THE WESTERN BOUNDARY CURRENT OF THE PACIFIC AND ITS ROLE IN THE CLIMATE*

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Abstract

On the basis of the CTD data gathered by the R / V *Science I* in each Oct. of 1986 – 1988 and the winter averaged temperature anomaly in southeast China, the interannual variability of the Western Boundary Current (WBC) is examined in terms of volume transport by inverse calculation and its role in the climate is studied by statistical method.

The estimated transport is 50, 20, and 33×10^6 m^3 / s for the Kuroshio and 24, 34, and 36×10^6 m^3 / s for the Mindanao Current (MC) in October of 1986, 1987, and 1988, respectively.

The WBC is the biggest channel in the ocean for transporting heat poleward and plays an extremely important role in establishing and maintaining the global heat balance. Results showed that meridional heat transport by the Kuroshio northeast of Luzon apparently dominates coldness or warmness in winter in southeast China.

Two phenomena observed in the western Pacific but not in the western Atlantic are the warm pool and the equatorward flowing MC which, together with the North Equatorial Counter-current (NECC) may play an important role in preventing the warm water from extending to the north. So in order to understand the dynamics of the warm pool formation and evolution, the MC and NECC must be studied as well as the Equatorial Current.

INTRODUCTION

The WBC is well known, not only because of its being one of the strongest currents

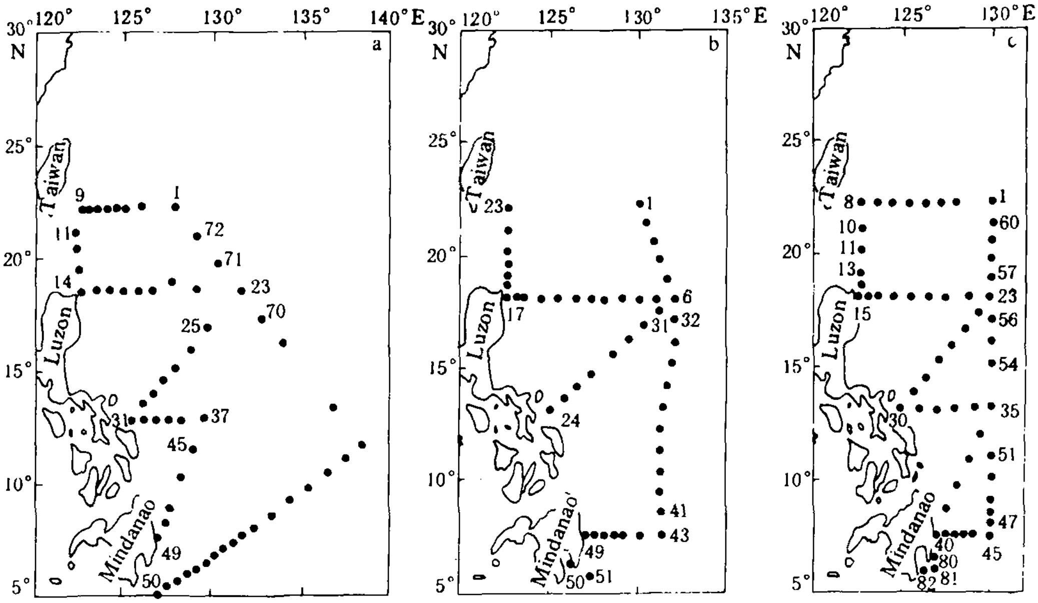

Fig.1 Cruise track
a. Oct. 1986, b. Oct. 1987, c. Oct. 1988

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in the world ocean, but also for its extremely important role in global transport and redistribution of heat. The WBC in the North Atlantic (the Gulf Stream) is quite well understood through a long period of various investigations. However, the WBC in the North Pacific (PWBC), especially east of the Philippines, is relatively poorly understood, except the Kuroshio south of Japan, which was well studied during the CSK (Cooperative Study of Kuroshio, 1965 – 1977). The PWBC is different from the North Atlantic WBC (which only consists of a northward current, the Gulf Stream) in that it consists of two currents east of the Philippines: the northward flowing Kuroshio, and the southward flowing MC.

About 70 CTD stations (Fig. 1) were occupied in October of 1986, 1987, and 1988 by the R / V *Science I* of the Academia Sinica, Institute of Oceanology. In the present study some features of the PWBC are extracted from the CTD data and examined by inversion manipulation.

METHOD

Since all the casts made with Neil Brown CTD or Sea-Bird CTD did not reach the bottom, but to just 1500 m, the inverse calculation should be modified (Cui and Hu, 1990). The geostrophic relation is as follows:

$$f\rho u = -\frac{\partial p}{\partial y}; \quad f\rho v = \frac{\partial p}{\partial x}.$$

Obviously, for any horizontal closed track c, the following is valid

$$\oint_c f\rho \vec{V} \times \vec{ds} \cdot \vec{k} = \oint_c -f\rho v\,dx + f\rho u\,dy = \iint_s \left(-\frac{\partial^2 p}{\partial x \partial y} + \frac{\partial^2 p}{\partial y \partial x}\right) dxdy = 0$$

where

$$\vec{V} = u\vec{i} + v\vec{j}, \quad \vec{ds} = dx\,\vec{i} + dy\,\vec{j},$$

and at the reference level,

$$\oint_c f\rho \vec{b} \times \vec{ds} \cdot \vec{k} = 0$$

is proposed to be added to

$$Ab = -\Gamma \tag{1}$$

where A is an $m \times n$ matrix, b — a column vector of n components, velocities at reference level, Γ — a column vector of residual terms, as described by Wunsch (1978). Then we have

$$\sum_{j=1}^{n} \delta_j f_j \rho_{rj} \Delta X_j b_j = 0 \tag{2}$$

for reference level, say, 1500 m, where δ_j is +1 or −1 depending on whether the water flows into or out of the box, ρ_{rj} — density at the reference level at the j-th station pair, ΔX_j — the separation of the j-th station pair, b_j — the reference velocity at the j-th station pair on reference level and

$$\Delta X_j = \| \Delta \vec{X}_j \|, \quad b_j = \frac{\| \vec{b}_j \times \Delta \vec{X}_j \|}{\Delta X_j}.$$

