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Some Features of Winter Convection in the Japan Sea

YOUNG-HO SEUNG[1] and JONG-HWAN YOON[2]

[1]*Dept. of Oceanography, Inha Univ., Korea*
[2]*RIAM, Kyushu Univ., Japan*

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Historical Russian data provide indication of winter convection reaching down to about 1000 m depth near Vladivostok. However, this kind of convection does not occur every winter. Further data analysis suggests that the location of convection is driven offshore by the coastal buoyant water, which otherwise would be the coastal area. The coastal buoyant water is mostly cold fresh water but occasionally warm coastal water in the south. Due to the large extent of fresh coastal water in the northern part of the basin, the convection does not happen in this area despite the most intense surface cooling.

1. Introduction

Most of the Japan Sea is isolated from open oceans except for small (narrow and shallow) straits which connect the basin to open oceans. Through these straits, the warm current called the Tsushima Current flows in from the south and out to the north. The warm water carried by the Tsushima Current dominates the surface layer from the south up to 40°N where a polar front forms. Most of the water in deeper part of the basin is nearly homogeneous in water property. Though the definition of water masses is different one from another depending on the viewpoint, this water mass is termed largely as the Japan Sea Proper Water (c.f., Moriyasu, 1972). Above the deep homogeneous water and below the surface layer, waters are found to be relatively fresh and rich in oxygen. This water is termed the upper portion of the Japan Sea Proper Water by Sudo (1986) and later discussed in detail by Senjyu and Sudo (1994). The water found in the southwestern part off the Korean coast, sems to be especially pronounced in freshness and high oxygen content and termed the East Sea Intermediate Water by Kim and Chung (1984).

Winter convection in the Japan Sea has great significance in that most of the isolated water in the basin should have been formed somewhere by convection. Hydrographic data accumulated for a few decades do not indicate any renewal of deep water, at least during the measurement period. The Water in the intermediate layer (or the upper portion of the Japan Sea Proper Water) of high oxygen content, however, may be continuously renewed by winter convection.

Attempts of capturing the evidence of convection (c.f., Nitani, 1972) have been very difficult due to the lack of measurements obtained in the candidate areas of convection in the north. Recently however, Senjyu and Sudo (1994) analysed the historical data to show that the upper portion of the Japan Sea Proper Water extending over the basin have the same initial nutrient contents meaning that these have the same origin. Distributions of properties on isopycnal surfaces suggest that the most probable source (convection) region is west of 136°E between 40° and 43°N.

Despite these efforts, further definite evidences are no doubt required to complement the above studies, which can only be accomplished by the measurements made at the right time and place of convection. Fortunately, some Russian historical data provide some pictures about the winter convection in this region. In the following sections, we therefore show an indication of convection, make attempts to figure out when and where this convection can occur based on some available data and finally, discuss the possible preconditioning of convection.

2. Data

The hydrocasting data on which this study is based are mostly a part of the historical data obtained by Far Eastern Hydrometeorological Institute, Russia. This Institute has routinely performed hydrographic measurements with observation network covering the whole basin (Fig. 1); but these stations are not all occupied in every cruise. Among the available data, we chose first those representing the winter season. These data were then checked for their qualities. Not knowing the accuracy of the Russian data, the best way of this may be the visual checking by contouring the data. This procedure seems to be necessary because it is known, through the inter-comparison of data on the *T-S* diagram, that salinities of Russian data are in general twice less accurate than Japanese data (Ichiki, 1994); for deep homogeneous water of temperature 1 to 2°C, the former show the dispersion rate about twice the latter. In fact, some contourings, especially those of salinity, showed unrealistic distributions and were rejected. The final chosen

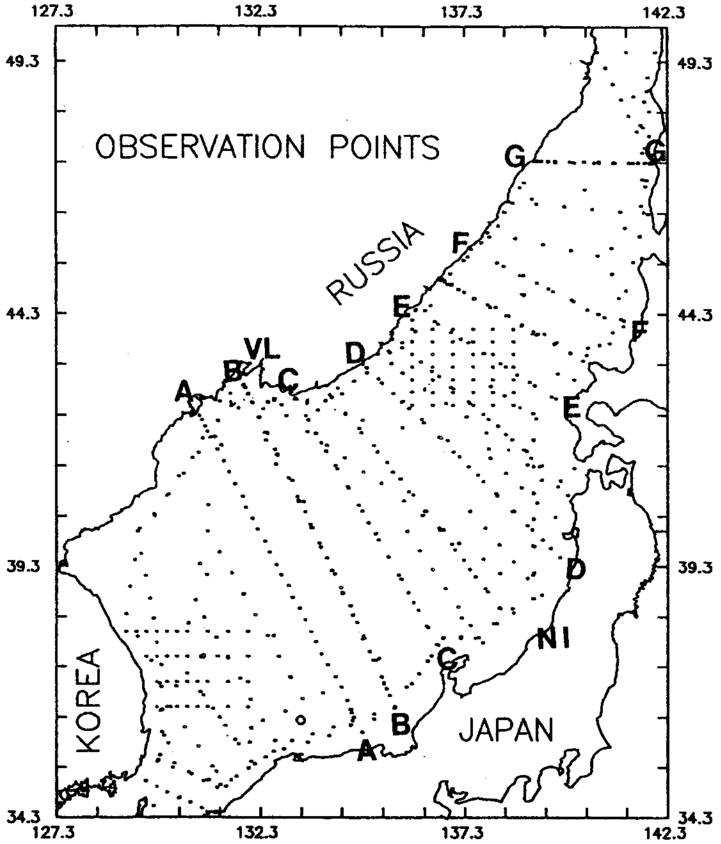

Fig. 1. Observation network of Russian hydrographic survey. Numbers along the abscissa and ordinate are longitude and latitude, respectively, both in degree unit. For convenience, sections A through G are defined. VL and NI denote Vladivostok and Niigata respectively.

