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The influence of Taiwan Strait waters on the circulation of the Southern East China Sea

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Abstract: The circulation on the shelf north of Taiwan is determined by the dynamic balance between outflow from Taiwan strait and intruding Kuroshio subsurface water. When the strait flow is strong, the Kuroshio intrusion is confined to the outer shelf and the salinity of the surface layer waters on the shelf has a typical value below 34 psu. With decreasing strait outflow, the cool and saline Kuroshio subsurface water penetrates further into the midshelf of the southern East China Sea. As this current provides a major source of salt, the salinity becomes greater than 34.1 psu for waters around northern Taiwan offshore area under these conditions.

1. Introduction

Taiwan strait is a channel of shallow water connecting the East China Sea (ECS) and the South China Sea. Previous studies showed that there is a persistent northward flow through the strait. This current reaches a maximum, about 50 cm/s, in summer and decreases to about 10 cm/s during the northeast monsoon season in winter (CHUANG 1986, CHERN and WANG, 1989).

Along the east coast of Taiwan, the Kuroshio current flows steadily northward. After leaving the coast of Taiwan, the main stream turns northeast along the continental slope in the ECS. At the turning point, some cold and saline Kuroshio subsurface waters branch onto the continental shelf as indicated by the pattern of averaged surface velocity (QIU *et al.*, 1990) and hydrographic surveys (CHERN and WANG, 1990a) in this area.

By using a primitive equation general circulation model, CHAO (1990) considered the influence of the northward intruding Kuroshio water and Taiwan Strait water on the circulation pattern over the broad shelf of the ECS. When the outflow from the strait is strong, the advance of the northward intruding water manifests itself as a tongue-like feature over the midshelf. When the strait flow is weak, the intruding Kuroshio water penetrates close to the China coastal area and its front outlines a lopsided shape. This change of the front shape is attributed to seasonal variations of the monsoon winds. Direct hydrographic surveys over the ECS are consistent with this description (WANG, 1987; SONG, 1987).

Because the Taiwan Strait is shallow, its transport is strongly affected by variations in the wind field (WANG, 1990). In addition to the seasonal variation, the flow pattern north of Taiwan responds to alterations of surface winds with a period of several days. We present here two typical CTD surveys of the shelf area north of Taiwan in summer to illustrate this point. These data show that the outflow from the strait is blocked by the westward intruding Kuroshio water when the southwesterly winds are weak. When the southwesterly winds become strong, the strait water flows directly into the ECS and the cold Kuroshio water is displaced farther offshore.

2. Hydrographic observation

The hydrographic surveys were conducted on board the R/V Ocean Research I, during the periods July 1–5 and August 16–19, 1988 over the shelf/slope area near northern Taiwan (Fig. 1). The winds were mainly southwesterlies in the survey area, but varied in strength, during these

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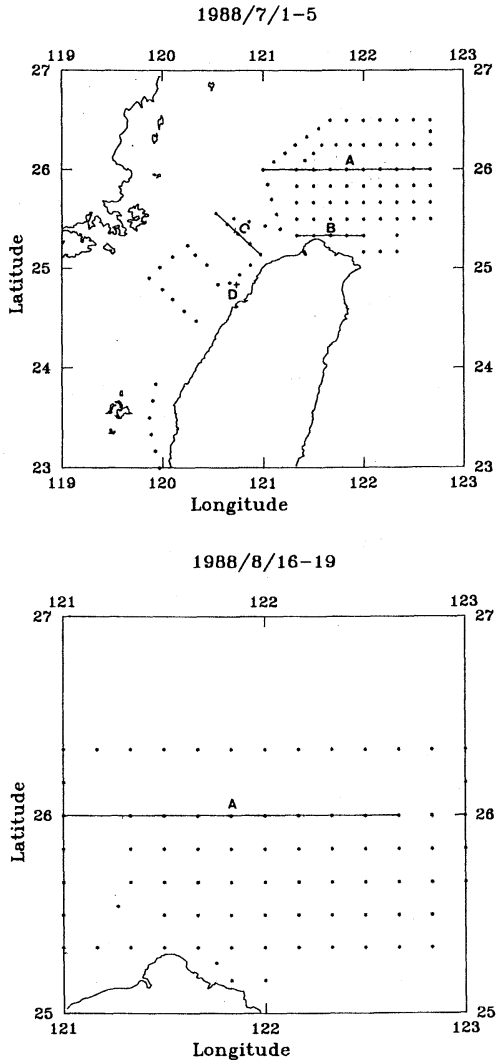

