ON THE SOURCES OF THE TAIWAN WARM CURRENT FROM THE SOUTH CHINA SEA

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Abstract

Historical hydrographic data across several sections in the South China Sea (SCS) and Taiwan Strait have been reconsidered. The year-around existence of the South China Sea Warm Current (SCSWC) along the shelf break off the Guangdong coast and the seemingly year-around southwestward current to the east of SCSWC are both evident in the data. The data also showed that the northward current in the Taiwan Strait seemed to be the extension of SCSWC.

A barotropic numerical model is employed to explain some of the observed features. Reasonable simulation of the circulation in the northeast part of SCS has been found.

I. INTRODUCTION

During 1958—1960 Chinese oceanographers organized an extensive study of the shelves along the entire China coast. Many major hydrographic features were identified. The discovery of the northward flowing Taiwan Warm Current (TWC) and the South China Sea Warm Current

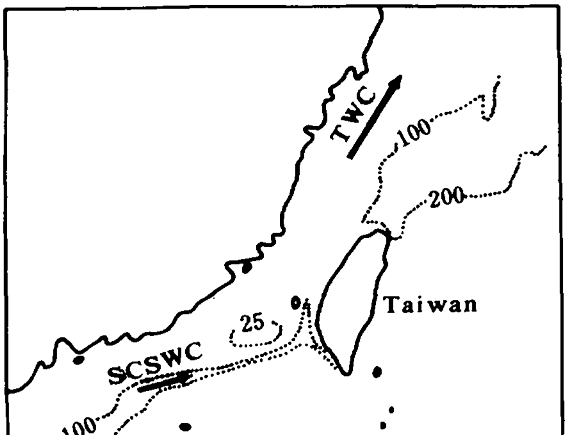

Fig. 1 Map of the Taiwan Warm Current and South China Sea Warm Current

(SCSWC) by Guan and Chen in 1964 were noteworthy (e. g., see Guan, 1984). These two currents were found to exist throughout the year, even in winter when strong northerly winds were prevailing. A schematic map showing these two currents is given in Fig.1.

It has been found that TWC is related to several prominent hydrographic features in the East China Sea (ECS). Upwelling along the Zhejiang coast was found to be associated closely with TWC[1,2]. The Changjiang River Plume was shown to be pushed northeastward in summer across the shelf by TWC (e. g., see Yu et al., 1983). The Yellow Sea Warm Current seemed to derive part of its water from the topographic steering of TWC (Yuan et al., 1985). So far, however, there is no general agreement as to the sources of TWC. Some scientists thought that TWC originated from the branching of the Kuroshio northeast of Taiwan (e.g., Inoue, 1975). Others believed that the branching of the Kuroshio northward along the southwest coast of Taiwan also contributed to the formation of TWC (e. g., Chuang, 1985). Guan (1984) has repeatedly argued that SCSWC off the Guangdong coast must contribute to part of TWC water.

The 1984—1985 State Oceanic Administration study on the "Kuroshio and its Influence on the Ocean Environment of the East China Sea" further clarified how the Kuroshio branches onto the shelf northeast of Taiwan and how it contributes to TWC water[3]. In this paper we will present an analysis on how the Kuroshio may contribute to TWC water through the South China Sea (SCS).

II. HYDROGRAPHIC RESULTS

During the "Cooperative Study of the Kuroshio" years, the Hong Kong Fisheries Research

