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A numerical study on the formation of the Kuroshio Counter Current and the Kuroshio Branch Current in the East China Sea

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Abstract—The Kuroshio Counter Current (KCC) and the Kuroshio Branch Current (KBC) are two unique features of the Kuroshio in the East China Sea. The mechanisms that generate the KCC and the KBC are studied using a barotropic inflow–outflow model with a simplified basin configuration of the East China Sea. The present study shows that the KCC can only exist on a β-plane frame of reference and its flow pattern is independent of the offshore Ryukyu Islands. In the East China Sea, the continental slope plays the role of a western boundary for the Kuroshio. Whether the Kuroshio protrudes onto the slope region, however, is found to have little influence on the KCC. Concerning the formation of the KBC, we found that the planetary β-effect and the existence of Taiwan Island are two indispensible conditions: the planetary β-effect drives part of the Kuroshio inflow to branch southwestward and Taiwan Island blocks this branched current causing it to protrude onto the continental shelf. Based on the numerical calculation, we further found that the branch current is reinforced by topographic Rossby waves induced by the repeated crossing of the Kuroshio over the continental slope.

1. INTRODUCTION

THE Kuroshio originates in the North Equatorial Current and flows into the East China Sea through the passage between Taiwan and Yonakuni-jima, an island at the southwestern tip of the Ryukyu Islands. Under the constraint of the steep continental slope, the main stream of the Kuroshio in the East China Sea runs stably along the 200 m isobath at a maximum velocity of 75–150 cm s^{-1} (NITANI, 1972). After it turns eastward around 30°29′N latitude and 129°E longitude, the Kuroshio eventually flows out into the Pacific through the Tokara Strait.

Figure 1 shows schematically the Kuroshio's flow pattern in the East China Sea. Notice that a counter current flowing southwestward exists between the main stream of the Kuroshio and the Ryukyu Islands. The observational evidence of the Kuroshio Counter Current (KCC) was obtained both from the movement of drifter bottles during winter in the East China Sea (KONDO and TAMAI, 1975) and from direct CTD and GEK measurements. Figure 2 shows geostrophic velocity profiles calculated by INOUE (1981) from the CTD measurements along the PN section (see Fig. 1 for its location). The KCC, as indicated by the offshore shaded regions, has a maximum speed ranging from 20 to 50 cm s^{-1} and its volume transport tends to weaken in autumn. This tendency is possibly related to the fact that the Kuroshio in the East China Sea has a smaller volume transport in

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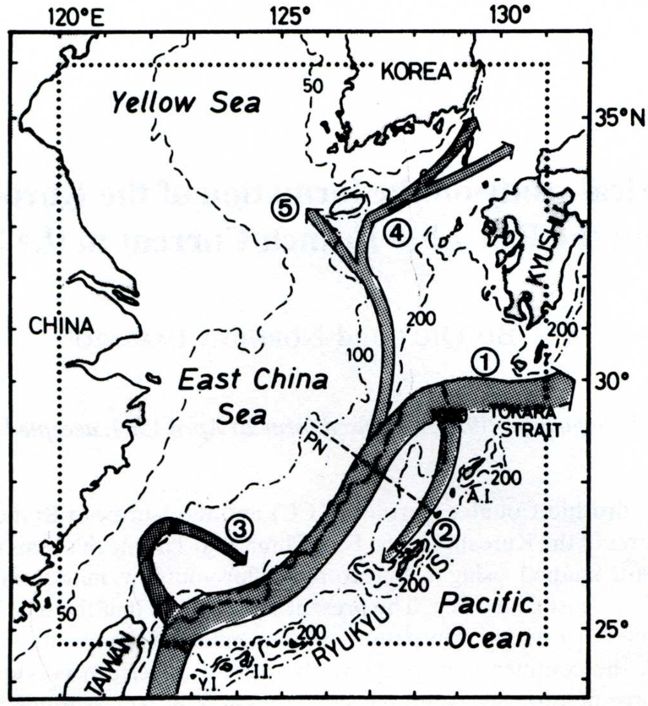

Fig. 1. Schematic flow pattern of the Kuroshio in the East China Sea: (1) the Kuroshio main stream; (2) the Kuroshio Counter Current (KCC); (3) the Kuroshio Branch Current (KBC); (4) the Tsushima Warm Current and (5) the Yellow Sea Warm Current. The depth contour of the bottom topography is in meters. Y.I., I.I. and A.I. indicate the islands of Yonakuni-jima, Ishigaki-jima and Amami-oshima, respectively. The dashed-line PN shows the stationary observational section by Nagasaki Marine Observatory.

autumn (19.78 Sv), as compared with its annual mean value of 22.67 Sv (FUJIWARA, 1981). Based on GEK data observed along the PN section from 1956 to 1975, GUAN and MAO (1982) also confirmed the existence of the KCC. They estimated the maximum speed of the KCC to be 20 cm s^{-1} on average. A more detailed long-term averaged surface velocity pattern for the entire East China Sea is shown in Fig. 3, wherein we averaged the GEK data compiled by the Japan Oceanographic Data Center for the period of 1953–1984 at each mesh area of 12′ × 12′. The result of Fig. 3 reveals that the KCC is not a flow confined near the PN section, but rather exists throughout the offshore areas from Amami-oshima Island to Ishigaki-jima Island between the Kuroshio and the Ryukyu Islands.