Fig. 1. Hydrographic station locations of the two cruises in July and August 1988. (A, B, C are positions of the three transect lines shown in Figs. 6, 8 and 3 respectively.)

two cruise periods. Fig. 2 is a stick diagram of winds measured, over these two periods, on a platform (station D in Fig. 1); about 25 km off the west coast of Taiwan winds were mild, with average speed of about 5 m/s, during the first cruise and increased to above 10 m/s in the period of the second cruise.

Temperature and salinity data were obtained at each station with a Neil Brown Instrument Systems conductivity-temperature-depth (CTD) meter. Fig. 3 shows temperature and salinity

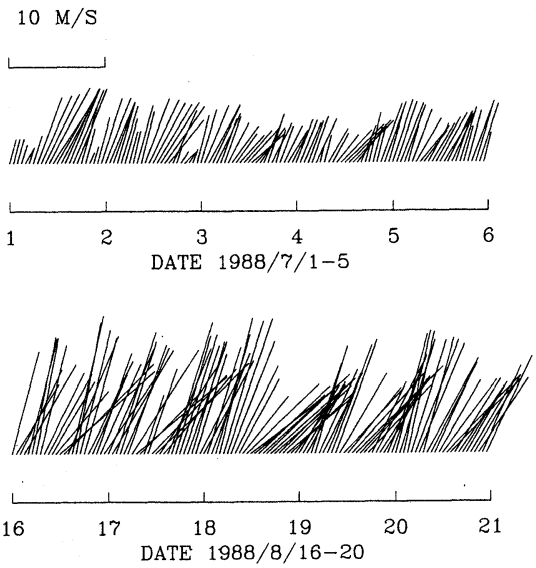

Fig. 2. Stick diagram of wind data measured on an offshore platform, station D in Fig. 1, during the two cruise periods.

transects across the strait (line C in Fig. 1) for the first cruise. The origin of line C is located at 25° 33.5' N, 120° 32' E. The water was weakly stratified with temperature > 27 °C and salinity < 34.1 psu in the eastern portion of the strait, whereas there emerged a distinct two-layer structure in the midstrait. This structure is typical of water in the Taiwan Strait during summer (WANG and CHERN, 1991).

Fig. 4 shows the distribution of temperature and salinity at 50 m depth for the first cruise. The Kuroshio, originating in cool and saline water with temperature < 26 °C and salinity $>$ 34.2 psu, extended westward and tended to block the northeastward warm and less saline water from the eastern strait. Fig. 5 shows the distribution of temperature and salinity at 50 m depth for the second cruise. With increasingly strong southwesterly winds, the eastern strait water flowed northeastward directly into the southern ECS. The upwelled Kuroshio subsurface water is confined to the seaward portion of the shelf/slope area northeast of Taiwan.

Fig. 6 shows temperature and salinity transects at 26° N between 121° E and 122° 40' E (line A in Fig. 1) for the first cruise, and Fig. 7 shows transects along this same line for the second cruise. For mild wind conditions (Fig. 6)

