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Temperature Stratification in the upper layer of Harima−Nada during summer

by

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Synopsis

Strength of upper temperature stratification (SUTS) was represented with difference in the water temperatures at surface and the depth of 10m and on the summer SUTS in Harima−Nada, the following characteristics were recognized, 1) that the frequency of total 680 SUTSs from 1976 to 1993 had a Poisson distribution like pattern with average value of 2.0 deg, 2) that the horizontal distribution of the stational median had the strongest SUTS above 3.0 deg in the northern part and the most weak SUTS under 1.0 deg in the east part near the Akashi strait, 3) that both linear regressions of the SUTS (Tus deg) on the surface salinity (Sss ‰) and on the transparency (Trs m) in the north areas had the significant correlation levels, 4) that the interannual variation of the annual median (Tua) had a long term tendency growing weak at a rate of about 0.2 deg per a decade and the periodicity with about six to seven cyclic years, 5) that the linear regression of the Tua on the Ssa separated into two significant groups with the Tua above 2.1 deg ($r = -0.746$) and under 1.9 deg ($r = -0.686$), but on the transparency was not significant.

Keywords : Temperature stratification, frequency, horizontal distribution, interannual variation, salinity, transparency.

1. Introduction

In order to maintain not only the inhabitant density and the specific variety but also the lives of the bottom marine organisms in eutrophic inland sea such as Harima−Nada, it is indispensable to prevent an occurance of the oxygen−deficient waters throughout the year. The dissolved oxygen (DO) in the bottom layer is supplied mainly with the vertical mixing of sea waters from the surface layer, but during summer, the amount of oxygen transported from the surface layer with the vertical mixing depends on the strength of temperature stratification (STS) because the vertical mixing induced by the tidal current and the wind, and waves can be weaken by the STS.

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In the previous paper$^{1)}$, we investigeted the characteristics of the summer STS under the depth of 5 m and its influence on the bottom DO content in Harima−Nada from 1976 to 1993. The total frequency of the STS had a Poisson distribution like pattern with mean of 2.7 deg and the horizontal distribution was similar to these of the bottom DO and the appeared year ratio of oxygen−deficient water mass$^{2)}$ in shape. Also the significant inverse correlation was recognized between the STS and the bottom DO content ($r = -0.56 \sim -0.94$) and it became clear that the amount of oxygen transported to the bottom layer with the vertical mixing depended on the STS under the depth of 5 m.

In this paper, we paid attention to strength of the upper temperature stratification (SUTS) represented with difference in the water temperatures at the sea surface and the depth of 10 m, and investigated the patterns of its frequency and horizontal distributions, the long term tendency and the periodicity in the interannual variation and the relations between the STUS and surface salinity or transparency.

2. Materials and Methods

Harima−Nada is located in the eastern part of the Seto Inland Sea (N.L 134° 10'~135° 00′ and E.L. 34° 15′ ~ 34° 45′). Its surface area, the average and the maximum depths are about 3400 km^2, 26 m and 43 m, respectively. The bathymetric contours and the situations of sampling stations had been shown in the previous paper$^{3)}$.

The strength of upper temperature stratification (SUTS) was represented with the difference in the water temperatures between the sea surface and the depth of 10 m , and was obtained as follows, $Tu = T(0) - T(10)$ deg, where T(0) and T(10) are the water temperatures measured at the depths of 0 and 10 m, respectively, together with the electric conductibity etc.

The data used in this paper were measured with Hydrolab model D *in−situ* water quality analyzer connected to a portable printer in the periods of late July to early August (except early July in 1977) from 1976 to 1993. The conductivity system of the analyzer was calibrated by the four kinds KCl solutions with conductivity of 38.05, 42.20, 45.60 and 49.65 mmho/cm at 25 deg, respectively. The temperature system was calibrated by the two standard mercury thermometer with accuracy of 0.1 deg as well as the calibration of the conductivity in our laboratory before going to and after returning from each field survey.

3. Results and Discussions

3.1 *Frequency distribution of the SUTS*

The frequency distribution of the SUTS (Tu) obtained during summers from 1976 to 1993 illustrates in Fig.1. There are 680 SUTSs in the histogram and 98% of them distributes in the region of 0.1 ~ 7.6 deg. This result indicates that in the summer upper layer of Harima−Nada, the water temperature hardly form a vertical stratification, though a large difference exist in the STUS due to the time and the place. The histogram has a total median of 2.0 deg and the upper and the lower total hinges of 3.2 deg and 1.0 deg, respectively. Its distribution is unsymmetric and expands to the strong side of the SUTS. The broken line in Fig. 1 shows a fitted Poission distribution used the median as the average value, $F = 0.135\ (2.0)^{Tu}\ /\ Tu!$, where F is the percentage of frequency. From this distribution, it is infered that frequency to form the strong SUTS above 7.0 deg is negligible.

