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Study on the storm surges induced by cold waves in the Northern East China Sea

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ABSTRACT

Cold wave, a kind of severe weather system, can bring strong wind and induce significant sea level rise to the Northern East China Sea. Based on CFSR data, the study shows the monthly distributions of invaded days and the spatiotemporal distributions of cold-wave wind direction and wind speed. A three-dimensional numerical model (ROMS) was developed to study storm surges induced by cold waves. The role of wind direction, wind speed, wind duration, extratropical cyclone and tide–surge interaction is investigated by conducting different sensitivity experiments. The results indicate that storm surges mainly happen at the coasts perpendicular to the wind directions. Surge range and time lag are related to the geometry of the basin and the continental shelf. The response of the sea-level fluctuations to cold wave indicates that there is a positive correlation between crests and wind speed, a negative correlation between troughs and wind speed, but no obvious correlations to wind duration. Coupled weather cold waves, which yield a larger range and a multi-peak structure of surges, can be classified according to cold wave tracks and extratropical cyclones. The tide–surge interaction has an obvious and different effect on the magnitudes and phases of storm surges for different tidal stages.
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1. Introduction

Storm surges are one of the world's most dangerous disasters (Andrade et al., 2013). Previous studies have investigated the sea level extremes in certain areas (e.g. Butler et al., 2007; Feng and Tsimplis, 2014; Hsueh and Romea, 1983; Hsueh et al., 1986; Torres and Tsimplis, 2014) and the storm surges induced by hurricanes or typhoons (e.g. As-Salek, 1998; Rego and Li, 2010; Wang et al., 2007; Weisberg and Zheng, 2006) in detail. However, studies on cold waves mostly focus on the accompanying unexpected freezes, frosts and intense northerly winds (e.g. Chen et al., 2002; Ding, 1990; Marengo et al., 1997; Schultz et al., 1997) but not the induced storm surges. Storm surges induced by cold waves, which international researchers paid less attention to, may also lead to sustained significant sea level rise and mountainous wave that have serious impact on human life and shipping (Hsueh and Romea, 1983). Researchers in China started to study this kind of storm surges in the 1980s. They defined them as ultra-shallow water storm surges (Qin and Feng, 1975; Sun et al., 1979; Sun et al., 1980) and focused on the numerical investigations (Feng and Shi, 1980; Sun, 1984; Wu and Qin, 1985). Some researchers used numerical models to simulate storm surges induced by cold waves for case analysis or hindcasting verification (e.g. Li et al., 2010; McInnes and Hubbert, 2003). Though these results verify the applicability and promote the practical application, there is still a lack of systematic studies on dynamics of marine disasters under the influence of cold waves. Consequently, improvement in forecasting surge elevations and related sea conditions caused by cold waves is required.

The Northern East China Sea (NECS), mainly the Bohai Sea and the northern Yellow Sea, is one of the most easily affected regions in the world. The Bohai Sea backs on the cardiac regions of China and is described as a hotspot among the world's marginal seas (Pelling et al., 2013). The Bohai Sea is a semi-enclosed sea ‘hugged’ by Liaodong Peninsula and Shandong Peninsula (Fig. 1). There are three bays, i.e., the Liaodong Bay, the Bohai Bay and the Laizhou Bay. The terrain is mostly flat and leaning from bays to the Bohai Strait. The surface area of the Bohai Sea is approximately 77,000 km^2, with a mean depth of 18 m below mean sea level (MSL) (Liu et al., 2014). The Yellow Sea is a marginal sea of the western North Pacific located between the Chinese mainland and the Korean peninsula (Hu et al., 2016). Many previous studies divide the Yellow Sea into the northern and southern parts. The dividing line is defined between Chengshan Cape of the Shandong Peninsula and Changyon of the Korean Peninsula. The northern Yellow Sea has an almost equal surface size (71,300 km^2) with the Bohai Sea.