Table 1. Description of data sets and approximate estimation of upper 500 m minimum static stability for each data set.

Observation period	Number of station	Maximum depth measured (m)	Minimum stability (10^{-6} sec^{-2})	Location (longitude) (latitude)
Nov. 4–Nov. 6, 1975	39	2500	19.69	132°50′ 41°18′
Mar. 26–Apr. 13, 1976	132	2000	0.65	132°16′ 42°15′
Nov. 10–Dec. 11, 1976	158	3000	4.47	133°56′ 41°42′
Jan. 15–Jan. 22, 1983	24	1750	0.08	132°44′ 41°31′
Jan. 28–Feb. 3, 1985	34	2500	–0.52	133°00′ 41°03′
Mar. 9–Apr. 8, 1985	162	3000	0.51	136°42′ 41°51′
Dec. 20, 1988–Jan. 21, 1989	185	3000	–0.05	133°25′ 42°17′

data sets are briefly described in Table 1.

Besides these data, we use also the data compiled by National Oceanographic Data Center (NODC) to know some climatological mean features of the basin. Though there are some NODC data in the area around the convection, unlike the Russian data, they are not synoptically obtained. However, both data are put together under statistical analysis. These whole data are grouped into different geographical positions and seasons; those falling on the same grid square of dimension 0.2° latitude by 0.2° longitude are assumed having the same position and those obtained within 3 months are assumed having the same season with January through March as winter. Those having the same position and season are checked for their quality before the statistical mean is obtained. First, those out of the range –2 through 30°C for temperature and 25 through 36 psu for salinity are eliminated and, secondly, those lying beyond 3 times the standard deviation from the mean are rejected.

3. Indication of Convection

The section B (c.f., Fig. 1) taken in late January provide an indication of convection (Fig. 2). Despite the concern about the accuracy of salinities, as mentioned earlier, those shown here do not seem to have any problem in showing the general feature. The convection reaches down to about 1000 m depth. The same section occupied about 45 days later shows nearly the same structure but the stratification in upper 200 m is restored (Fig. 3).

During the later period, the northern coastal region is occupied by fresh cold water (Fig. 4) with temperature and salinity less than about 1°C and 33.9 psu, respectively. The section G provides a good example of the vertical structure of this region (Fig. 5). Surface temperature is the lowest over the basin, falling below 0°C in most coastal areas, and temperature inversion occurs in subsurface layers. However, salinity is also the lowest over the basin so that vertical

