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Some Problems Relating to Fluctuation of Hydrographic Conditions in the Sea Northeast of Japan (Part 1)*

—Relation between the Patterns of the Kuroshio and the Oyashio—

Katsumi HATA**

Abstract: For this study are used mainly the data of oceanographic observations by the Hakodate Marine Observatory, the Meteorological Agency, the Tohoku Fisheries Research Institute and the Maritime Safety Agency from 1954 to 1966, and the old data obtained by the Imperial Fisheries Experimental Station from 1933 to 1941 are also examined.

The results are as follows:

When the Kuroshio extends more northward in the sea northeast of Japan between 142°E and 150°E, the Oyashio flows more southward between 143°E and 150°E, and the transition area is narrow and therefore the horizontal gradient of water temperature at the depth of 100 m is large.

On the other hand, when the Kuroshio exists more southward, the Oyashio lies more northward, the transition area becomes wide and the gradient is small.

1. Introduction

In the North Pacific the most complicated hydrographic conditions are encountered in the waters northeast of Japan. The Kuroshio follows closely along the coast of Japan as far north as about 35°N, sometimes 38°N, where it turns east. There are transition areas between the warm water of the Kuroshio and the cold water of the Oyashio, and the warm eddy are frequently cut off from the Kuroshio and make anticyclonic eddies with various sizes in the transition areas.

MASUZAWA (1955) analyzed the general current system of the Kuroshio in summer from 1933 to 1941 by the distribution of the depth of 10°C isotherm and showed the Kuroshio current in this region presents various shapes.

KAWAI (1955) analyzed the Polar Frontal Zone and its fluctuation in the waters to the northeast of Japan and suggested that there was no close relation between the Kuroshio Front and the Oyashio Front.

But in this paper some close relation between the pattern of the Kuroshio water and the Oyashio water is explained (TAKENOUCHI, 1950).

* Received Oct. 16, 1968

** Hakodate Marine Observatory

2. On the horizontal distribution of water temperature at the depth of 100 m

Recently, the horizontal distribution of water temperature at the 100 m depth has been frequently used for representing the general distribution of currents and water masses in the sea northeast of Japan.

FUGLISTER (1951) showed that in the Gulf Stream the isolines of the mean temperature of the upper 200 m layer are parallel to the current where the cross current temperature-gradient is sharpest.

The mean temperature of upper 200 m layer is nearly equal to the water temperature at the 100 m depth in this area.

Here, a question arises as to which depth should be selected to see the outline of the northern branch of the Kuroshio extension and the southern branch of the Oyashio.

Fig. 1 shows the serial stations observed by the *Ryofu-maru* and *Kofu-maru* in February to March and August to September 1963 in the area of 34°N–43°N and 141°E–150°E.

Figs. 2 and 3 show the relations between the water temperature and the salinity at the depths 0 m, 100 m and 200 m of the stations in Fig. 1.

For example, the salinity at a temperature of 20°C at the sea surface in summer is between 32.7 and 34.0‰ as shown in Fig. 2. But the salinity at a temperature of 5°C is between 33.2 and 33.6‰ at the 100 m depth in winter, and between 33.5 and 33.8 at the 200 m depth in winter, and between 33.5 and 33.9‰ at the 200 m depth in summer as shown in Figs. 2 and 3. Moreover, the salinity at a temperature of 15°C is between 34.5 and 34.8 in winter and between 32.3 and 33.0‰ in summer at the surface layer, and is between 34.5 and 34.6‰ both in winter and summer at the 100 m depth. The temperature-salinity relation in most uniform at the 100 m depth.

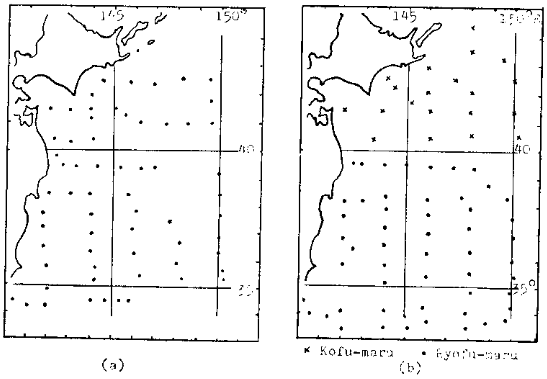

Fig. 1. Serial stations in (a) Feb.-Mar., (b) Aug.-Sept., 1963.

