simulation with tidal forcing were comparable to the observations, whereas the southward movement of the oil spill predicted by a simulation without tides was substantially faster than the observations.

In this study, we investigated the effect of tides on the travel time of the oil spill via subtidal flow, and examined the differences between subtidal flow simulations with and without tides. This study is the first step toward understanding oil spill dispersal in the YS using prediction system.

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2. Experimental methodology

2.1. General description of the model

The numerical model used in this study was based on the ROMS, which is a three-dimensional, free-surface, hydrostatic, primitive-equation model (Shchepetkin and McWilliams, 2005). The modeled area covered the YS and the East China Sea (ECS) (117.5–130.3°E, 24.8–41°N) (Fig. 1).

Bottom topography data were interpolated from a combination of two topographic data sources: a 30-s gridded bathymetric data domain (Seo, 2008) and Sungkyunkwan University's 1-min digital bathymetric data (Choi et al., 2002). The nominal horizontal grid spacing was ~3 km. Twenty levels were used in the vertical s-coordinate with a minimum depth of 4 m.

The Mellor–Yamada level 2.5 closure scheme was used for vertical parameterization (Mellor and Yamada, 1982; Durski et al., 2004). The open boundary conditions selected for this study were as follows: Chapman for the free-surface, Flather for the 2D momentum, and clamped for the 3D momentum and the tracers. The horizontal viscosity was set to 300 $m^2\ s^{-1}$.

Circulation in the YS and ECS was spun-up using open boundary data from the Northwest Pacific model (Cho et al., 2009), which provides the monthly mean temperature, salinity, and velocity. Changjiang River and the Huanghe River discharges were included as freshwater sources. We used the Changjiang river discharge observed at the Datong station. However, for the Huanghe river discharge, we used the climate monthly mean data from the Global River Discharge Database (Vörösmarty et al., 1996). The monthly mean river discharges of the Changjiang and the Huanghe rivers used for our model in December 2007 are 11,100 and 1150 $m^3\ s^{-1}$, respectively.

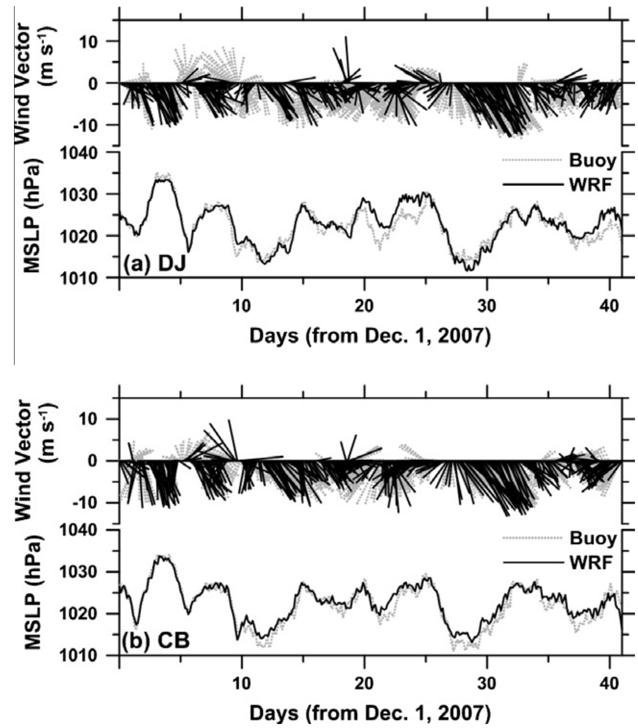

Fig. 2. Comparison of winds and MSLP from buoy observations and the model input data calculated using the WRF model for 42 days after the accident (from 0000 local time December 1, 2007, to 0000 local time January 11, 2008). The gray dotted lines indicate observations at buoys operated by the KMA and the black solid lines indicate the WRF model results for the same locations: (a) DJ, located about 10 km north of the accident site, and (b) CB (see ▲ markers in Fig. 1).

2.2. Atmospheric forcing data

The quality of the wind data is critical for predicting oil spill movements (Carracedo et al., 2006) because wind-driven currents dominate the winter circulation patterns in the YS. Therefore, high-resolution surface forcing in space and time is necessary for the prediction system.

For the simulation of the MV *Hebei Spirit* oil spill, meteorological data predicted by the nested regional Weather research and forecasting (WRF) model were used to generate realistic weather conditions, producing high-resolution data for coastal winds. The simulated winds were verified against observations from a buoy at Dukjok-Do (DJ), located ~40 km north of the accident site and operated by the Korea Meteorological Administration (KMA). The

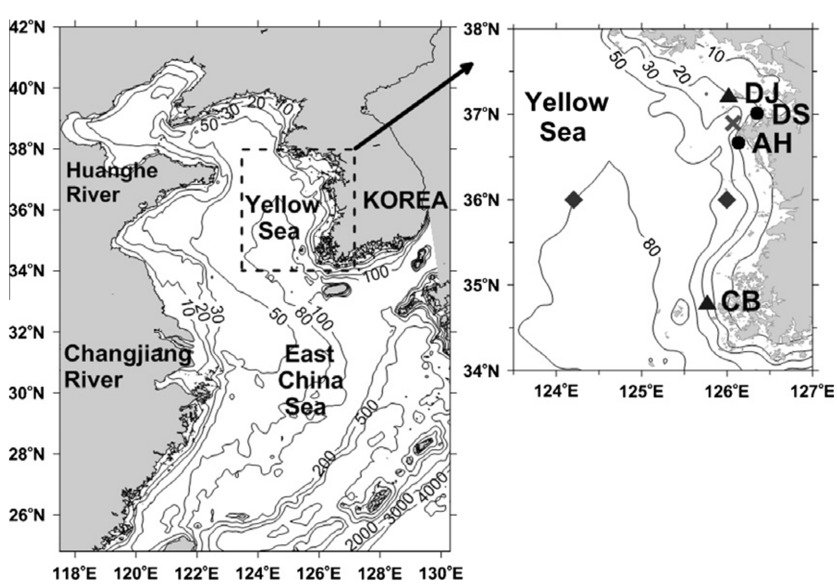

Fig. 1. Model domain and topography. Numbers represent the water depth (m). The X in the right panel represents the location of the MV *Hebei Spirit* accident (▲: buoy station, ●: tidal station, ♦: vertical profile station).

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