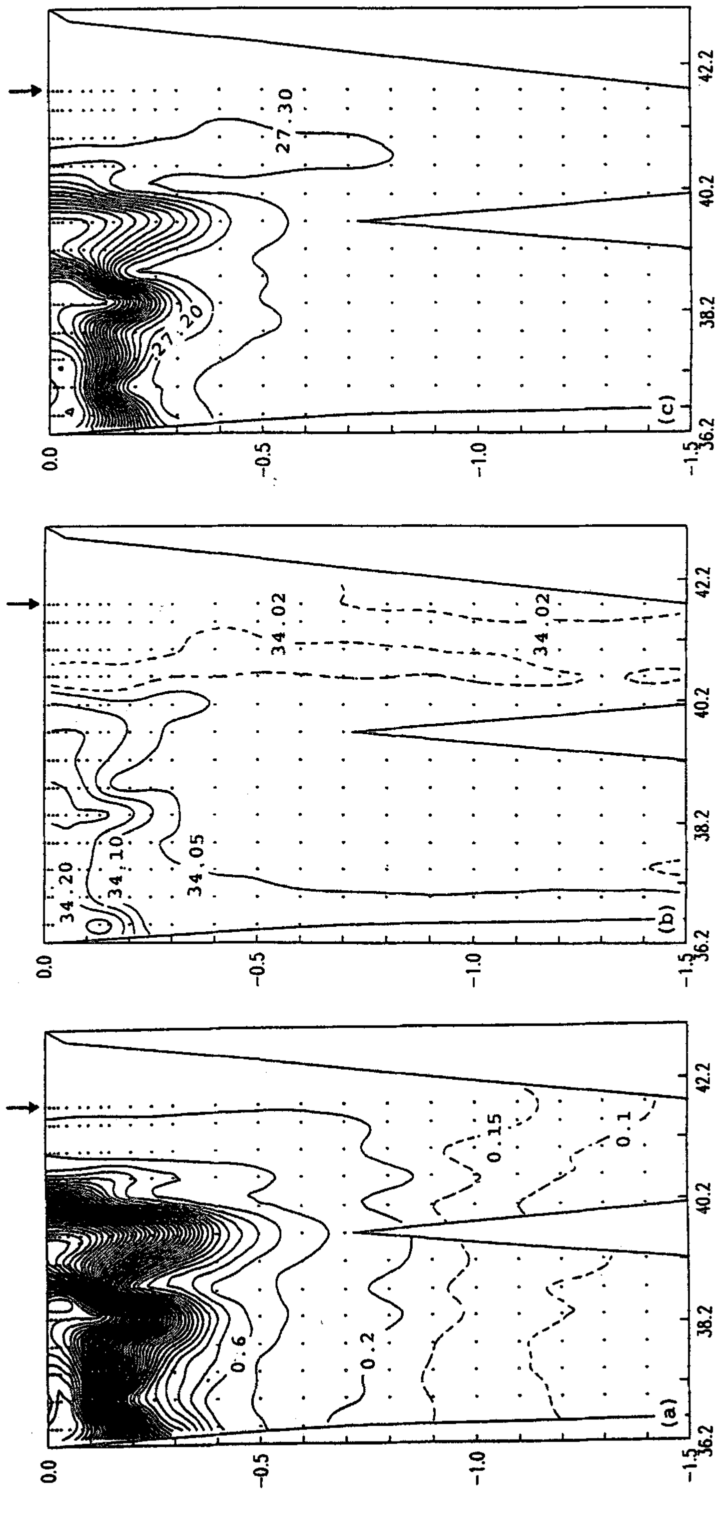

Fig. 2. Distributions of (a), potential temperature (in °C) referred to the surface; (b), salinity (in psu); and (c), potential density (in sigma unit) referred to the surface on section B measured from Jan. 28 to 30, 1985. Except dotted lines, contour intervals are 0.2°C, 0.05 psu and 0.05 sigma unit for temperature, salinity and density, respectively. Abscissa is latitude in degree and ordinate is depth in km. Small dots are data points.

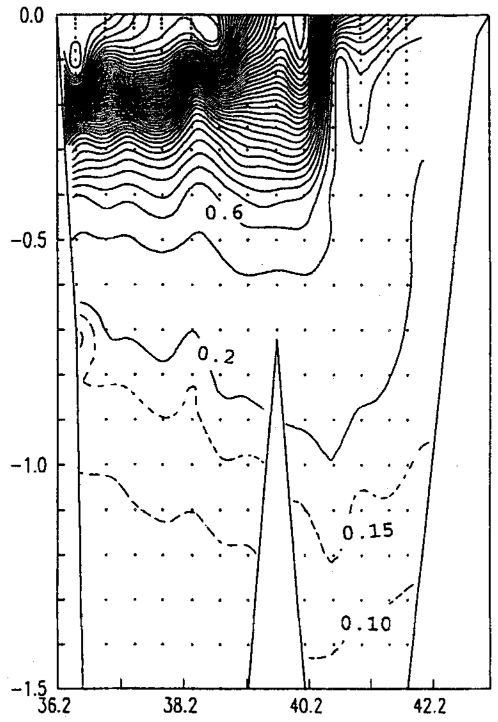

Fig. 3. Potential temperature on section B measured from Mar. 17 to 19, 1985. Others are the same as Fig. 2.