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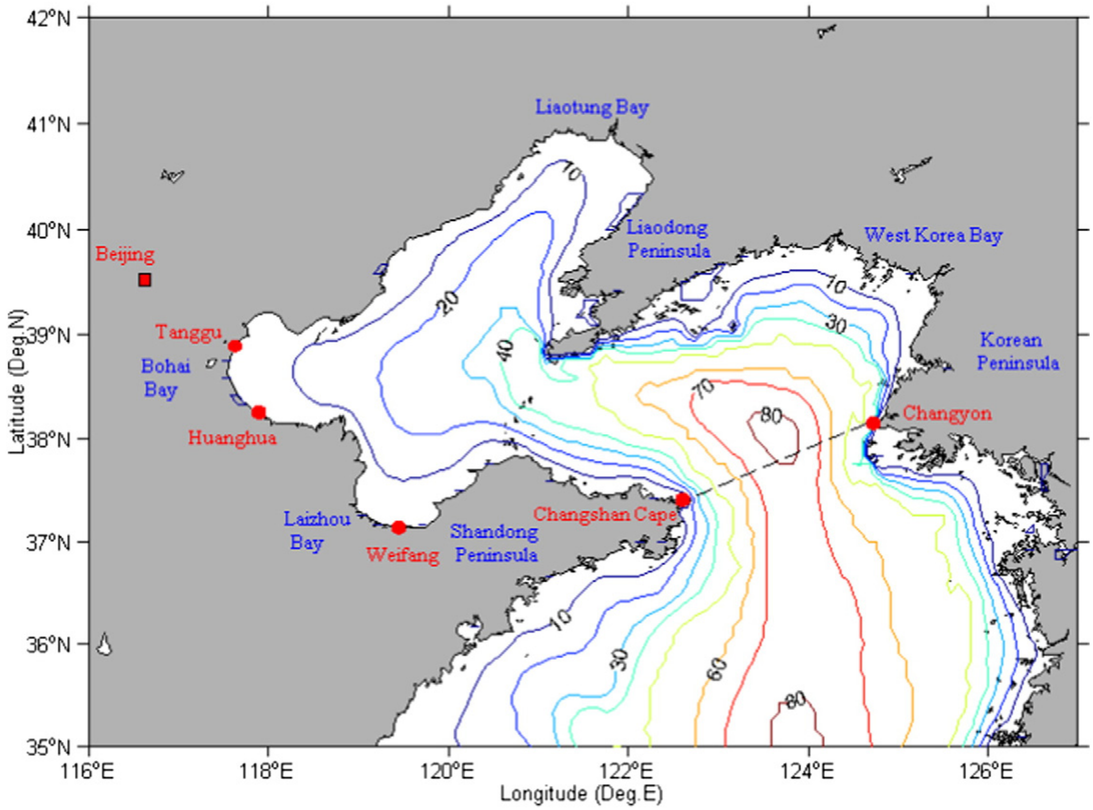

Fig. 1. The Northern East China Sea, showing names, locations and bottom topography (in meters with mean sea level (MSL) as the vertical datum). The black dashed line is the dividing line between northern and southern Yellow Sea.

The average depth of the northern Yellow Sea is about 38 m below MSL (Bao et al., 2009).

In Eurasia, cold air masses form over the ocean east of Novaya Zemlya, west of Novaya Zemlya or south of Iceland and invade to the south under the suitable atmospheric circulation. Thence the masses assemble at the Siberian key regions (70–90°E, 43–65°N) along three tracks: the north track, the northwest track and the west track (Fig. 2). As the Siberian High amplifying, cold air travels southward and affects the NECS. It is the so-called cold wave or cold surge (cold wave in this paper) (Ding and Krishnamurti, 1987). Different researchers use different definitions of cold wave in different regions. Specifically, as used by the China Meteorological Administration, a cold wave is defined when the regional averaged temperature within one or two days drops more than 10 °C and the lowest temperature drops below 5 °C. Some researchers define it by pressure gradient between inland and coast and prevailing wind speed (Lau and Chang, 1987).

Our research strategy is to perform several model experiments, conducting different wind scenarios and tidal scenarios to quantify different factors' influence on storm surges induced by cold waves. So this paper is organized as follows. In Section 2 monthly distribution of cold-wave days, frequency distribution of wind direction, and spatial distribution of wind speed are described. Section 3 gives a brief description of the simulated model used and its configuration, discusses the spatiotemporal variation of wind fields and storm surges through two

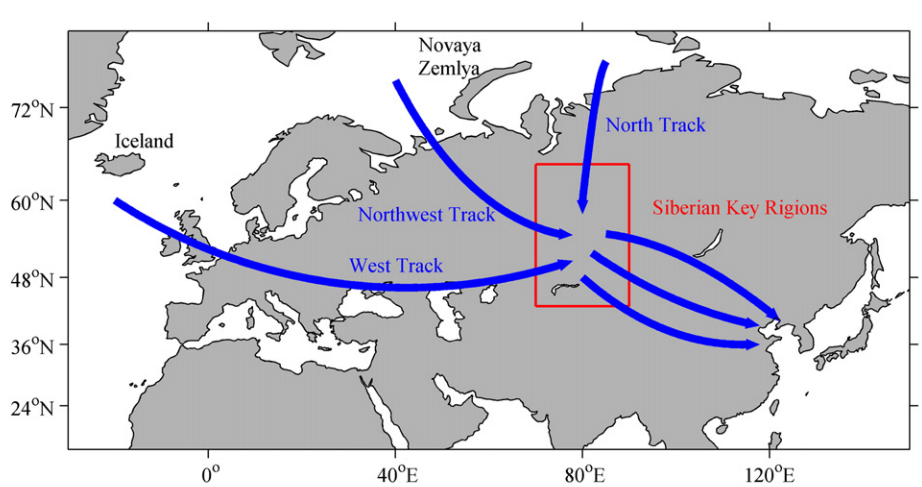

Fig. 2. Tracks (blue arrows) of cold air masses which travel southward and affect the NECS. The red rectangular box represents the Siberian key regions.

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