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Research papers

Temporal variations of volume transport through the Taiwan Strait, as identified by three-year measurements

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A B S T R A C T

The water characteristics of the East China Sea depend on influxes from river run-off, the Kuroshio, and the Taiwan Strait. A three-year observation using an acoustic Doppler current profiler (ADCP) operated on a ferry provides the first nearly continuous data set concerning the seasonal flow pattern and the volume transport from the Taiwan Strait to the East China Sea. The observed volume transport shows strong seasonality and linkage to the along-strait wind stress. An empirical regression formula between the volume transport and wind was derived to fill the gaps of observation so as to obtain a continuous data set. Based on this unique data set, the three-year mean of monthly volume transport is north-eastward throughout the year, large (nearly 3 Sv) in summer and low (nearly zero) in winter. The China Coastal Current flows southward in winter, while the northward-flowing Taiwan Strait Current may reverse direction during severe northeasterly winds in the winter or under typhoons. The sea level difference across Taiwan Strait is closely correlated to the transport through the strait, and their relation is found seasonally nearly stable.

1. Introduction

The East China Sea (ECS) is located at the western edge of the Pacific Ocean and is well-known as a marginal sea with important biological resources. Circulation in the shelf region of the ECS has been of interest to many researchers because various factors, such as the Kuroshio intrusion, Taiwan Warm Current, Changjiang discharge, tidal motions, and wind effects, contribute to its current system. The Taiwan Warm Current plays an especially important role in the circulation throughout the ECS (Fang et al., 1991). The major source of the Taiwan Warm Current is the water mass passing through the Taiwan Strait (TwS), the so-called Taiwan Strait Current. Therefore, understanding the behavior of the Taiwan Strait Current is important to understanding the shelf circulation of ECS.

Many reports have presented current observations in the TwS, but most were based on indirect measurements and measurements that were randomly distributed in space and time or consisted of a series of short-term measurements. Based on the observations of ship drifts, Wyrtki (1961) shows that the mean current in TwS is NE in April, June, and August and SW in February, October, and December. Because ship drift is a combination of the ship velocity and the wind drag and current drag on the ship, and the wind drag on the ship is unlikely to be estimated accurately, the accuracy of such surface current velocity decreases with the wind speed, which is higher during the NE monsoon that spans from fall to spring. The SW monsoon spans from late spring to early fall. Here spring season is defined as March to May. Summer, fall and winter seasons start from June, September, and December, respectively.

Measurements using moored arrays give the most accurate current velocity and are more desirable in the winter, when all other methods of observation fail. However, moored instruments suffer from fishing activities, such that the longest observation is 2.5 months in the fall season (Teague et al., 2003; Lin et al., 2005) in the three-year field surveys. The data show that the current in TwS is mostly NE, except during events of strong northeasterly wind. Model studies by Wu and Hsin (2005) and Jan et al. (2002)

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were based on this set of data. Ko et al. (2003) used model simulation to explain the reversal of current in TwS as the result of Kelvin wave propagation from ECS to TwS during strong northeasterly events.

Using shipboard acoustic Doppler current profiler (ADCP) surveys in 1999–2001, Wang et al. (2003) concluded that the annual mean volume transport Q through TwS is 1.8 Sv (10^6 m^3/s), being 0.9 Sv in winter and 2.7 Sv in summer. Isobe (2008) summarized many snapshots and short-term observations by Zhao and Fang (1991), Liu et al. (2000), Wang et al. (2003), and Jan et al. (2006) and proposed an approximation of Q through TwS: $Q = 1.2 + 1.3\cos(2\pi(\text{Julian Day-157})/365.2422)$. Hu et al. (2010) also reviewed various studies and concluded that Q is “approximately 2.3 Sv northward in summer but approximately 0.8 Sv northward in winter”. These numbers are higher than those of Isobe (2008): 1.2 Sv as the yearly mean, 0.29 Sv in winter, and 2.1 Sv in summer. A long-term observation is necessary to explain not only the difference in various reports, but also the characteristics of Q's variations of various time scales.

Ferry-mounted ADCP observations have been successfully applied to monitor the daily volume transport from ECS to the Sea of Japan through the Tsushima Strait (Takikawa and Yoon, 2005) and to resolve the tidal currents in the Marsdiep inlet of the Netherlands (Buijsman and Ridderinkhof, 2007). In the TwS, an ADCP was installed at the bottom of the Taima Ferry to survey the current beginning in January 2009. The Taima Ferry runs clockwise from Keelung (25°08'N, 121°44'E) at 22:00 local time to Matsu (25°58'30”N, 119°56'06”E) and Dongyin (26°22'36”N, 120°30'24”E), and return to arrive Keelung (Fig. 1) around 18:00 the next day. She runs counterclockwise the next day, and operates six times a week. Taima Ferry provides a unique platform for near-continuous measurements of currents in the northern end of TwS. The principal objectives of this implementation are to observe the total volume transport (Q) through TwS (between ECS and SCS) and determine the seasonality of volume transport entering ECS from TwS.