It is shown by our numerical experiments that Eq. (2) is important for the case where measurements do not reach bottom and / or when a solid boundary does not exist. Without Eq. (2) the result will be totally different, e. g., the signs for all of b_j for a box may be the same. As we know,

$$\vec{V} = \vec{V}_g + \vec{b}$$

where $\vec{V}_g$ is the geostrophic velocity relative to the reference level calculated by dynamic method and dynamic height at any point should be unique. Then we have

$$\oint_c f\rho \vec{V}_g \times \vec{ds} \cdot \vec{k} = 0.$$

And hence

$$\oint_c f\rho \vec{V} \times \vec{ds} \cdot \vec{k} = \oint_c f\rho \vec{b} \times \vec{ds} \cdot \vec{k} = \textit{non-zero constant}$$

which means that there will most likely be a source or sink of seawater with the same strength from the reference level up to the surface in the box for the whole water column. But that is no reality.

As geostrophy is not quite satisfied in the upper layer, the water column is divided into two layers by $\sigma_t = 27$ (for 1987 and 1988) or 27.5 (for 1986), values which have been tested and chosen as optimal. Some PWBC features obtained in this study are given in the following text.

SOME FEATURES OF THE PWBC

1. Kuroshio at its origin

Kuroshio is defined differently by different oceanographers (Kishido, 1931 ; Sverdrup et al., 1942 ; Wyrtki, 1961 ; Nitani, 1972). Nitani (1972) stated that the current from just north of the place where the North Equatorial Current is separated into two branches offshore east of the Philippines to the east of Japan where the current veers away from land can be called the Kuroshio in a broad sense. At least, the beginning of the Kuroshio is in the region off the east coast of Luzon.

In order to detect the Kuroshio, three sections east of northern Luzon and Taiwan were designated (Fig. 1), with the latitude of the section east of the north end of Luzon for 1986 being 1 / 2 degree higher than that for 1987 and 1988. Summarized results of inverse calculation on the Kuroshio are given as follows.

(1) Volume transport (VT) of the Kuroshio in its origin area

A. October 1986

The strength of the Kuroshio can be obtained by examining the westward VT through the meridional section east of Luzon Strait (approximately 122 °20 ′E) and northward through the zonal sections (18 °30 ′N and 22 °10 ′N). It is seen from Fig. 2 that the main flows are concentrated in the upper 600 m layer. The VT of the very narrow northward flow between St. 8 and 9 is more than 19×10^6 m^3 / s (Fig. 2a). There are two westward flows : one between St. 9 and 11 (southeast of Taiwan) with a VT of 11×10^6 m^3 / s, one between St. 12 and 14 (north of Luzon) with a VT of 19×10^6 m^3 / s (Fig. 2b). A narrow eastward flow in the meridional section has a VT of 3×10^6 m^3 / s (Fig. 2b). So the total VT of the flow from St. 7 to 14 is about

