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# High-precision measurement of tidal current structures using coastal acoustic tomography

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A B S T R A C T

A high-precision coastal acoustic tomography (CAT) experiment for reconstructing the current variation in Dalian Bay (DLB) was successfully conducted by 11 coastal acoustic tomography systems during March 7–8, 2015. The horizontal distributions of tidal currents and residual currents were mapped well by the inverse method, which used reciprocal travel time data along 51 successful sound transmission rays. The semi-diurnal tide is dominant in DLB, with a maximum speed of 0.69 m s$^{-1}$ at the eastern and southwestern parts near the bay mouth that gradually decreases toward the inner bay with an average velocity of 0.31 m s$^{-1}$. The residual current enters the observational domain from the two flanks of the bay mouth and flows out in the inner bay. One anticyclone and one cyclone were noted inside DLB as was one cyclone at the bay mouth. The maximum residual current in the observational domain reached 0.11 m s$^{-1}$, with a mean residual current of 0.03 m s$^{-1}$. The upper 15-m depth-averaged inverse velocities were in excellent agreement with the moored Acoustic Doppler Current Profiler (ADCP) at the center of the bay, with a root–mean–square difference (RMSD) of 0.04 m s$^{-1}$ for the eastward and northward components. The precision of the present tomography measurements was the highest thus far owing to the largest number of transmission rays ever recorded. Sensitivity experiments showed that the RMSD between CAT and moored-ADCP increased from 0.04 m s$^{-1}$ to 0.08 m s$^{-1}$ for both the eastward and northward velocities when reducing the number of transmission rays from 51 to 11. The observational accuracy was determined by the spatial resolution of acoustic ray in the CAT measurements. The cost-optimal scheme consisted of 29 transmission rays with a spatial resolution of acoustic ray of 2.03 $\sqrt{km^2/ray\ numbers}$. Moreover, a dynamic analysis of the residual currents showed that the horizontal pressure gradient of residual sea level and Coriolis force contribute 38.3% and 36.0%, respectively. This indicates that the two terms are the dominant factors of the residual currents in DLB.



## 1. Introduction

Continuous monitoring of tidal current structures using comprehensive oceanographic observations composed of moored and underway measurements is quite a difficult task to be conducted inside the coastal sea owing to the constraints imposed by aquaculture and heavy ship transportation, particularly near China.

Dalian Bay (DLB) is semi-enclosed by the coast of Dalian city on the western and northern sides and by two islands, Xiaosanshan and Dasanshan, on the eastern side. The water depth varies from 10 m at the northwestern part to 50 m at the bay mouth (Fig. 1). The bay connects to the Yellow Sea via Dasanshan Channel (DSS), Sanshan Channel (SS), and Xiaosanshan Channel (XSS) on the southern and eastern sides of the bay (Fig. 1). Although the residual currents are important because they affect the conservative pollutant transport in DLB, it is difficult to conduct traditional observations in this area.

Coastal acoustic tomography (CAT), an innovational oceanographic technology, which is a coastal sea application of ocean acoustic tomography (OAT), was developed by Hiroshima University in 1993 (Kaneko et al., 1994). The OAT technology was put