The temperature of 5°C shows the highest temperature of the Oyashio water at the 100 m depth and the salinity at 5°C is 33.6‰; on the

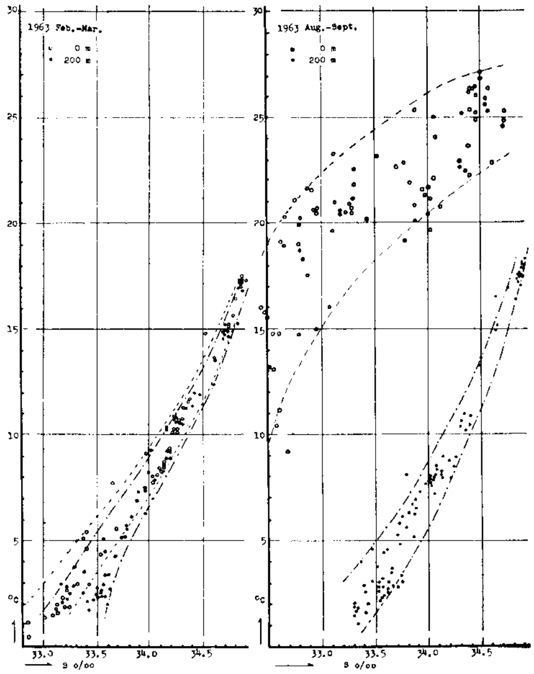

Fig. 2. T-S diagrams at the 0 m and 200 m depth (Feb.-Mar., Augr.-Sept., 1963).

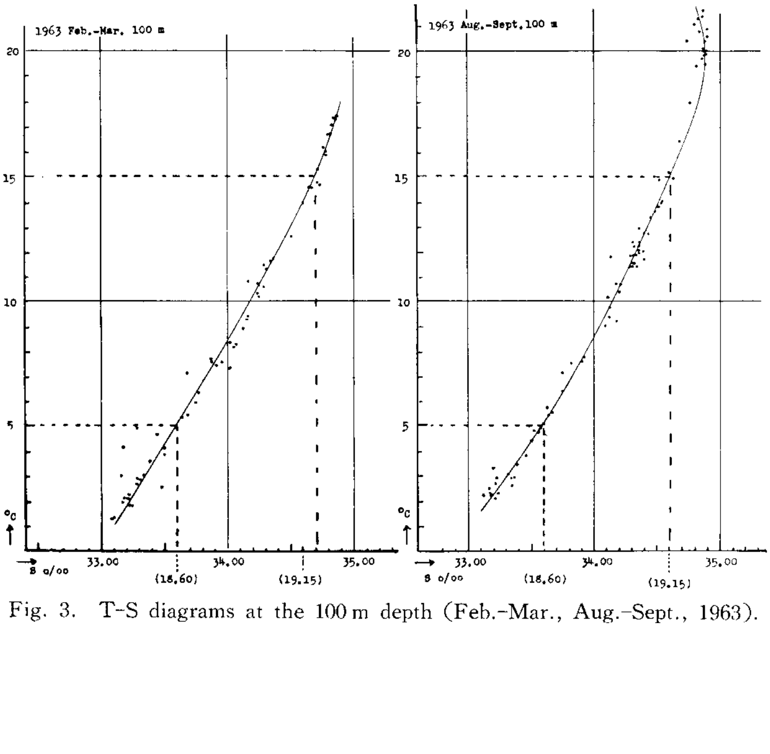

Fig. 3. T-S diagrams at the 100 m depth (Feb.-Mar., Aug.-Sept., 1963).

other hand, the temperature of 15°C shows the lowest temperature of the Kuroshio water and the salinity at 15°C is 34.6‰. Hence, it is conceivable that the isotherm of 15°C is the northern boundary of the Kuroshio water and the isothern of 5°C is the southern boundary of the Oyashio at the 100 m depth. (refer to Fig. 3)

3. Fluctuation of hydrographic condition in 1955 and 1963

Fig. 4 shows the distribution of water temperature at the 100 m depth in the winters and summers of 1955 and 1963. These are the years of peculiar hydrographic condition.

In 1955, the mean stream of the Kuroshio flows almost eastward from the coast to 150°E between 37°N and 38°N and the mean position of the Kuroshio is situated more north than in the normal year. On the contrary, in 1963, the Kuroshio flows between 34°N and 36°N and the position is situated more south.

Because the isotherm of 1 5°C at the 100 m depth is correspondent to the northern boundary of the Kuroshio water, the mean latitude of the isotherm of 15°C from 142°E to 150°E is regraded as the mean northern limit of the Kuroshio water. In the same way, the mean latitude of the isotherm of 5°C from 143°E to 150°E is regarded as the mean southern limit of the Oyashio water.

As seen in Table 1, in the winter of 1955, the mean latitude of 15°C isotherm is 36.8°N and the one of 5° is 39.2°N. This shows that the warm water of the Kuroshio extends northward and the cold water of the Oyashio is more south. In this case the transition water is narrower and the horizontal gradient of water temperature at the 100 m depth is greater.

On the contrary, in the winter of 1963, the mean latitude of 15°C isotherm is 35.4°N and one of 5°C is 40.6°N; that is, when the Kuroshio water retreats southward, the Oyashio water is more north. In this case, the transition water is wider and the water temperature gradient is smaller. This tendency in the hydrographic conditions almast continues from winter to summer in this area.

