La mer 33, 13–35, 1995
Société franco-japonaise d'océanographie, Tokyo

Temperature-salinity frequency distribution of the upper 10 m water of the Japan Sea*

Hideo SUDO**

Abstract: The Japan Sea except the northwestern part is divided into four areas according to seasonal variation pattern of sea surface temperature and salinity. Monthly temperature-salinity characteristics at the sea surface and at 10 m depth are examined by use of relative frequency distribution in bivariate class of 1℃×0.2 (‰ or psu) in salinity for each of four areas and for the whole study area. Two modes are seen in the frequency distributions nearly through a year because a frontal zone exists in the central area where cold, low salinity water of the north contacts warm, high salinity water of the south. The eastern part of the frontal zone occasionally extends northeastward along the Japan coast and there occurs another weak mode representing a little warm water in the southeast of the zone or in the west of northern Japan. The most frequently occurring water at 10 m through a year has characteristics of 5–13℃, 34.0–34.2, partly 33.8–34.0 or 34.2–34.4 seen in the south of the frontal zone mostly during January to May. Other significant waters are the coldest water centered at the class of 2–3℃, 33.8–34.0 occurring during December to April and the warm water of 17–21℃, 33.8–34.2 appearing mostly during July to December.

1. Introduction

The Japan Sea is a mid-latitude marginal sea located in the northwest of the North Pacific; large annual variations of sea surface temperature (SST) (exceeding 15℃) occur in the sea. Besides, sea surface salinity (SSS) shows wide variations, both annually and interannually, according to the salinity value of the Tsushima Warm Current water entering from the East China Sea and to fresh water amounts supplied by river discharges from the surrounding land. If sufficient hydrographic data are provided, we can estimate monthly means of both SST and SSS with their standard deviations for every unit area, e. g. 1 degree square. Their annual variations are given by monthly means through the year; their standard deviations show composites of spatial and interannual variations. Mapping of monthly mean SST and SSS of the Japan Sea with their variations (hereafter referred to as SUDO's Mapping) are now under way to be published. Temperatures and salinities are separately presented in the mapping.

The only dominant surface water of the Japan Sea is the warm, saline Tsushima Warm Current water; colder, lower salinity waters occupy a great portion of the surface of the sea and occasionally extremely low surface salinities are found not only near mouths of rivers but also far offshore. Low sea surface salinities affect SST values because of high vertical stabilities. In the open sea surface waters with low salinities are liable to be warmer or colder according to heating by inflow of solar energy or cooling by long wave radiation, conduction and evaporation; coastal waters show great variations in temperature through land heating or cooling and in autumn to spring waters discharged from rivers are colder than ambient sea surface waters. Therefore, SSS and SST are not always independent in the Japan Sea.

In order to show variation of SST and SSS, bivariate distributions are more useful. Volumetric potential temperature (θ)-salinity diagrams of the Japan Sea have been already provided for each of four seasons and through year (YASUI *et al.*, 1967). Since surface waters are small in absolute volume and show a wide variation, volumetric analysis is not always adequate for description of surface water

* Received January 20, 1995
** Tokyo University of Fisheries, Department of Marine Science and Technology, 5–7, Konan-4, Minato-ku, Tokyo, 108 Japan.

characteristics. This report uses relative presentation of *T-S* distributions of the surface water for every calendar month. The oceanic domain of the sea with enough observations in divided into four areas according to sea surface water characteristics; the distributions are examined for each of areas and for the whole domain. Frequencies at 10 m depth as well as at the sea surface are made to examine the structure of the surface mixed layer.

2. Data and analysis

I have tried to use all available historical data, but about 15,000 stations taken at least before and during the World War II are not adequate because of bad quality. Almost all of the stations taken during 1952－1988 (including partly in 1989 and 1990) are provided for the present analysis; more than 400 stations, about 2600 to 4400 stations since 1966, have been occupied in the Japan Sea including the Tsushima Strait region every year during the period. About 74,000 out of more than 110,000 stations taken since 1924 in the Japan Sea including the Tsushima Strait region are used for the present analysis. Details of data sources will be described in SUDO'S Mapping.

The northwestern part off the North Korean and the Russian coasts north of 38°30'N, where few available data have been taken since the end of the World War II, is excluded from the area for the analysis. The coastal areas from 135°E to 44°N, the Wakasa Bay and further northeast, are excluded as well, because surface water characteristics are seriously affected by river discharges. Some districts bounded by coastal lines and every half degree meridians and/or longitude lines are also excluded, because fewness of observations or locality of water characteristics. Hereafter, the area for the analysis, bordered with heavy solid lines in Fig. 1, is referred to as the whole area or the whole study area.

The whole area is divided into four areas by characteristics of annual variations of SST and SSS (Fig. 1). The whole area does not include the southwestern half of the Area I, west of 129°30′E and south of 34°30′N. For some portions of other three areas in which insufficient hydrographic data have been obtained, *T-S* frequency distribution analysis is excluded from the areas and included for the whole area. Some near-coast districts along the Japan Islansd, still showing coastal water characteristics (Fig. 1, hatched portions), cannot be applied to any of four areas; *T-S* frequency distributions for these districts are used only for the analysis for the whole study area.

For each calendar month, *T-S* frequency distributions at the sea surface and at 10 m depth are determined for the unit area, every 1° square, partly 30' square or 1°×30' rectangle. It is assumed that the relative *T-S* frequency distribution based on the samples taken through the month for each of years has an equal weight, a reciprocal of number of observation years, regardless of number of samples. *T-S* values observed are classified into every 1℃×0.2 (‰ or psu) bivariate classes and their relative frequencies are accumulated in their corresponding classes for each of calendar months for each of unit areas. Then, the relative frequencies for each of four areas are obtained by averaging the relative frequencies for unit areas according to area size. In the same way, the *T-S* frequency distributions for the whole area are yielded from the distributions for four areas including insufficient data portions and for near-coast districts excluded for four area analyses and excluding the southwest of the Tsushima Strait.

The class intervals of 1℃ and 0.2 (‰ or psu) are adequate because standard deviations of temperatures and salinities of the water entering the Tsushima Strait are mostly about 1℃ and 0.2‰ for the monthly means (OGAWA, 1983). These standard deviations must include time variations among the month and interannual variations besides spatial variations as frequency distributions will show in section 4. At about 10℃, an increase in σ_t with a temperature decrease of 1℃ is equivalent to that with a salinity increase of 0.2 psu; therefore this *T-S* class interval ratio is reasonable in density variation.

3. Division of the sea area

The oceanic domain of the sea with enough observations is divided into four areas according to sea surface water characteristics of unit areas (1 degree squares or half degree squares) (Fig. 1).

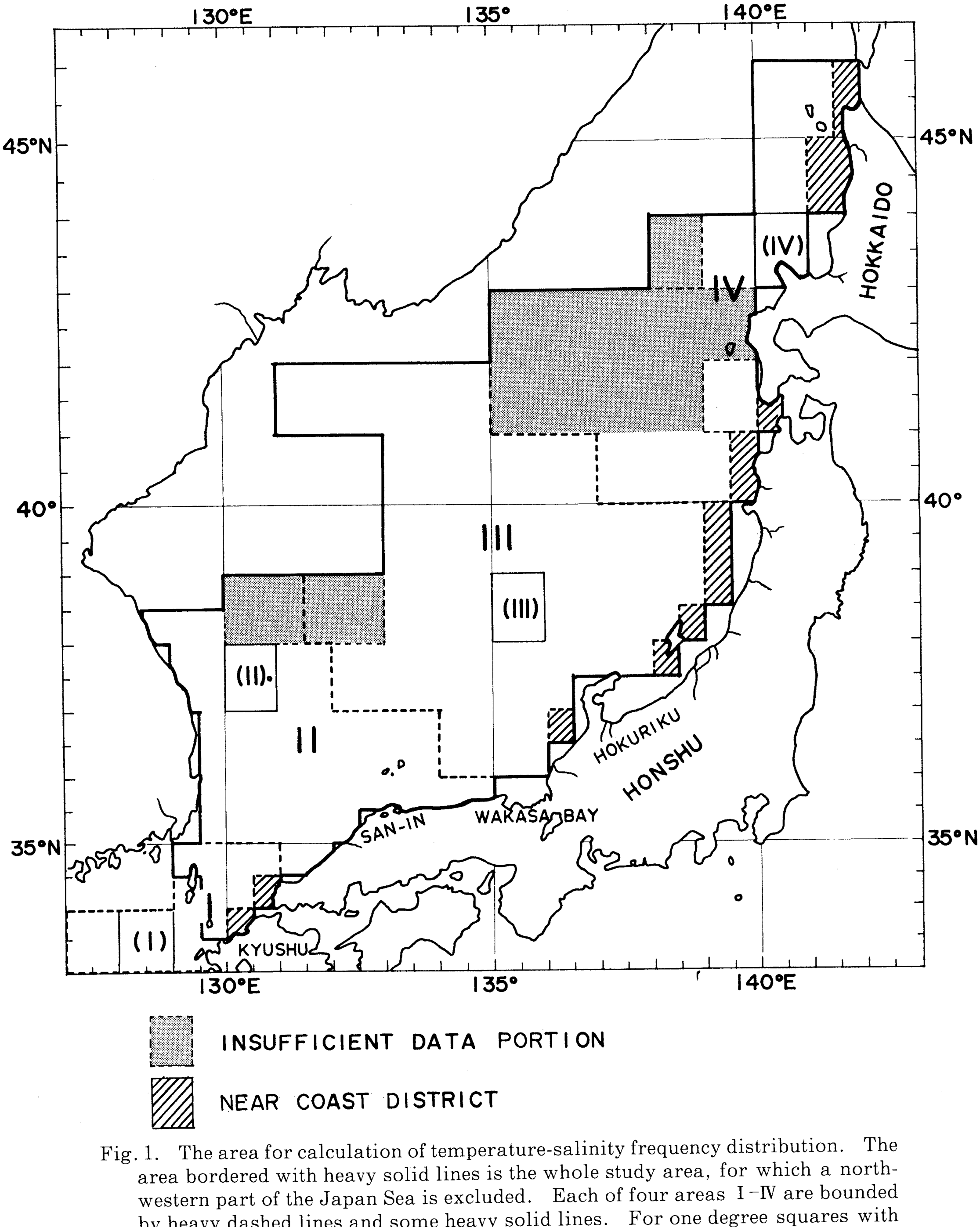


Fig. 1. The area for calculation of temperature-salinity frequency distribution. The area bordered with heavy solid lines is the whole study area, for which a northwestern part of the Japan Sea is excluded. Each of four areas I–IV are bounded by heavy dashed lines and some heavy solid lines. For one degree squares with parenthesized area numbers, annual variations of *T-S* relations at the sea surface and at 10 m depth are shown in Fig. 2. The *T-S* frequency distribution analysis for shaded portions with insufficient data is not made for each of Areas II, III and IV. Hatched portions are not included in any of four areas. *T-S* relations for shaded and hatched portions are used for the analysis of the whole area analysis.