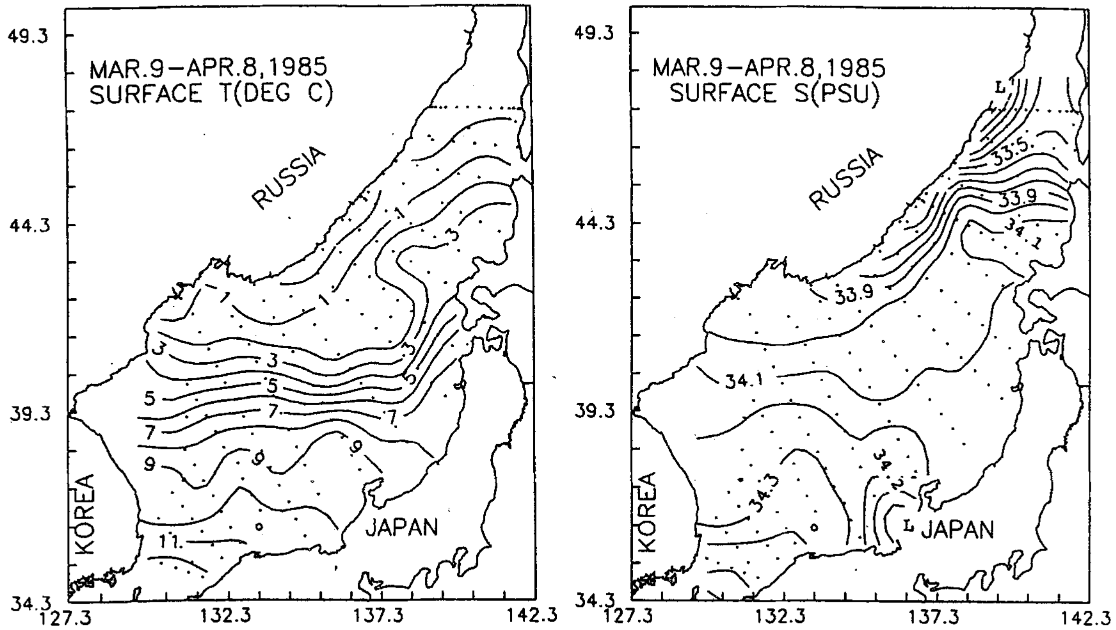

Fig. 4. Distributions of surface temperature and salinity measured from Mar. 9 to Apr. 8, 1985. Small dots are data points. Contour intervals are 1°C and 0.1 psu for temperature and salinity, respectively. Others are the same as Fig. 1.

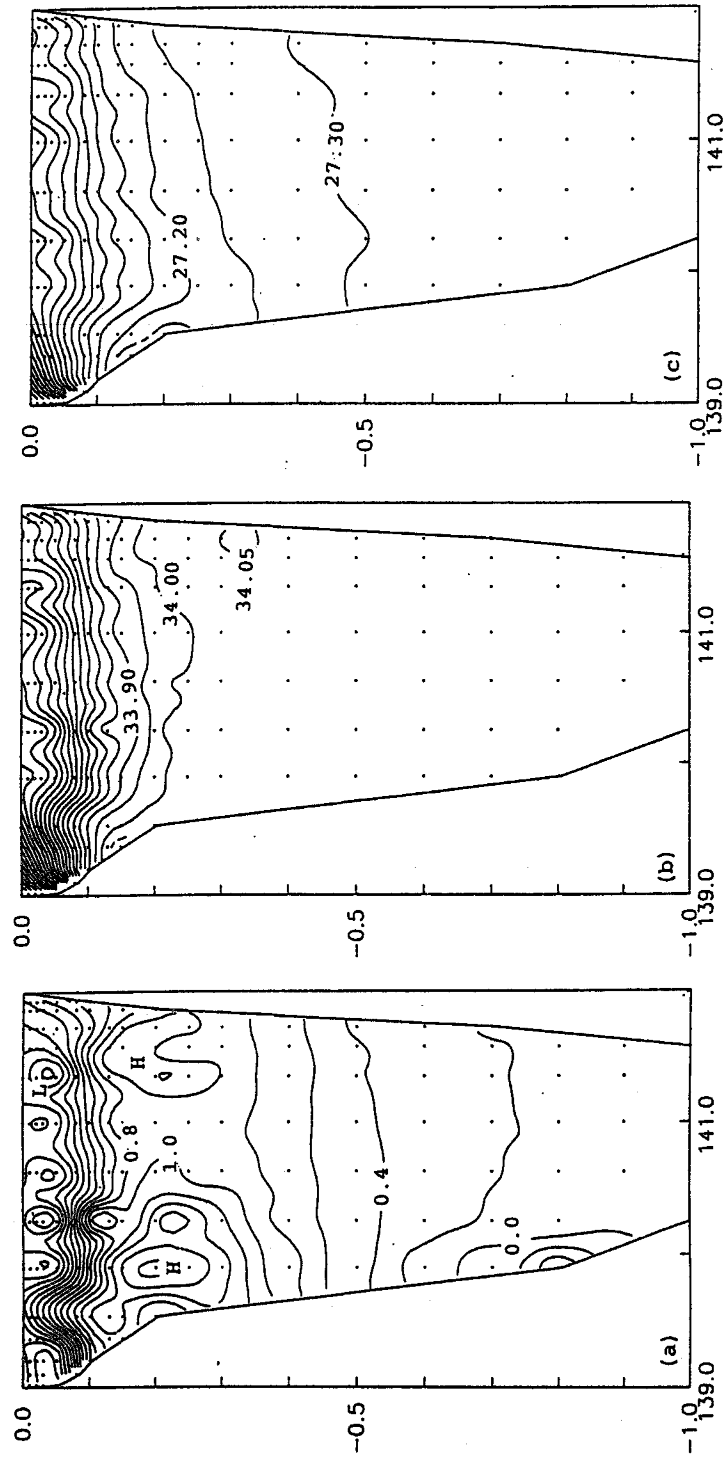

Fig. 5. Distributions of (a), potential temperature (in °C); (b), salinity (in psu); and (c), potential density (in sigma unit) on section G measured from Apr. 2 to 3, 1985. Abscissa is longitude in degree and ordinate is depth in km. Others are the same as Fig. 2.

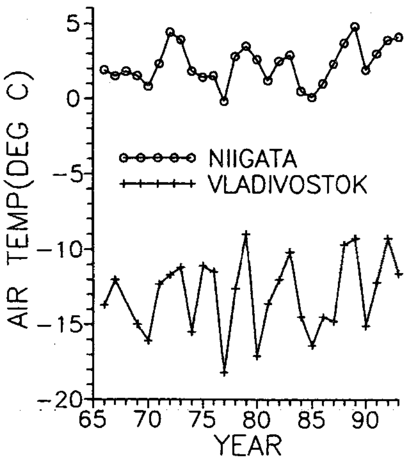

Fig. 6. Long-term variation of January air temperature at Vladivostok and Niigata.

stability is retained. This is due to the fact that the density becomes more dependent on salinity at low temperature.