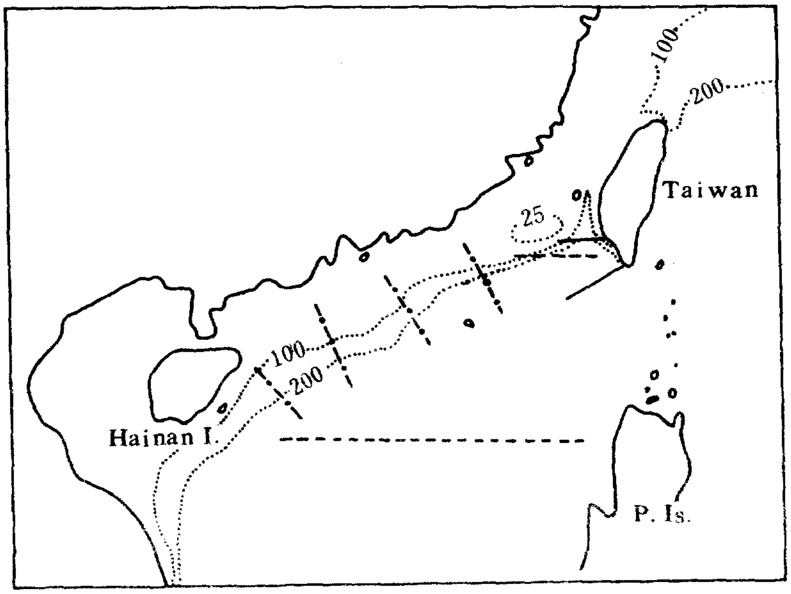

Fig. 2 Map of the historical hydrography transects in the South China Sea
—·—By W.Y.Tseng
····· and —·—·— By Hong Kong Fisheries Research Station

1) Yuan, Y.C., J.L. Su and S.Y.Xia, 1987. A Diagnostic Model of Summer Circulation on the Northwest Shelf of the East China Sea. Proceedings of the Third Japan and East China Seas Study Workshop. (in press)

2) Yuan, Y.C., J.L.Su and S.Y.Xia, 1987. Three dimensional diagnostic calculation of circulation over the East China Sea shelf. *Acta Oceanologica Sinica*. (in press)

3) Su, J.L. and Y.Q.Pan 1987. On the shelf circulation north of Taiwan. *Acta Oceanologica Sinica*.(in press)

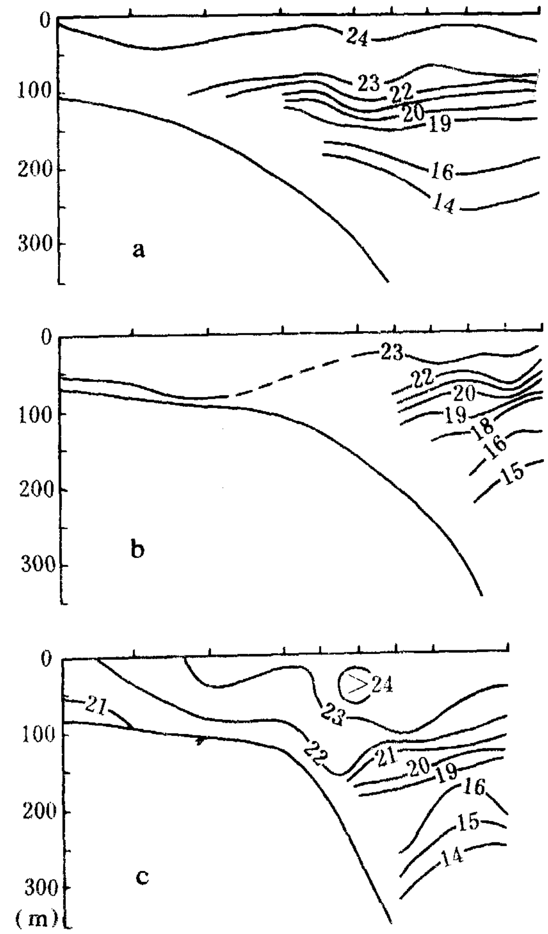

Fig. 3 Temperature sections across the shelf transects by Hong Kong Fisheries Research Station in January 1969
(a) Southern section (b) Middle south section
(c) Middle north section