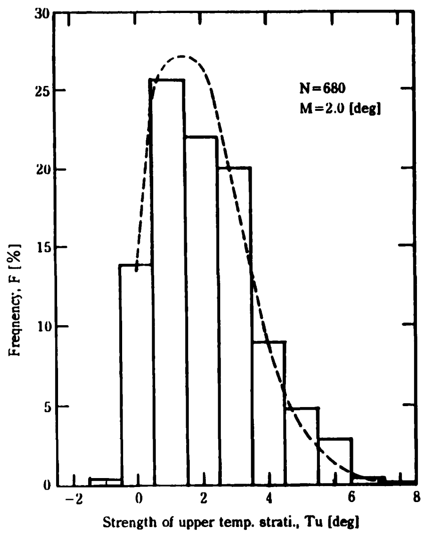

Fig. 1. Frequency distribution on the strength of upper temperatare stratification (SUTS) in Harima-Nada during the summers from 1976 to 1993. Broken curve shows a fitted Poisson distribution.

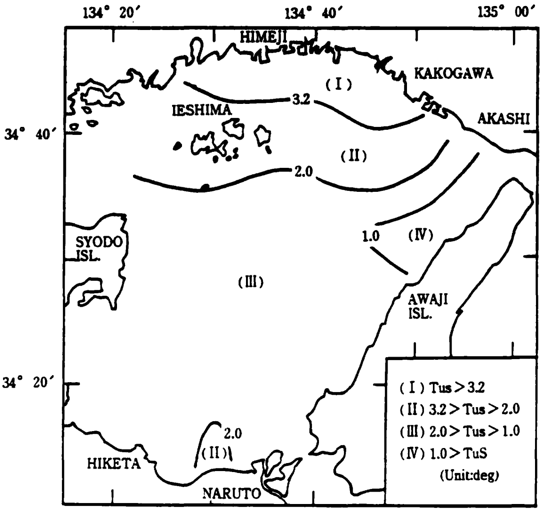

Fig. 2. Horizontal distribution of the SUTS illustrated with the 40 stational medians.The three contours represent the total median of 2.0 deg, the total upper hinge of 3.2 deg and the total lower hinge of 1.0 deg.

3.2 Horizontal distribution of the SUTS

Fig. 2 shows a horizontal distribution of the stational medians of the SUTS (Tus). The distribution is divided into the four parts classified with 3 contours equal to the total median of 2.0 deg, the upper total hinge of 3.2 deg and the lower that of 1.0 deg for 680 SUTSs. In Fig. 2, the area (I) extended offshore from the north coast between Kakogawa and Aioi cities is the region where the stational medians of the SUTS (Tus) were in the range of 3.2 deg ~ 4.2 deg and the mean SUTS was the strongest among four areas. The area (II) extended on the south side of the area (I) had the stational medians of the SUTS in the range of 2.0 deg ~ 3.2 deg and the mean SUTS next to the area (I) among them. On the other hand, the areas (III) and (IV) extended from the south side of the area (II) to the south region of Harima-Nada are relatively weak in the SUTS. Specially, the stational medians of the SUTS in the area (IV) were less than 1.0 deg and the mean SUTS was the most weak among them. The difference in the SUTSs between the areas (III) and (IV) is considered to be strength in the vertical mixing of the waters induced with the tidal current.

In the horizontal distribution of the SUTS, There is a tendency that SUTSs grow weaker according to increase of the distance from the north coastline. Then the effects of the surface salinity and the tranparency on the SUTS were examined with their stational medians. Fig.3 illustrates the relationship between both statonal medians of the SUTS (Tus) and the surface salinity (Sss). The solid and the open circles correspond to the measured values at the stations in the areas(I) and (II) and in the other two areas in Fig. 2, respectively. The solid circles have the lower surface salinities and the stronger SUTS than that of the open circles. As shown with broken line, there is a linear regression of Tus on Sss, that is, Tus = 56.7−1.77 Sss and, its correlation coefficient of −0.823 is signifcant because the 95% confidence limit is 0.312 (N = 40). Therfore, it is considered that the SUTSs in the areas (I) and (II) are intensified with the low surface salinities due to the inflow of a large quantity of fresh water on the north coast.

