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Assessment in marine environment for a hypothetic nuclear accident based on the database of tidal harmonic constants

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ABSTRACT

The eleven nuclear power plants in operation, under construction and a well-planned plant in the east coast of China generally use seawater for reactor cooling. In this study, an oceanic dispersion assessment system based on a database of tidal harmonic constants is developed. This system can calculate the tidal current without a large computational cost, and it is possible to calculate real-time predictions of pollutant dispersions in the ocean. Calculated amplitudes and phases have maximum errors of 10% and 20% with observations, respectively. A number of hypothetical simulations were performed according to varying of the release starting time and duration of pollutant for the six nuclear sites in China. The developed system requires a computational time of one hour for one month of real-time forecasting in Linux OS. Thus, it can use to evaluate rapidly the dispersion characteristics of the pollutants released into the sea from a nuclear accident.

1. Introduction

In recent years, in a context of increasing energy demand, many countries have expressed an interest in including nuclear power in their energy plans. In 2011, the Fukushima Daiichi nuclear disaster occurred in Japan, after which all nuclear plant approvals were frozen and ‘full safety checks’ of existing reactors were required. The current situation in the east coast of China is such that the eleven nuclear power plants at three sites are in operation (Hongyanhe, Tianwan, Qinshan), under construction (Hongshiding, Sanmen) and a well-planned plant (Haiyang). These plants are located in the Yellow sea coast and generally use seawater for reactor cooling (Fig. 1).

The marine dispersion of radionuclides from a nuclear accident has been an important issue since the Fukushima Daiichi accident in 2011 (Honda et al., 2012; Perianez et al., 2012; Tsumume et al., 2012; Min et al., 2013). Release of the radioactive materials may occur due to a major accident within a NPP or other reasons, such as spent fuel transportation or an accident involving a nuclear submarine. An emergency response system is necessary to preserve the marine environment in terms of stability and public safety. In an emergency, these systems determine the range of effects of the accident, and they can offer basic information for a protection plan.

In this study, an oceanic dispersion assessment system based on a database of tidal harmonic constants has been developed to evaluate the transport characteristics of the pollutant for a hypothetical nuclear accident located in the east coast of China. The hydrological characteristics in the Yellow Sea are mainly governed by tides, which are dominantly semidiurnal (rising twice a day). Amplitudes vary between 0.9 and 3 m along the coast of China. Tides are higher along the Korean Peninsula, typically ranging between 4 and 8 m. The speed of the tidal current is generally less than 1.6 km/h in the middle of the Yellow Sea, but it may increase to more than 5 km/h near the coast. Tidal predictions based on a database of tidal harmonic constants can calculate the tidal currents in fast without incurring a large computational cost, thus it is also possible to calculate real-time predictions of radioactivity in the ocean.

2. Tidal current forecast system

Numerical circulation models provide a useful and general view of ocean currents. A regional circulation model was firstly developed by Kirk Bryan and Michael Cox (Bryan, 1969) and it was expanded in a global scale, with a horizontal resolution of two degrees and with 12 levels in the vertical direction (Cox, 1975). After that, various numerical models have been developed to describe coastal currents, tides, and storm surges. The models extend from the beach to the continental slope and they included