A question arises on how often and how strong the convection occurs. Among the seven observations cited in Table 1, the two of which cover from November through December belong to late fall and another two of which cover from March through April, belong to late winter. The late fall observations do not show any indication of convection (not shown here) because this period is too early for convection. The late winter observations do not show any convective structure either, because of the restoration of stratification in the upper layer (e.g., Fig. 3). The absence of convection in these periods is also suggested by the positive stabilities shown in Table 1; the stabilities are estimated for upper 500 m water column as rough indications of convective structure. The remaining three observations correspond to mid-winter. Among these, only that of 1984–85 shows uncomparably deep convection as shown above (Fig. 2). It is interesting to remark that the stability is also the lowest in this period (Table 1) though the absolute value of the stability may not be an accurate measure of convection. Taking the air temperature as a rough measure of severity of winter, the winter of 1984–85 seems indeed to be one of the severe winters, whereas others seem to be mild as indicated by the yearly variation of the January monthly mean air temperature at Vladivostok and Niigata (Fig. 6). The three cases used in comparison are by no means sufficient. However, the above result seems to be quite interesting. According to Fig. 6, severe winters come with periodicity of 3–5 years. Convections deeper than that of Jan., 1985 may thus have happened in winters of 1976–77 and 1979–80.

4. Location of Convection

In the previous section, we knew that the convection reaching down to depth 1000 m really happens near Vladivostok in severe winter. However, this is only a part of probably much wider region of convection of which the geographical extension is not known. Quasi-synoptic measurements made in winter 1988–89 provide some information about the region of convection though the convection does not appear to be quite strong in this period (c.f., Table 1). Places of local convection centers are traced on various vertical sections (Figs. 7 and 8). The region around the axis connecting these places can then be considered as the most favored region of convection.

