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Interleaving Phenomena of the North Pacific Intermediate Water in the Offshore Area of the Kuroshio

Sung-Kee Yang and Byung-Gul Lee

Dept. of Ocean Civil Engineering, Cheju National University, Jeju 690-756, Korea

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To study the intruded phenomena of North Pacific Ocean around Boso peninsular, water property distribution in the adjacent seas to Japan is studied using the hydrographic data obtained by Japan Maritime Agency and Japan Fisheries Agency from 1973 to 1996, The scattering of water type in T-S diagram is relatively small in the Kuroshio Region. Both the envelopes of saline side and of fresh side of the scattered data points shifts gradually from saline side to fresh side as the observation Line moves from southwest to northeast. In mixed water region, the scattering of water type increases rapidly as the observation line moves north; the envelope of fresh cold side moves towards fresh cold side much faster than that of saline side. This suggests that the water does not advect along the salinity minimum layer, but the salinity minimum layer can be understood as a boundary of two different waters aligned vertically. We defined the typical water masses as the Oyashio Water and the Kuroshio Water. The water mass below the salinity minimum layer may be created by isopycnal mixing of these two water masses with a fixed mixing rate. While the water mass above the salinity minimum cannot be created simply by isopycnal mixing. The salinity minimum layer may be eroded from upper side due to active minxing processes in the surface layer, while the water of the salinity minimum layer moves gradually southward. This appears to give an explanation why the thermosteric anomaly value at salinity minimun decereases towards south.

Key Words : T-S diagram, North Pacific Ocean, Oyashio Water, Kuroshio Water, Salinity minimum layer

1. Introduction

The water formation of West North Part of Pacific Ocean and its circulation characteristics are strongly related with the seasonal variations of Oyashio current, the meandering and cold core-ring of Kuroshio current. In these effects, the Oyashio current that has the North Part of Pacific ocean water characteristics flows into Kuroshio region was studied by Uda[1]. After the Udas's study, the biological oceanographer also found the effects of the Oyashio current for the Kuroshio region[2]. The physical process of the intrusion of the Oyashio, however, has not much studied up to now. According to several ocean current observations, the Oyashio water often intrudes in the intermediate layer of Kuroshio region farther south into Sagami Bay along just off Boso coast[3,4].

The Oyashio flows from Hokaido of Japan to Samryu coastal area and its water characteristics contains the North Pacific intermediate ones with salinity minimum water layer. It was shown that the water characteristics of the typical Oyasahio water was found at the east of Hokkaido can be explained as a mixed water between the Subpolar Water supplied from the East Kamchatka Current and the Okhotsk water. And the intermediate water spreaded the south part of Kuroshio region and the one part of the Oyashio extended Chouban and Kagima current area and finally arrived at the Kuroshio region. However, the formation mechanism of the Oyashio has not been clarified, and the detailed flow pattern especially near the western margin of

Corresponding Author ; Sung-Kee Yang, Dept. of Ocean Civil Engineering, Cheju National University, Jeju 690-756, Korea
Phone : +82-64-754-3451
E-mail : skyang@cheju.ac.kr

the circulation area has not been determined[5,6].

Therefore, the Kuroshio flow pattern variation and the surface Oyashio current should be studied with Japan coastal water and its the coastal circulation characteristics. The study will support an reference factor for the characteristics of North Pacific intermediate water as well as the coastal water of Japan and the water front and the Oyashio Water related with the Japan coastal ocean water.

The intermediate water circulation is very important role to find out the abyssal and world ocean circulation with North Pacific intermediate and its deep circulation based on world ocean observation. However, the direct observation for the intermediate water circulation is not easy since it takes a lot of time and money so that the already observed ocean data will be very useful to find out the circulation pattern and its mechanism of North Pacific circulation. In this study, to find out the intrusion of the intermediate Oyashio water to the Kuroshio region along the Japan coastal area, we used the observation data at Sanrik area located off Japan east area, Inubosaki area near the Kuroshio region and Boso peninsular coastal area. The North Pacific intermediate water and its physical characteristics and the relationship between the Pacific current and the Kuroshio warm water one will be main topic of this research.