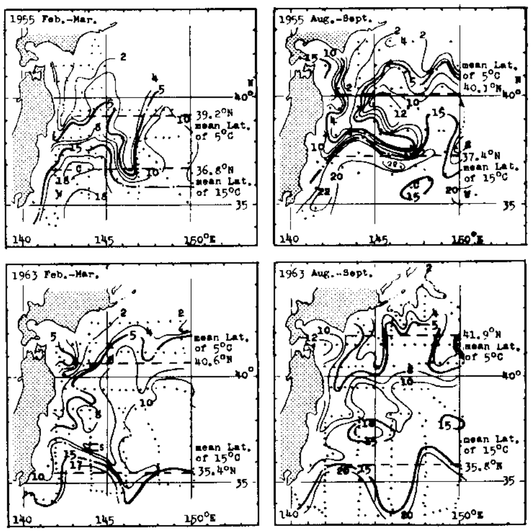

Fig. 4. Distributions of water temperature at the 100 m depth in Feb.-Mar. and Aug.-Sep. 1966, 1963.

Fig. 5 shows the vertical distribution of water temperature and salinity in the winters and summers of 1955 and 1963 along the meridian of 144°E; these stations were observed the R/V *Yushio-maru*, *Ryofu-maru* and *Kofu-maru*.

At the 100 m depth, the Kuroshio water masses are characterized by a salinity more than 34.6‰ and a temperature more than 15°C, and then the Kuroshio Front exists between 36.5°N and 37.5°N in 1955, but in 1963 between 35.0°N and 36.5°N more south than 1955.

Fig. 6 shows the vertical distribution of 5°C and 15°C isotherms (upper) and the horizontal gradient between the isotherm of 5°C and 15°C at each depth in 1955 and 1963 along 144°E

Table 1. The mean latitude of the 5°C and 15°C isotherms at the 100 m depth.

Isotherm	1955		1963	
	Feb.-Mar.	Aug.-Sept.	Feb.-Mar.	Aug.-Sept.
5°C	39.2°N	40.1°N	40.6°N	41.9°N
15°C	36.8°N	37.4°N	35.4°N	35.8°N

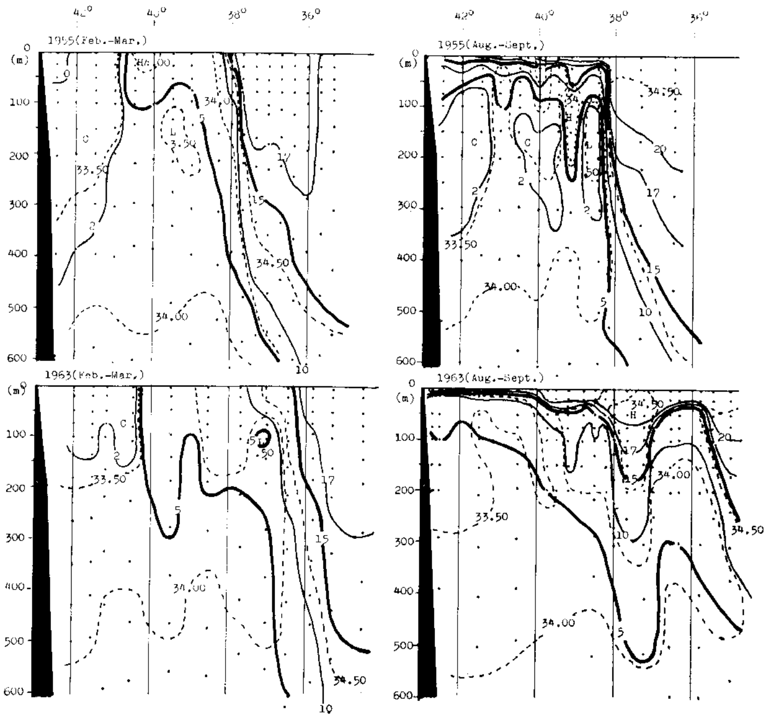

Fig. 5. Vertical distributions of water temperature and salinity along 144°E in 1955 and 1963.

(lower).

In the summer of 1955, the interval between isotherms of 5°C and 15°C is narrower than in the winter of 1955. Then, the horizontal gradient between isotherms of 5°C and 15°C is sharp, particularly from 100 m to about 200 m.

On the contrary, in the summer of 1963, the interval is wider than in the winter of 1963, and then the gradient is weak.

Fig. 7 shows the vertical distribution of the difference in temperature between Feb.-Mar. and Aug.-Sept. in 1955 (upper) and 1963 (lower).

In 1955, the area of increase in temperature is seen near 38°N, the value amounts to +10°C at the 150 m depth and is +6°C at the 300 m depth, because the Kuroshio Front extends northward from winter to summer.

But in 1963, the area of increase in temperature is seen near 38°N and the value amount to +6°C at the 100 m depth and to +4°C at the 300 m depth, being less than in 1955, and the area is formed by the warm water cut off northward from the Kuroshio water as seen in Fig. 4.