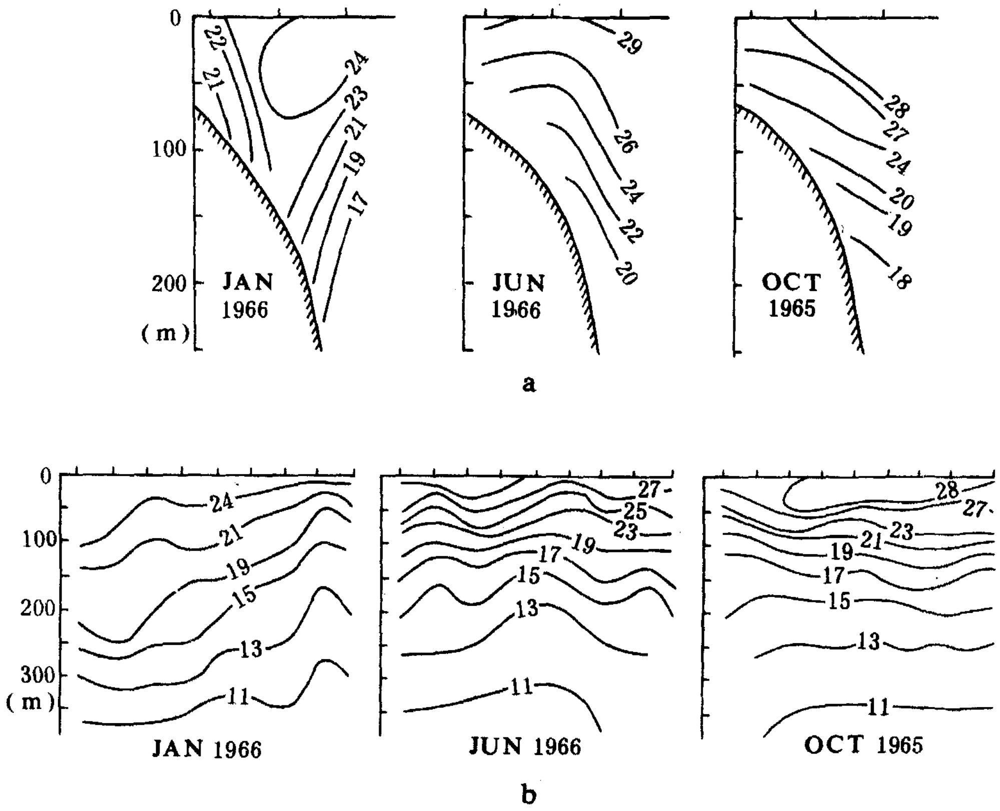

Fig. 4 Three temperature sections across the basin transects by Hong Kong Fisheries Research Station
(a) Northern section
(b) Southern section

Station repeated many sections in SCS. These sections can be grouped into two sets, one across the shelf off Guangdong Province and the other around SCS basin. The complete sections of the shelf set and part of the basin set are shown in Fig.2.

Using the shelf set hydrographic data as well as anchored current measurement results obtained by the State Oceanic Administration, Guan (1978) argued convincingly for the existence of SCSWC on SCS shelf which flowed northward against the wind in winter. Recent field studies by Chou et al. (1984), Guo et al. (1985) and Chuang (1986) showed that farther offshore from SCSWC there exists a southwestward current in both summer and winter between the 200 m and 1000 m isobaths. Evidences for this recently found current can actually be found in shelf set data mentioned earlier. In Fig. 3 the January 1969 temperature sections of the three southern transects of the shelf set are shown. The temperature distributions are rather representative of the data set, even for other seasons. The cross-shelf temperature gradient, a measure of the current strength, was larger at the northern section. The sloping of the isotherms suggested a northward current, i.e., SCSWC, near the shelf break and a southward current beyond the 200 m isobath.

Data on the basin set were obtained in three cruises. The temperature sections for all three cruises along the two transects chosen are shown in Fig. 4. Unfortunately the northern transect intersected the isobaths at a rather small angle (Fig. 2). Nevertheless it was clear that there was a northward current near the shelf break during all the cruises.