2. Data and Methods

The hydrographic data along several routine observation lines occupied by Japan Meteorological Agency are used in our study. And also, we used temperature, salinity and dissolved oxygen proposed by Japan Maritime Agency (JMA) and Japan Hydrographical Agency and the thermosteric anomaly using the observation data. Meteorological Agency data of KJ line (Fig. 1) of Boso peninsula from 1973 to 1996 and of the JMA from 1973 to 1996 were used. To investigate the characteristics of North Pacific intermediate and coastal ocean water, we used the observation data of KJ-line and St. 1 and St. 2. The thermosteric anomaly of the North Pacific ocean water were calculated based on T-D data diagram of the water. The diagram of salinity anomaly-thermosteric anomaly also are compared with the salinity-thermosteric anomaly.

The relationship between the Kuroshio flow trajectory and the minimum salinity layer that defined as 15℃ Kuroshio water and the North Pacific intermediate water was computed at St. 1 along KJ-line depth of 200 m, respectively. In the Kuroshio region, the Oyashio intermediate water temperature was compared to the North Pacific intermediate water by monitoring the flow pattern. Fig. 1 shows that TA, KJ, CB-Line at 200 m and at this station we defined the Kuroshio position. It means that the mean position of the Kuroshio current at Boso peninsula was calculated using the frequency of appearance of the Kuroshio flow axes. The total relationship between Onahama-FSS5, Choshi-IGI3, Mera-TA1, Mera-KJ1, Oshima-TB1, Oshima-KN19, Miyakejima-TA1, Miyakejima-KJ1, Hachijoshima-TA1 and Hachijoshima-KJ1 was considered. In these, the tidal height of Hchioijima and St. TA1 were compared. The tidal level data were used from 1955 to 1984(30 years) filtering 8 tidal components.

For the abnormal period in which the North Pacific intermediate water intrusion effect was

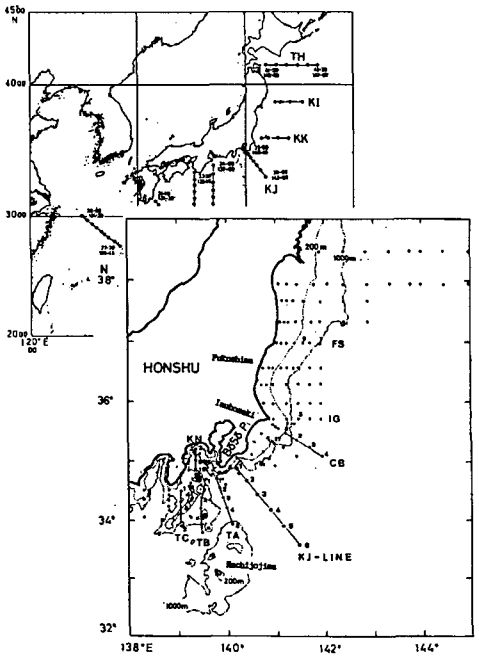

Fig. 1. Study area and oceanographic observation line. Hydrographic lines are present 200m and 1000m, respectively.

very strong to the coastal region, 1984, the salinity distribution on T-S diagram considering spatial and temporal variation was considered. In 1984, the water type of the Oyashio current was changed. From the observed data, we can find the dynamic relationship between the North Pacific intermediate water and Kuroshio meandering. Also, the surface and intermediate water characteristics of Boso peninsula will be shown from the dynamic relationship.

