Structure of the Tsushima Warm Current in the Northeastern Japan Sea

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By using Acoustic Doppler Current Profiler (ADCP) measurements with the four round-trips method to remove diurnal/semidiurnal tidal currents, the detailed current structure and volume transport of the Tsushima Warm Current (TWC) along the northwestern Japanese coast in the northeastern Japan Sea were examined in the period September–October 2000. The volume transport of the First Branch of the TWC (FBTWC) east of the Noto Peninsula was estimated as approximately 1.0 Sv (10^6 m^3/s), and the FBTWC continued to flow along the Honshu Island to the south of the Oga Peninsula. To the north of the Oga Peninsula, the Second Branch of Tsushima Warm Current and the eastward current established by the subarctic front were recombined with the FBTWC and the total volume transport increased to 1.9 Sv. The water properties at each ADCP line strongly suggested that most of the upper portion of the TWC with high temperature and low salinity flowed out to the North Pacific as the Tsugaru Warm Current. In the north of the Tsugaru Strait, the volume transport of the northward current was observed to be as almost 1 Sv. However, the component of the TWC water was small (approximately 0.3 Sv).

1. Introduction
The Tsushima Warm Current (hereafter TWC) is basically driven by the sea level difference between the East China Sea and the Japan Sea (Toba et al., 1982; Ohshima, 1994). The TWC carries both the subtropical water originating from the North Pacific and the runoff water from the continental self in the East China Sea to the Japan Sea through the Tsushima Straits (e.g. Isobe et al., 2002). After passing through the straits, the flow pattern of the TWC is very complicated and it has large variability (e.g. Suda et al., 1932; Uda, 1934; Naganuma, 1977; Kawabe, 1982; Katoh, 1994; Lee et al., 2000). According to Naganuma (1977), three branches of the TWC can be seen frequently: the First Branch of TWC (hereafter FBTWC) existing along Honshu Island; the Second Branch of the TWC (hereafter SBTWC) existing in the offshore area with large meanders; and the Third Branch of the TWC (hereafter TBTWC), which flows northward along the eastern Korean coast, which is also called the East Korean Warm Current. Hase et al. (1999) examined the distribution of the temperature fronts and suggested that the FBTWC flowed along the isobath shallower than 200 m and the mainstream of the SBTWC existed along the continental shelf break from spring to fall. However, east of the Noto Peninsula (at approximately 137°E), because the continental shelf becomes quite narrow, the paths of these two branches, especially the SBTWC, are highly complex and variable (Nakada and Isoda, 2000; Nakada et al., 2002). On the other hand, after leaving the Korean coast at about 38°N, the TBTWC merges into the subarctic front, and then a strong eastward current reaching around the northwestern Japanese coast is formed along approximately 40°N. This current contains both the TWC water and the subarctic water. Here we name it the Eastward Current established by the Subarctic Front (hereafter ECSF). As a result, these three branches of the TWC are recombined in the northeastern Japan Sea (e.g. Suda et al., 1932; Uda, 1934). This has not yet been fully clarified, however. After the recombination, more than half of the TWC flow out to the North Pacific through the Tsugaru Strait as the Tsugaru Warm Current (hereafter TGWC), and the residual northward current, which is the origin of the Soya Warm Current, exists along the west coast of Hokkaido (Onishi and Ohtani, 1997; Nakata and Tanaka, 2002; Ito et al., 2003). The current structure and the water mass structure of these currents have not yet been fully clarified, however.

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In this study, using shipboard Acoustic Doppler Current Profiler (ADCP) measurements with the four round-trips method to remove tidal currents, the current structures of the TWC and its branches in the northeastern Japan Sea are examined. The observations and data processing are explained in Section 2. The current structure and volume transport across the ADCP lines are examined in Subsections 3.1 and 3.2. In Subsection 3.3, the TWC water is divided into two portions, based on the water properties. Finally, the circulations and the water mass balances of the TWC waters along the Japanese coast are discussed in Section 4.

2. Observations and Data Processing

The data used in this paper were collected from September 16 to October 8 in 2000 by R/V Torishima (Tankai Senpaku Co., Ltd.). Figure 1 shows the locations of the CTD stations and shipboard ADCP lines in the northeastern Japan Sea along the northwestern Japanese coast. The CTD instrument was the “Sea-Bird 9/11plus”. The shipboard ADCP installed on the R/V Torishima was the “Ocean Surveyor” vessel-mounted phased array ADCP with a frequency of 150 kHz (RD Instruments Co., Ltd.). The depth of the first layer was set to 38 m and length of each layer was set to 16 m. The sampling interval was 60 s. Data for which the percent-good criterion fell below 80 % were rejected for the analyses. The instrument could track the sea bottom to approximately 700 m. Thus, all current profiles in the lines A, B, C1 (stations c1–c7), C2 (c7–c13), D, E, and H are calculated using the bottom-tracked current data. As for the lines of F, G, I and J, where the depth became partially greater than 700 m, current data calculated from navigation, for which the position of the vessel was detected by the Global Positioning System (GPS), were used instead of the bottom-tracked data (hereafter “navigation data”). The navigation data were calibrated using the method of Joyce (1989). There is a possibility that the navigation data sometimes contains irregularities when the vessel changed its speed frequently. However, in this study, a constant vessel speed was used in each measurement, and this thus increases the reliability of the navigation data. The dif-

![Fig. 1. Chart of the Japan Sea (lower right figure) and an enlargement of the observation area in the northeastern Japan Sea. Solid lines show the Japanese coast and isobaths of 200 m, 1000 m and 3000 m. Solid circles show the CTD stations observed by the R/V Torishima in September and October 2000. Capital letters A–J indicate the names of the CTD lines and lowercase letters with a number indicate the CTD stations. Pairs of two large solid circles indicate both ends of the ADCP measurements with four round-trips in 24h 50m (a1–a7, c1–c7, d1–d7, d7–d13, e1–e7, f2–f8, g2–g8, h3–h8, i1–i7, j1–j6).](image1)

![Fig. 2. Comparison between the velocities calculated from the bottom-tracked data and the navigation data in the line H. In the bottom-tracked mode, the vessel velocity was detected using the sea bottom. In the navigation mode it was calculated by GPS. The correlation factor and the RMS are 0.96 and 3.4 cm/s, respectively.](image2)