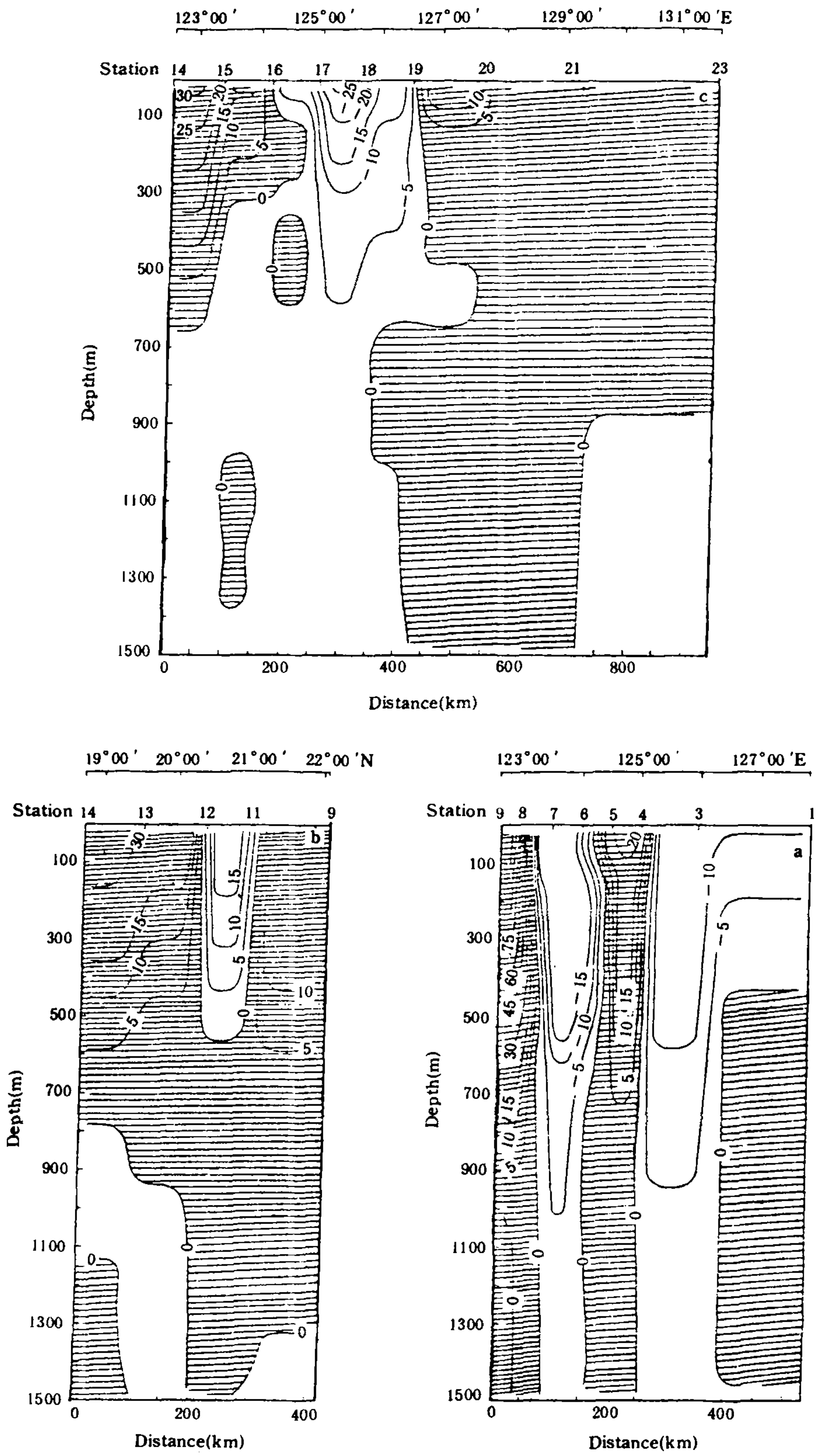

Fig.2 Velocity distribution Oct. 1986, determined by inverse method (shaded area — flow into the paper)
a. Along 22 °10 ′N, b. Along 122 °20 ′E, c. Along 18 °30 ′N

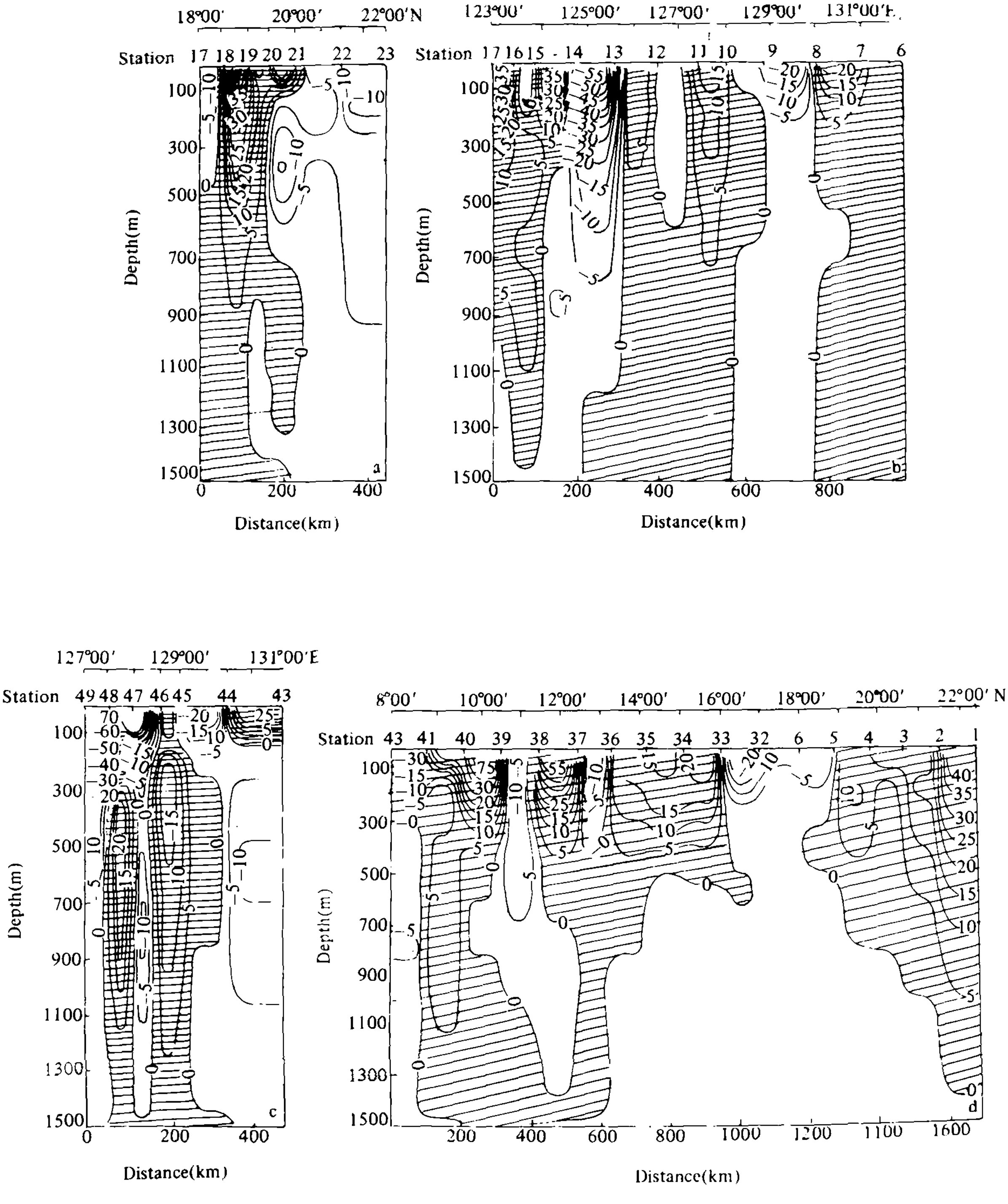

Fig.3 Velocity distribution Oct. 1987, determined by inverse method (shaded area — flow into the paper)