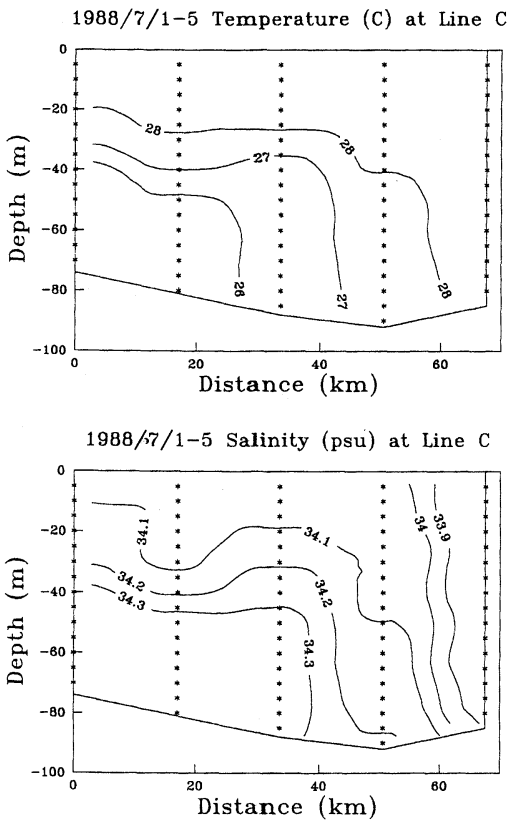

Fig. 3. Cross-strait transect of temperature (upper) and salinity (lower), along line C in Fig. 1, of the cruise during 1988/7/1-5.

over the whole observed shelf region a well stratified structure emerged, with the presence of cool and saline bottom water just below 50 m depth. The warm, little saline and weakly stratified eastern strait water was absent at this line.

For strong southwesterly wind conditions (Fig. 7), the upwelled Kuroshio water occurred at the outer part of the shelf and intruded into the midshelf only near the bottom. The warm and little saline strait water occupied the upper 60 m over the midshelf area.

3. Discussions

Previous observations showed that there is a permanent upwelling center of Kuroshio subsurface water above the shelf break northeast of Taiwan (UDA and KISHI, 1974; FAN 1980; CHERN *et al.*, 1990). The thermal wind effect associated with this upwelling pattern maintains

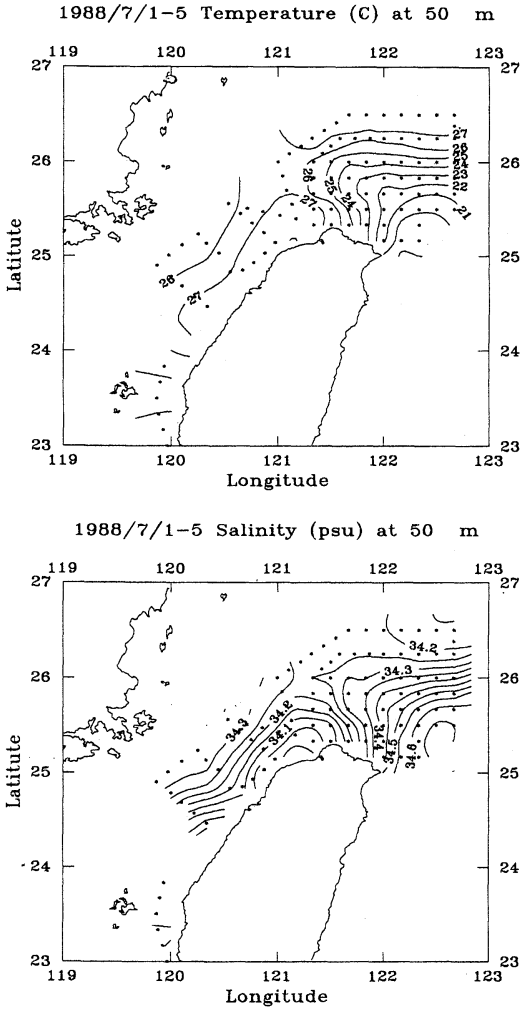

Fig. 4. Horizontal distribution of temperature (upper) and salinity (lower) at 50 m of the cruise during 1988/7/1-5.

a vertical velocity shear in the direction across the stream for incoming flow south of the upwelling front. Cross-stream baroclinic circulation of this kind favors the shoreward intrusion of upwelled Kuroshio water near the bottom of the shelf north of Taiwan. Our previous current measurements at north of Taiwan have shown the existence of a northwestward mean flow of about of 10-20 cm/s near the bottom with water temperature about of 17° C all the year round (CHERN and WANG, 1989).