3. Characteristics of North Pacific Intermediate Water off the Boso Peninsula

To understand the water mass characteristics of Kuroshio current, the T-S diagram at station 1 the nearest region of coastal zone, was compared with the station 2, the result was displayed in Fig. 2, the furthest one of the coastal zone. In the figure, the maximum salinity zone shows σ_t = 26.6~ 26.9, temperature 5~7℃ that called the North Pacific intermediate water[7]. The T-S distribution looks very similar to those of south part of Honshu and the Kuroshio region, however, a little bit different water characteristics were also found. The station 1 to 5 along KJ-line shows that 34.25~34.5‰ frequency happens very often. From st. 1 to 4, the frequency happens rare as decreasing the salinity intensity. However, st. 6 shows the typical Kuroshio water characteristics, the pattern also shown in st. 5. Lower salinity such as 34.0‰ happen many times at st. 1 only. This type water produced at the Oyahiso region has low temperature and salinity, that was changed from the original water type. The water finally becomes high temperature and salinity as it intruded to the Kuroshio region. However, the changed water also manifestly was different from the original Kuroshio water.

4. Characteristics of density of low salinity water occurrence near Boso Peninisulal area

Next, salinity anomaly-thermosteric anomaly diagram was calculated from T-S diagram based on long time the observation data to investigate the relationship between the Kuroshio water type and the North Pacific intermediate water type at the coastal region.

Fig. 3 shows the anomaly of $\triangle_{ST}$(5cl/t interval) divided by the standard deviation of the value. The range of salinity anomaly that is larger than -1σ is different from the figure. In August 1984, the lower salinity is very strong, $\triangle_{ST}$=110~168cl/t, the depth is 160~500m, the thick is 124 m only. This characteristic was also shown in the dissolved oxygen pattern. So that

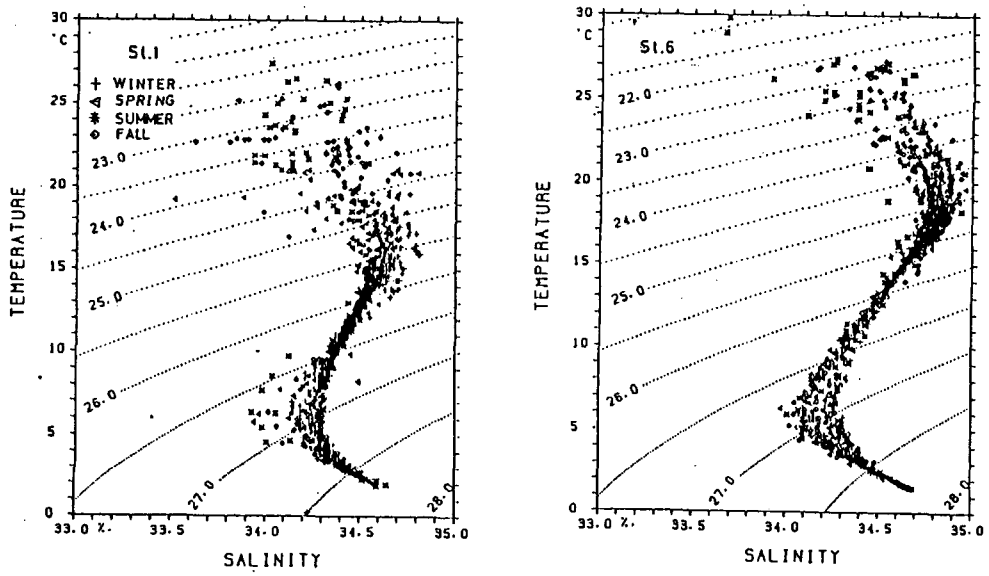

Fig. 2 T-S diagram at St. 1 and St. 6 on KJ-Line. Dotted line are presented sigma-t.

the reference low salinity $\triangle_{ST}$ is 130cl/t, in October 1979 and June 1985, 135 cl/t in August 1984, and 140cl/t in 1975.

