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Research papers

Numerical simulation of the abrupt occurrence of strong current in the southeastern Japan Sea

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ABSTRACT

Coastal set-net fisheries have been frequently damaged by the occurrence of sudden current (known as kyucho) in the Japan Sea. In this study, a high-resolution coastal ocean model is developed to provide a means to predict this stormy current. The 1.5 km-mesh model nested in a regional ocean data assimilation system is driven by mesoscale atmospheric conditions at 1-hour intervals. The modeled results show rapid changes of the coastal current along the San-in Coast, on the eastern side of the Tango Peninsula, and around the Noto Peninsula and Sado Island, mostly associated with strong wind events. These modeled coastal water responses are consistent with in-situ velocity measurements. The simulation also shows that the vortex separated from the Tango Peninsula frequently grows to a bay-scale anticyclonic eddy in Wakasa Bay. Evidently, the coastal branch of the Tsushima Warm Current becomes unstable due to a strong meteorological disturbance resulting in the generation of this harmful eddy.

1. Introduction

Numerical simulation and prediction of abrupt change in the nearshore current were successfully established for the eastern side of the Noto Peninsula by Asa et al. (2007), and Nakada et al. (2014). The strong and rapid coastal current, sometimes associated with shocking temperature change, has been empirically called "kyucho" in Japan. Since the major cause of kyucho in the southern Japan Sea has already been identified to meteorological disturbances, the numerical forecast was demonstrated to be a useful tool to help preparation for this stormy current (Nakada et al., 2014). The modeling ability to predict the kyucho occurrences, together with the efforts of local governments and fishery operators, actually contributes to reduce damages to set-net fisheries in Toyama Bay (Okei et al., 2012).

In this study, we extend and improve the numerical model of Nakada et al. (2014). The set-nets have been occasionally destroyed by rapid kyucho currents in Toyama Bay as well as along the San-in Coast, in Wakasa Bay and Ryotsu Bay, and in other coastal waters (e.g., Maruyama, 2009a). Each set-net structure is quite large (on the order of 1 km), and thus the total financial damage to the hundreds of structures can exceed one billion Japanese Yen after even one event.

Among these waters, in-situ measurement efforts of strong currents have been well documented for Wakasa Bay. For example, Kumaki (2012) reports in detail the characteristics of the kyuchos around the Tango Peninsula along with a discussion of the physical processes. He concludes that most of the measured strong currents around the Tango Peninsula were caused by wave propagations excited by strong winds such as those from typhoons. In terms of numerical modeling, Umatani and Yamagata (1987), Igeta et al. (2007), and Kumaki et al. (2012) clarify the physical processes of sudden current based on an idealized representations of the conditions in this region.

Kumaki (2012) also mentions that several cases of kyucho (statistically less than 10%) remain unexplained solely by the wind forcing. One possibility is a clockwise eddy formed in Wakasa Bay. The bay-scale anticyclonic circulation was initially reported by Uda (1931). Later, Wada and Yamada (1997) categorized the flow patterns based on acoustic Doppler current profiler (ADCP)

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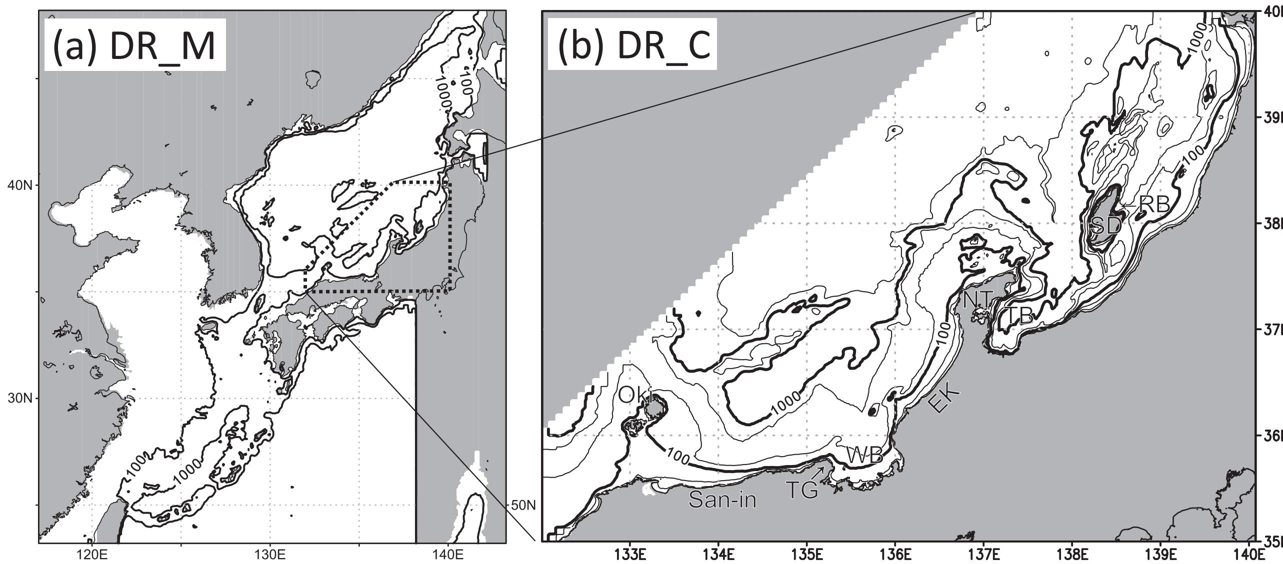

