Continental Shelf Research 29 (2009) 1549–1564

Contents lists available at ScienceDirect

Continental Shelf Research

journal homepage: www.elsevier.com/locate/csr

Response of the Changjiang diluted water around Jeju Island to external forcings: A modeling study of 2002 and 2006

Jae-Hong Moon [a,*], Ig-Chan Pang [b], Jong-Hwan Yoon [c]

[a] Department of Earth System Science and Technology, Interdisciplinary Graduate School of Engineering Science, Kyushu University, Kasuga-Koen, Kasuga 816-8580, Japan
[b] Department of Oceanography, Cheju National University, Jeju 690-756, Korea
[c] Research Institute for Applied Mechanics, Kyushu University, Kasuga-Koen, Kasuga 816-8580, Japan

ARTICLE INFO

Article history:
Received 24 August 2008
Received in revised form
20 November 2008
Accepted 7 April 2009
Available online 22 April 2009

Keywords:
Changjiang diluted water
Jeju Island
Wind-induced Ekman flow
Tidal forcing
Freshwater export

ABSTRACT

The Changjiang diluted water (CDW) around Jeju Island between 2002 and 2006 in response to external forcings, such as wind, tidal forcing and low river discharge, is studied using a three-dimensional model. The model results suggest that wind largely determines spatial differences of CDW and the freshwater export toward Jeju Island between two years. In 2006, when northwestward wind blows during mid June to mid August, the wind-induced Ekman flow causes a broad northeastward extension of CDW and carries a significant amount of freshwater northeastward Jeju Island in August. On the other hand, in 2002 northward wind during mid July to early August drives the CDW to the southwest of Jeju Island, and thereafter the CDW is mainly advected northeastward along the Cheju Current during mid August when the wind becomes weak. Therefore, the amount of freshwater around Jeju Island increases in September, not in August. The response to tidal forcing shows that tide-induced vertical mixing tends to enhance a meander of CDW around Changjiang Bank and shift the CDW flowing into the Yellow Sea southeastward toward Jeju Island. As a result, the amount of freshwater toward Jeju Island becomes larger than that in no-tides case. The summer low river discharge as a flood control scenario has little influence on the spatial behavior of CDW around Jeju Island although the discharge contributes to the amount of freshwater around Jeju Island.

1. Introduction

In the sea around Jeju Island where is located about 450 km northeast from the Changjiang river mouth (Fig. 1), the surface salinity is high during wintertime by the Tsushima warm current (TWC), but becomes significantly low during summertime. It is commonly thought that the low-salinity water during summer originates from the Changjiang diluted water (CDW). The CDW has long been known to extend during summer toward Jeju Island every year (Wang, 1988; Kim et al., 1991; Kim and Rho, 1994), and the approach of low-salinity water occasionally causes a mass mortality around Jeju Island.

National Fisheries Research and Development Institute (NFRDI, in Korea) has been carrying out the serial hydrographic survey around northern region of the East China Sea (NECS) with 4 times per year (February, May, August and October). The summer surveys clearly show low-salinity water around Jeju Island originating from CDW as shown in Fig. 2. The northeastward movement of CDW was also suggested in the satellite-tracked drifters deployed off the Changjiang river mouth in July (Beardsley et al., 1992). The drifters moved northeastward through the Jeju Strait and entered the Korea/Tsushima Strait.

As mentioned above, the low-salinity water occasionally causes severe damages to fishery industry on Jeju Island, especially along the coasts of Jeju Island. However, it is difficult to predict the behavior of CDW around Jeju Island because spatial and temporal characteristics of the low-salinity water during summer are diverse every year as shown in Fig. 2. From this point of view, the results of hydrographic survey in 2002 and 2006 provide a good motivation to investigate the spatial and temporal behavior of CDW around Jeju Island (Fig. 2). In 2002 the outer boundary of CDW by 30 psu (Lie, 1984; Kim et al., 1991) mainly appears in the southwestern region of Jeju Island and high-salinity water originating from the TWC distributes in the eastern region of Jeju Island including the Korea/Tsushima Strait. On the other hand, low-salinity water less than 30 widely distributes from the western region of Jeju Island to the Korea/Tsushima Strait in 2006. The spatial pattern of CDW around Jeju Island and its time approaching Jeju Island are appreciably different comparing data of 2 years.