a. Along 122 °40 ′E, b. Along 18 °N,

c. Along 7 °30 ′N, d. Along 132 °E

46×10^6 m^3/s without considering the leakage between St. 14 and the Luzon coast about 46 km away. The velocity near St. 14 is more than 30 cm /s. On the supposition that the average velocity in the upper 600 m layer southwest of St. 14 is 18 cm/s, then the transport leaked is about 6×10^6 m^3/s. Therefore, the VT of the Kuroshio east of Luzon and Taiwan is about 50×10^6 m^3/s, which is about 1. 5 times the normal transport (Hu ,1989). This can be circumstantially verified by the $\sigma_t=26$ topography (Fig. 5a).

B. October 1987

The westward flow in the 122 °40 ′E section (Fig.3a)between St. 18 and 21 has a VT of 18×10^6 m^3/s, the eastward flow through the northern segment of the section has a VT of 18.7×10^6 m^3/s, and a narrow eastward flow between St. 17 and 18 has a VT of 1.5×10^6 m^3/s. The 18 °N section (Fig. 3b) has a northward flow between St. 17 and 14 (transport is about 15×10^6 m^3/s), and two bands of southward flow offshore with transport of 19×10^6 m^3/s between St. 14 and 13 and 5×10^6 m^3/s between St.9 and 8 in the upper layer. As St. 17 is about 50 km away from land, the northwestward leakage between St. 17 and Luzon might be about 5×10^6 m^3/s, so that the transport of the Kuroshio through this section is only about 20×10^6 m^3/s, which is only half of the normal (Hu, 1989). Obviously, the Kuroshio is weaker during this time. A great volume of water that passes through the 132 ° E section (Fig. 3d — St. 5 to 1) turns right to the north in the area west of St. 1. This can also be verified by the $\sigma_t=26$ topography (Fig. 5b).

C. October 1988

There is an obvious westward flow through the 122 °40 ′E section (Fig. 4a) between St. 10 and 15 (mainly in the upper 600 m layer) with a VT of about 30×10^6 m^3/s. Between St. 8 and 10 is a return (eastward) flow in the upper 300 m layer with VT of 7×10^6 m^3/s. The section along 18 °N (Fig. 4b) has a strong (28×10^6 m^3/s) and about 300 km wide northward flow in the upper 600 m layer between St. 15 and 18 and a 300 km wide return flow with VT of 10×10^6 m^3/s in the upper 500 m layer between St. 18 and 21. This year the VT of the Kuroshio here is about 33×10^6 m^3/s. This agrees with the same estimate as above since the distance between St. 15 and Luzon is about 33 km. This tendency can be verified from Fig. 5c.

In sum, the transport of the Kuroshio east of Luzon Strait was about 50, 20 and 33×10^6 m^3/s for October of 1986, 1987 and 1988, respectively. Besides the difference in VT, there were some differences in flow pattern from year to year. For 1986, more than half (30×10^6 m^3/s) of the transport of the Kuroshio came directly from offshore east of Taiwan and about 24×10^6 m^3/s from the area northeast of Luzon. For 1987, the main feature were westward flow near Luzon, eastward flow near Taiwan, and net flux through the meridional section approaching to zero. The Kuroshio in 1988 had a dominant westward flow near Luzon through the 122 °40 ′ section and a weak eastward return flow.

(2) Velocities

1986. Maximum velocity of about 107 cm / s occurs between St. 8 and 9 (Fig. 2a). The maximum velocity near the north end of Luzon is about 37 cm / s between St. 13 and 14 (Fig. 2b). Flow with velocity greater than 5 cm / s appears in the upper 600 m layer of the 122 °40 ′section (Fig. 2b) and in the upper 900 m layer of the 22 °10 ′section (Fig. 2a).