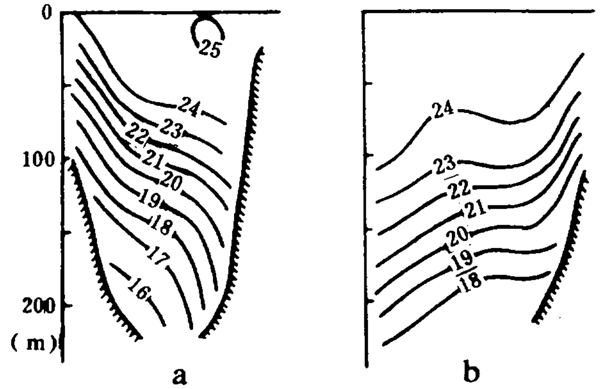

Fig. 5 Temperature sections across the transects by Tseng (1972)

(a) Across the submarine canyon

(b) Off the southern tip of Taiwan

We found only one cruise transect that ran across the shelf next to Taiwan Island (Tseng, 1972). This cruise was conducted in December and the location of the two southernmost transects are shown in Fig. 2. The temperature sections of these transects are plotted in Fig. 5. We see that there were evidences of a current flowing southward along the southwest coast of Taiwan. Farther north into a submarine canyon off the west coast of Taiwan there seemed to be a strong northward flow along the western side of the canyon. This flow might be related to the northward current (SCSWC) at the shelf break to the south as discussed earlier. Mooring measurements by Chuang (1985, 1986) showed the persistence of a northward current inside the canyon from April to May in 1983 and from January to April in 1986.

III. A BAROTROPIC NUMERICAL MODEL

Su and Pan[1)] employed a simple model to study the dynamics of the intrusion of the Kuroshio

1) See footnote p.

onto the shelf north of Taiwan. It was shown that the lack of the Taiwan coast's support to the surface elevation gradient of the Kuroshio as it passes Taiwan is one of the major factors responsible for the intrusion dynamics. Because of the role of Luzon Island in supporting the Kuroshio and the closeness of water properties on both sides of the Bashi Strait, Su and Pan speculated that a barotropic model could also be used to study the main features of the circulation in SCS. They suggested that the continental slope on the western side of SCS would trap some of the Kuroshio water intruding into SCS and would also guide the trapped water northward. To see whether this speculation is true we adopt a barotropic numerical model[1] to explain some of the circulation dynamics in ECS.

The model domain and the idealized topography are shown in Fig. 6, where the maximum water depth has been taken to be 700 m. Both the east and south boundaries have been replaced by land boundaries. Taiwan is represented by a rectangular land and the southern tip of Taiwan is modeled by a small shelf. Small islands and shoals north of Luzon have also been replaced by a small shelf.

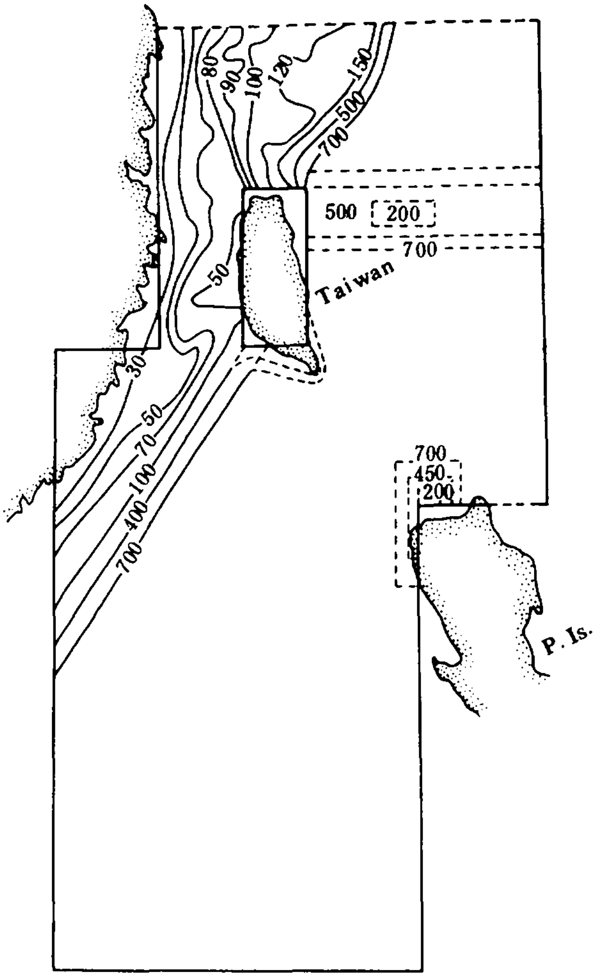

Fig. 6 Model bathymetry (depths in meters)