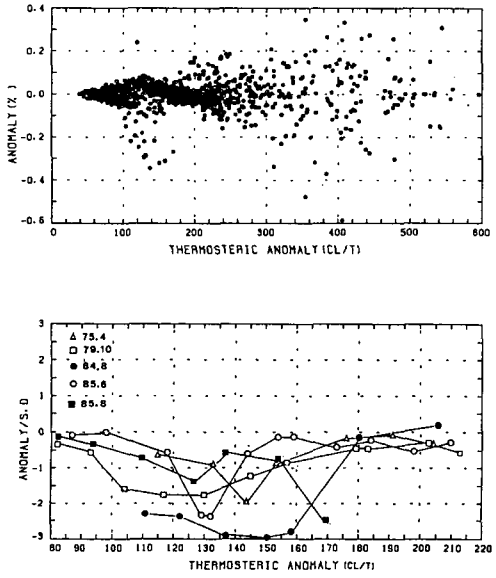

Fig. 3. Relationship of salinity anomaly-thermosteric anomaly(upper) and standard anomaly (lower) for 5 cases at St.1. Salinity anomaly values were calculated in five centiliter per ton intervals.

5. Relationship between occurrence of the Salinity Minimum Water and Kuroshio path

Along KJ-line at st. 1, we confirmed the salinity minimum to find out the Kuroshio flow variations. The variation was shown in Fig. 4. As comparing the minimum salinity along KJ line to Kuroship path(15℃ less than 200 m depth), we can find that the Kuroshio flow region was located at around 34° 40′ N in 1970, in 1980, the path variation was very strong, particularly, from 1984 to 1986 and 1989. The strongest variation also happens when the path withdrawn around 33° 20′ N. This pattern continued until 1990. The minimum salinity was very low during 1984 and 1985. In 1995, also same phenomena happened. The relationship between the minimum salinity and the Kuroshio path was found at Japan east south ocean area, this pattern was called type 4 of the Kuroshio. Fig. 5 shows the typical Kuroshio flow path 4. In the region, we can easily find out the several types of Kuroshio path.

In February 1981, August 1984 and 1985 and July 1986, the Kuroshio meandering was very strong, particularly in 1984 and 1985. However,

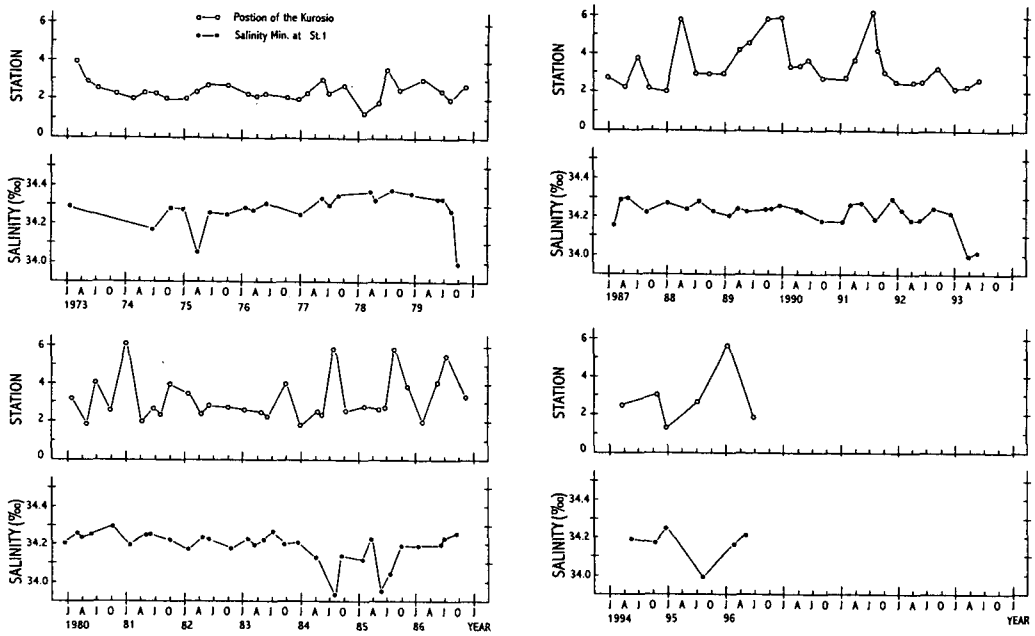

Fig. 4 Time series of Salinity Minimum value and Kuroshio path at St.1 on KJ-Line.