This article is organized as follows. Section 2 introduces the method for acquiring the data used in this study. The results and analysis are presented in Section 3. Section 4–6 discusses the relationship between the volume transport and the wind, the response of the volume transport and the sea level difference to the wind, and the China Coastal Current. The conclusions of this study are presented in Section 7.

2. Data acquisition

2.1. ADCP survey from ferry boat

The Taima Ferry is 102.7 m long with a draft of 4.5 m and 5039 gross tonnage. An RDI 300 kHz Mariner ADCP was installed at the bottom of the ferry in December 2008. The sampling is averaged every minute over 4 m-depth bins starting at 8.2 m below the sea surface. The ship's heading, roll, and pitch data were recorded, and the bottom-tracking mode was selected to log the ship velocity. The crew of the Taima Ferry initiated the ADCP at the beginning of every cruise to collect ocean current profile data between Matsu and Keelung, that is, across the northern entrance of TwS (Fig. 1). After deducting approximately 60 days for annual maintenance work, one day off per week, days of no service due to severe

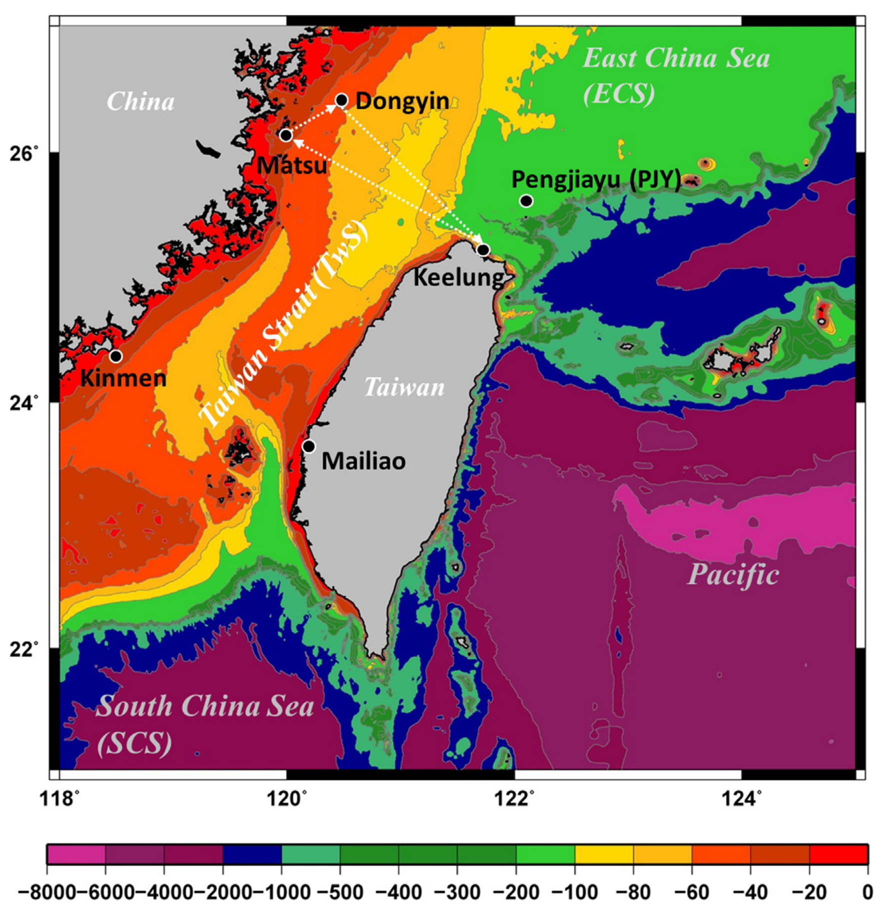

Fig. 1. The geography and topography along the Taima Ferry cruise track across TwS. Pengjiayu is the weather station to provide the wind data. Tide gauge stations at Mailiao and Kinmen measure the sea level height respectively. Taima Ferry sails either clockwise or counterclockwise between Keelung, Matsu, and Dongyin. The departure times at Keelung and Matsu are usually at 22:00 and 09:30, and it takes about 8.5 h from Keelung to Matsu, about 8 h to Dongyin, and 2.5 h for Matsu–Dongyin leg.