The shoreward intrusion of upwelled Kuroshio water is a result of adjustment of Kuroshio as it

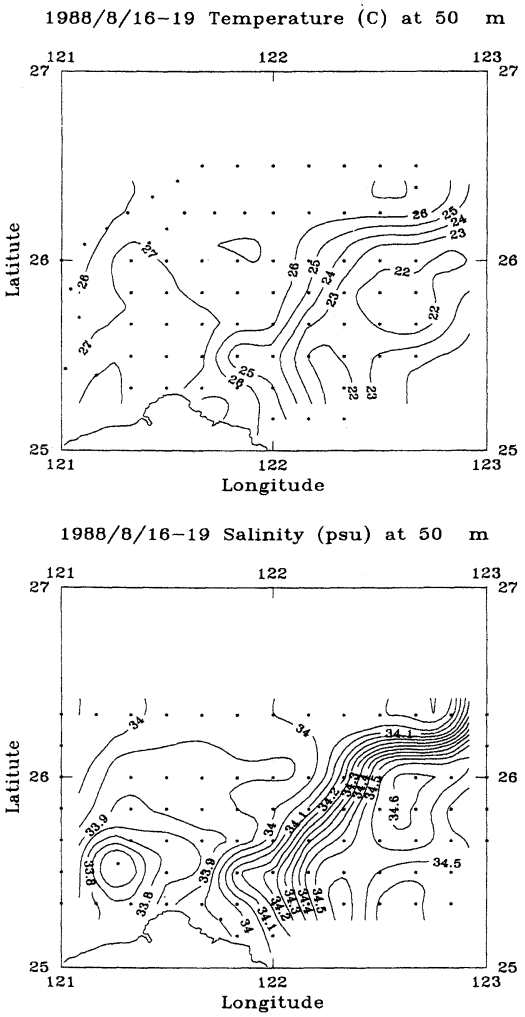

Fig. 5. Horizontal distribution of temperature (upper) and salinity (lower) at 50 m of the cruise during 1988/8/16-19.

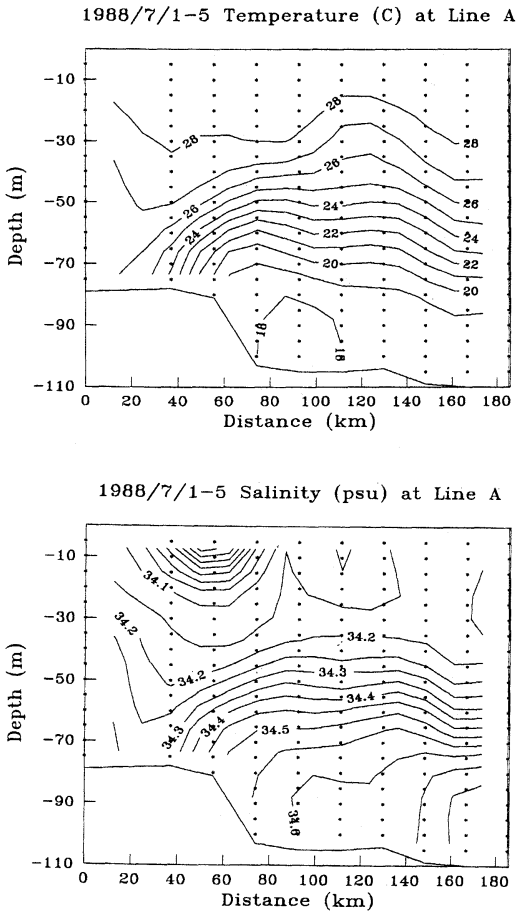

Fig. 6. East-west transect of temperature (upper) and salinity (lower), along line A in Fig. 1, of the cruise during 1988/7/1-5.

flows toward the steep shelf break of ECS; then local winds modulate its strength. In contrast, the flow in the Taiwan Strait shows strong wind-dependent variations. Because the circulation on the shelf north of Taiwan is determined mainly by the dynamic balance between the two jets from both sides of the island, its pattern is sensitive to changes in the wind field. The hydrographic data described above show this feature.

The shelf-edge upwelling of Kuroshio subsurface water provides a major source of salt for waters of the ECS. Our present surveys show that the outflow from the strait has a strong influence on the spreading of the upwelled water. As the strait flow weakens during periods of calm wind, the cool and highly saline upwelled water penetrate deeply into the midshelf region. Under these conditions and with strong vertical mixing maintained by the shear of internal tidal motions in this area (CHERN and WANG, 1990b), the salinity in the surface layer (>34.1 psu) becomes larger than the typical value (<34 psu) for surface water in the southern part of Taiwan Strait. When the strait flow intensifies during a period of strong southwesterlies, surface waters on the shelf near northern Taiwan retain little saline values.

