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Interannual variation of freshwater transport and its causes in the Korea Strait: A modeling study

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ABSTRACT

The variability of freshwater transport in the Korea Strait (FTKS) affects the circulation and ecosystem of the East/Japan Sea. Numerical simulations using realistic surface forcing, Changjiang River discharge (CRD), and open boundary values were performed to quantify the interannual variation of FTKS and to investigate its underlying physical processes. The simulated salinity and volume transport, which determine the variability of FTKS, were verified by comparing with observations. Salinity played a more important role than volume transport in inducing the interannual variation of FTKS. FTKS has a positive correlation with CRD, difference between precipitation and evaporation (P–E), southeasterly wind, and freshwater transport in the Taiwan Strait (FTTS). FTKS has its best correlation (0.62) with FTTS. The correlations with CRD (0.25) and P–E (0.37) are weaker, probably due to wind stress. The southeasterly wind that drives Changjiang diluted water toward the Korea Strait by Ekman flow in the East China Sea has good correlation (0.51) with FTKS. The vertical structures of FTKS and its variability are more effectively affected by CRD and P–E in the surface layer, FTTS in the middle layer, and the wind in the subsurface layer.

1. Introduction

The Korea Strait connects the East China Sea (ECS) to the East/Japan Sea (EJS) (Fig. 1). A large volume of freshwater enters the EJS from the ECS through the Korea Strait in summer (Isobe et al., 2002). The freshwater might play a crucial role in the circulation and ecosystem of the EJS (Kuroda and Hirai, 2000; Nof, 2001; Ogawa et al., 1977; Senjyu, 1999). Nof (2001) suggested that a decrease in freshwater supply to the EJS can lead to active formation of bottom water in the northern part of the EJS; thus, the construction of the Three Gorges Dam might change the salinity of the Tsushima Current passing through the Korea Strait.

The water characteristics in the Korea Strait are closely associated with the current system and the water masses in the ECS. The four major water masses in the ECS are Changjiang diluted water (CDW), coastal water, Yellow Sea (YS) water, and Kuroshio water (Beardsley et al., 1985; Chen et al., 1994; Watanabe, 2007), and the three major freshwater sources in the YS and the ECS are river discharge, the Taiwan Current, and precipitation (Chang and Isobe, 2003).

In particular, the Changjiang River supplies about 80% of the total freshwater to the ECS and the neighboring sea, and is the most important source of freshwater (Chang and Isobe, 2005; Chen et al., 1994). Variation in Changjiang River discharge (CRD) and the path of CDW might alter the salinity distribution in the ECS and change freshwater transport through the Korea Strait (FTKS) (Chang and Isobe, 2005; Ichikawa and Beardsley, 2002). CDW with salinity less than 30 appears frequently at the entrance of the Korea Strait (northeastern part of the ECS) in summer. Hydrographic observations, which have been made routinely by the National Fisheries Research and Development Institute (NFRDI) of Korea, show the interannual variation in low-salinity water. The salinity structure in the ECS varies markedly due to advection of CDW in August. CDW appeared off the west coast of Jeju Island in August 1996 (Fig. 2a), whereas it was distributed south of Jeju Island in August 1998 (Fig. 2b). The salinity of CDW in August 1998 was higher than that in August 1996. Seasonal variation of the CDW path is associated with the wind direction (Chang and Isobe, 2003; Lie et al., 2003; Moon et al., 2009; Oh and Park, 2004). CDW flows southward toward the Taiwan Strait along the Chinese coast in winter, but it flows northeastward toward the Korea Strait in summer (Beardsley et al., 1985; Chang and Isobe, 2003).

Several studies on the variation in salinity and FTKS have been carried out using observational data (Isobe et al., 2002; Senjyu et al., 2006). Isobe et al. (2002) reported that the annual mean freshwater transport through the Korea Strait is about 33×10^3 m^3 s^{-1}, and that the maximum transport occurs in summer. Senjyu et al. (2006) showed that the time coefficients of the empirical orthogonal function first mode in summer show weak negative correlation with CRD and argued that the salinity in the Korea Strait tends to decrease with CRD. An

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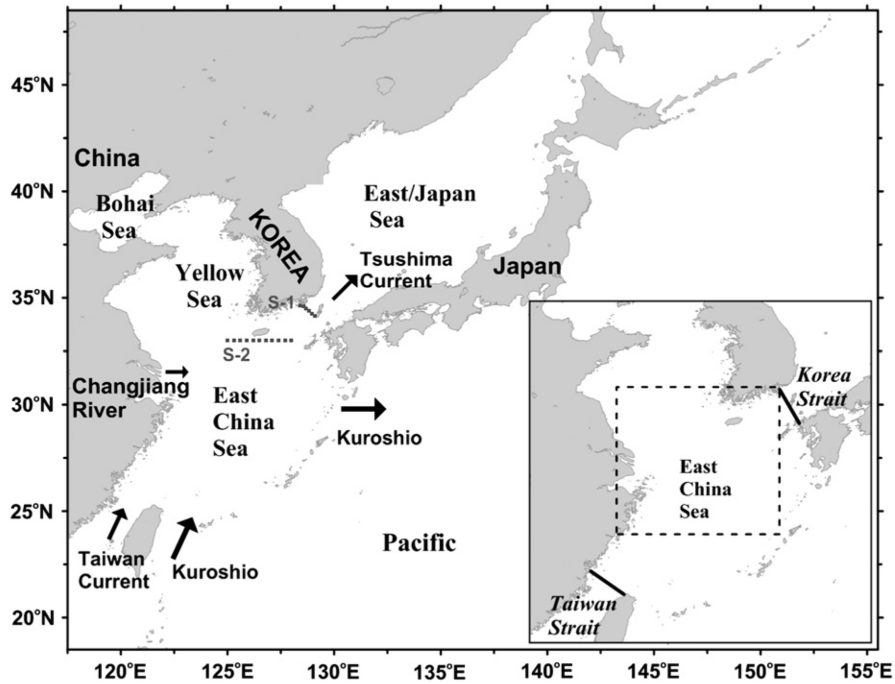