In 1955, the area of decrease in temperature exists around 40°N and the value amounts to −2°C at the 200 m depth, because the dichothermal water flows more southward than in winter.

On the contrary, in 1963, because the Kuroshio Front is moved southward from winter to summer, the area of decrease in temperature exists between 34°N and 35°N and the value amounts to −8°C from 300 m to 600 m.

Fig. 8 shows the vertical distribution of oxygen (ml/l) in Feb.-Mar. and Aug.-Sept. of 1955 and 1963 along the meridian of 144°E which corresponds to the section in Fig. 5.

A minimum oxygen content of about 1 ml/l is found at the depths of about 900 m in the Oyashio area, about 1,000 m in the transition area and about 1,200 m in the Kuroshio area.

In Fig. 8, the water which has a relatively high oxygen content over 4 ml/l sinks remarkablely at the northern edge of the Kuroshio Front in 1955. But in 1963, the sinking water is not found there. These fact may be worthy of note in the connection which the frontal activity.

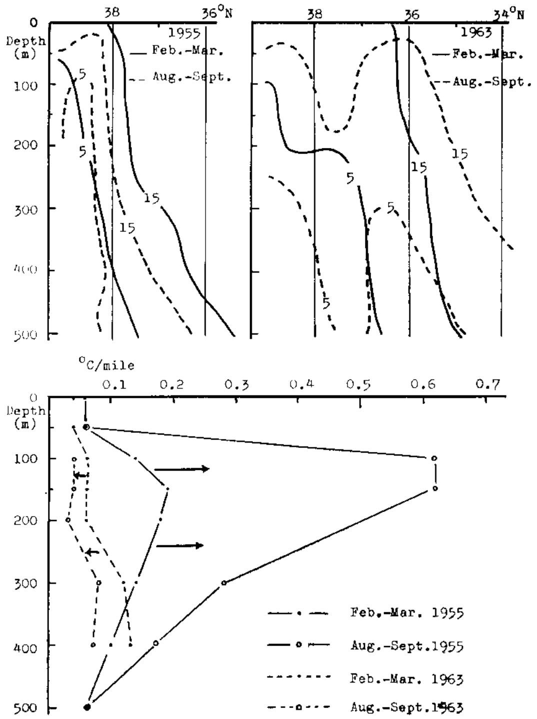

Fig. 6. Vertical distributions of the isotherms of 5°C and 15°C along 144°E in 1955 and 1963 (upper), horizontal gradient between the isotherm 5°C and 15°C (at the same layers) along 144°E (lower).

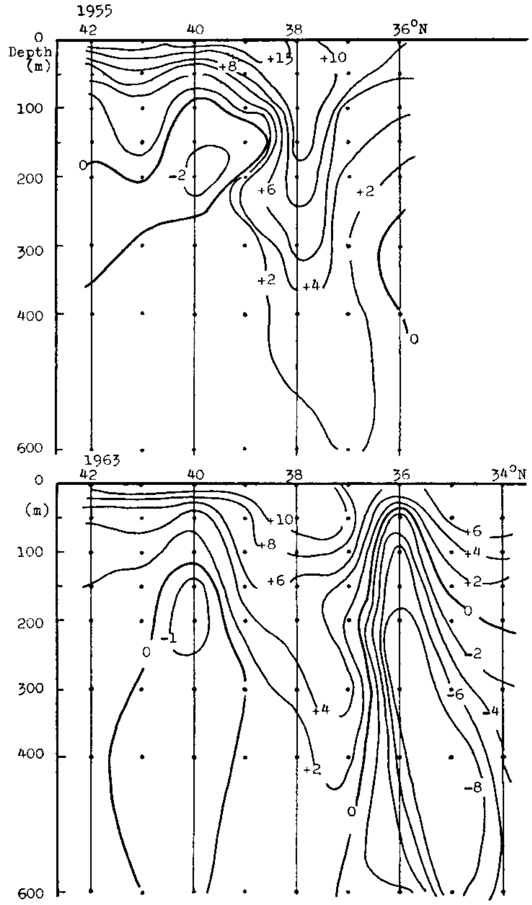

Fig. 7. Vertical distribution of the difference in temperature between Feb.-Mar. and Aug.-Sept. in 1955 and 1963.

The geopotential anomaly on isobaric surfaces relative to the 1,000-decibar surface along the meridian of 144°E which corresponds to the section in Fig. 5 is illustrated in Fig. 9.

The boundary of currents through the section can be easily determined by the slope of isobaric surfaces. The section may be divided into three majer zones: (1) the Kuroshio, (2) the eddy, (3) the Oyashio.

The fluctuation of these currents are shown in Table 2.

In Aug.-Sept. of 1955, the largest slope of sea surface between Ry 458 (38°31′N) and Ry 456 (36°28′N) corresponds to almost the swift current of the Kuroshio. The difference is geopotential at the sea surface between these stations is 1.45 dynamic meter. There is a westward flow between Yu 1024 (39°35′N) and Yu 1014 (39°10′N), and Yu 1024 is located at the center of the eddy; the difference in geopotential at the sea surface between both limits of the westward flow amounts to 0.11 dynamic meter, which is only 8 % of the difference in the Kuroshio.