The Changjiang river discharge has been known to change seasonally from about 10,000 to 50,000 $m^3 s^{-1}$ (Shen et al., 1998). The summer high river discharge has been suggested as a major force driving CDW east/northeastward toward Jeju Island as a

* Corresponding author. Tel./fax: +81 92 583 7492.
E-mail address: jhmoon@riam.kyushu-u.ac.jp (J.-H. Moon).

0278-4343/$ - see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.csr.2009.04.007

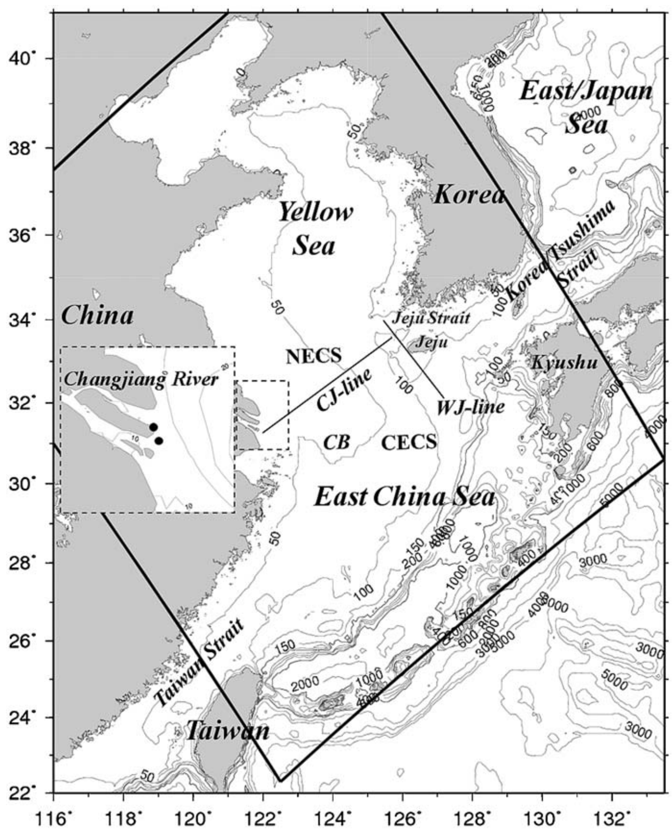

Fig. 1. Model domain and bottom topography (m). Rotated square box indicates the model domain and black circle symbols in the square with dashed line indicate the launching locations of Lagrangian particles in Section 3.2. Black solid lines are the locations of the vertical sections and freshwater volume calculation in Section 3.3. (NECS: Northern region of the ECS, CECS: Central region of the ECS, CB: Changjiang Bank).

result of vortex stretching (Beardsley et al., 1985). Bang and Lie (1999) suggested that northward wind is responsible for the eastward extension of CDW, based on simple numerical model without an ambient along-shelf current in the ECS. Chang and Isobe (2003) emphasized the effect of advection due to east/northeastward currents between the Taiwan Strait and the Korea/Tsushima Strait, and also suggested that wind effect is non-negligible as suggested by Bang and Lie (1999), based on the numerical model considering the realistic inflow–outflow condition. However, most of them are mainly focused on the seasonal or interannual behavior of CDW in the ECS circulation.