1) Wang, W. and J.L.Su, 1987. A barotropic model of the Kuroshio system and eddy phenomena in the East China Sea. *Acta Oceanologica Sinica*. (in press)

The ocean is assumed to be homogeneous and the vertically integrated time-dependent equations are used. Since the slope area is in fact much steeper and the basin much deeper we employed a quadratic friction law with a bottom friction linearly decreasing with depth to zero at 300 m and identically zero for depths beyond 300 m. The wind stress is taken to be zero because we

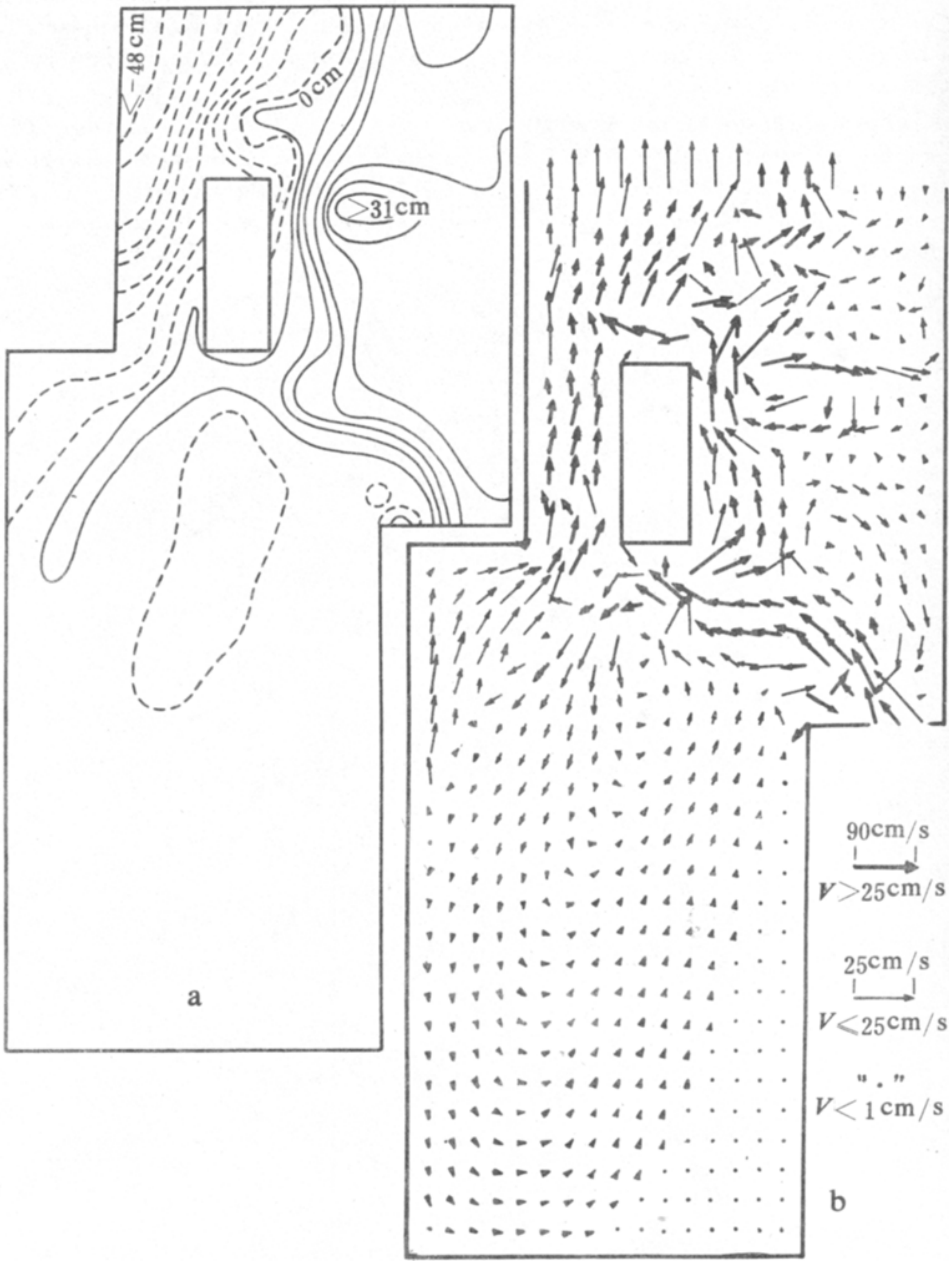

Fig. 7 Model results
(a) Sea-level contours (5.3 cm increment)
(b) Velocity field

are interested primarily in the circulation driven by the Kuroshio. Besides, for a wind driven circulation, the east and south boundaries have to be open boundaries where the boundary conditions will be difficult to specify.

Non-slip boundary condition is imposed at all land boundaries.