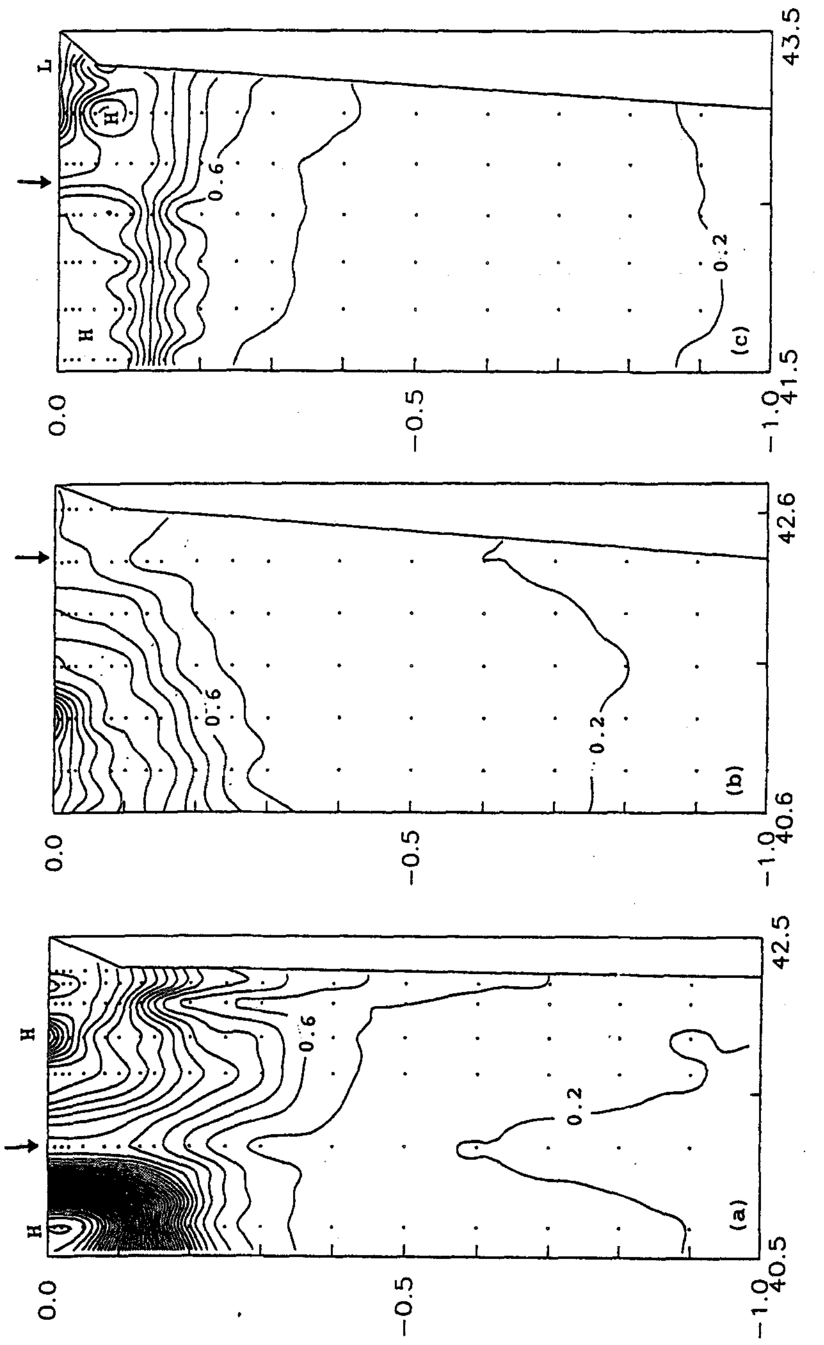

Fig. 7. Distributions of potential temperature (in °C) on: (a), section A measured from Dec. 20 to 24, 1988; (b), section C measured from Jan. 12 to 14, 1989; and (c), section D measured from Jan. 5 to 7, 1989. Abscissa is latitude in degree. Arrows on top of figures indicate local minimum static stabilities. Others are the same as Fig. 2.

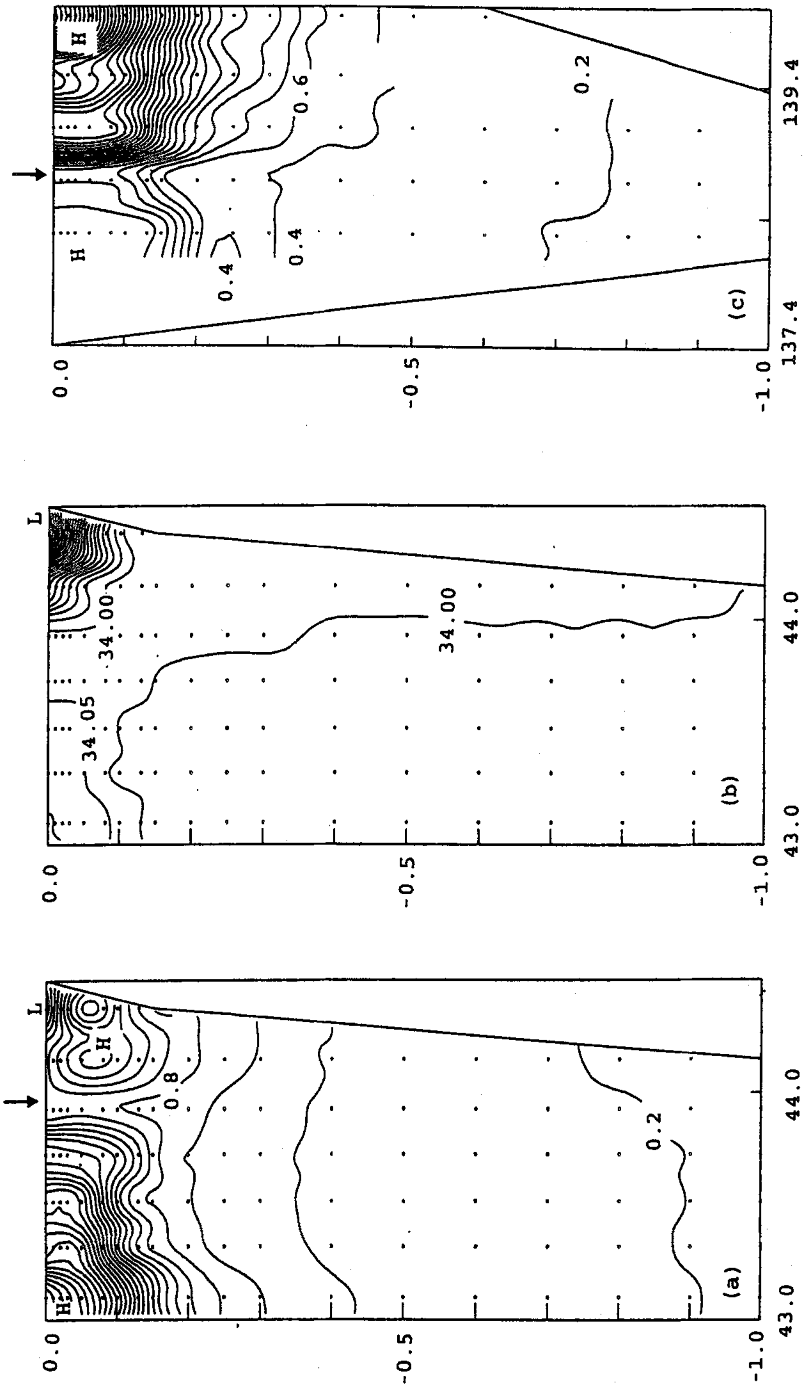

Fig. 8. Same as Fig. 7 except that (a) is for section E measured from Jan. 1 to 2, 1989 and (c) is for section F measured from Dec. 29 to 30, 1988. As an example, salinity (in psu) on section E is also presented in (b). Abscissa of section F is longitude in degree.