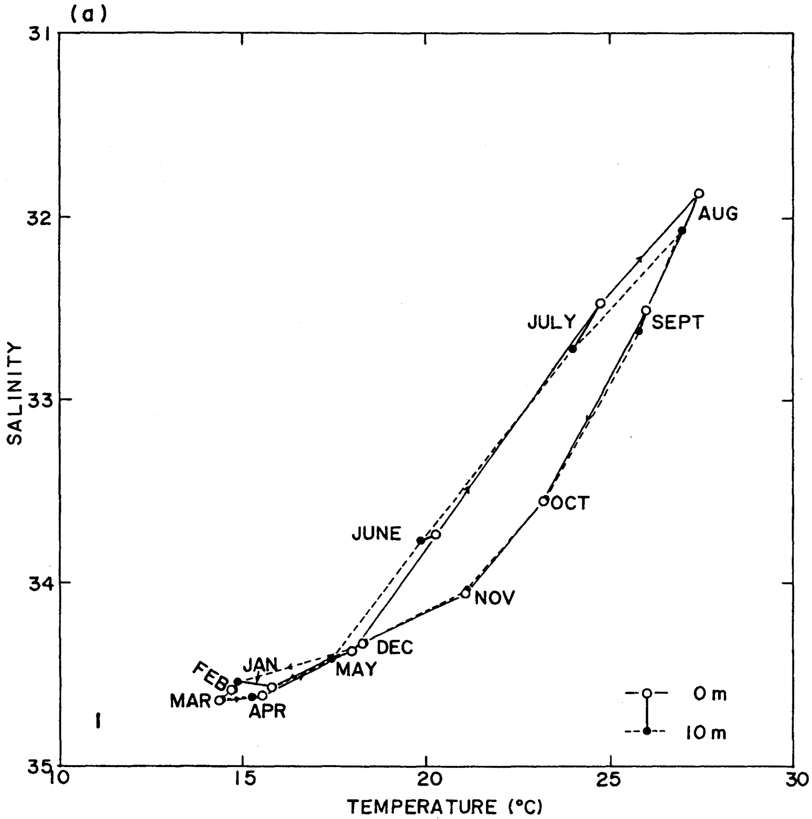


Fig. 2. Annual variations of monthly mean temperature-salinity relations at the sea surface and at 10 m depth for 1° squares selected for (a) Area I, (b) Area II, (c) Area III and (d) Area IV. The 1° squares are shown in Fig. 1.

Examples of annual variations in the *T-S* relation at the sea surface and 10 m depth for the four areas are shown in Fig. 2. This division is purely tentative and would not be applied to the remainder of the Japan Sea.

Area I, the Tsushima Strait (Korea Strait) region, is defined as the area in which monthly mean SST is 13.0℃ or more and monthly mean SSS is 34.5 or more both in February and in March (Fig. 2a). Variations during December to May are small; the ranges are 4–5℃ in temperature and less than 0.4 in salinity. In particular, the mean SST and SSS show little variation in January to April. Long winter and small winter variations are common features of surface water characteristics of the Japan Sea. In other seasons, in June to November, monthly mean SSS decreases rapidly with monthly mean SST.

Area II is the southwestern part of the Japan Sea, a fan-like area between the San-in coast and the Korean coast. It is defined as the area in which the monthly mean SSS shows 34.2 or more in April or May and decreases to less than 33.0 in any or both of August and September (Fig. 2b). Basically, the pattern of the annual variation of surface water characteristics is not different from that in Area I except that the water is fresher in the cooling season than in the warming season for a specified temperature.

Area III is the central part of the sea, a vast area ranging from off the eastern San-in coast and north of the Wakasa Bay to 42°N off the shelf of Primorye (Enkai). It is defined as the area in which the monthly mean SSS with annual range of 0.5 or more shows 34.0 or more at least in one of April to June and 33.0 or more both in August and in September (Fig. 2c). The annual range of the monthly mean SST amounting to 15℃ or more is the largest of the four areas.

Fig. 2b.

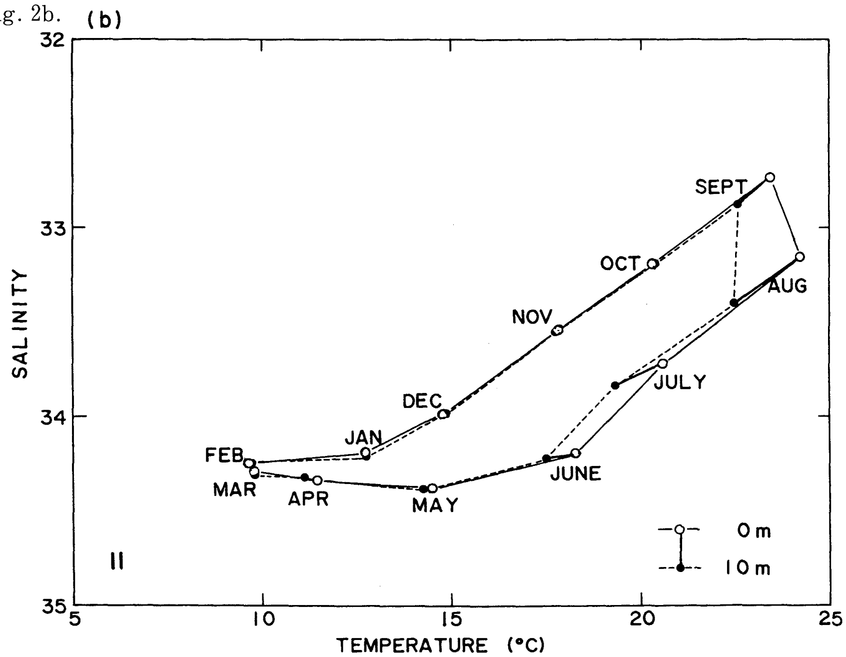


Fig. 2c.

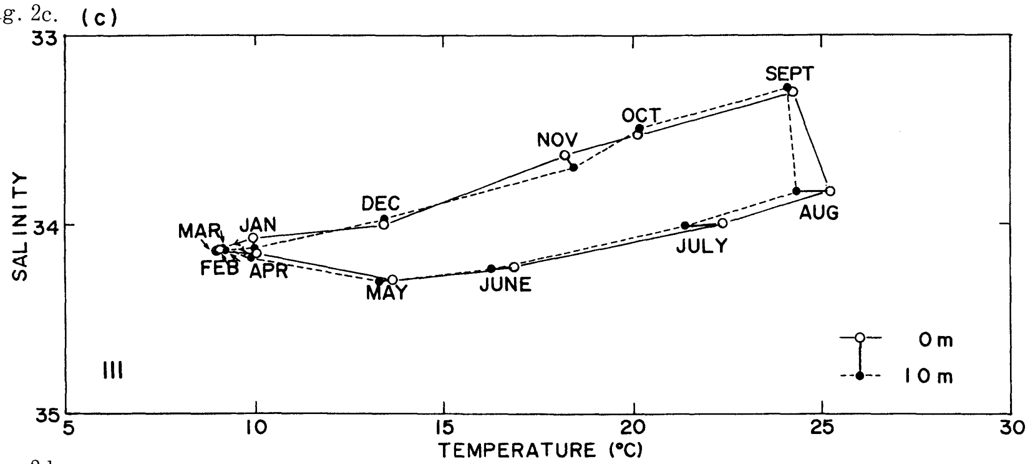


Fig. 2d.

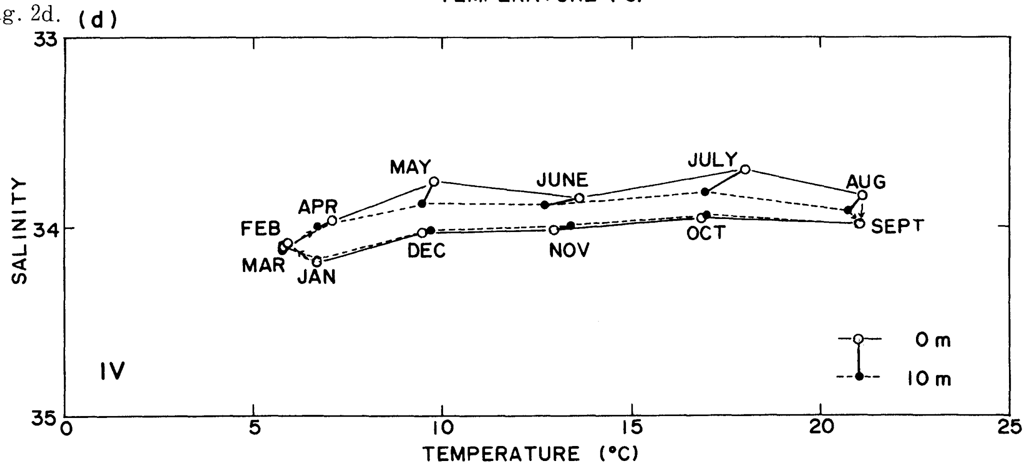


Table 1. Figure numbers of temperature-salinity frequency distributions shown in the present paper.

	Whole Area		Area I		Area II		Area III		Area IV	
	0 m	10 m	0 m	10 m	0 m	10 m	0 m	10 m	0 m	10 m
January	-	-	-	-	-	-	-	-	-	-
February	Fig. 3a	-	-	-	-	-	Fig. 3b	-	-	-
March	Fig. 6a	-	Fig. 6b	-	-	-	-	-	-	-
April	Fig. 7a	-	-	-	-	-	Fig. 7b	Fig. 7c	-	-
May	Fig. 8a	-	-	-	-	-	Fig. 8b	Fig. 8c	Fig. 8d	-
June	Fig. 9a	-	-	-	-	-	-	-	Fig. 9b	-
July	Fig. 10	-	-	-	-	-	-	-	-	-
August	Fig. 11a	-	-	-	Fig. 11b	Fig. 11c	-	-	Fig. 11d	-
September	Fig. 12	-	-	-	-	-	-	-	-	-
October	Fig. 13	-	-	-	-	-	-	-	-	-
November	Fig. 14	-	-	-	Fig. 18	-	-	-	-	-
December	Fig. 15	-	-	-	-	-	-	-	-	-

(a)

Whole Area February 0 m 5064 stations

	-2 to -1	-1 to 0	0 to 1	1 to 2	2 to 3	3 to 4	4 to 5	5 to 6	6 to 7	7 to 8	8 to 9	9 to 10	10 to 11	11 to 12	12 to 13	13 to 14	14 to 15	15 to 16	16 to 17 (°C)	Total
-32.0								0												0
32.0-32.2	1																			1
32.2-32.4	1										0		0							1
32.4-32.6							0							0						0
32.6-32.8												0								0
32.8-33.0		0																		0
33.0-33.2		1											0							1
33.2-33.4		0		0							0		0			0				1
33.4-33.6			0			0			0		1	0								2
33.6-33.8			5	2	0		0	0	1	1	2	2	0	1						15
33.8-34.0			11	13	24	5	5	4	0	6	11	17	10	6	1	0				*113*
34.0-34.2			*70*	*43*	*35*	*47*	*52*	21	21	27	*37*	*64*	*49*	26	8	2	0			*502*
34.2-34.4			1	4	0	5	2	8	16	*34*	32	*45*	*51*	29	18	5	2	0		*251*
34.4-34.6						1		1	1	1	4	4	9	12	21	17	5	1		*76*
34.6-34.8											0	0	1	4	9	10	6	2	0	32
34.8-35.0													0	2	1	1	1	0		5
Total	1	1	*87*	*62*	*60*	*57*	*60*	34	*39*	*68*	*87*	132	*119*	*81*	*58*	36	14	3	0	1000

(b)

Area III February 0 m 1884 stations

	0 to 1	1 to 2	2 to 3	3 to 4	4 to 5	5 to 6	6 to 7	7 to 8	8 to 9	9 to 10	10 to 11	11 to 12	12 to 13	13 to 14	14 to 15	15 to 16 (°C)	Total
33.0-33.2											0						0
33.2-33.4																	-
33.4-33.6							0		0								0
33.6-33.8		0	0			0	2		2	2	0	2					9
33.8-34.0	15	14	40	2	1	4		5	5	28	17	12	1	0			*143*
34.0-34.2	*77*	*52*	26	37	36	26	33	*42*	*43*	*92*	*81*	40	10	0			*596*
34.2-34.4	2	2	1	1	1	4	7	*27*	*40*	*56*	*51*	19	18	0			*229*
34.4-34.6				2			0	0	4	4	4	2	3				19
34.6-34.8												2	0				2
34.8-35.0												1				0	1
Total	*94*	*68*	*68*	*42*	*38*	34	*42*	*75*	*94*	*182*	*153*	*77*	32	1	-	0	1000

Fig. 3. Temperature-salinity frequency distributions at the sea surface in February (a) for the whole area and (b) for Area III. Relative frequencies in per mille are shown in bivariate class intervals of 1℃×0.2 (‰ or psu). The range for which summed frequencies are not less than 75% is shown in shaded areas and constituents of the range of not less than 50% in italics. Italics of total frequencies for each of temperature and salinity denote constituents of the range of not less than 90%. The frequency '0' means a frequency of less than 0.5 per mille (0.05 per cent).