As warm and little saline water leaves the

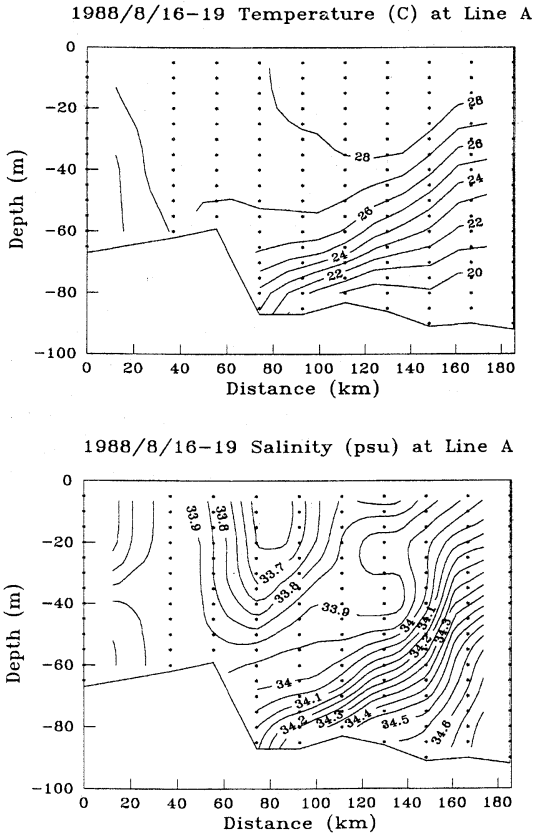

Fig. 7. East-west transect of temperarure (upper) and salinity (lower), along line A in Fig. 1, of the cruise during 1988/8/16–19.

northern end of Taiwan Strait, part of it tends to turn toward the open sea along the northern coast of Taiwan. The temperature and salinity transects (Fig. 8) at 25° 20′ N (line B in Fig. 1), of the first cruise show that waters of the eastern strait, having temperature $>$ 27 °C and salinity $<$ 34.1 psu, occur in the upper 60 to 40 m over the slope region. The data of the second cruise show similar distribution of temperature and salinity along this line. We have also observed a similar offshore transport of shelf waters, but with a larger volume transport under northeasterly wind conditions (CHERN *et al.*, 1990).

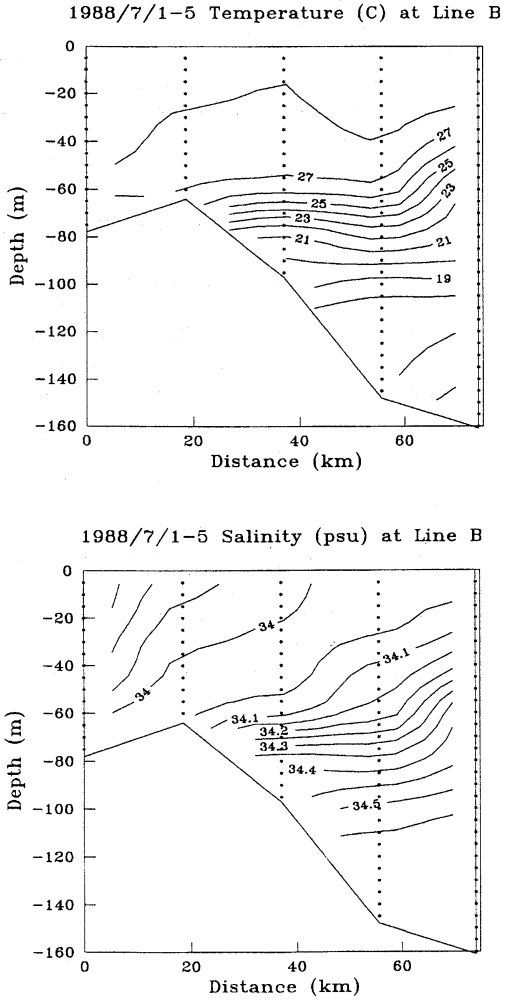

Fig. 8. East-west transect of temperature (upper) and salinity (lower), along line B in Fig. 1, of the cruise during 1988/7/1–5.

Acknowledgment

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