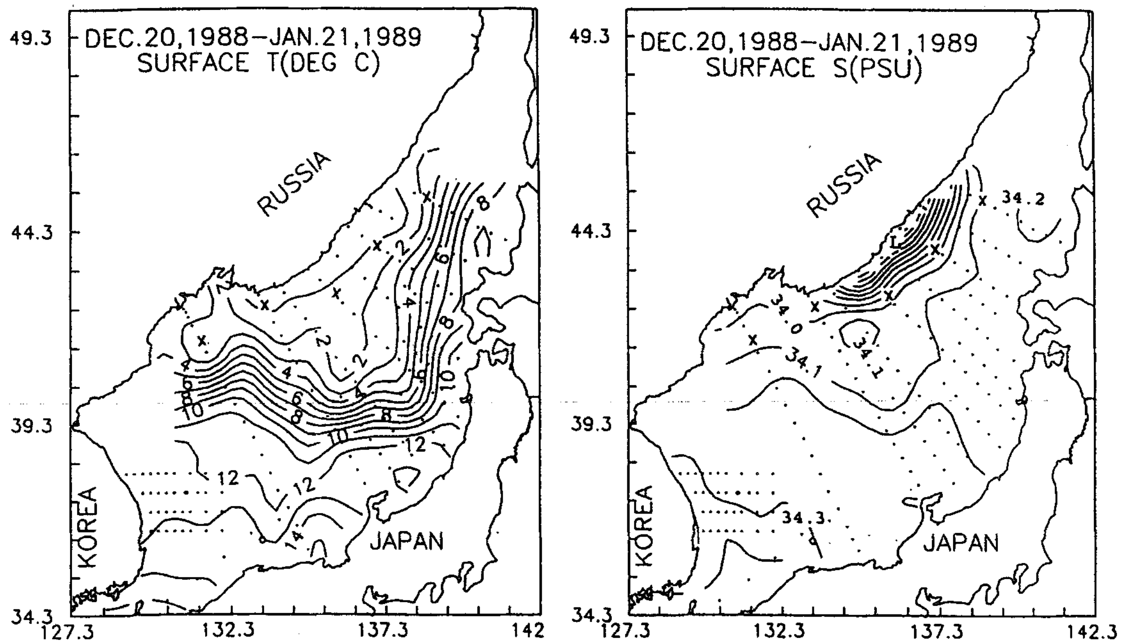

Fig. 9. Distributions of surface temperature and salinity measured from Dec. 20, 1988 to Jan. 21, 1989. Crosses are positions of local minimum static stabilities as indicated in Figs. 7 and 8. Others are the same as Fig. 4.

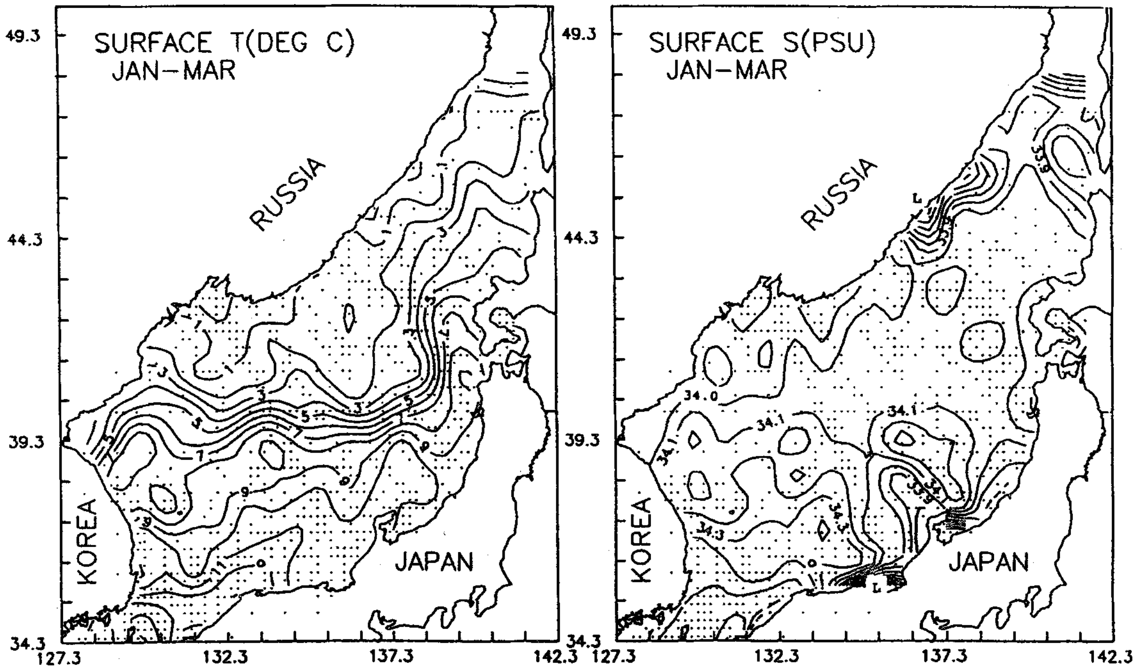

Fig. 10. Distributions of climatological mean surface temperature and salinity in winter season. Others are the same as Fig. 4.

On section A, the local convection is centered between warm waters both nearshore and offshore. The latter one seems to be the direct effect of the polar front formed by the northward extension of Tsushima Current Water (hereafter TCW). The former one may be the coastal water which might also be affected by the TCW. It seems that the convection is more or less supressed by the presence of TCW at this location. This region might thus be the southern limit of convection (refer also to Fig. 9).