Another noteworthy feature of the Kuroshio in the East China Sea is that a branch current separating from the Kuroshio forms immediately after the Kuroshio passes by the east coast of Taiwan (see Fig. 1). The existence of this branch current (the Kuroshio Branch Current, KBC) is verified by the averaged flow pattern of Fig. 3. Figure 3 shows that the KBC has a tendency to turn to east–southeast to rejoin the main stream of the Kuroshio after it flows onto the continental shelf north of Taiwan. The KBC's presence on the shelf north of Taiwan is also confirmed by recent satellite pictures. One such picture taken by the NOAA-8 satellite on 3 January 1984 is shown in Fig. 4. The dark tones in the picture represent warm Kuroshio water and the light tones represent cold shelf-originated waters. From Fig. 4, it is clear that a dark-toned water mass extends over the continental shelf north of Taiwan, suggesting that a part of the Kuroshio has been transported onto the

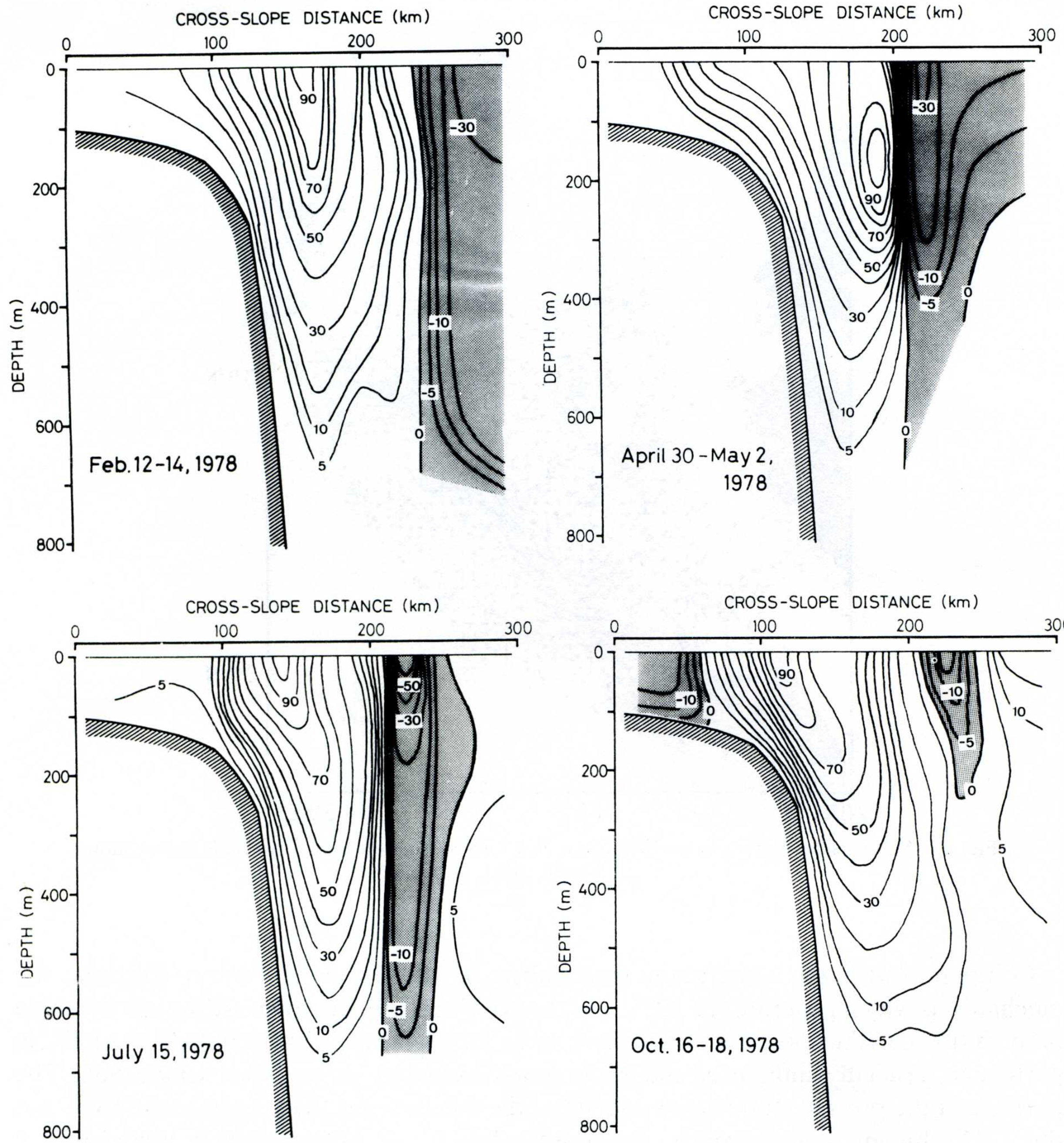

Fig. 2. Geostrophic velocity profiles along the PN section in four different seasons in 1978 (after INOUE, 1981). The unit for velocity contours is in cm s^{-1} and the offshore hatched regions indicate the KCC.

shelf by the KBC. According to INOUE (1981), the warm water mass of the KBC can sometimes reach the mouth of Yangtze River.

In addition to the KCC and the KBC, the Tsushima Warm Current is another important branch of the Kuroshio in the East China Sea. Evidence that the Tsushima Warm Current separates from the Kuroshio was presented by HUH (1982a,b). MINATO and KIMURA (1980) claimed that the generation mechanism of the Tsushima Warm Current is a result of the pressure difference between the East China Sea and the Tsugaru Strait. On the other hand, ICHIYE (1984) proposed that the residual lateral transport of the Kuroshio through the Reynolds' stresses causes the Tsushima Warm Current.