the other year the meandering was not so strong. In 1981 and 1986, although the meandering was strong, the minimum salinity was not observed. Therefore, it is very hard to define the relationship between the minimum salinity and the strong meandering. Around Boso peninsular coastal area, low salinity less than 34.1‰ was found at 300-500 m depth. Off the coastal area, the depth was almost 700-900 m[8,9].

Fig. 5 also shows the mean Kuroshio position of the south part of Boso peninsular based on the observation of appearance frequency along TA, KJ and CB-Line(Fig. 1). Two mode happened in the center of Miyakejima along TA-Line and in center of st. 2 and st. 3 long KJ-Line and at the coastal region along CB-Line. Therefore, the mean Kuroshio path was similar to N-type and distorted toward the coastal area(Fig. 5).

The relationship between the tidal level of Hachiojima and the intermediate water of st. TA1 was investigated (Fig. 6). The tidal level data was filtrated for 8 tidal components. The calculated correlation coefficient with 99 % confidence is 0.78. C-type of the Kuroshio path has the lower salinity of the North Pacific intermediate water characteristics was found. However, the other observation stations did not show the clear relationship between the Kuroshio and the tidal level. The relationship will be studied more detail in future.

6. The intrusion to South Part of Boso peninsula of North Pacific Intermediate Water

In April, May, July and August of 1984, the Kuroshio meandering was strong and the minimum salinity happened around coastal region. Fig. 7 shows $\triangle_{ST}$=135cl/t during the periods. In the figure, 33.5‰ Oyashio water flowed to the southern area of Jouban area that was found. However, during the time, the Oyashio water could not approach to the Juban area directly since the Kuroshio flow was so close to Boso

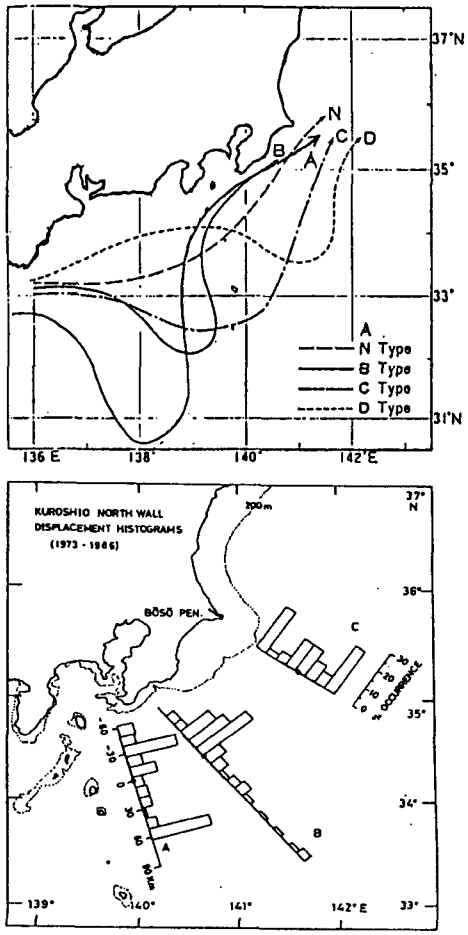

Fig. 5. 4 types of the patterns of the Kuroshio near the Izu Isaland by Soji(left, 1972) and Kuroshio north wall displacement histogram(right, 1973-1996).