On section C, the vertical stability is generally low compared to other sections and the local convection center occurs near the coast with somewhat larger offshore extension. It seems that the surface cooling is the strongest at the coast and decreases offshore. Unfortunately, there is no measurement on section B and further detailed description about the convection here is impossible.

On sections D and E, the local convection centers are found offshore again. Like the previous sections, there is a warm water offshore. Nearshore, however, we find the same temperature inversion as those mentioned earlier. It is no doubt due to the cold fresh surface water (temperature and salinity less than 1°C and 33.9 psu, respectively, as defined above) as shown on section E for example. This cold fresh water has large amount of buoyancy which greatly prevents convection. Even though the cooling is the most intense in this area, with water temperature descending to freezing point near the coast, the buoyancy hardly changes as long as the salinity remains the same, as already mentioned earlier.

On section F, the northernmost section of 1988–89 cruise, the amount of the cold fresh coastal water defined above seems to be greatly reduced (c.f., Fig. 9). It is not known whether this coastal water is again found further north. However, in regard to the situation in winter 1984–85 (Fig. 4) and also that of climatological mean which will be shown later (c.f., Fig. 10), it is most probable that this cold fresh coastal water is continuously found northward with its reduction in amount on section F being only occasional and local. In fact, the largest source of fresh water in this region seems to be the Amur River found further north near the Tatarskiy Strait (Martin *et al.*, 1992) which discharges large amount of fresh water in May; the salinity near this region greatly reduces from more than 32 psu to about 27 psu in May (Academy of Sciences, USSR, 1961, p. 172).

The geographical distribution of these local convection centers (crosses in Fig. 9) indicates that the presence of both the cold fresh coastal water defined above and the warm TCW greatly control the localization of convection. The southernmost local convection center (on section A) seems to be driven northward off the polar front and the others in the north except that on section C, off the area of cold fresh coastal water defined above, though it is off the warm coastal water in the south. Locations of convection can therefore be restricted to the region north of the polar front and outside of cold fresh (occasionally warm) coastal water. It is remarked that, even within this region, convections tend to occur nearshore. A tentative explanation might be as follows: first, surface cooling is the most intense at the coast and decrease offshore because the cold, dry continental air mass is modified while moving offshore from the coast (c.f., Seung, 1987) and second, surface buoyancy is supplied by northward diffusion of warm water from the polar front.

The presence of cold fresh coastal water is thus the major factor to prevent the convection in the northern part where the surface cooling might be the most intense over the basin (Martin *et al.*, 1992). In this regard, the climatological mean feature of this region emerges as quite important. In fact, the presence of cold fresh water seems to be usually observed in winter (Fig. 10), as well as in summer (not shown here), in this region. This fresh water extends its influence further southward along the Russian coast though its salinity becomes much higher in the south.

A very low temperature area (lower than 1°C) is remarked near to Vladivostok. This area is not far from the location of low static stability observed above (on section C, Fig. 7). In fact, it is possible that convection is stronger nearer to Vladivostok as indicated by the mean surface temperature distribution. Concerning this, it is interesting to remark that the access from the sea to the land across the coastline is greatly hindered by highlands along the Russian and Korean coasts only except the area around Vladivostok (refer to ordinary geographic map). Cold and dry northerly wind in winter will therefore be the most direct and thus effective at this location. Similar example about geographic effect can be found in the MEDOC area (MEDOC Group, 1970).

5. Discussion

The present study confirms the suggestion about the location of convection proposed previously by Senjyu and Sudo (1994) and provides some information about convection. However, it is not yet sufficient to fully understand the convection in the Japan Sea.

Most of early studies on open ocean convection suggest the model physics as follows (MEDOC Group, 1970; Killworth, 1983): first, the preconditioning phase in which large- or small-scale cyclonic gyres, bottom topography or baroclinic instability plays the role of removing the existing buoyancy and making the area eligible for convection; second, the violent mixing phase in which deep homogeneous water columns called chimneys are formed; and finally, the sinking and spreading phase in which baroclinic instability plays also an important role (Gascard, 1978; Jones and Marshall, 1993).

Compared to these typical cases, the convection in the Japan Sea seems to be much weaker both in depth and frequency of occurrence. The pre-existing buoyancy, mostly near the coast, emerges as a critical factor in the preconditioning phase if we borrow the traditional concepts mentioned above. The offshore decreasing surface cooling should also take part in this process. As for the location of the most intense convection, probably near Vladivostok, the geographic effect mentioned in the previous section may play an important role. These possibilities should be more clarified in the near future.

As in most of the typical open ocean convections, this area has also been believed to have one or two large-scale cyclonic gyres around the convection areas (Uda, 1934); the periphery of this gyre (gyres) consists of the Liman Current flowing southward along the Siberian/North Korean coast and the offshore extension of this current flowing eastward along the polar front. However, this (these) does not seem to play any role in convection process. To understand the processes like those other than the preconditioning phase, among the above mentioned three phases in typical open ocean convection, specially designed observations are required but no attempt has been made until now.

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