In Aug.-Sept. of 1963, the differences in the Kuroshio between Ry 1862 (35°45′N) and Ry 1865 (33°38′N) is 0.89, which is smaller than in 1955. There is a westward flow between Ry 1860 (37°16′N) and Ry 1016 (36°33′N) and Ry 1960 is located at the center of the eddy shown in Fig. 4; the difference in geopotential at the sea surface between both limits of the westward flow amounts to 0.37 dynamic meter, which is 42% of the difference in the Kuroshio (Table 2).

Assuming no current at the 1,000 m depth, the fluctuation of volume transport between two adjacent stations along the meridian of 144°E in Feb.-Mar. and Aug.-Sept. of 1955 and 1963 is illustrated in Fig. 10, which corresponds to the

Table 2. Fluctuations of currents through the section along 144°E in Feb.-Mar. and Aug.-Sept. of 1955 and 1963.

	Year	1955		1963	
	Month	Feb.-Mar.	Aug.-Sep.	Feb.-Mar.	Aug.-Sept.
Kuroshio	Rage	Ry 359-Ry 308 38°18′-35°27′N	Ry 458-Ry 456 38°31′-36°28′N	Ry 1175-Ry 1179 27°00′-34°30′N	Ry 1862-Ry 1895 35°45′-33°38′N
	Width (mile)	161	(123)	150	138
	Difference of sea surface (dyn. cm)	−107	(−145)	−97	−89
Oyashio	Rage	—	Yu 1011-Yu 1003 42°00′-41°30′N	Yu 2147-Yu 2148 41°07′-40°26′N	—
	Width (mile)	—	(30)	41	—
	Difference of sea surface (dyn. cm)	—	+4.3	+4.3	—
Eddy	Range	Yu 937-Yu 935 40°30′-39°57′N	Yu 1024-Yu 1014 39°35′-39°10′N	Ry 1802-Ry 1773 39°26′-38°31′N	Ry 1869-Ry 1861 37°16′-37°33′N
	Width (mile)	33	25	55	43
	Dfference of sea surface (dyn. cm)	+5.1	+11.0	+4.2	+37.0

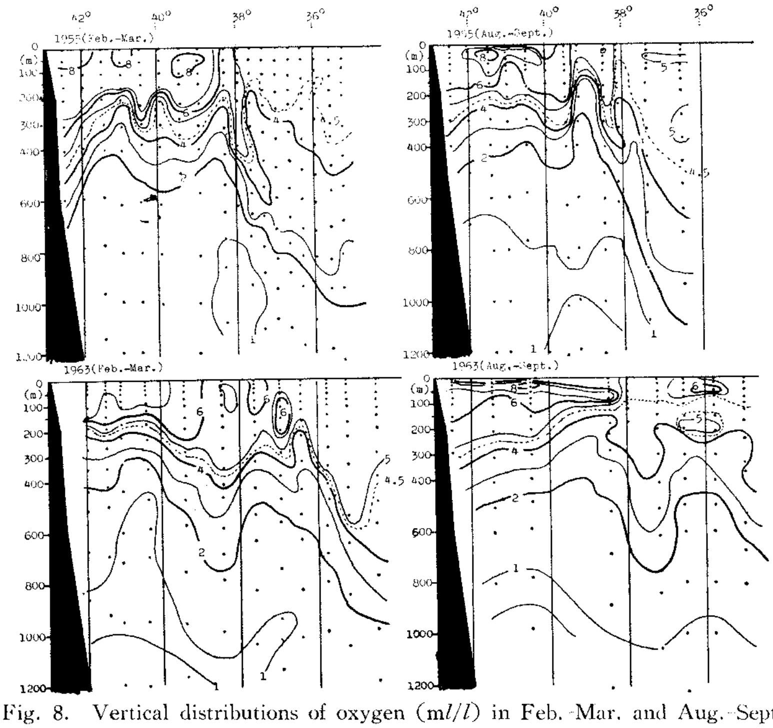

Fig. 8. Vertical distributions of oxygen (ml/l) in Feb.-Mar. and Aug.-Sept., 1955 and 1963.