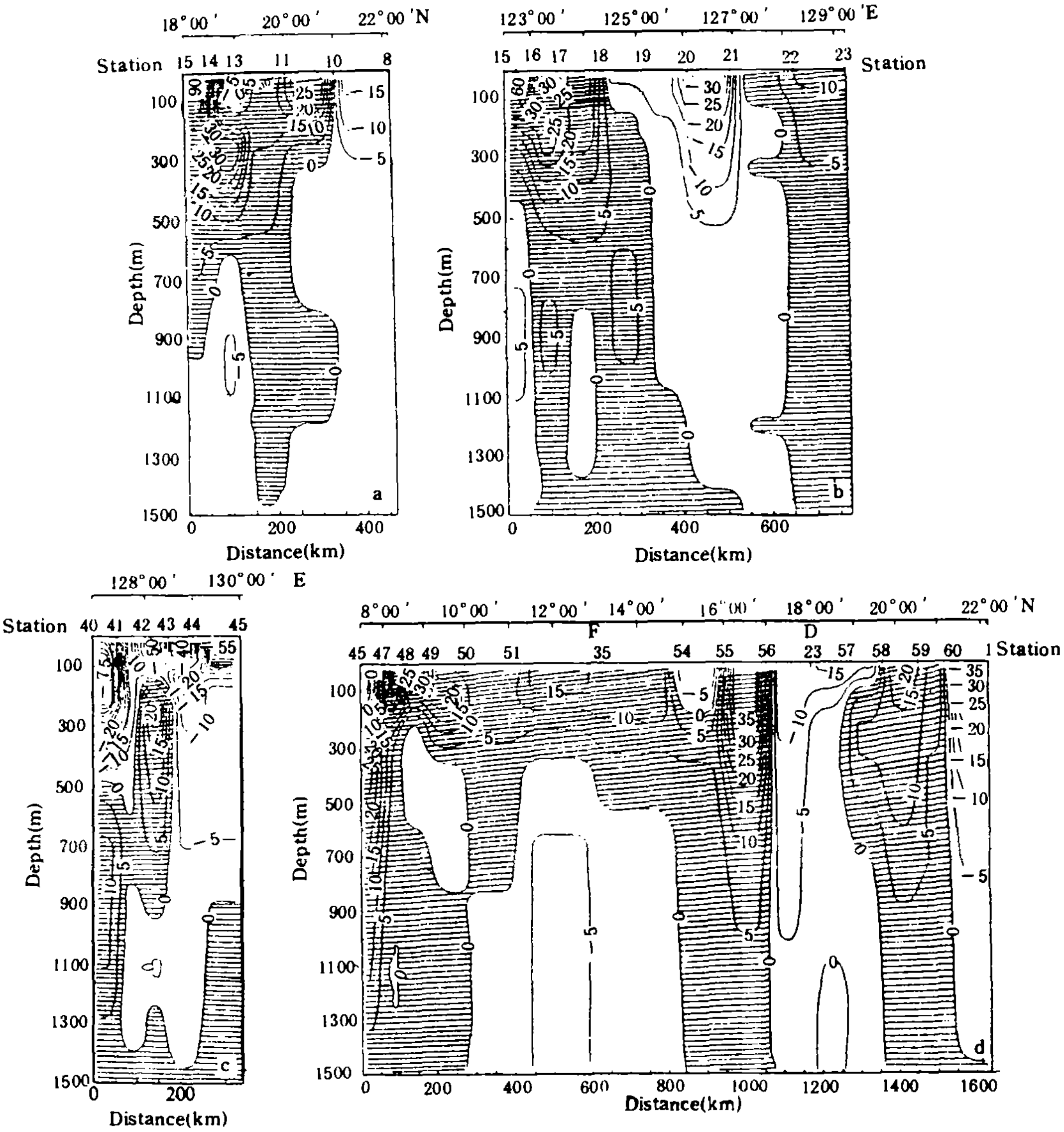

Fig.4 Velocity distribution Oct. 1988, determined by inverse method (shaded area — flow into the paper)
a. Along 122 °40 ′E, b. Along 18 °N, c. Along 7 °30 ′N, d. Along 130 °E

1987. Flow with maximum velocity of 54 cm / s takes place between St. 19 and 18 north of Luzon (Fig.3a), that with velocity greater than 5 cm / s occurs mainly in the upper 800 m layer (deeper than 1986).

1988. Flow with maximum velocity of 96 cm / s occurs between St. 14 and 15 (Fig.4a). Main (greater than 5 cm /s) flow is concentrated in the upper 600 m layer. A striking feature different from 1986 and 1987 is the occurrence north of Luzon of an undercurrent (Fig.4a, b) below 500 m centered at 900 – 1000 m with maximum velocity of 6 – 7 cm / s and transport of about 2×10^6 m^3 / s.

(3) Eddies surrounding the Kuroshio

It is easily seen from various sections that quite a number of eddies (cyclonic and anticyclonic) are located around the Kuroshio, for instance, between St. 3 and 4, 5 and 6, 7 and 8, around St. 12, 11, 17, 19 for 1986 (Fig.2); around St. 8, 11 – 12, 13, 14,