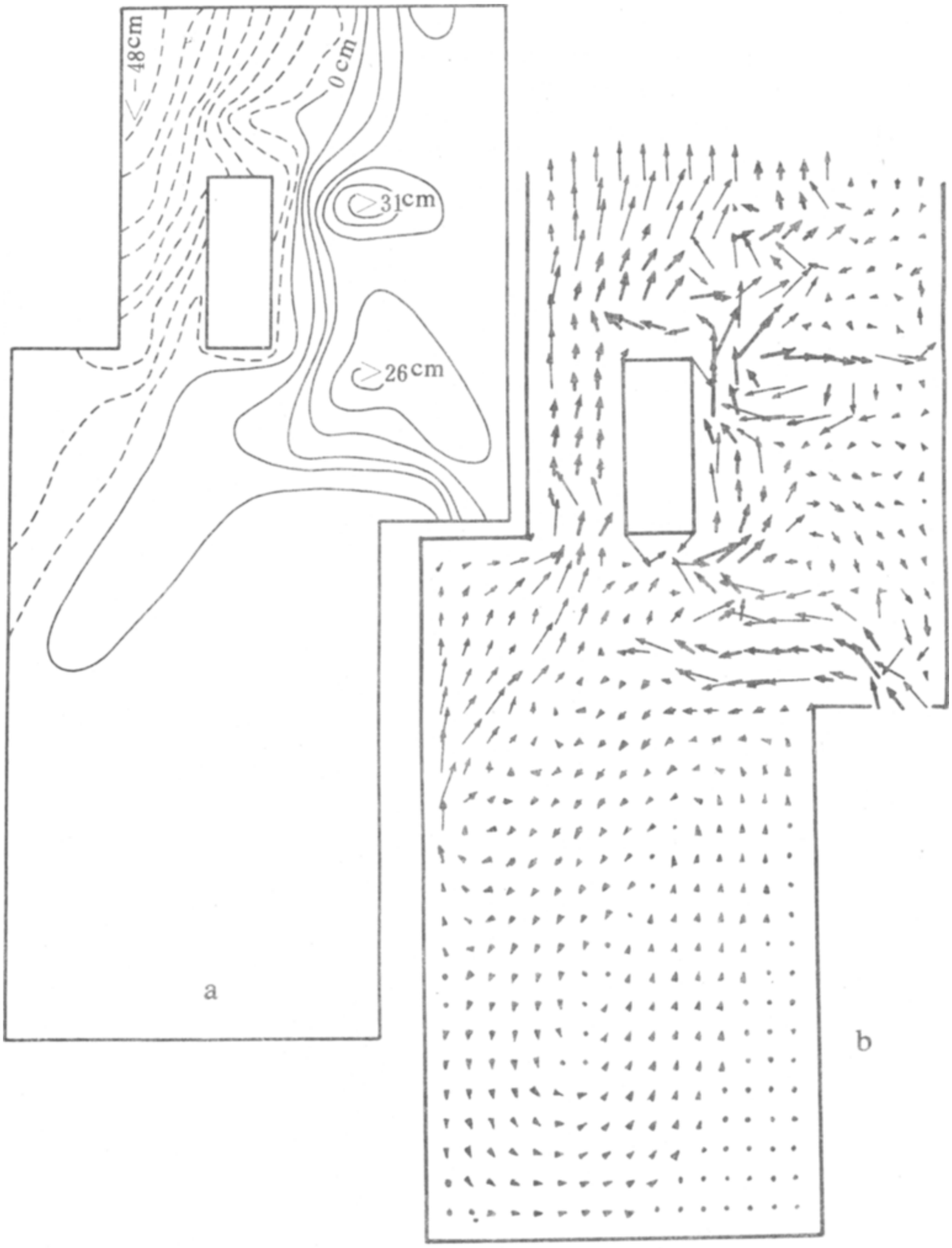

Fig. 8 Numerical results of the model without the shelf north of Luzon

(a) Sea-level contours (5.3 cm increment)

(b) Velocity field

The Kuroshio enters the domain through the lower right corner in a direction parallel to the coast of Luzon Island. Its volume transport is chosen to be 30 SV. The Kuroshio leaves the domain through the northern boundary, and its distribution there is self-determined except for the constraints that the volume flux has no east-west component and that the net outflow equals the inflow from the south. The model was driven from the static state