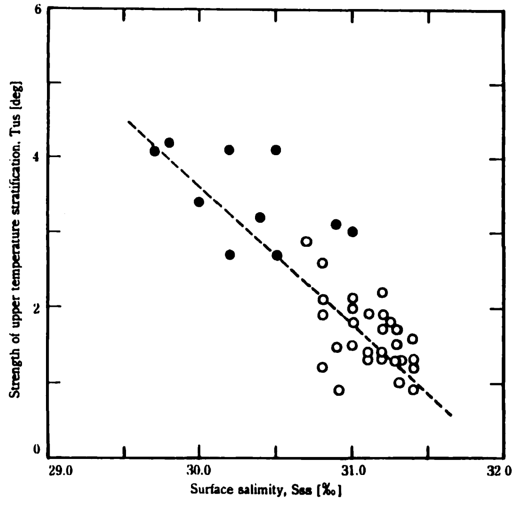

Fig. 3. Relationship between both stational medians of the SUTS (Tus) and of the surface salinity (Sss).
Solid and open circles correspond to the stations in the areas (I) and (II) and in the other areas in Fig. 2, respectively. Broken line shows a linear regression of the SUTS (Tus) on the surface salinity (Sss).

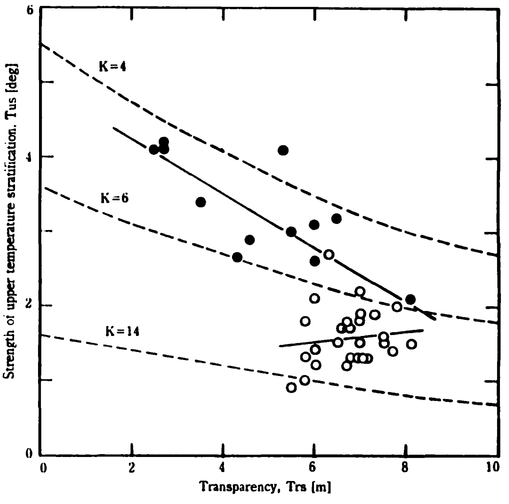

Fig. 4. Relationship between both stational medians of the SUTS and of the transparency (Tus). Solid and open circles are same in Fig.3 and two solid lines show the linear regressions of them. Three broken curves show estimated relations with a formula presented by Yanagi and Fujimoto and K is vertical heat diffusion coefficients.

The relationship between the SUTS and the transparenvy (Trs) illustrates with both stational medians in Fig.4. The solid and open circles correspond to the measured values in the areas (I) and (II) and in the areas (III) and (IV) shown in Fig.2, respectively. Although in the areas (III) and (IV), any siginificant linear regression is not recognized, there is a linear regression of the SUTS on the transparency, Tus = 5.0 − 0.36 Trs ($r = -0.784 >$ 95% C.L. of 0.531) in the areas (I) and (II) as shown with the solid line in Fig.4. Three broken curves were obtained due to apply an approximated constant on the product of the transparency and the attenuation coefficient in Harima-Nada, C = 1.6 to the formula presented by Yanagi and Fujimoto[4)] in order to examine the effect of the vertical heat diffusion on the relation between the SUTS and the transparency. The vertical heat diffusion coefficients, K, of the curves are 4, 6 and 14 cm/sec from top to downward, respectively and the coefficients in the areas (III) and (IV) are in the range of about two times as larg as that in the other areas. This is considered to be a main reasion that in the areas (III) and (IV), the linear regression of the SUTS on the transparency is insiginificant.

3.3 Interannual variation of the SUTS

Fig.5 illustrates the between-year variation of the SUTS during the summers from 1976 to 1993. Solid circles are the annual medians of the SUTSs, Tua, measured at 31~40 stations per summer, and the error bars are equal to the annual hinge spreads which are given with the differences between the annual upper and lower hinges.