The pattern of the annual variation of the *T-S* relation can be identical with that in Area II except for smaller salinity range.

Area IV is the northeastern part of the sea, west of the northernmost Honshu and Hokkaido. It is defined as the area in which the monthly mean SSS shows the maximum 34.0 or more in winter and its annual range is less than 0.5 (Fig. 2d). Observations have been sparse in the western half portion. The example is taken from the near-coast district with sufficient data.

The features described above are nothing but the results based on the monthly mean characteristics. Fluctuations among the month and the area and interannual variations are not shown. They can be shown in the *T-S* frequency distribution as overall variations.

4. Seasonal variation of temperature-salinity frequency distributions

A total of 120 *T-S* frequency distribution figures are provided; significant ones of them are shown in the following (Table 1).

Because of lack of data in most parts, temperature-salinity frequency distributions for January are not presented in this paper.

The frequency distribution for the whole area in February clearly shows two modes (Fig. 3a, [0–1℃, 34.0–34.2], 7.0% and [9–10℃, 34.0–34.2], 6.4%). These two modes are more noticeable at 10 m (7.5% and 6.8%). This is due to the existence of the polar front indicated by a sharp meridional gradient in SST found between 39° and 42°N (ISODA *et al.*, 1991). The value of the cold mode is only 7.7% in Area III (Fig. 3b), the central part, because a smaller portion of the area occupies the north of the polar front. The warm mode is conspicuous in Area III (9.2%). The mean SST distribution in February (SUDO's Mapping) shows that four every one degree isotherms of 9–12℃, extending roughly zonally from the Korean coast to the Japan coast between 36° and 39°N, make a little broad zones between meighboring isotherms. The distance between east and west coasts or zonal width of the Japan Sea increases with latitude; therefore, the northernmost zone between 9 and 10℃ is the largest area. In Area II, the southwestern part, the distribution has the mode [11–12℃, 34.2–34.4] (10.1%). The mean SSS in February decreases northeastward from the Tsushima Strait and an isohaline of 34.2 runs with an arc shape from 38°N at the eastern coast of Korea to the west of the Wakasa Bay. In the whole study area the mean SSS in February is more than 34.0 except the northwestern part and near the Japan coast east of 135° E. A water with a salinity of 34.0–34.2 exceeds 50% of the whole surface water (Fig. 3a, the rightmost row) and amounts 60% in the central parts (Fig. 3b). The mode in Area I, the Tsushima Strait area, is [14–15℃, 34.6–34.8] (14.4%) in February as expected from Fig. 2a. A weak mode [4–5℃, 34.0–34.2] (5.2%) in Fig. 3a corresponds to the mode at the same class in Area IV (22.4%), the northeastern part. Probably this represents the Tsushima Warm Corrent water at the sea surface west of Hokkaido, but the relation between the water and the polar front is not clear.

The bivariate classes containing at least 50% and 75% of the surface water of the whole area are 11 and 21 in number, respectively (Fig. 3a). The 75% range is about twice the 50% range in class number regardless of area, month and depth; however, the number of classes for the sea surface is about the same or a little more

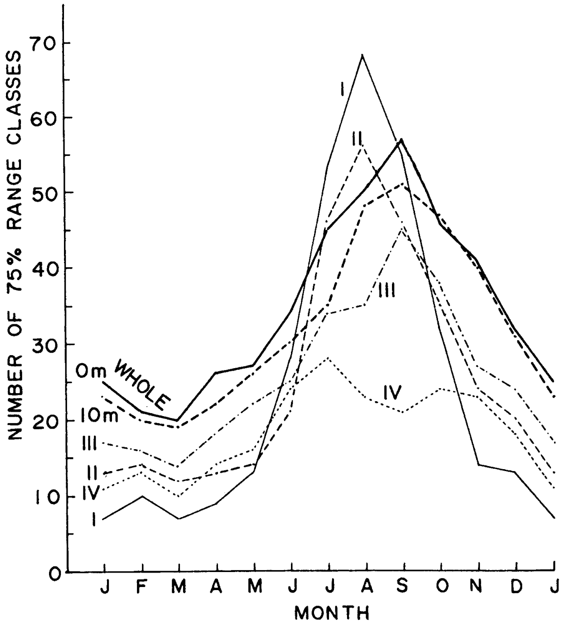


Fig. 4. Numbers of *T-S* frequency classes constituting the range of not less than 75% at the sea surface.

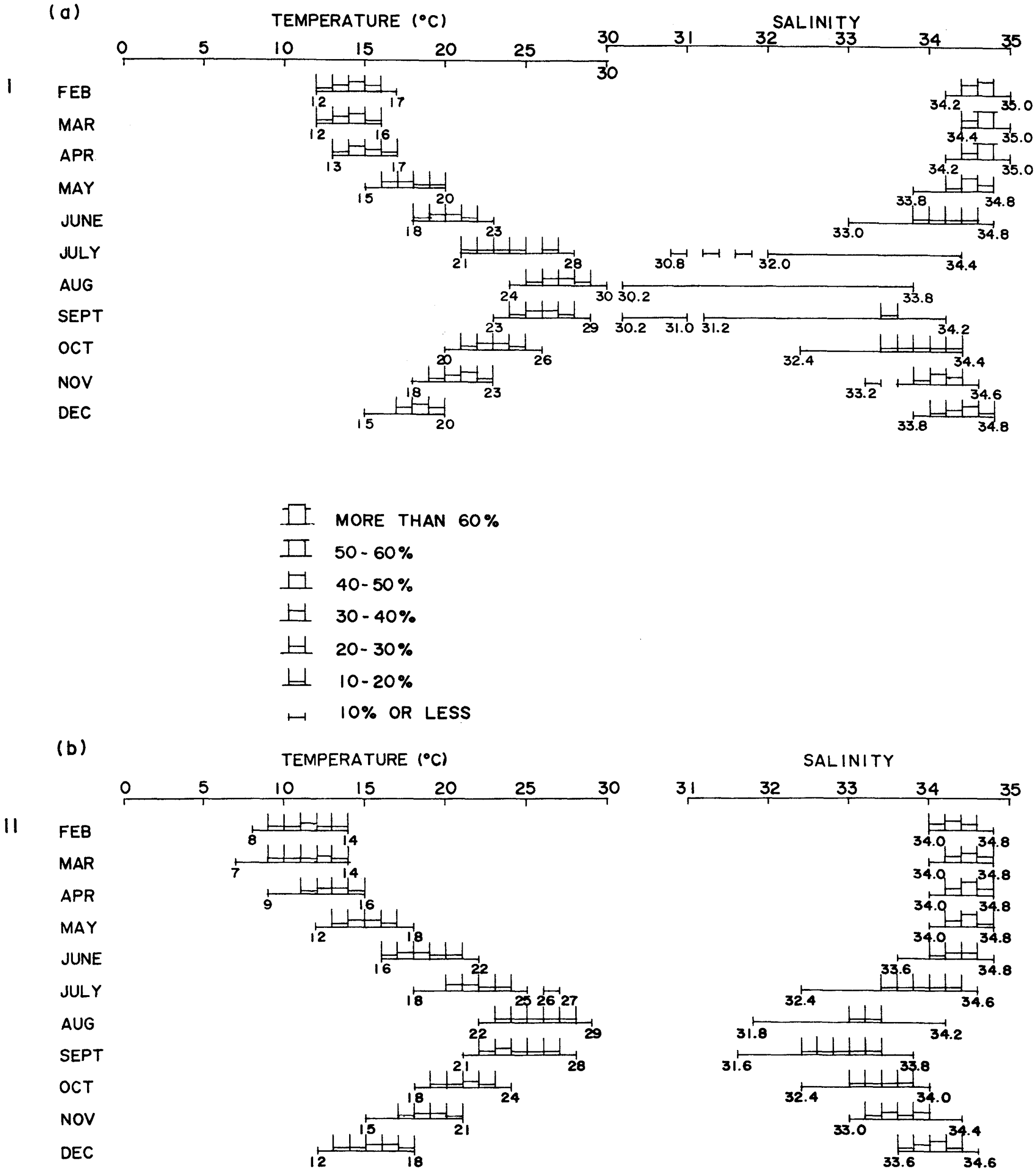
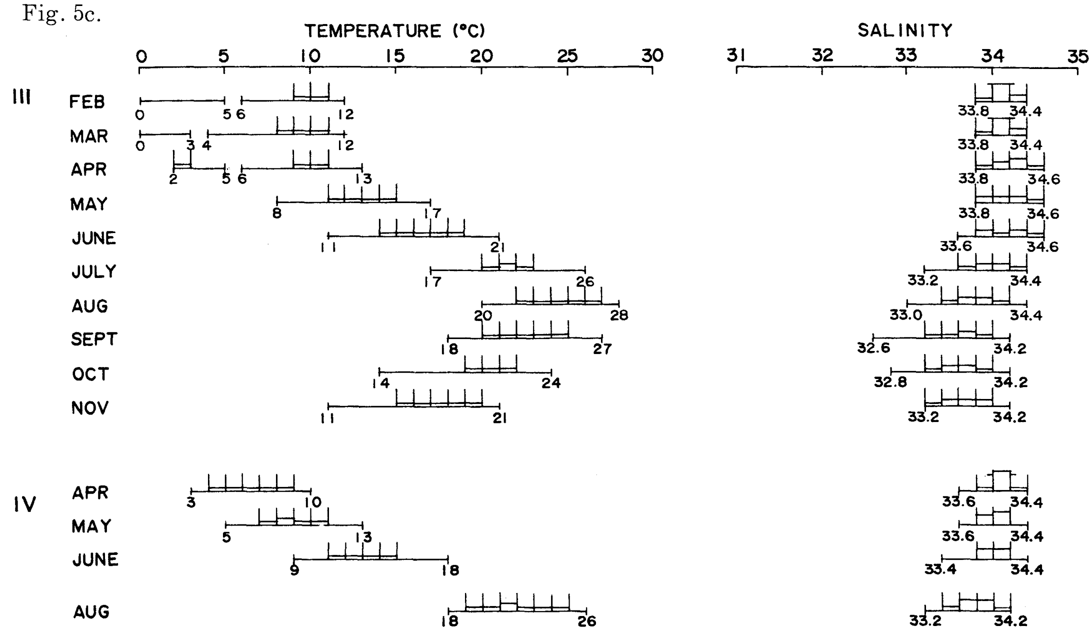


Fig. 5. Not less than 90% frequency ranges of SST and SSS (a) for Area Ⅰ, (b) for Area Ⅱ and (c) for Areas Ⅲ and Ⅳ. The ranges for months in which less than 800 stations are taken are omitted.

than that for 10 m depth except for Area Ⅱ in August (Fig. 11b-c). These numbers indicate scattering or variation of water properties (Fig. 4). For the sake of simplicity, separated frequency distributions of SST and SSS for 90% range are shown instead of bivariate distributions for each of four areas (Fig. 5).

T-S frequency distributions in March are slightly different from those in February. Winter convection derived from strong surface cooling and evaporation lasts until February or March; therefore, SST minimum in the Japan

Fig. 5c.



(a)

Whole Area March 0 m 4903 stations

	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16 (°C)	Total
-32.0											0									0
32.0-32.2										0			0							0
32.2-32.4		0								0										0
32.4-32.6		0								0	0		0							0
32.6-32.8	0										0	0								1
32.8-33.0										0		0								0
33.0-33.2									0		0	0		0						1
33.2-33.4		0							0	0	0	0				0				1
33.4-33.6					0	0	0		0	1	1	1	1	0						4
33.6-33.8				0	0				1	1	4	3	3	0	0					12
33.8-34.0			26	10	6	8	2	5	2	5	17	15	6	1		0	0			103
34.0-34.2			21	78	46	46	57	45	41	38	43	43	25	8	1	0				490
34.2-34.4			1		1	2	3	10	14	12	39	49	43	19	3	2	1	0		198
34.4-34.6							0	0	1	0	4	8	22	28	29	12	2	0		105
34.6-34.8									0		0	3	5	13	25	22	4	0		74
34.8-35.0												0	1	3	1	2	1	1		9
35.0-35.2													0	0			0	0		1
Total	1	0	48	88	53	56	63	59	59	58	108	122	104	72	59	38	8	2		1000

(b)

Area I Mar 0 m 1134 stations

	10	11	12	13	14	15	16	17 (°C)	Total
33.6-33.8			1						1
33.8-34.0									0
34.0-34.2		0		0					1
34.2-34.4	0	2	7	6	16	12			43
34.4-34.6	1	6	49	109	91	30	3		288
34.6-34.8	1	34	71	158	201	102	2		569
34.8-35.0	1	17	5	25	17	22	7		94
35.0-35.2		1				3			5
Total	3	61	133	298	324	169	12		1000

Fig. 6. As in Fig. 3 but in March (a) for the whole area and (b) for Area I .