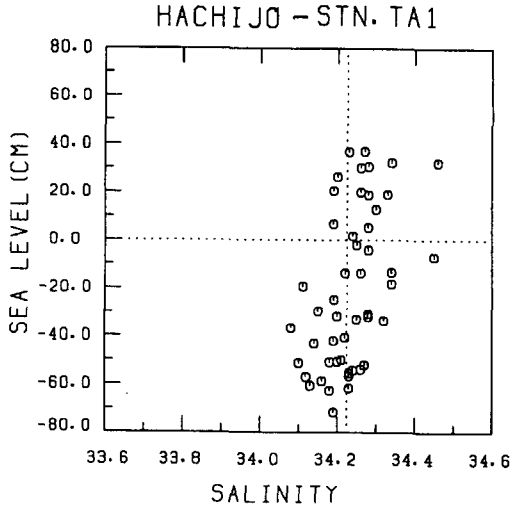

Fig. 6. Correlation between the daily mean sea level after removal of 8 tidal component at Hachijo and salinity minimum value at St. 1 on TA-Line.

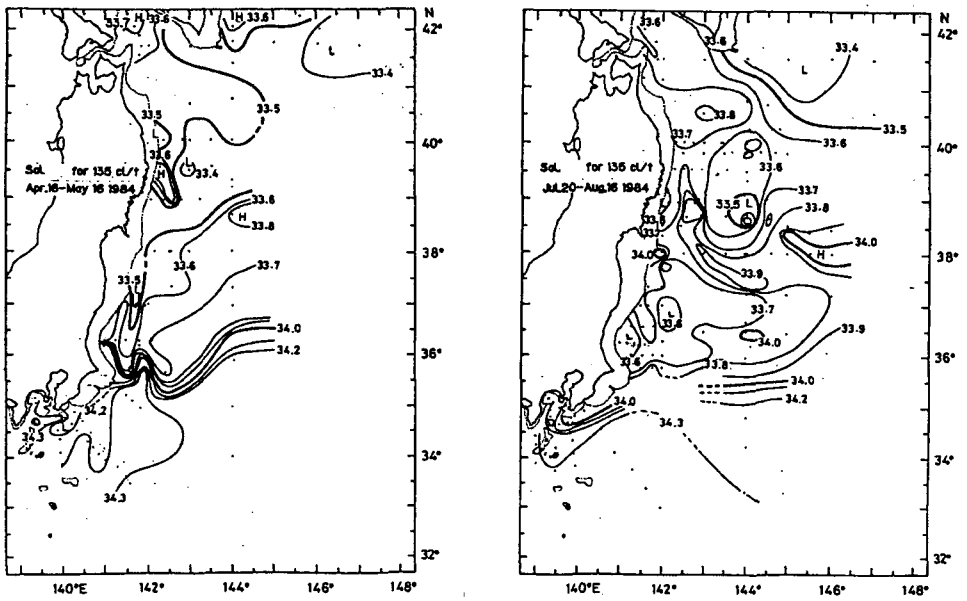

Fig. 7. Horizontal distribution of salinity for 135 cl/t level on April 16 - May 16(left) and July 20 - August 16(right), 1984.

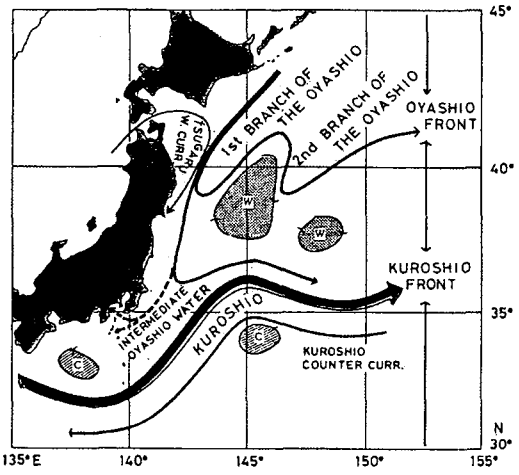

Fig. 8. Schematic presentation of various water circulation in the Northwest Pacific area.