Fig. 1. The model domain covers the Yellow Sea and the East China Sea with 0.1° horizontal grid spacing. S-1 and S-2 indicate salinity observation points by the National Fisheries Research and Development Institute (NFRDI) of Korea. Spatially difference between precipitation and evaporation (P–E) and wind over the East China Sea were calculated in the interior of the dashed lines of the insert in the lower right corner. The thick solid lines indicate the sections selected for the calculation of volume transport and freshwater transport in the Korea Strait and the Taiwan Strait.

analysis of the observational data, which were limited in time and space, was not enough to quantitatively understand the variation in FTKS and the processes responsible for it.

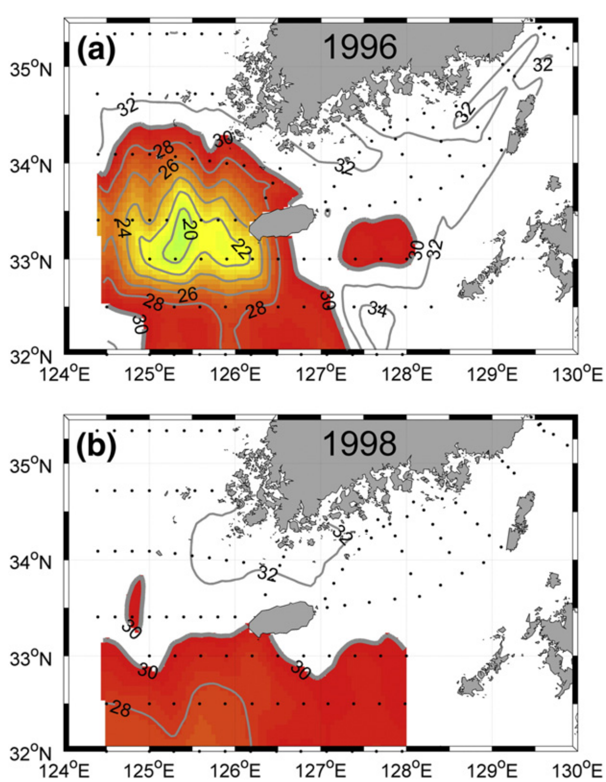

Fig. 2. Horizontal distribution of sea surface salinity in August (a) 1996 and (b) 1998. The dots indicate observation stations. The hatched area indicates low-salinity water with salinity less than 30.

Interannual variation in the CDW path, which might be a primary factor in determining the FTKS, is not yet well known due to limitations in the available observational data. Numerical modeling experiments offer an alternative to compensate for the sparse observations. Numerical models have been used to investigate the behavior of a river plume caused by changes in wind forcing and river discharge (Bang and Lie, 1999; Chen et al., 2008; Choi and Wilkin, 2007).

River discharge and wind forcing in the ECS have both interannual and seasonal variations (Chang and Isobe, 2005; Senjyu et al., 2006). However, most numerical studies on the FTKS and the CDW path have been conducted under idealized or climatological mean conditions. In particular, they did not consider simultaneous interannual variation in the wind and the volume transport through the Korea Strait (VTKS). Based on long-term numerical simulations using idealized periodic interannually varied river discharge and wind, Chang and Isobe (2005) suggested the possibility that the variable river discharge and wind stress may induce the interannual variation of the FTKS. They used fixed values for temperature, salinity, and momentum along an open boundary, which might affect the variation in the CDW path. Moon et al. (2009) studied the response of the CDW path to external forcing using a numerical model and examined the effects of tide and daily wind variation only under a climatological mean condition of open boundary.

In this study, a numerical experiment using realistic river discharge and surface and open boundary forcing, from 1980 to 2009, was used to calculate FTKS to gain insight into its interannual variation. The contributions of salinity and volume transport to the variation of FTKS were evaluated. The effects of the external forcing on the interannual variability of FTKS were investigated quantitatively.

2. Model description

The numerical model used for this study is the Regional Oceanic Modeling System (ROMS). ROMS is a three-dimensional, free-surface, hydrostatic primitive-equation model, whose domain covers the Northwest Pacific area (117.5–155.5°E, 18.5–48.5°N), and the region of interest is the