(a)

Whole Area April 0 m 6277 stations

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19(°C)	Total
-31.0				0	0	0	0	0	0	0	0		0			0				2
31.0-31.2							0			0										0
31.2-31.4				0	0	0	0			0	0		0							1
31.4-31.6				0									0							0
31.6-31.8					0	0	0	0	0			0	0							1
31.8-32.0						0	0		0	0										0
32.0-32.2					0		0		0	0	0	0								0
32.2-32.4					0	0	0	0	0	0		0	0							1
32.4-32.6					0	0	0	0	0	0		0	0							1
32.6-32.8						0	0	0	0	0	0	0	0							1
32.8-33.0					0	0	0	0	0	0	0	0					0			1
33.0-33.2				0	1	0	0	0	0	0	0	0	0			0				3
33.2-33.4			0	0	0	0	0	1	1	0	0	0	0							4
33.4-33.6	13	0	1	5	0	1	1	3	1	1	1	0	0		0					28
33.6-33.8	0	0	1	1	1	1	3	3	2	2	2	1	0	0		0	0			18
33.8-34.0	16	38	14	11	5	5	5	7	9	7	4	1	0	0	0	0	0			124
34.0-34.2	5	23	21	35	43	40	38	45	31	23	10	3	2	1	1	0	0	0		322
34.2-34.4	10	2	0	1	2	5	34	19	65	46	27	15	8	3	1	0	0			239
34.4-34.6	10	1			0	0	0	4	7	20	33	34	25	19	7	1	0	0		162
34.6-34.8							1	2	2	4	9	17	22	17	6	1	0			79
34.8-35.0							1	0	0		1	2	2	5	1	0				12
35.0-35.2							0	0					0	0	0					1
Total	54	65	38	55	54	54	86	86	120	104	87	75	61	44	16	3	1	0		1000

(b)

Area III April 0 m 1331 stations

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19(°C)	Total
31.2-31.4													0							0
31.4-31.6																				-
31.6-31.8													0							0
31.8-32.0																				-
32.0-32.2												0								0
32.2-32.4																				-
32.4-32.6										0			0							1
32.6-32.8													0							0
32.8-33.0									0			0					0			0
33.0-33.2									0	0		0				0				1
33.2-33.4								0	0	0	0	0								1
33.4-33.6	9		3	12				2	0	1	2	0	0							29
33.6-33.8						1	2	1	1	2	3	1	0	0		0				12
33.8-34.0		91	31	15	1	3	6	4	10	9	8	2	0	0	0	0	0			181
34.0-34.2		13	21	46	20	35	24	34	44	34	15	6	4	0	0	0	1	0		298
34.2-34.4		2	1	1	1	10	48	30	122	68	22	13	3	2	0	0	0			324
34.4-34.6		2			0		1	5	9	37	32	13	5	5	0	1	0	0		112
34.6-34.8							3	3	3	4	4	9	4	1	0					32
34.8-35.0							3	1			1	1	0	1						7
35.0-35.2							0	1												1
Total	9	109	57	74	23	49	86	81	189	156	87	47	17	9	1	1	2	0		1000

(c)

Area III April 10 m 1101 stations

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15 (°C)	Total
32.4-32.6									0							0
32.6-32.8																-
32.8-33.0											0					0
33.0-33.2												1				1
33.2-33.4									0	1						1
33.4-33.6								0	0	0	0	1				2
33.6-33.8							2	1	2	5	1					10
33.8-34.0	0	114	40	19	1	8	3	2	10	9	8	1	0			216
34.0-34.2		9	1	32	39	9	31	58	67	40	15	4	0	0		307
34.2-34.4	5	0	0	7	1	9	18	26	116	82	26	10	2	1		302
34.4-34.6							3	6	21	29	45	14	8	5		131
34.6-34.8							4	3	2	3	2	3	5	0		22
34.8-35.0							3	2				1				6
35.0-35.2							0	1								2
Total	5	124	42	57	41	25	65	98	219	169	98	36	15	6		1000

Fig. 7. As in Fig. 3 but in April (a) for the whole area and for Area III (b) at the sea surface and (c) at 10 m.

Sea occurs in February or March. In March the cold mode shifts to 1℃ warmer class, [1–2℃, 34.0–34.2] (7.8% for the whole area (Fig. 6a); 8.0% for Area Ⅲ), and the warm one to 0.2 higher salinity class [9–10℃, 34.2-34.4] for the whole area (Fig. 6a, 4.9%) and the same as in February for Area Ⅲ (8.0%).

Areal and time variations of surface water characteristics in March are smaller than those in any other month; 50% and 75% frequency ranges show fewest classes for all of the areas (Fig.4). In particular, 50% and 75% of the surface of Area I are characterized by only four and seven *T-S* bivariate classes with a mode [14–15℃, 34.6–34,8] (Fig. 6b, 20.1%). In Area Ⅳ the frequency of salinity range 34.0 – 34.2 amounts to 69% (at the sea surface) and 80% (at 10 m).

There is not much difference in surface water characteristics between in March and in April (Figs. 2 and 5). On the whole, the surface water is a little warmed and its salinity distribution is slightly diffused (Fig. 7a). A cold water of less than 1℃ completely disappears. The cold mode is weaken shifting to a lower salinity class [2–3℃, 33.8–34.0] and its frequency (3.8%) is less than that of the middle mode [5–6℃, 34.0–34.2] (4.3%). The salinity mode of 34.0–34.2 is less than that in March by 16.8%; 6.2% of this decrease is diffused to lower classes and 10.6% to higher classes. On the average the monthly mean SSS in April is the highest in a year. In particular, in Area Ⅱ, the southwestern part, there is an alternation of 8.2% from low salinity water (<34.4) to high salinity water (>34.4) (Fig. 5b). On the contrary, in the Tsushima Strait region, surface water freshening already starts in the month; 7.5% of the sea surface is altered from high salinity water (>34.4) to low salinity water (<34.4) during March to April. Salinity dispersion in Area Ⅲ is noticeable (Fig. 7b). The water with a salinity of 34.0–34.2 occupying more than a half in March shows a decrease by 24.0%. This decrease is replaced by increases of lower one by 6.4% and higher one by 17.6%. The cold mode shifts to 0.2 lower class [2–3℃, 33.8–34.0] (9.1%) and the warm mode to 0.2 higher class

(a)

Whole Area May 0 m 7185 stations

	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23 (°C)	Total
-30.0						0	0	0	0	0	0	0										1
30.0-30.2				0									0									0
30.2-30.4									0	0		0				0						0
30.4-30.6								0	0	0	0	0										0
30.6-30.8							0	0		0	0	0										0
30.8-31.0									0	0	0	0	0	0								1
31.0-31.2								0	0	0	0		0		0							1
31.2-31.4							0	0	0	0	0	0		0	0							0
31.4-31.6						0	0	0			0	0		0								0
31.6-31.8					0		0		0	0	0			0	0	0						1
31.8-32.0				0			0	0	0	0	0	0	0									1
32.0-32.2					0	0		0	0		0	0	0			0						1
32.2-32.4				0		0		0	0	0	0	0	0		0							2
32.4-32.6			0			0		0	0	0	0		0	0	0							2
32.6-32.8							0	0	0	0	0	0	1	0	0	0						3
32.8-33.0				0		0	0	0	1	0	1	0	1	0	0	0						4
33.0-33.2			0	0	0	0	2	0	0	1	0	0	0	0	0			0				5
33.2-33.4					0	0	2	2	1	1	1	1	0	0	0	0						9
33.4-33.6	0	0	0		0	2	2	1	1	2	2	1	0	2	0							13
33.6-33.8	0		0	1	1	6	4	4	5	2	3	3	2	0	0	0						31
33.8-34.0	3	1	8	16	22	*40*	*40*	26	18	9	5	6	4	3	1		0					*203*
34.0-34.2		5	5	15	*31*	*34*	*43*	*36*	26	*30*	25	18	8	4	2	1	0					*284*
34.2-34.4					0	5	6	15	23	*38*	*32*	*33*	22	11	7	2	1	0	0			*196*
34.4-34.6							0	1	4	7	*31*	*35*	*43*	*36*	18	5	1	1	0	0		*182*
34.6-34.8										0	2	10	17	14	9	3	0	0	0	0		*57*
34.8-35.0									0	0	0	0	1	1		0						3
35.0-35.2													0									0
Total	4	7	14	32	*55*	*88*	*99*	*88*	*81*	*93*	*103*	*108*	*102*	*73*	*37*	12	3	1	0	0		1000

Fig. 8. As in Fig. 3 but in May (a) for the whole area, for Area Ⅲ (b) at the sea surface and (c) at 10 m and (d) for Area Ⅳ.

Fig. 8b.

Area III May 0 m 2824 stations

	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23 (°C)	Total
30.8-31.0													0									0
31.0-31.2											0											0
31.2-31.4														0								0
31.4-31.6														0								0
31.6-31.8										0												0
31.8-32.0																						-
32.0-32.2																						-
32.2-32.4										0												0
32.4-32.6										0	0		0									0
32.6-32.8										0												0
32.8-33.0								1		0	0	0				0						1
33.0-33.2										2			0		0							2
33.2-33.4								0	1	1	1	1	1	1	0	0						5
33.4-33.6						3		1	1	2	3	1	0	1								11
33.6-33.8						9	2	3	9	2	3	5	3	0	0	0		0				37
33.8-34.0	8		8	1	21	*40*	*56*	30	23	17	8	7	6	3								*228*
34.0-34.2		0	1	2	15	24	21	*40*	*40*	*46*	*35*	24	12	3	2	0	0					*265*
34.2-34.4					0	5	8	19	*44*	*60*	*45*	*42*	23	12	6	1	1					*268*
34.4-34.6							0	3	7	12	*38*	33	32	20	8	0	0	1		0		*156*
34.6-34.8										1	1	8	6	8	2	0						27
34.8-35.0									1	0						0						1
Total	8	0	9	2	36	*82*	*87*	*97*	*126*	*143*	*134*	*121*	*84*	*47*	18	3	2	1	-	0		1000

Fig. 8c.

Area III May 10 m 1751 stations

	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22 (°C)	Total
31.0-31.2											0										0
31.2-31.4													0								0
31.4-31.6													0								0
31.6-31.8													0								0
31.8-32.6																					-
32.6-32.8									0	0											0
32.8-33.0										0	0		0								0
33.0-33.2										1		0		0							1
33.2-33.4								2	1	1	2	1	1								7
33.4-33.6						4		0	3	2	0	1	1	1							12
33.6-33.8						11	1	1	13	4	4	2	1		0						36
33.8-34.0	8	0	5	1	34	*63*	22	*52*	13	15	11	11	2	1							*238*
34.0-34.2		0	4	0	0	*42*	23	*41*	*47*	*45*	30	18	15	2	1	0					*268*
34.2-34.4				0	0	13	8	22	*48*	*51*	*42*	*37*	23	10	3	0	0		1		*258*
34.4-34.6								3	10	10	*38*	33	37	16	7	1					*155*
34.6-34.8										1	1	7	5	7							21
34.8-35.0									1	0			1	0							3
Total	8	1	9	2	35	*133*	*54*	*121*	*135*	*130*	*127*	*111*	*86*	*36*	11	2	0		1		1000

[9–10℃, 34.2–34.4] (12.2%). Both modes are strengthened, especially the former at 10 m (Fig. 7c, 11.4%). This indicates that the polar front appears in the surface water most clearly in April. In Area IV, the northeastern part, a little freshening is seen, but the salinity mode (34.0–34.2) still exceeds 60% (Fig. 5c). The salinity increase of the sea is due to a northeastward transport of the high salinity Tsushima Warm Current water. The freshening observed in the central and northern parts is likely due to the discharge of the snow melted fresh water from the land, mainly northern Japan.