by gradually increasing the inflow and the computation went on until a quasi-equilibrium state was reached. A modified numerical scheme after Hurlburt and Thompson (1980) was used.

In Fig. 7 the computed results of the free surface anomaly and the velocity field, i.e., transport flux divided by the depth, were plotted. Part of the Kuroshio is seen to make a slight detour into the Bashi Strait and most of the current keeps on northward along the east coast of Taiwan. It

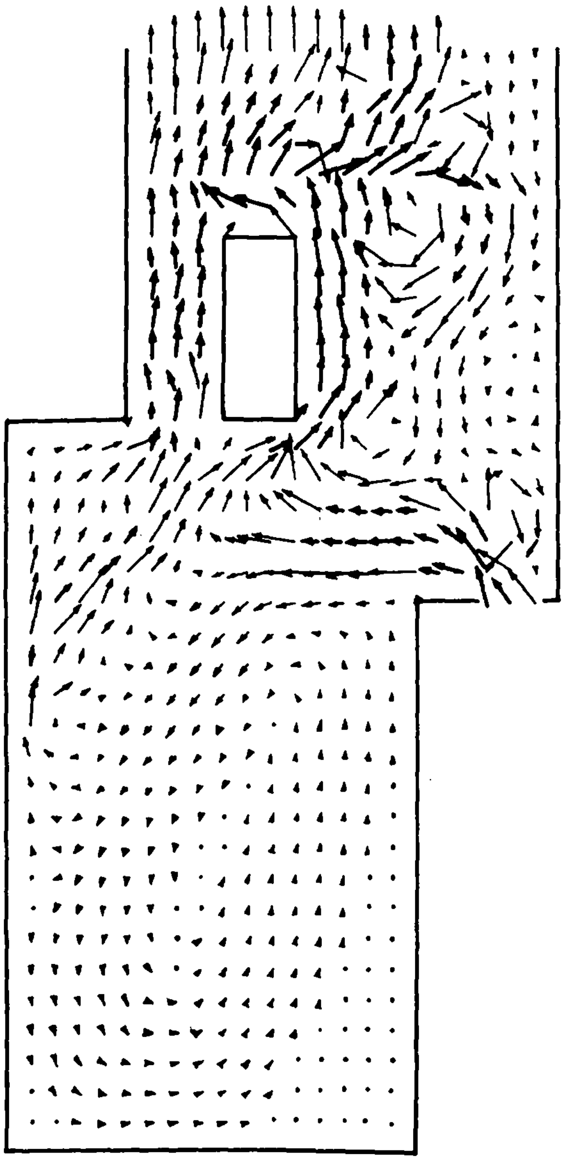

Fig. 9 Velocity field of the model without shelves north of Luzon, south of Taiwan, and east of Taiwan