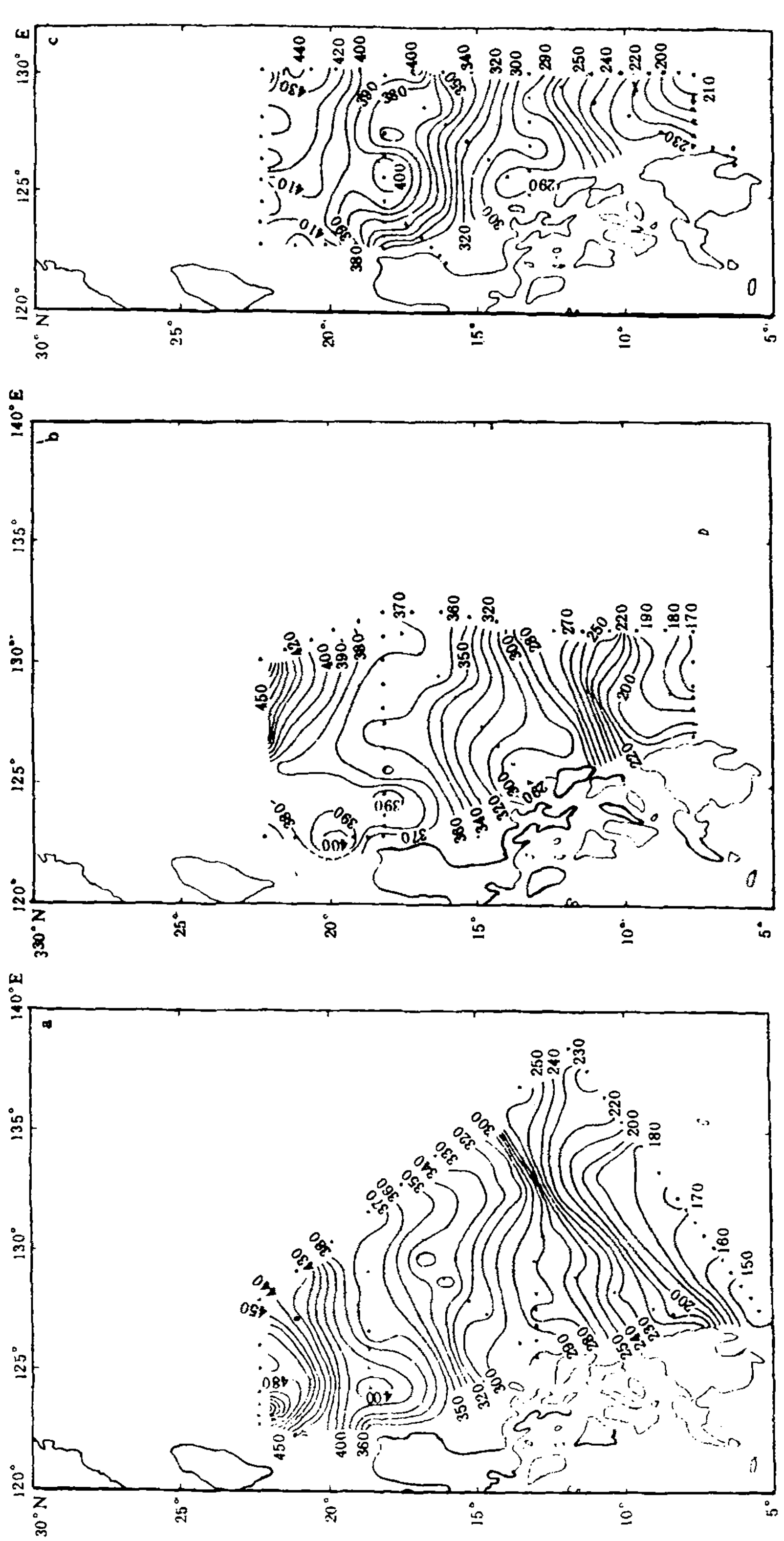

Fig. 5 Sigmat 26 topography
a. Oct. 1986, b. Oct. 1987, c. Oct. 1988

18, 20 – 21 for 1987 (Fig. 3); around St. 10, 18, 21 for 1988 (Fig. 4).

2. The Mindanao Current (MC) and the Mindanao Undercurrent (MUC)

(1) The Mindanao Current

The MC is an easily distinguished branch of the WBC east of the Philippines. According to Nitani (1970) the MC east of Mindanao is stronger than the Kuroshio east of Luzon. Its volume transport is about 40×10^6 m^3 /s, while the Kuroshio 's is only 30×10^6 m^3 / s.

In the present research the MC is studied by examining a section along 7 °30′ N from a station (126 °55 ′E), about 37 km away from the Mindanao coast, to a station at 130 °E (Figs. 3c and 4c). This section was occupied in October of 1987 and 1988. For convenience, it is described year by year first.

A. 1986.

Since the position of the section east of Mindanao is different from the later year's the VT of the MC is calculated by adding southward transport at the west end of the 50 – 67 sections and the southwestward transport between St. 49 and 50 which is about 24×10^6 m^3 / s.

B. 1987 (Fig. 3c)

The MC is restricted to within about 200 km from the coast of Mindanao in the upper 600 m layer (velocity greater than 5 cm / s). There are two cores located between St. 48 and 49 (maximum velocity — about 80 cm / s) and between St. 44 and 45 (maximum velocity — about 25 cm / s). The calculated southward VT from St. 49 to 44 is about 28×10^6 m^3 /s. Judging from Fig. 3 and supposing the leakage between St. 49 and land can be estimated from the average southward velocity of 30 cm / s in the upper 500 m layer to be about 6×10^6 m^3 / s, the total VT of the MC, in a broad sense, should be about 34×10^6 m^3 / s.

C. 1988 (Fig. 4c)

As Cui and Hu (1989) stated the MC has three cores in the upper 600 m layer: (1) The strongest has maximum velocity of about 77 cm /s at 120 m near the coast in the upper 500 m layer. Its transport is approximately 15×10^6 m^3 /s. (2) Adjacent to the above is a shallow one in the upper 150 m with a VT of 4×10^6 m^3 / s and a maximum velocity of 50 cm /s between St. 41 and 43 (127 °45 ′ – 128 °30 ′E). (3) Separated by a northward surface flow between St. 43 and 44 (128 °30 ′ – 129 °E) from the one above, is a thicker one reaching 1000 m between St. 43 and 45 (128 °30 ′ – 130 °E). Its transport is about 12×10^6 m^3 /s and its maximum velocity is about 56 cm /s. Our calculation of the leakage between St. 40 and land with a box consisting of St. 40, 80, 81 and 82, showed the leakage should be about 5×10^6 m^3 /s. So the total MC volume transport is approximately 36×10^6 m^3 /s.

(2) The Mindanao Undercurrent

The MUC is definitely revealed on the 7 °30 ′N section (Figs. 3c and 4c). It seems to have a multicore feature, penetrates into the MC, and should be considered as a wide flow spanning from the coast of Mindanao to about 130 °E, since generally the Mindanao eddy is centered at about 130 °E (Guan, 1989).

A. 1987 (Fig. 3c)

There are two northward quasi-subsurface flow cores separated by an extremely narrow southward flow. The two subsurface flows look like twins and have almost the same transport of 9×10^6 m^3/s extending from about 200 m to 1200 m, with main core from 300 m to 1000 m. The one closer to the coast is centered at about 470 m and is 75 km in width. Between 127 °25 ′and 128 °5 ′E, the other is centered at about 350 m, occupying the whole column with main core 200 to 900 m long and 150 km wide. It seems that the northward flow between St. 43 and 44 (130 ° – 131 °E) and the southward flow between 129 °E and 130 °E form an eddy and upwelling around St. 44 (130 °E) in the upper 150 m layer.