In May frequency distributions in 50% and 75% ranges are flattened in the whole area; all of the 14 classes included in the 50% range at the sea surface show relative frequencies of 3.0% to 4.3% (Fig. 8a). Three modes are still distinguished ([9-10℃, 34.0-34.2], 4.3%, [12-13℃, 34.2-34.4], 3.8% and [15-16℃, 34.4-34.6], 4.3%). At 10 m the middle mode disappears. Unlike in February to April, the cold mode corresponds to a single mode in Area IV (Fig. 8d, [8-9℃, 34.0-34.2], 9.6%). In Area III, frequency values of modes are flattened and temperature differences between modes are diminished both at 0 m and 10 m. Four modes including two middle modes (Fig. 7b, [4-5℃, 34.0-34.2], 4.6% and [7-8℃,

Fig. 8d.

Area IV May 0 m 966 stations

	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18 (°C)	Total
30.2-30.4									0			0					1
30.4-30.6																	-
30.6-30.8							0	1									1
30.8-31.0																	-
31.0-31.2																	-
31.2-31.4							0	0	0			0					1
31.4-31.6							0										0
31.6-31.8							0										0
31.8-32.0												0					0
32.0-32.2								0	0								1
32.2-32.4						0		1									1
32.4-32.6						1		1	1		1						4
32.6-32.8							0	0	0				6				7
32.8-33.0							0	0	4	1							6
33.0-33.2			1	0		1	0	1	2	0	1						8
33.2-33.4						0	1	11	4	1	0	1	0				20
33.4-33.6		1	1		1	4	5	4	3	4	2	0			1		25
33.6-33.8			1	2	2	8	14	8	5	1	7	0					47
33.8-34.0	1	4	19	28	44	73	72	37	28	11	0	4	2				323
34.0-34.2		31	21	38	76	96	84	46	40	24	14	3	3	3			480
34.2-34.4					2	17	14	9	12	11	3	1	1				71
34.4-34.6													1	3			5
Total	1	36	43	68	125	201	192	120	99	55	29	11	13	7	1		1000

(a)

Whole Area June 0 m 7605 stations

	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26 (°C)	Total
-31.0										0		0	0	0			0		0					1
31.0-31.2													0	0	0									0
31.2-31.4												0	0	0	0									0
31.4-31.6							1	0					0	0	0									2
31.6-31.8												0	0	0	0		0	0						1
31.8-32.0											0	0	0	0	0	0	0							1
32.0-32.2								0	0	0	0	0	0	0	0	0	0	0	0					2
32.2-32.4										0		0	0	0	0	0	0	0	0					1
32.4-32.6								0		0	0	0	0	0	0	0	0	0	0					2
32.6-32.8							0	0	0	0	0	1	1	0	0	0	0	0	0					3
32.8-33.0							0	0	0	0	0	0	1	0	1	0	0	0	0					5
33.0-33.2						0	0	0	0	0	0	1	0	1	1	1	0	0	0					7
33.2-33.4						0	0	1	1	1	1	1	2	2	2	1	1	0	0					13
33.4-33.6				1	0	0	2	1	1	1	1	1	4	4	5	2	1	0	0	0				26
33.6-33.8	0		1	1	3	5	8	8	10	12	16	5	6	6	5	5	3	1	0					94
33.8-34.0				0	5	17	24	44	26	32	24	16	9	12	11	8	4	2	0	1	1			235
34.0-34.2			0	1	3	6	10	14	10	23	33	23	27	22	16	8	4	1	2	0	0			203
34.2-34.4						0	3	5	5	6	14	21	37	43	37	26	14	5	4	1	0			220
34.4-34.6						1	1		1	0	2	14	23	33	37	25	12	3	2	1				155
34.6-34.8							0	0	0	1	1	2	3	6	3	4	5	1	0	0		0		26
34.8-35.0								1			0	0	0		0	1	0	0		0				3
35.0-35.2															0	0								0
Total	0	-	1	4	11	29	49	74	53	77	94	88	114	131	120	82	45	15	9	4	1	0		1000

Fig. 9. As in Fig. 3 but in June (a) for the whole area and (b) for Area IV.

34.2–34.4], 4.8%) found at the sea surface in April are reduced to two in May (Fig. 8b); the two colder modes in April must be merged into the cold one ([9–10℃, 33.8–34.0], 5.6%) in May and the two warmer ones into the warmer one ([12–13℃, 34.2–34.4], 6.0%). At 10 m there is a weak middle mode in April (Fig. 7c, [5–6℃, 34.0–34.2], 3.9%) and in May three modes still exist two degrees apart for each neighboring two (Fig. 8c, [8–9℃, 33.8–34.0], 6.3%, [10–11℃, 33.8–34.0], 5.2% and [12-13℃, 34.2–34.4], 5.1%). Apparently the cold mode in Area III corresponds to the mode in Area IV as in the whole area though the former is 0.2 lower in salinity

Fig. 9b.

Area IV June 0 m 1365 stations

	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21 (°C)	Total
31.2-31.4											0					0
31.4-31.6													0			0
31.6-31.8													1			1
31.8-32.0									0	1	1					2
32.0-32.2							0	1		0	1	1				3
32.2-32.4								0		1		0	0			2
32.4-32.6										1						1
32.6-32.8							0		0	4	2	1	0			7
32.8-33.0							2	2	1	1	4			0		9
33.0-33.2					1	3	1	1	3	5		0	1			15
33.2-33.4				1	1	0	3	4	1	1	4	0	2			17
33.4-33.6				2	9	2	2	5	5	1	3	3	3	1		35
33.6-33.8			2	1	4	19	22	14	17	5	5	6	1	0		93
33.8-34.0		3	8	31	39	71	53	57	38	27	17	13	2	5		363
34.0-34.2	3	8	16	34	22	30	25	58	52	30	35	9	7	1	0	330
34.2-34.4				0	15	19	9	5	12	14	7	5	4	1		93
34.4-34.6								0	1	8	4	1	10	3		27
34.6-34.8										1			2			3
Total	3	10	26	68	90	143	117	147	132	98	82	38	33	12	0	1000

Whole Area July 0 m 5581 stations

	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23	23-24	24-25	25-26	26-27	27-28	28-29	29-30	30-31 (°C)	Total
-29.0									0	1	0		0				0				1
29.0-30.0									0	0	0			0	0		0				1
30.0-30.2									0	0	0			0							0
30.2-30.4														0							0
30.4-30.6												0		0			0				0
30.6-30.8											0	0		0	0	0	0				1
30.8-31.0										0	0			0		0	0				1
31.0-31.2									0	1	0	0		0		0					1
31.2-31.4									0	1	0		0	0	0	0	0		0		2
31.4-31.6									0	0	0	0	0	0		0	0	0			2
31.6-31.8									0	0		0	0	1	0	1	0	0			3
31.8-32.0								0	0	0	0	1	1	1	0	1	1	0			6
32.0-32.2			0		0			0		1	0	0	2	2	0	0	0	0			6
32.2-32.4				0				0	0	1	0	1	1	1	1	0	1	0	0		7
32.4-32.6							1	0	0	1	1	1	2	2	0	1	1	1	0		10
32.6-32.8				0		0	1	0	1	1	1	2	2	1	2	0	1	0			12
32.8-33.0					0	1	1	0	2	2	1	2	3	2	1	0	0				15
33.0-33.2					0	0	0	2	1	2	4	4	4	4	1	1	1	0			24
33.2-33.4				0	5	1	2	5	2	4	9	7	7	6	4	1	1	0			54
33.4-33.6	0	0	0	1	2	3	7	8	9	10	17	15	9	6	3	2	2	0	0		92
33.6-33.8		1	3	9	16	16	22	22	17	24	25	17	10	10	4	2	1	0	0		199
33.8-34.0	1	5	6	6	9	18	29	21	18	24	31	26	21	17	7	4	2	0		0	244
34.0-34.2	0		4	4	7	7	9	17	19	33	43	22	11	8	5	4	1	0			194
34.2-34.4		0		3	1	0	0	2	9	25	26	16	6	3	3	2	0	0			98
34.4-34.6					1	1	0	1	1	6	4	6	4	1	0	0					25
34.6-34.8							0	0	0	0	0	0									1
34.8-35.0							0	1													1
Total	1	6	14	23	42	47	72	81	79	136	164	121	83	66	31	19	11	4	1	0	1000

Fig. 10. As in Fig. 3 but in July for whole area.

than the latter at the sea surface. These mode characteristics imply that the polar front is weakened and the surface water north of the front is warmed by 6–7℃ during April to May except for the northeastern part. Whether this rapid warming is due to only solar radiation absorption or partly current pattern variation cannot be explained owing to insufficient data. Though the cold mode is concealed in total temperature frequency distribution (the bottom line) in Fig. 8b, it is discernible at 9–10℃ (9.9%) in Fig. 8a and clearly seen at 8-9℃ at 10 m in Area Ⅲ (Fig. 8c, 13.3%) as well as in the whole area (11.3%).

Overall freshening of the surface water continues. The water of salinity >34.0 decreases by 9.3% compared with in April, but high salinity water (>34.4) decrease is only 1.2% (Fig. 8a). In Area I the water >34.4 decreases by 17.9% (Fig 5a) and the lower limit shifts from 33.0 to 31.0. This saline water (>34.4) decrease is 4.6% ia Area II (Fig. 5b); on the contrary in Area III the saline water increases by 3.2% (Fig. 8b).

Salinity dispersion and overall freshening continue until September and northeastward transport of high salinity water continues at least until June. Cold modes are common to upper 10 m depths ([11–12℃, 33.8–34.0], 4.4% at 0 m (Fig. 9a); 4.7% at 10 m) and warm modes shift to 0.2 lower salinity class ([17–18℃, 34.2–34.4], 4.3% at 0 m (Fig. 9a); [16–17℃, 34.2–34.4] 4.9% at 10 m). In Area III both modes being the same as in the whole area are clearly seen at 10 m (cold 6.0% and warm 7.3%), but the cold mode is indiscernible through total temperature frequencies in upper 10 m depths. In Area IV two cold modes are clearly seen at the sea surface (Fig. 9b, [11–12℃, 33.8–34.0] 7.1% and [13–14℃, 34.0–34.2] 5.8%). The saline water (>34.4) shows a sudden decrease in Area I (46.8%) and in Area II (29.2%) and a slight increase in Area III (0.6%) on the frequency of the previous month; in the whole area it decreases by 5.8%.

A marked warming and freshening occur during June and July for all of the areas. Areas I and II are remarkable for salinity decrease and dispersion (Fig. 5a-b). *T-S* bivariate classes of 50% and 75% ranges in both areas in July are about twice in June (Fig. 4). High salinity water (>34.4) decreases to less than 1.0% Area I and to 2.4–3.7% in Areas II-IV. The cold modes in the whole area and Area III are still discernible in salinity range 33.8–34.0 (17–18℃, 2.9% at 0 m (Fig. 10) and 16–17℃, 3.3% at 10 m in the whole area; 18–19℃, 2.7% at 0 m and 17–18℃, 2.5% at 10 m in Area III), though they are weakened and corresponding total temperature frequencies are flattened.