intrudes into ECS shelf after it passes Taiwan, just as shown in our previous work[1]. There is an intense anti–cyclonic gyre over the sill east of Taiwan. How the imposed boundary condition at the north and east boundaries affects the strength of this gyre was not investigated in this study. Inside SCS a cyclonic gyre around the basin was induced, although the temperature sections across SCS basin (Fig. 4) did not show clearly the existence of such a gyre. However, current measurements do show the existence of a southwest flowing offshore current of SCS shelf in winter (Guo et al., 1985), spring (Chuang, 1986), and summer (Chou et al., 1984).

The noteworthy feature of the model results is the absence of a northward flow into the Taiwan Strait along the suthern coast of Taiwan and the presence of a northward SCS shelf current which feeds into the Taiwan Strait. It seems that as the southwestward current flows offshore from SCS shelf, a small part of the current is trapped by the slope along the way. The cross–shelf sea surface elevaltion gradient then drives the trapped current northward along the shelf, while the alongshelf gradient compensates for the alongshelf bottom stress component. The northward transport amounts to about 3.5 SV in the Taiwan Strait. As a matter of fact all our experiments yielded about the same amount of transport through the Taiwan Strait. In all the experiments, the Kuroshio influx was the same, only the topographic features, including the shelf and SCS basin widths, were modified.

When the small shelf north of Luzon is removed, part of the Kuroshio bends across the Bashi Strait immediately upon entering the domain (Fig. 8). However, it does not intrude too far into SCS again but turns back across the Bashi Strait to rejoin the main stream northward. The cyclonic gyre in SCS mentioned earlier is now shifted eastward and the northward flow previously confined to the shelf now spreads offshelf over a width of a few hundred kilometers. However, only the flow over the shelf is intensified as it flows north and is guided into the Taiwan Strait by the topography. The offshelf part of the flow is gradually turned eastward on its way north, and there does not seem to be a flow going into the Taiwan Strait from the southern coast of Taiwan. If the small shelf south of Taiwan is removed, a similar flow pattern can also be found (Fig. 9). Actually in the experiment of Fig. 9, the sill east of Taiwan was also removed, but this removal affected primarily the circulation in the northeast domain. Other experiments (by narrowing SCS basin width or widening the Taiwan Strait) showed no current flowing into the Taiwan Strait from the southern coast of Taiwan.

IV. SUMMARY AND DISCUSSION

1. Available published results and historical data showed that there existed seemingly around the year two northward currents: SCSWC near the shelf break off the Guangdong coast and the northward current at the submarine canyon in the Taiwan Strait. It was likely that the latter was the extension of the former, guided by the continental slope. Seaward of SCSWC there was a southwestward current also seemingly around the year. Available data, though limited, showed that the current along the southwest coast of Taiwan flowed to the south.

2. A barotropic numberical model was used to explain some of the observed features. It was shown that the lack of the Luzon coast's support to the surface elevation gradient of the Kuroshio results in a slight intrusion of the Kuroshio across the Bashi Strait. This intrusion induced in SCS a cyclonic gyre which contributed strongly at its northwest corner to the southwestward offshelf current of the Guangdong coast. Water trapped by the shelf was guided northward through the Taiwan Strait. No current was found entering the Taiwan Strait from the southern coast of Taiwan.

3. Baroclinic effects are important in SCS, especially near the shelf slope (Fig.3—5), so they

1) See footnote p.

must be taken into consideration in models.

4. The circulation pattern is SCS certainly has widely different time scales (e.g., Fig.4). It would be of interest to study if eddies are shedded from the intrusion of Kuroshio into SCS, as could be inferred from the dynamic computation of surface currents near Bashi Strait by Chu (1972). Chu's computation showed that the intruding Kuroshio formed an anti-cyclonic loop which might be pinched off later on. The strong shear between the northeastward SCSWC and the seawardsouthwestward current will surely result in some instability. The phenomenon is worth studying.

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