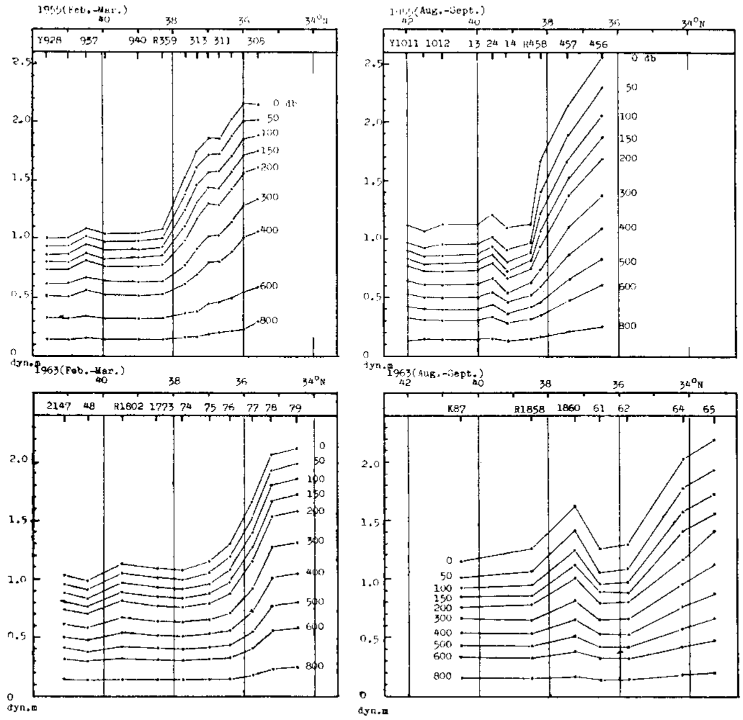

Fig. 9. Geopotential anomaly on isobaric surfaces relative to the 1000 db surface along 144°E, Y: Yushio-maru, R: Ryofu-maru, K: Kofu-maru.

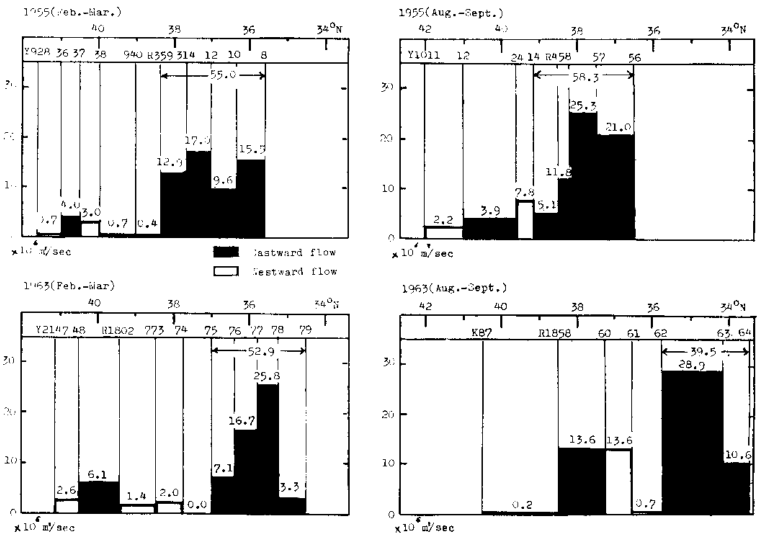

Fig. 10. Volume transports along 144°E in 1955 and 1963.

section in Fig. 9. The black lines indicate the eastward transport in the upper 1,000 m and the white lines indicate the westward transport.

In 1955, the volume transport of eastward flow of the Kuroshio between Ry 359 and Ry 308 amounts to $55.0\times10^6 m^3/sec$ in Feb.-Mar. and between Ry 458 and 456 amounts to $58.3\times10^6 m^3/sec$ in Aug.-Sept. which is equivalent to the transport in Feb.-Mar.

In 1963, the volume transport of eastward flow of the Kuroshio between Ry 1175 and Ry 1179 amounts to $52.9\times10^6 m^3/sec$ in Feb.-Mar., but the volume transport remarkably decreases to $39.5\times10^6 m^3/sec$ in Aug.-Sept., which is 76% of the transport in Feb.-Mar.

In Aug.-Sept. of 1963, the volume transport of westward and eastward flow of the anticyclonic eddy (refer to Figs. 4, 7, 9) amounts to $13.9\times10^6 m^3/sec$, so that the volume transport of the Kuroshio plus the warm eddy is $53.4\times10^6 m^3/sec$ which is equivalent to the transport of the Kuroshio in other periods.

The width of the Kuroshio is shown in Table 2. The distribution of volume transport in the Kuroshio varies seasonally and yearly, that is, the maximum volume transport appears more north than the center of eastward flow of the Kuroshio water in Feb.-Mar. and Aug.-Sept. of 1955, but the maximum volume transport appears more south than the center in Feb.-Mar. of 1963. In Aug.-Sept. of 1963, the distance of the two adjacent stations, Ry 862 and 863 is so wide that the distribution of the volume transport of the Kuroshio is obscured.