A further salinity decrease in the sea continues until September. The water of more than salinity 33.8 at the sea surface in August de-

(a)

Whole Area August 0 m 7483 stations

	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31 (°C)	Total
-29.0												0	0	0		0				1
29.0-30.0													0	0	0	0	0			1
30.0-30.2													0	0	0	0	0			0
30.2-30.4														0	0	0	0			1
30.4-30.6														0	0	0	0			1
30.6-30.8													0	0	0	0	0	0		1
30.8-31.0											0	0	0	0	1	1	0			3
31.0-31.2										0		0	0	0	1	0	0			2
31.2-31.4												0	0	0	1	1	1			3
31.4-31.6									0		0	0	0	1	1	1	1	0		5
31.6-31.8						0			0		0	0	1	1	3	1	1	0		7
31.8-32.0										0	0	1	2	3	2	2	1	0		11
32.0-32.2									0	0	0	1	3	2	4	2	1	0	0	13
32.2-32.4							0	0	0	0	1	2	3	3	4	3	1	0		18
32.4-32.6						0		0	1	0	1	2	5	3	4	4	3	0	0	23
32.6-32.8								0	1	1	2	5	5	4	5	6	3	0		32
32.8-33.0			4					0	0	1	2	4	7	10	8	6	3	0		45
33.0-33.2		1			0			2	1	4	4	5	11	9	11	7	3	0		58
33.2-33.4							0	2	7	7	6	15	16	17	12	6	3	0		92
33.4-33.6						5	3	12	23	16	16	13	23	14	13	12	4	0		153
33.6-33.8				1	1	6	7	12	22	40	38	32	23	18	16	10	2	0	0	227
33.8-34.0				0	3	2	7	12	16	21	20	28	23	20	15	8	2	1		177
34.0-34.2			0		0	1	3	1	6	12	15	15	18	10	10	6	1			97
34.2-34.4							0	1	1	0	3	5	4	2	4	2	1			23
34.4-34.6						0	0	0	1	1	0	1	0	1	1	0	0	0		4
34.6-34.8								0	0					0	0	0	0			1
34.8-35.0																				-
Total		1	4	1	4	14	21	41	79	104	108	129	145	119	116	80	31	3	0	

Fig. 11. As in Fig. 3 but in August (a) for the whole area and for Area II (b) at the sea surface and (c) at 10 m and (d) for Area IV.

Fig. 11b.

Area II August 0 m 2458 stations

	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30 (°C)	Total
-29.0											1				0			1
29.0-30.0														0	0			1
30.0-30.2															0			0
30.2-30.4													1	0	1			2
30.4-30.6													1		1	0		2
30.6-30.8													0	1	1	0	0	2
30.8-31.0												1	1		6			8
31.0-31.2									0		1	0	1	2	2	2		8
31.2-31.4											1	1	2	2	2	3		11
31.4-31.6										1	1	1	4	5	3	0	0	16
31.6-31.8					0			0		1	2	2	3	9	3	1	0	21
31.8-32.0									0	2	3	5	11	4	8	1		34
32.0-32.2								0	2	2	3	12	7	13	3	2		43
32.2-32.4						0	1	1	2	3	8	16	10	11	8	3		61
32.4-32.6					0		0	1	1	3	9	18	12	14	12	9	1	81
32.6-32.8							0	2	3	7	11	20	11	13	16	10	1	95
32.8-33.0							1	1	3	2	12	17	20	15	14	8	1	94
33.0-33.2				0			1	1	5	12	16	22	14	17	17	3		108
33.2-33.4							0	2	9	12	16	26	22	22	12	6	2	130
33.4-33.6						1	2	2	4	9	13	22	20	9	11	3	1	97
33.6-33.8					1	1	2	4	7	7	18	19	10	15	10	1		95
33.8-34.0					0		1	0	4	4	13	10	5	4	4	1	0	48
34.0-34.2		0		1	0		1	0	2	1	7	3	4	3	3			25
34.2-34.4						0	0	0		2	3	5	0	3	1			15
34.4-34.6					0		0	1	1		1				0			3
34.6-34.8							0	0								0		1
Total		0		1	2	2	10	17	42	67	137	199	157	162	139	56	7	1000

Fig. 11c.

Area II August 10 m 2365 stations

	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30 (°C)	Total
30.0-30.2																	1					1
30.2-30.4																	0	1	1			2
30.4-30.6																			0	0		0
30.6-30.8																1	1	0	0			2
30.8-31.0															0	0		0	1	0		1
31.0-31.2												0			1	0	0		2			3
31.2-31.4														1		1	1	2	7			11
31.4-31.6															1	0	1	2	2			6
31.6-31.8												0			0	2	4	4	0	1		12
31.8-32.0													2	4	1	3	11	5	5	4		34
32.0-32.2											0	0	1	2	2	13	6	4	4			33
32.2-32.4							1				0	1	2	3	7	12	9	12	2	2		50
32.4-32.6								0	1	1		1	2	2	13	15	15	10	7	4		71
32.6-32.8								0	0	0	1	2	3	4	12	10	14	8	10	3		67
32.8-33.0							0	2	0	4	2	4	4	7	10	17	15	19	7	0		91
33.0-33.2						1	0	3	3	4	2	2	4	6	13	23	9	18	9	2		98
33.2-33.4				1	1	1	1	1	4	3	5	7	8	11	8	16	20	13	15	2		118
33.4-33.6				0	0	2	4	1	5	5	4	7	17	15	19	15	21	12	7	0	0	136
33.6-33.8				0	1	1	1	3	3	4	5	9	10	10	24	11	8	8	10	0		111
33.8-34.0			1		2	2	2	3	2	4	2	5	10	4	21	12	2	1	4			77
34.0-34.2			1	0	1	2	3	2	2	2	1	4	5	5	8	8	2	2	1			48
34.2-34.4		1		1	1	1	1		0	1	1	1	3	1	5	6						23
34.4-34.6								0		1	0	1		0	0	0						3
34.6-34.8										1												1
34.8-35.0									0													0
Total		1	2	3	6	10	15	15	21	28	23	46	72	77	144	164	137	123	94	19	0	1000

creases by 26.1% compared with July (Figs. 10 and 11a). In the Tsushima Strait region, SSS decreases to the minimum of the year and the *T*-*S* bivariate distribution shows the maximum number of 50% and 75% classes (36 and 68) that the analysis has yielded for the surface (Fig. 4). The high salinity water (>34.4) completely disappears and warm water of 27–29°C is scattered over the large salinity range of 28.0–34.4 at the sea surface in Area I. In Area II 50% range

Fig. 11d.

Area IV August 0 m 927 stations

	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29 (°C)	Total
30.6-30.8										1						1
32.4-32.6						3										3
32.6-32.8										1		1				2
32.8-33.0								0	0		1					2
33.0-33.2						2	2			3	1	4				12
33.2-33.4				4	8	1	9	10	4	12	9	0				*58*
33.4-33.6				4	6	10	*46*	18	9	14	8	5	1			*122*
33.6-33.8		2	11	15	*38*	29	*74*	*34*	*42*	13	18	5	2			*283*
33.8-34.0	0	22	16	27	*60*	*36*	*47*	*32*	*32*	*32*	10	5	1			*322*
34.0-34.2			1	22	2	*31*	29	16	20	29	7	5	2	1		*164*
34.2-34.4				1	1	2		6	3	3	1	6	2	2		26
34.4-34.6									5					1		6
Total	0	25	28	*74*	*115*	*114*	*207*	*116*	*115*	*107*	*56*	33	7	4		1000

Whole Area September 0 m 5425 stations

	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30 (°C)	Total
-29.0												0	0	0							1
29.0-29.2																					-
29.2-29.4												0					0				1
29.4-29.6																	0				0
29.6-29.8																0	0	0			1
29.8-30.0																0	0	0			0
30.0-30.2															0		1				1
30.2-30.4													0	0	0	0	0				1
30.4-30.6														0	0		0				1
30.6-30.8												0		0	0	0	0	0			1
30.8-31.0														1	0	0	2	0			4
31.0-31.2														0	0	0	1	0			2
31.2-31.4										0		0	0	0	2	2	1				6
31.4-31.6												1	1	2	1	1	0	0			5
31.6-31.8											0	0	1	2	2	2	1	0			8
31.8-32.0										0	1	2	4	1	2	4	1	0			15
32.0-32.2										0	0	3	5	4	3	3	2	0			20
32.2-32.4								0			1	4	4	6	5	4	1	0	0		26
32.4-32.6								0	0	2	5	7	8	6	7	4	1	1			*40*
32.6-32.8			0						0	2	6	6	7	10	10	3	1	1			*48*
32.8-33.0							0	3	1	6	7	10	8	9	*11*	7	4	1	1		*67*
33.0-33.2			0					0	1	5	9	7	10	*14*	*11*	4	4	1	0		*66*
33.2-33.4						0	1	4	3	5	10	*12*	*13*	*20*	*14*	9	4	0	0		*96*
33.4-33.6						11	6	2	8	8	*14*	*24*	*19*	*16*	*12*	9	1	0			*130*
33.6-33.8	0		0	1	2	5	4	*25*	*32*	*27*	*29*	*21*	*18*	*15*	10	8	2		0		*198*
33.8-34.0					0	7	3	10	*14*	*20*	*24*	*24*	*18*	10	5	3	1	0	0		*138*
34.0-34.2					0	1	1	3	*14*	*17*	*18*	*12*	9	7	4	1	1				*88*
34.2-34.4								3	4	10	4	3	2	3	1	1					*30*
34.4-34.6									1	2	1	1	1	1	0	0					6
34.6-34.8											0	1	1								2
34.8-35.0														0	0						0
Total	0	-	1	1	2	24	16	*49*	*77*	*104*	*130*	*138*	*127*	*127*	*102*	*65*	30	5	1		1000

Fig. 12. As in Fig. 3 but in September for the whole area.

amounts to 69 in bivariate class number at 10 m, because a great vertical temperature gradient in the surface water yields a wider temperature range below the sea surface, while the number reduces to 56 at the sea surface (Figs. 4 and 11b-c). The mode in the area must lie around 25℃, 33.4 at the sea surface and at a little colder side at 10 m, though the distribution evens out.

There is no mode other than [21–22℃, 33.6–33.8] (4.0%) at the sea surface in the whole area (Fig. 11a); however, it seems to deviate slightly towards a colder, fresher side from the midpoint. In Area Ⅲ, a weak mode [19–20℃, 33.4–33.6] (1.8%) is formed at the sea surface besides the first mode [23–24℃, 33.8–34.0] (4.6%).

Double modes are clear at the sea surface in Area Ⅳ (Fig. 11d, [21–22℃, 33.6–33.8], 7.4%

Whole Area October 0 m 8155 stations

	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23	23-24	24-25	25-26	26-27	27-28 (°C)	Total
-31.0												0		0	0						0
31.0-31.2														0	0						0
31.2-31.4										0	0	0		0							0
31.4-31.6												0		0							0
31.6-31.8													0	0	0	0					1
31.8-32.0												0	1	1	0						2
32.0-32.2										0	0	1	2	1	1	2	0				6
32.2-32.4									0	0	2	1	2	4	0	1	1				11
32.4-32.6										0	2	2	3	5	3	3	1	0			21
32.6-32.8								0	0	1	4	6	4	5	5	2	0	0			28
32.8-33.0							0	0	1	2	5	8	8	9	5	3	1	0			43
33.0-33.2							0	0	2	2	7	11	11	15	9	4	1	0			65
33.2-33.4					0	1	1	1	2	3	9	19	28	22	11	6	1		0		105
33.4-33.6				0	2	2	9	7	6	19	13	20	25	28	16	8	3	1		0	158
33.6-33.8				4	14	14	12	25	16	19	14	17	21	20	14	9	2	1	0		201
33.8-34.0		2	2	2	5	8	11	14	26	34	24	22	17	13	6	5	2	1			195
34.0-34.2			1	6	5	3	18	20	18	21	10	7	7	3	4	2	1	0			126
34.2-34.4						4	2	2	0	9	8	3	1	1	2	1	1	0			34
34.4-34.6							1			1	1		1	1	0	0	0				4
34.6-34.8													0	0	0	0					0
34.8-35.0																0					0
Total		2	3	13	25	31	54	70	71	113	99	116	133	128	76	46	15	3	0	0	1000

Fig. 13. As in Fig. 3 but in October for the whole area.