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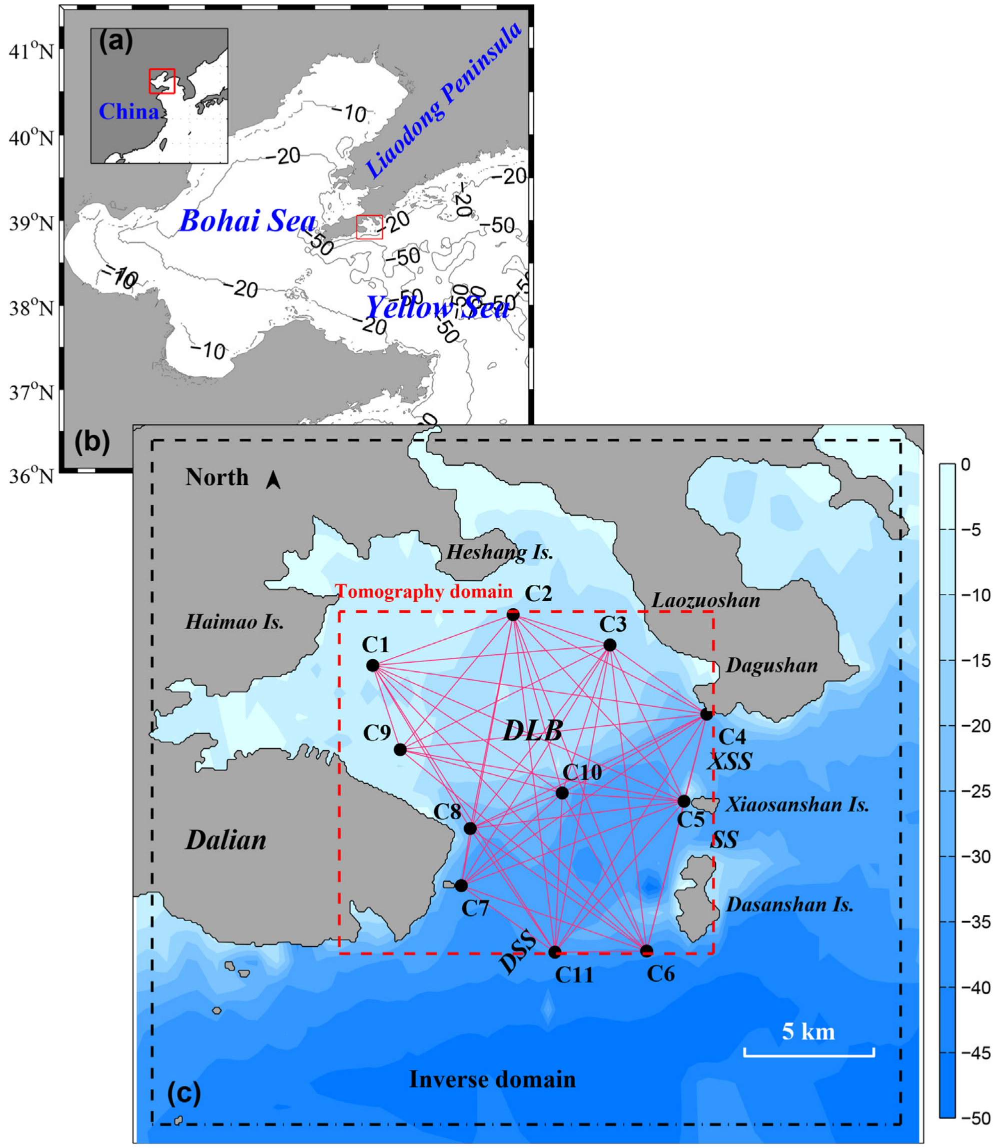


**Fig. 1.** (a) Geographical location of Liaodong Peninsula and its neighboring areas. (b) Location map of Dalian Bay (DLB) and (c) topographic map of the experimental regions. The black dots represent coastal acoustic tomography (CAT) observation stations (C1–C11). The light red solid lines that connect the acoustic station pairs indicate sound transmission rays, and red and black dashed lines enclose the tomography domain and inverse domain, respectively. DSS, XSS, and SS represent Dasanshan Channel, Xiaosanshan Channel, and Sanshan Channel, respectively. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

forward by Munk and Wunsch in 1979 as an effective tool for mapping the structure of currents and sound speeds related mainly to temperature over large-scale areas of oceans (Munk and Wunsch, 1979; Munk et al., 1995). The CAT application has been used for obtaining images of tidal currents in bays, straits, and inland seas without disturbing ship transportation, fish, and marine aquaculture activities (Zheng et al., 1997; Kaneko et al., 2005; Adityawarman et al., 2011; Zhu et al., 2015; Zhang et al., 2015, 2016).

Multi-station measurements of current structures were performed by the pioneer works of the Hiroshima University Group (Park and Kaneko, 2001; Yamaoka et al., 2002; Yamaguchi et al., 2005). The number of transmission rays in previous multi-station experiments has increased from 7 (Yamaoka et al., 2002) to 21 (Zhu et al., 2013), and additional significant tidal current distributions have been obtained in coastal seas. However, there were some differences when compared with the Acoustic Doppler Current Profiler (ADCP). Numerical simulation studies have shown that tidal velocities are better reconstructed when increments of the spatial resolution of acoustic ray are determined by the number of transmission rays (Park and Kaneko, 2001). The agreement between CAT and ADCP has also been improved by data assimilation (Lin et al., 2005). However, the details of increments, including increases in tendency and degree, have not been verified by field experiments in coastal seas because observational data has not been able to the requirements thus far.

We conducted a CAT experiment with 11 CAT systems in DLB, China in 2015 (Fig. 1). In this study, the main objectives are to obtain high-precision tidal current data of DLB and to analyze the factors of the residual current generation. An additional objective is to examine the observational accuracy variation from different spatial resolution of acoustic ray values determined by different numbers of transmission rays.