B. 1988 (Fig. 4c)

There are three northward cores. (1) A protruding northward subsurface current about 85 km wide exists between 127 °45 ′and 128 °30′ E. It has a maximum velocity of 22 cm /s at the 260 m level, a thickness of about 650 m (150 – 800 m), and VT of about 5×10^6 m^3/s. (2) Connected with the above is the nearshore subsurface northward flow below 500 m within less than 100 km from the coast of Mindanao. The core is located at 750 m and has velocity of 12 cm / s and VT of approximately 3×10^6 m^3/s. (3) A northward upper 100 m surface flow with a maximum velocity of 39 cm / s and a weak transport of 1.5×10^6 m^3/s takes place between St. 43 and 44.

Even though the MUC in 1987 is different from and stronger than that in 1988, there are some things in common, for example, a northward current (MUC) does exist and the three cores seem to be somewhat connected.

The formation mechanism and characteristics of the MUC need to be further investigated and studied.

3. The North Equatorial Current (NEC)

(1) Volume transport

For 1986, the transport estimated by the dynamical method was about 41×10^6 m^3/s between St. 56 and 71. Addition of 17×10^6 m^3/s (calculated by the inverse method) for St. 71-1 (Fig. 1a) gives 58×10^6 m^3/s as the NEC transport through around 130 °E from 7 °30 ′N to 22 °10 ′N. For 1987, the transport of the NEC as calculated by inversion manipulation is 61×10^6 m^3/s, about half of which is transported to the north, west of St. 1 (Fig. 3d). For 1988, 45×10^6 m^3/s is transported westward through the 130 °E section from 7 °30 ′to 22 °10 ′N (Fig. 4d). There is almost no northward transport through the 22 °10 ′N section.

(2) Flow pattern

Since there is no meridional section for 1986 along 130 °E, comparison is meaningless. For 1987, there are three strong westward flows between St. 40 and 39, 38 and 37, and 3 and 1, which constitute the main body of the NEC (Fig. 3d). There are also a few bands of eastward flows: (1) 4×10^6 m^3/s between St. 43 and 41 (7 °30 ′ – 8 °27 ′N) below 300 m; (2) 7×10^6 m^3/s mainly between St. 39 and 38 (10 °20 ′ – 11 °17 ′N) with a maximum velocity of 23 cm /s; (3) 3×10^6 m^3/s between St. 37 and 36 (12 °13 ′ – 13 °10 ′N) in the upper 400 m, with a maximum velocity of 14 cm /s; and (4) 16×10^6 m^3/s between St. 33 and 5 (16 ° – 18 °50 ′N) in the upper 500 m and between St. 36 and 3 (13 °10 ′ – 20 °30 ′N) below 500 m. It seems there are three swift eastward flows near 11 °, 12 °30 ′and 16 °30 ′N in the upper 400 m layer. In the lower layer below 600 m there exists a wide sluggish eastward flow. In sum, the westward transport in the upper layer (0 – 600 m) is 9×10^6 m^3/s; eastward transport in the lower layer (600 – 1500 m) is 7×10^6 m^3/s.

For 1988, westward and eastward flows alternate (Fig. 4d). There are two swift westward flows: one near 8 °N, with maximum velocity of about 122 cm / s, and another near 16 °30 ′N, with a maximum velocity of 37 cm / s. Also there appear a few bands of eastward flows: one from 10 °to 15 °N in the lower layer (500 – 1500 m), with transport of about 16×10^6 m^3 / s, the second from 17 ° – 20 °N from surface to 1500 m, with VT of 15×10^6 m^3 / s, and maximum velocity of about 16 cm /s at the surface near 18 °30 ′N. As a whole, westward transport in the upper layer (0 – 600 m) is 49×10^6 m^3 / s, and eastward transport in the lower layer (600 – 1500 m) is 5×10^6 m^3 / s.

In summary, the NEC consists of quite a number of alternating zonal flows, the eastward components of which are quite similar to those mentioned by various authors (Hasunuma and Yoshida, 1978; Nitani, 1970; Uda, 1955; Yamanaka et al., 1965; Yoshida and Kidokoro, 1967a and 1967b; and Hu and Cui, 1989). The zonal flow near 20 ° N can be part of the Subtropical Countercurrent (Yoshida and Kidokoro, 1967a and 1967b). The flow being westward in the upper layer (0 – 600m) and eastward in the lower layer (600 – 1500 m) implies the existence of undercurrents.

4. Dynamical aspects of the PWBC

(1) Dynamical structure of the circulation in the western Pacific

As is known, the NEC is divided into two branches offshore east of the Philippines — the Kuroshio and the Mindanao Current. That is true for the surface layer. What about the lower layer?

The 1987 and 1988 velocity sections along 7 °30 ′N (Figs. 3c and 4c) show existence of a prominent northward undercurrent (MUC) with considerable transport. Eastward flow in the lower layer is obvious from the 132 °E (1987) or 130 °E (1988) meridional section.

Now, let us examine the situation off the Luzon coast. First of all, from the 122 ° 40 ′E section of 1988 (Fig. 3a) is an eastward subsurface flow centered at 1000 m with a VT of 2×10^6 m^3 / s and a maximum velocity of 6 cm / s. From the 18 ° N section is a southward subsurface flow centered at 900 m with a VT of 2.5×10^6 m^3 / s and a maximum velocity of 7 cm / s.

Judging from the above, the dynamical structure of the circulation in the western Pacific can apparently be described as follows. In the surface layer, the NEC is divided into the Kuroshio and the MC. In the lower layer, the northward flowing MUC and the southward flowing subsurface current off Luzon converge somewhere around 15 °N east of Luzon and Samar and cause eastward flow through the 130 °E section. This is consistent with the calculated transport through the section at 130 ° E or 132 °E.