Whole Area November 0 m 3958 stations

	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23	23-24 (°C)	Total
-32.0								0						0	0	0					1
32.0-32.2															0	0					0
32.2-32.4							0	0				0	0		0		1				2
32.4-32.6											0			1	1						1
32.6-32.8										0			1	2	2	0					5
32.8-33.0								0			0	0	5	6	4	3	0				19
33.0-33.2							0	4	4		1	4	9	7	6	7	2				45
33.2-33.4					1					3	5	15	19	17	19	14	5	0			99
33.4-33.6					2	0		15	2	5	19	24	18	22	32	24	8	0			170
33.6-33.8					2		8	4	5	19	23	20	16	31	23	21	14	2			189
33.8-34.0	11			31	6	10	18	23	37	2	12	14	13	22	23	19	17	6	1		265
34.0-34.2			8	3	1	4	10	15	8	13	11	5	7	4	8	9	12	5	1		124
34.2-34.4		1	15	1	6	2	4	4	4	4	4	1	2	3	3	4	7	4	0	0	69
34.4-34.6								0		1	1	0	2	1	1	2	1	1	0	0	10
34.6-34.8													1	0	0	1	0	0		0	2
34.8-35.0																					
Total	11	1	23	35	16	17	41	66	59	47	76	83	93	117	123	104	67	18	2	0	1000

Fig. 14. As in Fig. 3 but in November for the whole area.

and [19–20℃, 33.8–34.0], 6.0%), but the latter disappears at 10 m.

In September SSS in the sea shows the minimum of the year and 50% and 75% ranges occupy 28 and 57 classes, maxima of the year, at the sea surface (Fig. 12). The upper 10 m water of Area I shows an increase of total salinity frequency of every class of more than 32.8 over those in August. On the contrary, total salinity frequencies in Area II decrease in classes of more than 33.2 at the sea surface and of more than 33.4 at 10 m. In Area III, the salinity frequency decrease is limited to classes of more than 33.8 through upper 10 m. The surface water of the northeastern part, Area IV, shows a weak salinity maximum in September (Fig. 2d). The saline water (>34.0) increases by 17.8% in September and decreases by 2.0% in October. The mode at the sea surface in the whole area shifts to two degrees lower class (Fig. 12, [19–20℃, 33.6–33.8], 3.2%), deviating towards a colder, lower salinity side as in August. The weak second mode of high temperature is seem at [24–25℃, 33.2–33.4] (2.0%). Two modes are discernible at both depths in Area III ([19–20℃, 33.6–33.8] 3.7% at 0 m and 3.3% at 10 m; [23–24℃, 33.4–33.6] 3.1% at 0 m and [24–25℃, 33.6–33.8] 3.1% at 10 m) as well, Whole Area December 0 m 3429 station

	2–3	3–4	4–5	5–6	6–7	7–8	8–9	9–10	10–11	11–12	12–13	13–14	14–15	15–16	16–17	17–18	18–19	19–20	20–21 (°C)	Total
-32.0													0							0
32.0-32.2											0									0
32.2-32.4			0												0					0
32.4-32.6		0								0	0				0					1
32.6-32.8							0	0						0						1
32.8-33.0					1	0							0	0						1
33.0-33.2				0					2	0	0	2	2	4	1	0				10
33.2-33.4										0	1	6	9	2	2	0				20
33.4-33.6	0	0	0				0		3	0	4	2	10	7	8	0			0	35
33.6-33.8		0	0		0	0	3	2	1	6	6	13	20	19	18	5	0			94
33.8-34.0	59	24	4	0	14	9	7	11	7	19	43	33	34	38	25	13	2	0		342
34.0-34.2		5	14	4	44	39	17	22	13	12	10	28	25	35	23	11	3	0		304
34.2-34.4				0	4	8	4	12	2	9	26	16	13	14	16	11	4	2		142
34.4-34.6							3			1	1	5	3	5	7	7	5	1		37
34.6-34.8													1	2	3	3	2	1		10
34.8-35.0												1			0	0	0	0		2
35.0-35.2																0	0			0
Total	59	29	18	5	62	56	35	47	27	48	91	106	117	127	103	50	16	4	0	1000

Fig. 15. As in Fig. 3 but in December for the whole area.

(a)

Whole Area Year 0 m 66,263 stations

	-2–-1	-1–0	0–1	1–2	2–3	3–4	4–5	5–6	6–7	7–8	8–9	9–10	10–11	11–12	12–13	13–14	14–15	15–16	16–17	17–18	18–19	19–20	20–21	21–22	22–23	23–24	24–25	25–26	26–27	27–28	28–29	29–30	30–31 (°C)	Total
-30.0																																		1
30.0-31.0																																		2
31.0-31.2																																		1
31.2-31.4																																		1
31.4-31.6																																		1
31.6-31.8																																		2
31.8-32.0																													1					3
32.0-32.2																										1	1		1					4
32.2-32.4																										1	1	1	1					6
32.4-32.6																							1	1	1	1	1	1	1					8
32.6-32.8																					1	1	1	1	1	1	1	1	1	1				11
32.8-33.0																			1	1	1	1	1	1	2	1	2	2	1	1				17
33.0-33.2																		1	1	1	1	2	2	3	2	2	3	2	1	1				24
33.2-33.4																1	1	2	2	2	3	3	4	4	3	3	4	3	2	1				41
33.4-33.6				1							1		1	2	1	1	3	4	4	5	5	6	6	6	6	4	4	2	2	1				68
33.6-33.8										1	2	2	2	3	3	6	7	8	7	8	8	9	9	10	8	6	4	3	2	1				109
33.8-34.0			3	3	12	5	3	4	3	7	8	11	11	13	12	8	10	9	9	10	8	8	8	8	6	6	4	3	2	1				195
34.0-34.2			8	12	11	11	16	12	16	17	16	20	22	18	10	11	11	8	7	6	5	5	7	7	5	3	3	2	1	1				269
34.2-34.4				2	1	1	1	3	6	8	9	16	15	10	11	8	7	6	6	6	5	4	5	3	2	1	1	1	1					139
34.4-34.6				1							1	2	5	7	8	9	7	8	6	5	4	2	2	1	1	1								70
34.6-34.8													1	2	5	5	4	3	2	2	1	1												26
34.8-35.0														1		1	1																	3
35.0-35.2																																		0
Total	0	0	11	19	24	17	21	19	26	34	38	53	57	55	51	51	52	49	45	46	43	42	47	47	38	32	29	21	17	10	3	0	0	1000

Fig. 16. As in Fig. 3 but yearly mean for the whole area (a) at the sea surface and (b) at 10 m. The frequency '0' (less than 0.5 per mille (0.05 per cent)) for bivariate classes is omitted. Solid lines in (b) denotes the same limits as inner limits in Fig. 17.

though total temperature frequency shows a single mode at the sea surface.

After September the surface water of the sea steadily decreases in temperature and increases in salinity; *T-S* bivariate classes of 50% and 75% ranges decrease until winter or early spring. Available stations in the whole area in October make up the greatest number of the year. Figure 13 shows that classes of 2.0% or more spreads widely over the range of 15–22℃, 33.2–34.2 at the sea surface. The mode [17–18 ℃, 33.8–34.0] (3.4%) deviates towards a colder, more saline class from the center; the second mode seems to be around 21℃, 33.5. On the contrary, the first mode is warmer one at 10 m ([17-18℃, 33.8–34.0], 2.9% and [20–21℃, 33.2–

Fig. 16b.

Whole Area Year 10 m 53,343 stations

	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29 30(° C)	Total
-30.0																																	0
30.0-31.0																																	1
31.0-31.2																																	0
31.2-31.4																																	1
31.4-31.6																																	1
31.6-31.8																																	1
31.8-32.0																																	2
32.0-32.2																										1	1	1					4
32.2-32.4																								1	1	1	1	1	1				5
32.4-32.6																						1	1	1	1	1	1	1					7
32.6-32.8																				1	1	1	1	1	1	1	1	1	1				11
32.8-33.0																				1	1	1	2	1	2	2	2	1	1	1			17
33.0-33.2															1		1	1	2	1	2	2	2	2	2	1	2	2	1				24
33.2-33.4																1	2	2	2	2	4	4	5	4	4	3	3	2	1	1			*40*
33.4-33.6											1	1		2	1	2	4	4	4	5	5	6	7	5	6	5	4	2	2	1			*66*
33.6-33.8										3	2	2	3	3	4	*7*	*7*	*8*	*8*	*7*	8	*9*	*10*	*9*	*7*	6	4	2	2				*113*
33.8-34.0				3	*13*	5	2	4	4	*7*	*12*	*12*	*12*	*8*	*12*	*9*	*10*	*11*	*10*	*9*	8	*8*	*8*	*9*	8	5	3	2	1	1			*197*
34.0-34.2			*8*	*10*	*10*	*9*	*14*	*13*	*18*	*20*	*19*	*21*	*23*	*17*	*14*	*10*	*11*	7	7	5	5	6	7	8	5	3	2	1	1				*275*
34.2-34.4				4	1	1	1	2	2	6	*9*	*16*	*15*	*14*	8	7	*8*	6	8	6	5	4	5	3	1	1	1						*135*
34.4-34.6													2	5	*7*	*9*	*8*	*9*	*9*	7	6	4	2	1	1								*72*
34.6-34.8														1	1	4	5	4	3	2	1	1	1										23
34.8-35.0																		1															2
35.0-35.2																																	0
Total	0	0	9	17	*24*	16	17	*19*	*25*	*37*	*43*	*53*	*60*	*54*	*53*	*50*	*57*	*52*	*51*	*45*	*43*	*46*	*50*	*46*	*40*	*30*	*26*	18	12	6	1	0	1000

33.4], 3.4%). In addition, a cold mode [15–16 ℃, 33.6–33.8] (4.5% at 0 m and 3.9% at 10 m) appears in Area Ⅲ forming a clear second mode in total temperature frequencies. In Area Ⅳ, two modes are clearly ([15–16℃, 34.0–34.2] 9.4% at 0 m and [16–17℃, 34.0–34.2] 7.3% at 10 m; [18–19℃, 33.8–34.0] 7.4% at 0 m and 10.1% at 10 m).

As total temperature frequencies show in Figs. 14 and 15, three modes are formed in November and December ([7–8℃, 33.8–34.0] 3.1%, [12–13℃, 33.8–34.0] 3.7% and [18–19℃, 33.4–33.6] 3.2% in November; [2–3℃, 33.8–34.0] 5.9%, [6–7℃, 34.0–34.2] 4.4% and [12–13℃, 33.8–34.0] 4.3% in December). The coldest mode must be formed rapidly after October and grows until March.

5. Overall characteristics of *T-S* frequency distributions

The yearly mean *T-S* frequency distributions for the whole study area are obtained with the averages of relative distributions in January through December for the area (Fig. 16). According to a previous analysis, mostly *T-S* relation points for more than 5℃ at the sea surface fall on the lower salinity sides of the line connecting (17℃, 34.7), (13℃, 34.7) and (5℃, 34.1) and of the salinity 34.1 line for less than 5℃ in winter to spring; the upper limit of salinity for more than 17℃ decreases with temperature in spring to summer. This generally agrees with Fig. 16 except that the upper limit of salinity for low temperatures is about 34.4. Figure 16 shows that the highest salinity of more than 34.8 occurs at about 13℃ or a little warmer temperatures. The limit does not depend on temperature for the cold water of less than 8-9℃.

There are five to six modes or large frequency class groups in Fig. 16. They nearly correspond to the class groups of 1.0% or more during five months or more shown in Fig.17. The group centered at the class [10–11℃, 34.0–34.2] (W_2) is conspicuous among them. As stated in section 3 or shown in Fig. 2, little variation during long winter is one of the outstanding characteristics of the surface water of the sea. This group (W_2) shows frequency of 1.0% or more mostly during January to May partly in November, December, or June. The period of the frequency (1.0% or more) for the centered class [10–11℃, 34.0–34.2] covers eight months. The W_2 group mainly denotes *T-S* relations south of the polar front, but probably its colder portion includes the surface water west of northern Japan. The W_1, the only class [2–3℃, 33.8–34.0], definitely shows a water characteristic north of the polar front. These two groups of waters must keep lying on the proper sea areas almost during the period.

