On the Tsushima Current*

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1. Introduction

We have had many reports about the Tsushima current which flows to the north from the Tsushima Straits into the Japan Sea. After World War II, oceanographical observations have been carried out periodically by the Maritime Safety Agency with new instruments such as GEK, BT, and others. Consequently, we have more accurate current chart than in the former time.

Utilizing these data the author intends to show that the bottom topography has a great influence on the path of the Tsushima current.

2. The flow pattern of the Tsushima current

M. Uda (1934, 36), K. Suda (1932) and others studied the hydrography of the Tsushima current. According to these papers, the flow pattern such as shown in figure 1 is of the general type. However, according to the recent data it seems that the flow pattern of this figure is rather inaccurate. The present author has drawn the flow patterns for 1950 to 1956, among which the patterns of 1952, 1953 and 1956 are shown in figures 2, 3 and 4, respectively. These patterns were obtained from dynamical computations referred to 300 db surface. From these figures, we can see that the most characteristic feature of the Tsushima current is the meandering which is found north of the Oki Islands. This meandering is always observed in all seasons and all years in the data of the present study. It is clear that they are stable. In figure 4, values of current direction and speed obtained with GEK are shown together with isobaric lines. From the current speed it is seen that the northward current north of the Oki Islands is more dominant than the eastward current

through the channel between the Oki Islands and Honshu. Namely, current speed of the former is 1.2–1.4 knots and that of the latter is 0.5–0.6 knots. Assuming that the width and depth of both currents are equal to each other, the volume of the northward transport may be twice or three times as much as the volume transport through the channel between the Oki Islands and Honshu. The volume of the northward transport should be actually more than three times as much as the latter transport, because the depth of the northward current reaches to 300 m, while the depth of the latter current only reaches to about 80 m.

Supposing that the mean current velocity from sea surface to bottom is 20 cm/s through the Tsushima Straits (between Cape Konzetsu (Cape Kanjō in English) and Tsunojima in Honshu), the volume transport through this strait is about 3.3×10^6 m³/s. Now, the mean depth and width of the Tsushima Straits are 110 m and 116.5 km, respectively. The volume transport through the channel between the Oki Islands and Honshu is 0.5×10^6 m³/s which is about $\frac{1}{6} \sim \frac{1}{7}$ of the former. The mean velocity is 15 cm/s and the current width and depth are 45 km and 75 m, respectively. From these data, it is natural that the northward volume transport predominates more and more in comparison with the transport along Honshu. The value of 0.5×10^6 m³/s may be accurate because the volume transport north of the Kyoga Misaki is about 0.7×10^6 m³/s referring to the observations of the Maizuru Marine Observatory (1955).

When we study the distributions of water temperature and salinity, the areas of high temperature and salinity are found near the coast of Honshu. These areas of high temperature and salinity were regarded as the littoral first branch of the Tsushima current (Shimomura and Miyata, 1953). But, from

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Fig. 5. Bottom topography of Japan Sea.
Depth: in meter.

ridge, the high pressure occupies rather east of submarine ridge and the low pressure is found near the deep place. Referring to figure 4, currents which traverse over the submarine ridge north of the Oki Islands (shallower than 300 m) can not be seen.

4. Application of simple vorticity equation to the Tsushima current

In meteorology the meandering of the jet stream has been explained by orographical effect. The author intends to apply the vorticity equation to the Tsushima current. Referring to figures 4 and 5, we see that a

Fig. 6. Deformation of narrow current by mountain effect.

Upper: horizontal plane.
Lower: vertical plane.

submarine ridge (shallower than 300 m) stretches about 85 nautical miles to the north of the Oki Islands, while the width of the Tsushima current is only 20 nautical miles. So we may treat the problem after Bolin's narrow jet stream theory (1950). Let the axes of x and y be directed to the east and the north, respectively. Before the Tsushima current reaches the submarine ridge, this current is yet undisturbed and so the relative vorticity may be regarded as zero. It is supposed that the relative vorticity is generated in the area of the submarine ridge. Now let the thickness of the Tsushima current be D_0 and h the height of the bottom configuration (figure 6). The Coriolis parameter, f_0 , is a constant. Let ζ be the relative vorticity, then we have the following equations:

$$\frac{\zeta + f_0}{D_0 - h} = \frac{f}{D_0} \quad (1)$$

$$\zeta = -\frac{f_0}{D_0} h \quad (2)$$

Disregarding the changes in the horizontal shear, we have

$$\frac{1}{R} = -\frac{f_0}{CD_0} h \quad (3)$$

when R is the radius of curvature of the current, and C the current velocity. Using the analytical expression for R , (3) becomes

$$\frac{\frac{d^2 y}{dx^2}}{\left[1 + \left(\frac{dy}{dx}\right)^2\right]^{3/2}} = -\frac{f_0}{CD_0} h \quad (4)$$

$$\text{i.e. } d\left(\frac{\frac{dy}{dx}}{\left[1 + \left(\frac{dy}{dx}\right)^2\right]^{1/2}}\right) = -\frac{f_0}{CD_0} h \quad (5)$$

$$\text{i.e. } d(\sin \alpha) = -\frac{f_0}{CD_0} h dx$$

where α is the angle between the direction of the jet and the x -axis. Since the undisturbed current may be regarded of flowing from due west to due east, we have

$$\sin \alpha = -\frac{f_0}{CD_0} \int_{x_0}^{x_1} h dx \quad (6)$$

If the current is to cross the mountain, α must be less than 90° everywhere. Hence

$$C > \frac{f_0}{D_0} \int_{x_0}^{x_1} h dx \quad (7)$$

A critical velocity C_{cr} is defined as follows :

$$C_{cr} = \frac{D_0}{f_0} \int_0^{\Delta x} h dx \quad (8)$$

where $\Delta x = x_1 - x_0$

If $C > C_{cr}$, the current can traverse over the submarine ridge. Next, it is necessary to know how deep does the Tsushima current extend down to motionless layer. Judging from a small gradient of water temperature at the 400 m layer, it seems that the current at this layer is very weak. Supposing that the 400 m layer is the motionless layer in question, D_0 is 400 m and h 100 m. As Δx is 74 km, we have $C_{cr} = 1.8$ m/s.

If the current velocity could not reach the value of 1.8 m/s (3.3 knots), it could not go across the submarine ridge. As the velocity of the Tsushima current is 1-1.5 knots actually, it is natural that the Tsushima current can not traverse this ridge, but flows around it near 38° N.

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