Fig. 1. Bottom topography of the parent (DR_M) and child (DR_C) models. Thick contours show 100 and 1000 m depths. (b) Thin contours indicate 20, 50, 200, 500, 2000, and 5000 m depths. The capital letters "TG", "WB", "EK", "NT", "TB", "SD", and "RB" indicate Tango Peninsula, Wakasa Bay, Echizen-Kaga Coast, Noto Peninsula, Toyama Bay, Sado Island, and Ryotsu Bay, respectively.

Table 1
Major differences in the configurations of the three models compared in this study.

	DR_M	DR_I	DR_C
domain	Japan and East China Seas	around Noto Pen.	from San-in Coast to Sado Is.
$\Delta x \times \Delta y$	$5' \times 4'$ ($\sim$7.4 km)	$1' \times 0.8'$ ($\sim$1.5 km)	←
top Δz	8 m	←	2 m
grid number	$320 \times 384 \times 38$	$192 \times 256 \times 34$	$485 \times 384 \times 36$
barotropic and baroclinic Δt	6 and 120 s	2 and 20 sec	←
horizontal eddy viscosity	biharmonic + harmonic	←	Smagorinsky (1963)
surface forcing	JMA-GSM, 6-hourly	JMA-MSM, hourly	←
open boundary condition	DR_B (Hirose, 2011)+ tide (Matsumoto et al., 2000)	DR_M	←
data assimilation	Yes	No	←
publication	Hirose et al. (2013)	Nakada et al. (2014)	This study

measurement in Wakasa Bay. The former studies also suggested the relationship with the coastal branch of the Tsushima Warm Current (TWC) from San-in Coast.

These studies imply that we need to consider realistic conditions such as the TWC system including mesoscale eddies, complex horizontal and vertical mixing processes, or high-resolution wind forcing in time and space, to simulate various types of the stormy currents. For instance, none of the previous modeling studies considered the effect of incoming coastal currents on the generation of sudden current in Wakasa Bay.

The threatening situation of kyucho at San-in Coast, Sado Island, and other set-net fishery areas may be more or less similar to Wakasa Bay (e.g., Maruyama, 2009a, 2009b). Therefore, this study aims to provide a more realistic numerical simulation of the rapid change in nearshore currents along the complex coastline of the total extension over 2500 km (Fig. 1). For this purpose, a high-resolution model may be required as suggested by the previous numerical studies (Igeta et al., 2007; Kumaki et al., 2012; Nakada et al., 2014). In this paper, the effect of grid spacing will be examined by comparison with the large-scale model already provided by Hirose et al. (2013). Then we will examine the important factors and processes affecting our ability to predict kyuchos.

2. Model configuration

In this study, we develop a new coastal ocean model. Since the target area is limited to *coastal* waters (Fig. 1), we name it DR_C. The open boundary condition is given by a regional, eddy-resolving, data assimilation model (Hirose et al., 2013) in one-way connection at the north and western faces. The parent model covers the two *marginal* seas of the Japan and East China Seas and is thus abbreviated as DR_M. The diagonal interface between the two models is configured from 36°N, 132°E to 40°N, 137°E considering the parallel computing efficiency with the Message Passing Interface (MPI) program of the RIAM Ocean Model (Lee et al., 2003). The provided variables from DR_M to DR_C are the sea surface height, temperature, salinity, and horizontal velocity components.

The RIAM Ocean Model is a z-coordinate primitive OGCM with Arakawa's B-grid spacing on the spherical coordinate developed originally by Lee (1996) and Lee et al. (2003). The generalized Arakawa scheme is used for the advection term in the horizontal momentum equations. We follow the formulation suggested by Ishizaki and Motoi (1999) including the slant advection effect. The governing equations are separated into barotropic and baroclinic modes and thus allow longer time steps for internal dynamics.

The earlier version of the high-resolution coastal model was developed by Nakada et al. (2014) for a small region around the Noto Peninsula or Ishikawa Prefecture. This result will be distinguished by DR_I. The major differences of the three models (DR_M, DR_I, and DR_C) are given in Table 1.

The bottom topography of DR_C is given by a simple average of JTOPO30v2 (Marine Information Research Center) and J-EGG500 (JODC–Expert Grid data for Geography–500 m) as shown in Fig. 1b. The J-EGG500 covers the coastal area only and the offshore topography of this model is equivalent to JTOPO30v2. In addition, coastal grids are often corrected manually to maintain the realistic coastlines in this finite-resolution model to generate small channels (such as Douzen Islands of Oki) or to create small islands and