(2) Possible role of the PWBC in the climate

A. The role of the Kuroshio in the climate of southeast China

The ocean plays one of the central roles in the variability of global climate and appears to be as important as the atmosphere in the global transport and redistribution of heat. The PWBC transports heat poleward in a narrow band and is the main channel of heat transport in the world ocean. On the other hand, the effect of the ocean on climate can be classified into two categories: remote effect and local effect. The first means that the ocean affects the general atmospheric circulation, which in turn affects climate in various areas. The second means that the effect is more direct. For example, the area near coastal upwelling or cold currents will be colder than other places at the same latitudes. In terms of local response, East Asia, especially southeast China, should be heavily influenced by the northward-flowing PWBC (Hu, 1989).

Usually, one, even meteorologists, would deem the cold waves from Siberia dominate the warmness / coldness throughout China. In what follows, we conclude the northward heat transport by the WBC in the Pacific plays an important role in determining the warmness / coldness in southeast China.

As described above in Octobers of 1986, 1987, and 1988 the northward volume transport by the warm current are 50, 20, and 33×10^6 m^3/s, respectively. An average of about 30×10^6 m^3/s is suggested by others. In 1986 October it was at least 1.5 times the usual value, in 1987 October only about half the usual, and in 1988 October a little stronger than usual. The winter averaged temperature anomaly from a 30 year mean (1951 – 1980) of 8 meteorological stations located in southeast China is +1.0, −0.3, and +0.6 ℃ respectively for the years 1986, 1987 and 1988, which are roughly consistent with the northward ocean transport in those years. At the same time, when looking at the cold wave indices calculated by the formula

$$I = \frac{1}{8} \sum_{j=1}^{8} \sum_{i=1}^{N} \Delta \max t_{ij},$$

where $\Delta \max t_{ij}$, is the maximum temperature drop for each cold wave (i) passing the station j, we will find the following indices (in percentage, compared with a 20 year mean): 74% (1986 / 87 winter), 70% (1987 / 88 winter), 112% (1988 / 89 winter). It should be especially mentioned here that the 1986 / 87 winter was the warmest winter in China since 1949. That is easy to understand because both (weaker) cold wave and (stronger) northward ocean transport are favorable influencing factors for having a warm winter. However, the 1987 / 88 winter was colder in southeast China (warmer in the north). So the northward heat and volume transport by the WBC seems to play an important, even dominant role in the warmness / coldness.

B. Possible role of the Mindanao Current in formation and maintenance of the warm pool in the western Pacific

Surface warm water is driven west by the trade wind and piled up in the equatorial western Pacific. Since the western boundary near the equator, such as the Papua New Guinea and Indonesia coast is more zonal (at an acute angle with the equator) than meridional, the following questions will naturally arise. How can the warm water be formed near the equator and how can the warm pool be maintained? Why does the Atlantic Ocean not have a warm pool near the western equatorial Atlantic? It is speculated that the MC and its continuation, NECC, play important roles (as a solid boundary) in preventing the warm water from extending to the north, and that there is no counterpart of the MC (equatorward flow) in the western Atlantic. So the MC and NECC may be important for study of the warm pool dynamics. This is only a hypothesis. Much work needs to be done for verification.

SUMMARY

1. Dynamics of the circulation in the western Pacific

(1) The WBC in the Pacific Ocean possesses obvious interannual variability in

terms of volume transport. The estimated transport is 50, 20 and 33×10^6 m^3/s for the Kuroshio in October of 1986, 1987, and 1988, respectively, and 24, 34 and 36×10^6 m^3/s for the Mindanao Current in October of 1986, 1987, and 1988, respectively.

(2) NEC consists of a few bands of westward flows with a few eastward flows within it. The estimates of the NEC VT through 130 °E are 58, 61, and 45×10^6 m^3/s for October of 1986, 1987 and 1988, respectively. It seems that eastward flows are dominant below 600 m.

(3) A northward subsurface current off Mindanao was discovered in a geostrophic section. The Mindanao Undercurrent (MUC) named by Hu and Cui (1989) is generally multicore current, extending from 200 m to 1000 m in depth, and 100 – 200 km in width with a maximum velocity of about 20 cm/s and transport of over 10×10^6 m^3/s. It seems that southeastward subsurface flow (with center at about 900 – 1000 m, transport of about 2×10^6 m^3/s, and maximum velocity of about 7 cm/s) occurs under the Kuroshio.

The circulation in the western Pacific (east of the Philippines) can be summarized as follows. The NEC is bifurcated into a northward flow (the Kuroshio) and a southward flow (MC) with downwelling east of Legaspi and Samar, the Philippines. In the lower layer the MUC and the southward flow under the Kuroshio converge east of the central Philippines, leading to formation of an eastward flow under the NEC and resulting in mass balance.

2. Possible role of the Western Boundary Current in the Pacific (PWBC) in the climate

(1) The WBC is the biggest channel in the ocean for poleward heat transport and plays an extremely important role in establishing and maintaining global heat balance. Results (Hu, 1989) showed that meridional heat transport by the Kuroshio northeast of Luzon apparently dominates coldness or warmness in winter in southeast China.

(2) A speculation. Two phenomena observed in the western Pacific but not in the western Atlantic are the warm pool and the equatorward flowing MC. Are the two features related? It is inferred that the MC and the NECC may play an important role in preventing the warm water from extending to the north. So in order to understand the dynamics of the warm pool formation and evolution, the MC and NECC must be studied as well as the Equatorial Current.

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