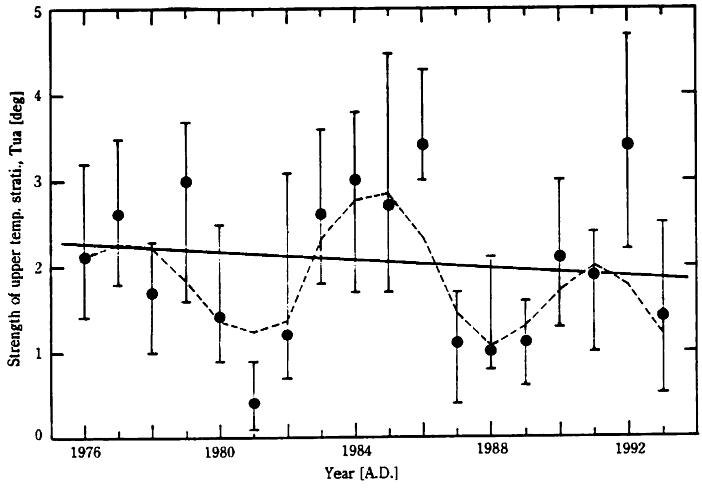

Fig. 5. Interannual variation of the SUTS during the summers from 1976 to 1993. Solid circles are the annual medians of the SUTSs, Tua. Error bars are equal to the annual hinge spreads estimated from the annual upper and lower hinges. Solid line is a resistance line of the annual medians, and broken lines represent a smoothed variation of the Tua computed by the methods of running median with the span of 3 years and of the Hanning's weighted running mean.

A solid line shows resistance line obtained by the EDA, that is, Tua = 4.0 − 0.023X, where X = year (A.D)−1900 and as a long term tendency of the summer SUTS, the interannual decrease of about 0.2 deg per decade is infered. The broken lines represent a smoothed between−year variation of the SUTS obtained by the methods of running median with the span of three years and of the Hanning's weighted running mean. From this smoothing, it is recognized that the summer SUTS annually variate with a periodicity of about 6 ~ 7 cyclic years and the maximum amplitude from the resistance line of about 1 meter.

Fig.6 illustrates the relationship between the annual median of the SUTS shown in Fig.5 and that of the surface salinity, Ssa. The annual medians in Fig.6 are nearly separated into two groups by the Tus of about 2.0 deg in the region of the surface salinity above 29.8 ‰, and between both annual medians of the SUTS and the surface salinity, there are expected two relationships. Solid and open circles correspond to the years with the Tua more than 2.1 deg and less than 1.9 deg, respectively, and two lines show linear regressions for solid and broken cricles, that is, Tus = 23.6−0.665 Ssa, r = −0.746 > 95% C.L.(= 0.705)and Tua = 15.9 − 0.470 Ssa, r = −0.686 > 95% C.L.(= 0.630).

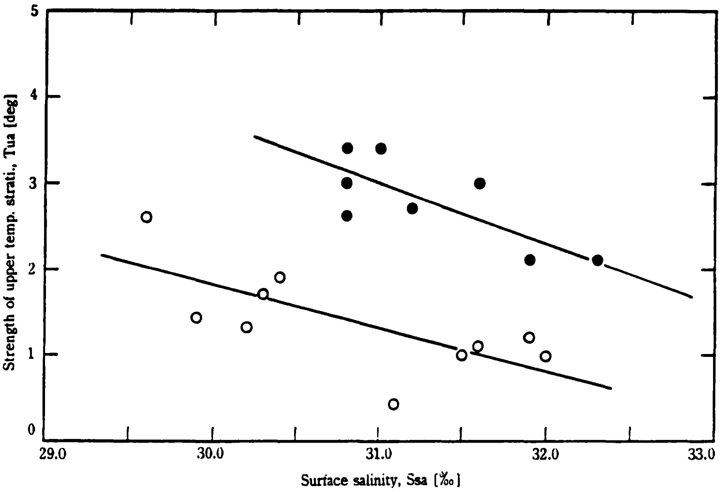

Fig. 6. Relationship between both annual medians of the SUTS (Tua) and of the surface salinity (Sss). There are two relationship between both annual medians in the region of the surface salinity above 29.8 ‰. Solid and open circles correspond to the years with the annual median more than 2.1 deg and less than 1.9 deg, respectively. Two lines show linear regressions for the 8 years with Tua above 2.1 deg and for the 9 years with Tua under 1.9 deg, respectively.

These slopes of 0.665 deg / ‰ and 0.47 deg / ‰ are one third and forth of the solpe for the stational median described above, respectively. Also, a linear regression of the SUTS on the transparency in the annual medians was insiginificant. Then the main factors induced the large between year variation of the SUTSs is considered to be the oceanographic reasons separated the 18 SUTSs into two groups as shown in Fig.6. And it is infered the variations in penetrative solar radiation and wind–powered vertical mixing had important roles as the oceanographic factors.

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