In this paper, we will elucidate spatial and temporal pattern of CDW around Jeju Island and evaluate fresh water budget toward Jeju Island during summertime using a numerical model. In order to emphasize distinct differences in spatial and temporal pattern of CDW, the results of hydrographic surveys in 2002 and 2006 are adopted in this study as mentioned above. The general features and conditions of numerical model are described in the next section. Results of the simulation in 2002 and 2006 with Lagrangian particle-tracking experiment are presented in Section 3. They are compared with the sea surface salinity field investigated by NFRDI, and with some trajectories of satellite-tracked drifters. Estimation of freshwater export toward Jeju Island is also shown in Section 3. The responses to northwestward wind forcing, no tidal mixing and low river discharge during summer are discussed in Section 4. Finally, interpretations of numerical simulations are summarized in Section 5.

2. Numerical model and conditions

The numerical model in this study is used the Regional Ocean Modeling System (ROMS). The ROMS is a three dimensional, free surface, hydrostatic, primitive equation numerical ocean model based on the nonlinear terrain-following coordinate (*s*-coordinate) of Song and Haidvogel (1994). The horizontal and vertical diffusions are calculated using the Smagorinsky diffusion parameterization and the Mellor and Yamada level 2.5 turbulence scheme (Mellor and Yamada, 1982), respectively. Details of the ROMS computational algorithms are suggested by Shchepetkin and McWilliams (2005). The model domain is a rotated rectangular with a wall on the northern side and three open boundaries including the Yellow Sea (YS) and ECS as shown in Fig. 1. The model horizontal resolution is $\frac{1}{12}$ (about 10 km) degree with 20 levels in the vertical stretched terrain-following coordinate. The bottom topography is extracted from a combination of two topographic data sets, ETOPO5 (National Geophysical Data Center, NGDC) and SKKU (1 min horizontal resolution; Choi et al., 2002).

The model initialization for the spin-up is with the temperature and salinity for the month of January obtained from the northwestern Pacific model with $\frac{1}{6}$ horizontal resolution (Moon et al., 2009). The surface forcing except wind stress is monthly mean heat and freshwater flux derived from the Comprehensive Ocean–Atmosphere Data Set (COADS) (da Silva et al., 1994). The total heat flux Q is applied to the surface grid level and formulated as in Barnier et al. (1995). A correction with respect to surface temperature, dQ/dT derived from bulk formulas, is used to introduce thermal feedback (Marchesiello et al., 2001). Wind stress is forced by QuikSCAT daily mean data in 2002 and 2006. The model includes only one river source, the Changjiang which is the largest river in Asia (Chang and Isobe, 2003). Monthly variation of the Changjiang river discharge is used (Shen et al., 1998), and the volume flux (at zero salinity) enters at the model cells of river outflow.

For the lateral boundary conditions, the monthly mean temperature, salinity and velocity of the northwestern Pacific model (Moon et al., 2009) are used in this study. This climatology is used at open boundaries for all prognostic variables following the method described in Marchesiello et al. (2001), and tidal harmonic forcing (10 constituents) from the TPXO6 analysis (Egbert et al., 1994; Egbert and Erofeeva, 2002) are applied as surface height and depth-averaged velocity boundary conditions. The seasonal volume transport through the Taiwan Strait is set to 0.8 Sv in winter and 2.7 Sv in summer, and the outflow transport through the Korea/Tsushima Strait is set to 2.3 Sv in winter and 3.2 Sv in summer from the northwestern pacific model. The seasonally varying transport east of Taiwan also has a maximum of 23 Sv in summer with a weaker secondary maximum in winter, and a minimum of 16 Sv in autumn. The model was spun up with the climatology fields and tidal forcing for 1 model year. After 1 year of spin-up, the model was run for additional 1 year with the QuickSCAT daily wind of 2002 and 2006, respectively.

3. Results

3.1. Distributions of low-salinity water around Jeju Island in 2002 and 2006

Simulated surface salinity and current fields on August 10, 2002 and 2006 are shown in Figs. 3 and 4, respectively. Horizontal distributions of surface salinity around Jeju Island observed by NFRDI are also shown in right-lower panels of Figs. 3 and 4 for comparison. The Kuroshio, entering the ECS at the east of Taiwan, flows northeastward along the continental shelf break of ECS and