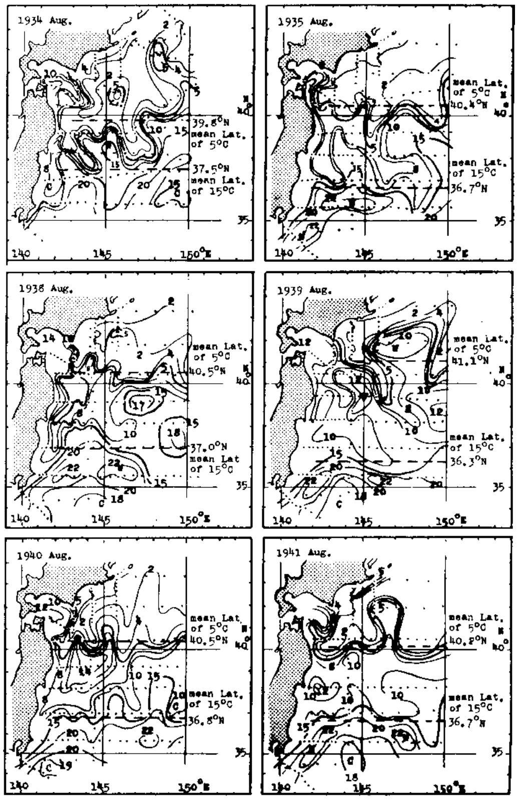

Fig. 11. Distributions of water temperature at the 100 m depth in Aug. 1934-1941.

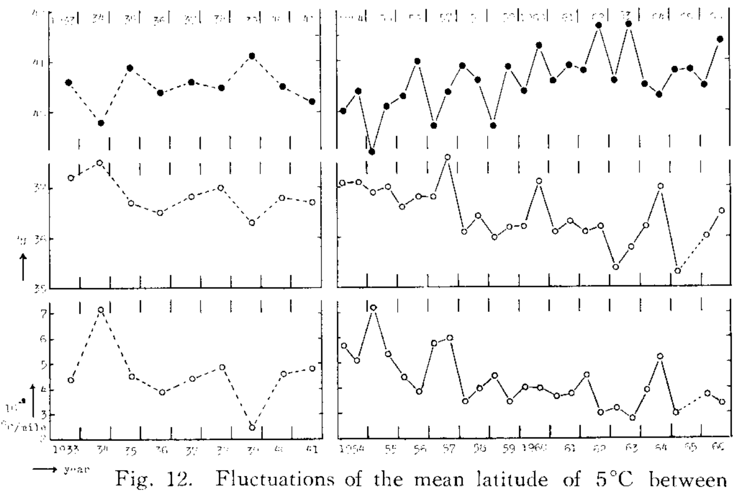

Fig. 12. Fluctuations of the mean latitude of 5°C between 143°E and 150°E (upper), 15°C between 142°E and 150°E (middle), and the gradient of water temperature (°C/mile) between 5°C and 15°C at the 100 m depth (lower).

4. Relation between the mean latitude of the isotherms of 5°C and 15°C at the 100 m depth

Fig. 11 shows the distribution of water temperature at the 100 m depth in August from 1934 to 1941 and inserted numbers indicate the mean latitude of 5°C isotherm from 143°E to 150°E and the mean latitude of 15°C isotherm from 142°E to 150°E, but there is included with the warm eddies more than 15°C and the cold eddies below 5°C.

1934 and 1939 in Aug. are the years of peculiar hydrographic condition in the same look as 1955 and 1963, and the hydrographic condition in 1934 is similar to 1955 and 1939 is similar to 1963. That is, in 1934, the mean latitude of 15°C is 37.5°N, being more north than in the normal year and the mean latitude of 5°C is 39.5°N, being more south than in the normal year. In 1939, on the contrary, the position of 15°C is 36.3°N more south and the position of 5°C is 41.1°N more north. But the distributions of water temperature in other years show almost the intermediate distributions between the types of 1934 and 1939.

The fluctuations of the mean latitudes of the isotherms of 5°C and 15°C at the 100 m depth and the gradient of water temperature between 5°C and 15°C are illustrated in Fig. 12. Available values are the one in summer from 1933 to 1941, and in winter and summer from 1954 to 1966.

Here, the relation between the pattern of the Kuroshio and the Oyashio is generally explained from the fluctuations of mean latitudes of 15°C and 5°C as shown in Fig. 12. When the Kuroshio water extends more northward, the Oyashio water flows southward and the horizontal gradient of water temperature is large, which value amounts to more than 0.05°C/mile, especially about 0.07°C/mile in 1934 and 1955. On the

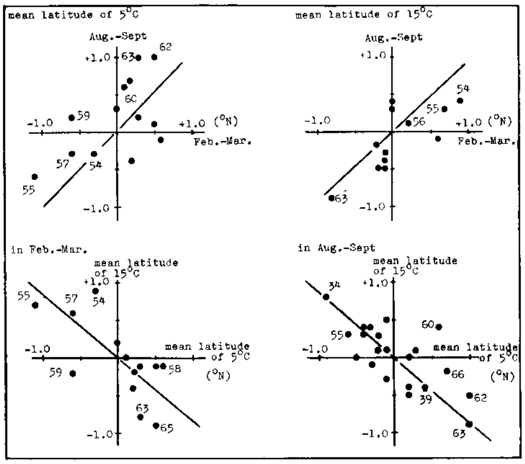

Fig. 13. Relations of the isotherms of 5°C and 15°C between Feb.-Mar. and Aug.-Sept. (upper), and relations between the isotherms of 5°C and 15°C in Feb.-Mar. and Aug.-Sept. (lower).