peninsular. The salinity front during August approached to Boso peninsular from around Inubosaki area which is adjacent to the Kuroshio. The lower salinity of 34.2‰ intruded into Sagami bay. This intrusion phenomena will be strongly related with long gravity wave around Boso peninsular and Sagami bay. The main effects causing the North Pacific intermediate water circulation and current pattern are related to the Kuroshio warm current and its path variation, the seasonal variation of the Oyashio current, the warm core ring, and cold core ring of the currents. There are still unsolved problem with relationship between the intermediate Oyashio current and the Kuroshio one located off Inubosaki and Boso peninsular. From the results, the schematic diagram of the circulation pattern of the North Pacific intermediate water at the north west Pacific Ocean area was shown in Fig. 8. The more detail description of the flow diagram can be proposed using detail current observation and CTD data in future.

7. Conclusions

Although the seasonal variation of the Oyashio current always happens seasonal variation, the current has the North Pacific intermediate water characteristics with the minimum salinity after arriving Samryun coastal area located off Hokaido of Japan. The intermediate water movement extended to Ouban and Kajima area along the east coastal area of Japan. However, its mechanism of the movement is not found. The water mass characteristics of the Oyashio, however, was not much changed from Sinriku area to Hukushima coastal area in a year. In the area, the Kuroshio path, its warm and cold core ring can be important role for the water mass cha-

racteristics. Particularly, the relationship between the Kuroshio path and the minimum salinity was also found. From this study, the lower salinity of the North Pacific intermediate water intruded into Sagami bay was found. This intrusion phenomena can be extended to Boso area and Sagami bay area and be effected to gravity current phenomena. Therefore, around Boso peninsular, the Oyashio physical mechanism can be solved by the Kuroshio path variation and surface and intermediate Oyashio current. This study will be a reference factor to find out the characteristics of coastal water mass type and the front formed by the North Pacific intermediate water and the east part of Japan and Oyashio current.

Acknowledgements

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References

1) Uda, M., 1937, Results of hydrographical investigation in the Sagami Bay in connection with the "Buri" fishing, J. Imperial Fish. Exp. Sta., 8, 1-50.
2) Omori, M., 1967, Calanus cristatus and submergence of the Oyashio water, Deep-Sea Res., 14, 525-532.
3) Yang, S. K., Y. Nagata, K. Taira and M. Kawabe, 1993a, The Southward Intrusion of the Intermediate Oyashio Water along the east coast of the Boso Peninsula - Coastal Salinity-Minimun-Layer Water off the Boso Peninsula. J. Oceanogr. Soc. Japan. J. Oceanogra. Japan, 49(1), 89-114.
4) Yang, S. K., Y. Nagate, K. Taira and M. Kaeabe, 1993b, The Southward Intrusion of the Intermediate Oyashio Water along the east coast of the Boso Peninsula - Intrusion events into Sagami Bay. J. Oceanogr. Soc. Japan. J. Oceanogra. Japan, 49(2), 174-179.
5) Hasunuma, K., 1978, Formation of the Salinity Minimun in the Nort hwestern Pacific ocean. Bull. of O.R.I., Univ. of Tokyo, 1-47pp.
6) Yang, S. K. 1994, North Pacific Intermediate water in the Northwest Pacific. J. Kor. Env. Soc., 3(30), 229-239.
7) Soji, 1972, Hydrography of the Kuroshio Extension, in Kuroshio, Univ. of Washington Press, Seattle, 450-466pp.
8) Ishikawa, K., 1988, The Oyashio Water system in the sea of south Hokkaido. Umi to Sora, 64, 9-18(in Japanese).
9) Kawai, H., 1972, Hydrography of the Kuroshio Extension. Kuroshio, Univ. of Tokyo Press. ed. Stommel and Yoshioda, 235-352pp.