Since temperature and salinity values of the

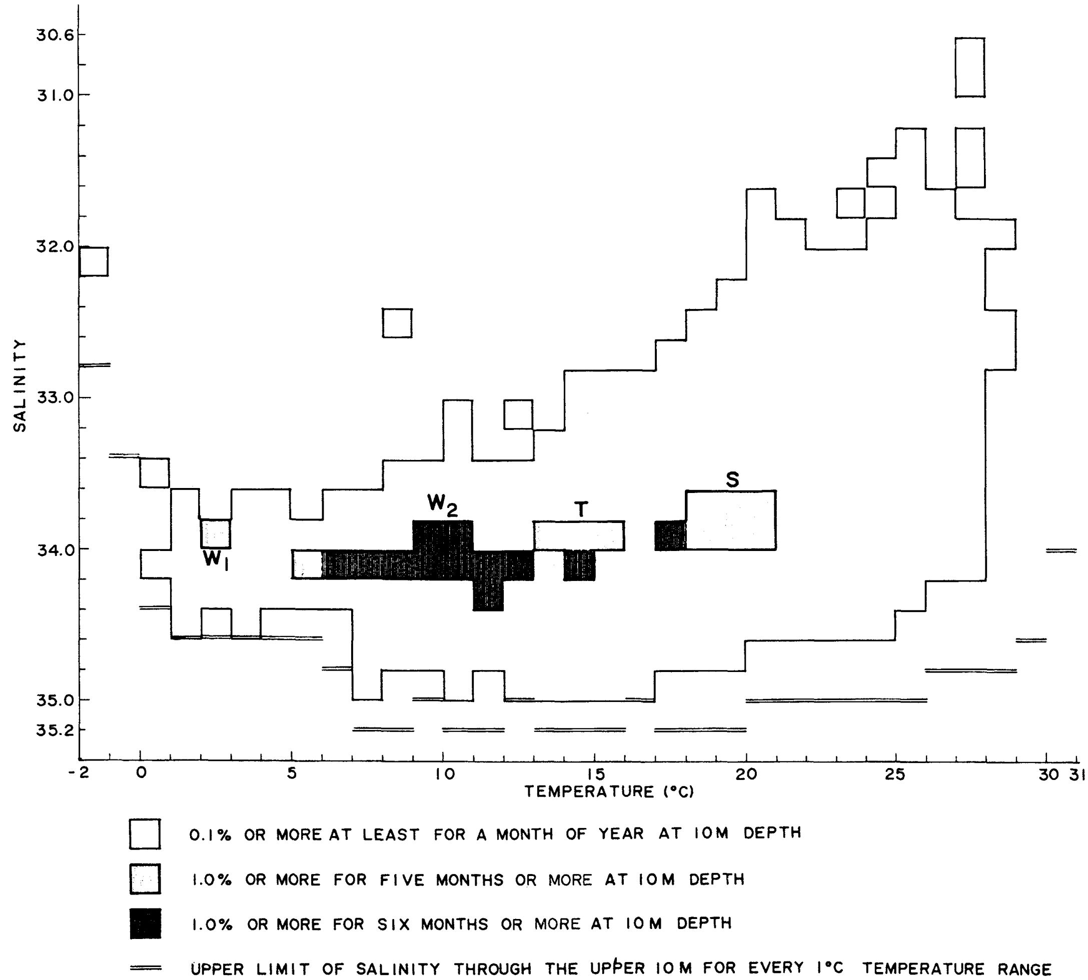


Fig. 17. Overall characteristics of *T-S* frequency distributions of the surface water of the whole study area. Outer solid lines denote the limits within which *T-S* values of 1℃×0.2 (‰ or psu) bivariate classes show frequencies of 0.1% or more at least for a month of year at 10 m depth. Inner solid lines denote the limits within which *T-S* values of the classes show frequencies of 1.0% or more for five months or more of year at 10 m and shaded areas 1.0% or more for six months or more of year at 10 m. Classes of W_1 and W_2 are seen in winter, S in summer and T in transitional seasons (see text). Double horizontal lines show the upper limit of salinity range through the upper 10 m for every 1℃ temperature range. (Higher salinities than the limits have never been observed.

surface water scatter and their variations are great in spring, summer and autumn, frequently occurring classes of warm water during several months are fewer than those of cold water. The S group, extending from the warmest mode [20–21℃, 33.6–33.8] to colder, more saline classes, shows five month's duration (July-November) of the frequency of 1.0% or more excepting that the coldest class [17–18℃, 33.8–34.0] shows the frequency in June to August and in October to December. Figure 18 is an example of the *T-S* frequency distribution with the summer mode. Surface waters included in this group do not always occupy proper sea areas, that is, the water of the same range of *T-S* relation can be found in various places according to seasonal variation.

Area II	November 0 m	1174 stations											
	13	14	15	16	17	18	19	20	21	22	23	(°C)	Total
-32.0						0							0
32.0-32.2							0						0
32.2-32.4							1						1
32.4-32.6							3						3
32.6-32.8					2	1	2	0					5
32.8-33.0					8	3	12	11	0				35
33.0-33.2			2	10	12	20	13	15	8				*80*
33.2-33.4		2	8	34	7	10	34	25	13				*134*
33.4-33.6		8	7	35	28	33	47	37	19	1			*215*
33.6-33.8				1	5	38	32	40	33	8			*158*
33.8-34.0				3	15	35	44	36	55	22			*210*
34.0-34.2				3	2	1	12	22	34	10	1		*86*
34.2-34.4				0	2	4	13	13	17	11	1		*61*
34.4-34.6					1	0	6	2	3	0			12
34.6-34.8								1					1
Total		11	17	*86*	*82*	*146*	*219*	*202*	*182*	53	2		1000

Fig. 18. As in Fig. 3 but in November for Area II.

The last group T, centered at the class [14–15℃, 34.0–34.2], shows the frequency twice or three times in a year. The frequency of the centered class occurs in May, June and October to January, other three classes do not show the frequency in October or November.

6. Concluding remarks

On the basis of available hydrographic data taken in 1952-1988 (including partly in 1989-1990), I have divided the Japan Sea except the northwestern part into four areas according to pattern of seasonal variation of SST and SSS. Then I have obtained monthly relative frequency distributions of *T-S* relations in bivariate class of 1℃×0.2 in salinity at the sea surface and at 10 m depth for each of four areas and for the whole study area.

The water entering through Tsushima Strait clearly shows seasonal variations in water characteristics with standard deviations of mostly less than about 1℃ in temperature and 0.2 in salinity for the monthly means (e.g. OGAWA, 1983). The water is transported northeastward along the western margin of Japan showing propagation of high salinity during winter to summer and low salinity during spring to autumn (e.g. TANIOKA, 1962; KOLPACK, 1982).

For example, the maximum of SSS occurring in the Tsushima Strait region in March appears in the central area in June about three months behind and in the northeastern part in September about six months behind.

One of the most striking features is that two or three modes are seen in *T-S* frequency distributions nearly through a year in the whole study area. This is due to the existence of the frontal zone between about 39° and 42°N in the central area. The frontal zone separating the surface water into the warm, high salinity water of the south and the cold, low salinity water of the north is well depicted in the SST distributions in winter to spring (e.g. ISODA *et al*, 1991, Fig. 4; Maizuru Marine Observatory, 1990, Fig. 1). Two modes of *T-S* frequencies suggest that this separation occurs even in summer, though scattered distributions and decreased meridional temperature gradients obscure separation of two modes (e.g. Figs. 10 and 12). According to ISODA *et al* (1991), the eastern part of the polar front is more stable than the western one throughout a year and its eastern end exists around the Tsugaru Strait. However, another weak mode often appears at a class a few degrees warmer than the class of the cold mode (e.g. Figs. 3a, 7a and 14). This corresponds to the warmer one of the two modes, about two degrees apart, found in Area IV, west of northern Japan. We have little knowledge of the surface water characteristics or current structure in the northeastern part of the Japan Sea north of 41°N except near the coast because of few observations. Nevertheless, front-like isotherms of SST occasionally extend northeastward along the coast of northern Japan (e.g. ISODA *et al*, 1991, Fig. 4). Besides, the subsurface high salinity core along the coast of Japan reaches as far north as northern Hokkaido, though its salinity is rapidly reduced west of Hokkaido (KOLPACK, 1982). Therefore, a weak mode seen for Area III or the whole area in autumn to spring and a warm mode seen for Area IV, both mode classes being a few degrees warmer than the cold mode classes, must represent the surface water on the southeast side of the front-like zone or in the west of northern Japan. This mode occasionally merges into the cold mode during spring to summer. This frontal structure may be indiscernible at least in the topmost surface water in summer.

The yearly mean *T-S* frequency distribution for the whole study area suggests about four groups of significant surface water characteristics (Figs. 16 and 17). The first is the winter mode water of 5–13℃, 34.0–34.2, partly 33.8–34.0 or 34.2–34.4, seen in the south of the frontal zone at least during January to May; this possibly includes the surface water of west of northern Japan. The coldest water centered at the class [2–3℃, 33.8–34.0] exists in the north of the frontal zone during December to April. The third is the summer mode water of 17–21℃, 33.8–34.2 appearing mostly during July to December, this water cannot occupy proper sea areas during the months unlike the first two waters. The last group is the transitional water centered at the class [14–15℃, 34.0–34.2] occurring twice or three times in a year according to seasonal variations of surface water characteristics.

Acknowledgements

This paper benefited greatly from the suggestion of a reviewer. I thank Dr. Kuniaki OKUDA for providing oceanographical observation data of Fishery Agency. A great portion of hydrographic data were provided by the Japan Oceanographic Data Center (Serial Oceanographic Observation Data, 88–110). This research was partially supported by Grant-in-Aid for Scientific Research (C) (Project No. 63540310) from the Ministry of Education, Science and Culture.

References

ISODA, Y., S. SAITOH and M. MIHARA (1991): SST structure of the polar front in the Japan Sea. p. 103–112. *In*: Oceanography of Asian Marginal Seas. K. TAKANO, (ed). Elsevier, Amsterdam.

KOLPACK, R. L. (1982): Temperature and salinity changes in the Tsushima Current. La mer, **20**, 199–209.

Maizuru Marine Observatory (1990). Climatology of hydrographic and chemical properties of the Japan Sea. Maizuru Marine Observatory, 51 pp.

OGAWA, Y. (1983): Seasonal changes in temperature and salinity of water flowing into the Japan Sea through the Tsushima Straits (in Japanese with English abstract). Bull. Japan. Soc. Fish. Oceanogr. **43**, 1–8.

TANIOKA, K. (1962): The Oceanographical conditions of the Japan-Sea (1)—On the annual variations of chlorinity— (in Japanese with English abstrace). Umi to Sora, **38**, 90–100.

YASUI, M., T. YASUOKA, K. TANIOKA, and O. SHIOTA (1967). Oceanographic studies of the Japan Sea—Water characteristics. Oceanogr. Mag., **19**, 177–192.

日本海の海面と10m深とにおける水温—塩分度数分布

須　藤　英　雄

要旨：北西部を除いた日本海は，海面水温—塩分の年変化の型により，4つの海域に分けられる。そのそれぞれおよび全海域について，海面と10m深とにおける水温—塩分特性を水温1℃×塩分0.2（‰またはpsu）でクラス分けしたときの相対度数分布を月ごとに求めた。日本海中央部には，北からの低温低塩分水と南からの高温高塩分水とが接触するフロント構造が存在するため，ほぼ年間を通して，この度数分布には2つのモードがみられる。このフロント帯の東端部分は，しばしば北日本ぞいに北上するらしく，その南東側すなわち北日本西方に存在するやや暖かい表層水を示す第3のモードが現れる。10m深において年間を通してもっとも多く現れるのは，5-13℃，塩分34.0-34.2，部分的には33.8以上あるいは34.4以下の特性をもった水で，1月～5月にフロント帯の南側にみられる。他には，2-3℃，33.8-34.0のクラスを中心とし，12～4月にフロント帯の北側に現れる冷たい水があり，これらは存在海域もほぼ一定しているとみられる。夏季には17-21℃，33.8-34.0の特性をもった水が，7～12月に広い範囲にわたりみられるが，同一海域に長く存続することはない。