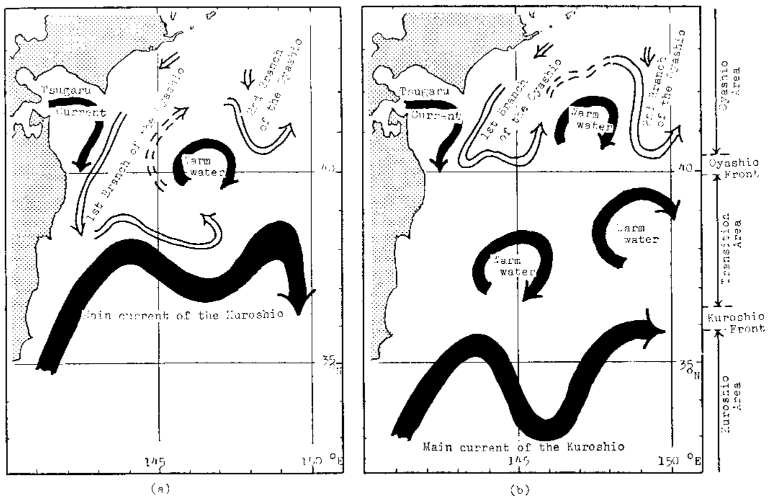

Fig. 14. Schematic representation of the hydrographic conditions in the neighbourhood of the Polar Frontal Zone in Aug.-Sept., (a) 1955 and (b) 1963.

contrary, when the Kuroshio water exists more south, the Oyashio water is more north and in this case the temperature gradient is small which values amounts to below 0.04°C/mile, especially below 0.03°C/mile in 1939 and 1963, that is, less than half of the values in 1934 and 1955.

Using the mean latitudes of 5°C and 15°C at the 100 m depth, the relation between winters and summers in the large scale from the coast to the east of about 500 nautical miles is illustrated in Fig. 13 (upper) to see the durability of the isotherms from winter to summer.

With two or three exceptions, it is recongnized that when the deviations of the mean latitudes of 5°C and 15°C isotherms are positive in winter, the deviations in summer are positive, and when the deviation is negative in winter, the deviations in summer is negative. This relation between winters and summers shows a positive correlation. It is, therefore, assumed to be sure that the hydrographic conditions characterized by the mean latitudes of 5°C and 15°C isotherms at the 100 m depth have considerable durability in the region.

The relation between the mean latitudes of 5°C and 15°C isotherms in winter and summer also is illustrated in Fig. 13 (lower) to see the relation between the pattern of the Kuroshio and the Oyashio.

With two or three exceptions, in winter and summer when the deviation of the mean latitude of 15°C is positive, the deviation of the mean latitude of 5°C is negative, and when the deviation of 15°C is negative, the deviation of 5°C is positive. From this, it is clear that the negative correlation between the mean latitude of 15°C and 5°C exists.

Fig. 14 shows the schematic representation of the hydrographic conditions in the neighbourhood of the Polar Frontal Zone with the unusual patterns between the Kuroshio and the Oyashio in Aug.-Sept. of 1955 and 1963, these have been illustrated in Chapter 3 too.

When the Kuroshio water in this area extends more northward than in the normal year, the volume transport of the first branch of the Oyashio which flowed southward is larger, and when the Kuroshio water exists more south, the volume transport of the Oyashio is smaller. (HATA, 1965)

On the above fact, we find some close relation between the pattern of the Kuroshio water and the Oyashio water.

Acknowledgments

The author wishes to express his hearty thanks to Dr. J. SUGIURA and the member of the Oceanographic Section of Hakodate Marine Observatory and Mr. AKAGAWA for their kind advices.

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東北海区における海況変動に関する二，三の問題点（1）

―黒潮と親潮のパターンとの間の関係について―

秦　克己

要旨　東北海区は黒潮系水の北上と親潮系水の南下との間に混合域があって種々雑多な暖水塊や暖水域が見られ，日本近海で最も複雑な変動を示している．この海域（33～43°N，141～150°E）おいて，現在の観測体制でその変動・持続性等をミクロに取り上げて解明出来る問題は少ない．今回マクロに見て，海況変動に関する二，三の問題点のうち，第1報として黒潮と親潮とのパターンとの間の関係について，100 m 層水温分布・144°E 線上の鉛直断面図等から解析した．

黒潮系水（100 m 層で 15°C，34.6‰ 以上の水塊）と親潮系水（100 m 層で 5°C，33.60‰ 以下の水塊）との相互の位置について，黒潮系水の北上が著しい時，親潮系水の南下が著しく，その両者の間の水温傾度が急であり，又逆に黒潮系水の北上が弱い時，親潮系水の南下が弱く，両者の水温傾度がゆるやかになっている．