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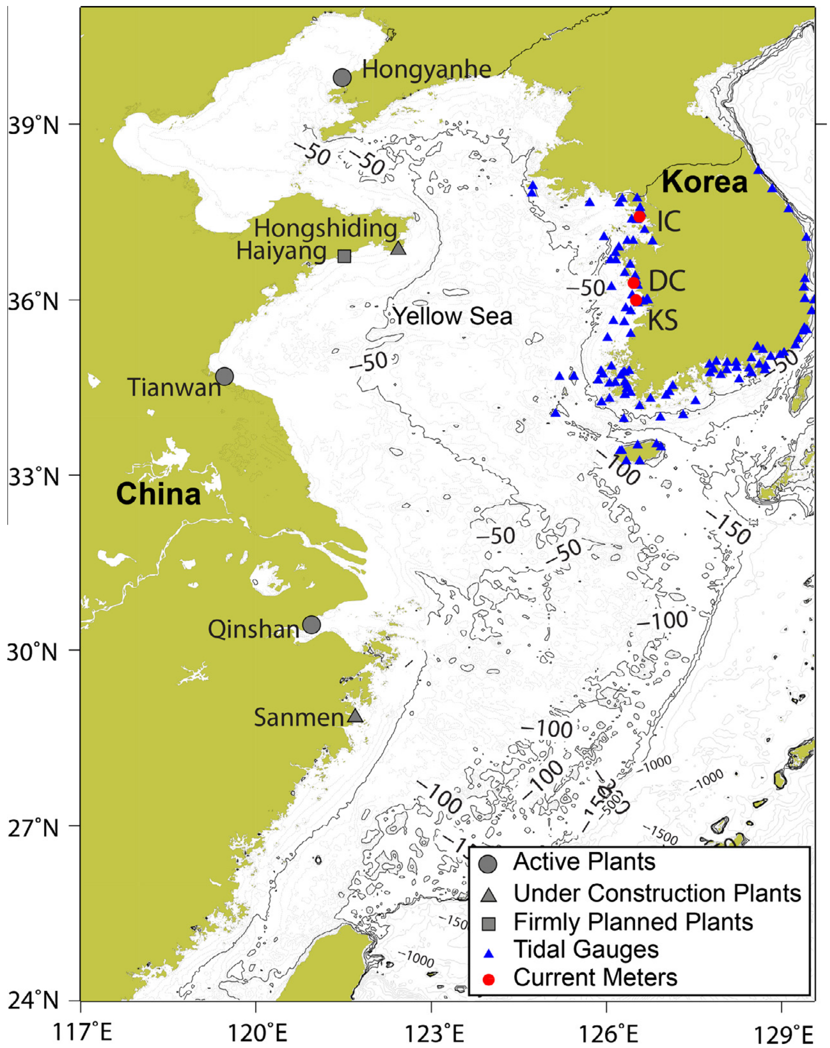

Fig. 1. Map of the Yellow Sea. The locations of six nuclear sites, three current meters and tidal gauges are indicated. Bathymetry (m) is also shown: IC:Incheon, DC:Daechun, KS:Kunsan.

a free surface, realistic coasts, bottom features, river runoff and atmospheric forcing data. The coastal models have many different goals and implementations. Thus, it is important to select of a proper circulation model to understand the characteristics of the dominant physical processes in each particular area.

Numerical studies of tidal current predictions use circulation models and focus on strong tidally driven systems. In this case, the flow may be considered to obey two-dimensional (2D) averaged dynamics vertically (Panchang et al., 1997; Dudley et al., 2000). Tides define with the periodic rise and fall of sea levels caused by the combined effects of the gravitational forces exerted by the Moon and the Sun, and the rotation of the Earth. When periodic data is analyzed, the standard approach is to employ Fourier series with a form of analysis that uses sinusoidal functions having frequencies that are zero, one, two, etc. times the frequency of a particular fundamental cycle. These multiples are called with 'harmonics' of the fundamental frequency and the process is termed in harmonic analysis. Doodson (1921) introduced the Doodson Number notation to organize hundreds of harmonics constants. This approach has been the international standard since then. Real tides can be explained by a sum of harmonics in the following form.

$$z(t) = \sum_{i=1}^{N} A_i \cos(w_i t + p_i) \qquad (1)$$

Here, z is the sea surface displacement or tidal current of each U and V components from the mean sea level produced by the tide and N is the number of harmonics (tidal constituents). For each constituent, A is the amplitude, w is angular frequency, p is the phase offset with regard to the astronomical state at time $t = 0$ and t is time measured in hours. The amplitude (A) and phase offset (p) denoted as tidal constants, are not uniform in space for each constituent. There are several ways to obtain them. First, a harmonic analysis of direct measurements of water levels in the region of interest is the most accurate way, but it is difficult to obtain tidal constants with spatial continuity. This method is mainly used for hydrographic surveys, and has been used in national institutions (for example, the NOAA of the USA, the POL of the UK and the KHOA of the Republic of Korea). Second, satellite observations have spatial continuity but the level of accuracy is low. The satellite data of TOPEX/Poseidon (Smith et al., 1997) and JASON-1 (Ardalan and Hashemi, 2008) can be used for this purpose. Third, numerical models can be used to calculate these harmonic constants. But numerical models and available observation data are generally applied to complement the disadvantages of each method.

In this study, the five-minute interval DB of Min et al. (2011) is applied to carry out predictions of tidal currents. The DB includes harmonic constants of the sea surface displacement and tidal current of each U and V components. Details are presented by Min