Spatio-Temporal Characteristics of the Ullung Warm Lens*

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We studied the spatio-temporal characteristics of the Ullung Warm Lens (UWL) using the historical oceanographic data of the National Fisheries Research and Development Agency of Korea in the East Sea from 1967 to 1983. The UWL is basically a subsurface phenomenin found in 100 to 300*m* depths, and its existence is not well posed in the distribution of the sea surface temperature. The UWL has a typical size of 100 *km* diameter, and its center migrates within the region of 150 by 150 *km* south of the Ullung Island. The UWL is almost a permanent feature, and the probability of its occurence within our study area (129~132°E, 36~38°N) was 86%.

Introduction

The spatio-temporal variability of the sea water temperature in the southwestern part of the East Sea (Japan Sea) is closely related with the ocean current system in that region. The Tsushima Warm Current, which enters the East Sea through the Korea Strait, separates into two or three branches (Kawabe, 1982; Kim and Legechis, 1986). The East Korea Warm Current, which is the western branch of the Tsushima Current, flows northward along the east coast of Korea and separates from the coast. On the other hand, the North Korea Cold Current, which is an extension of the Liman Current flowing southward along Siberian coast, flows southward along the east coast of Korea and also separates from the coast. The extensions of the East Korea Warm Current and of the North Korea Cold Current, after they leave the east coast of Korea, from the Polar Thermal Front in the East Sea. The positions and variabilities of the thermal fronts in the southern East Sea were documented by Gong and Lie (1984).

The Polar Thermal Front has a meandering feature near the Ullung Island (130°55′E, 37°30′N). The meandering feature of the Polar Thermal Front is represented well in the distributions of subsurface water temperature. Fig. 1. shows the annual means of water temperature at 0, 100 and 200*m* depths in the East Sea, which were constructed from the data reported by Naganuma and Ichibashi (1985). Fig. 1 yields that the water temperatures in the subsurface layer (100 and 200*m*) near the Ullung Island are relatively higher than those in its surrounding. This relatively warmer water near the Ullung Island is called as the Warm Core in the East Sea (Na and Kim, 1990), the Ullung Warm Eddy (Seung et al., 1990), or the Ullung Warm Lens (Cho et al., 1990). In this paper we call it as the Ullung Warm Lens (hereafter, it is abbreviated to the UWL). The mean oceanographic charts of the water temperatures in the neighbouring seas of Korea, which was published by the Fisheries Research and Development Agency of Korea (1986), also show the existence of the UWL.

Cho et al.(1990) presented the three-dimensional

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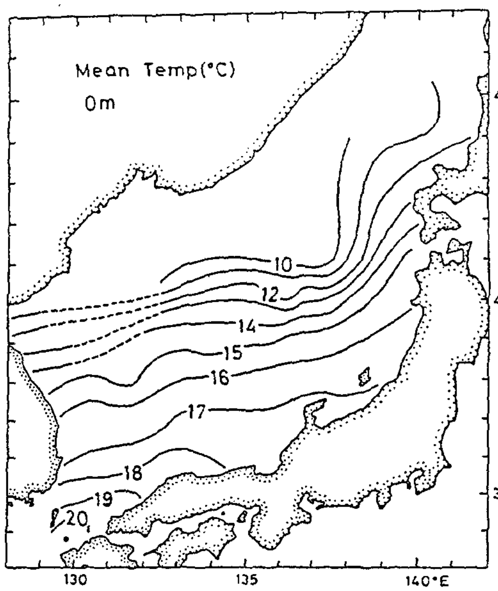
structure of the UWL using the temperature distributions in Augusts of 1981, 1982 and 1986. In this paper we present not only the spatial distribution but also the temporal variability of the UWL using the bimonthly time series of temperature distributions for 17 years (1967~1983). The main objective of this paper is to answer the followings: Is the appearance of the UWL a persistent or intermittent? Does the UWL occur at the same place or its location differ from time to time? What are the horizontal and vertical scales of the UWL?



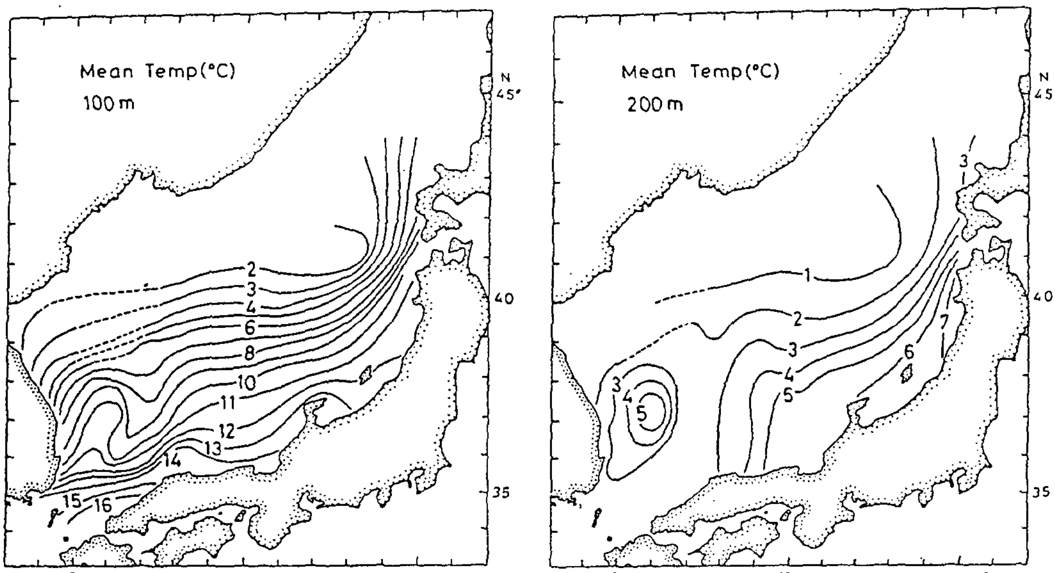


Fig. 1. Distributions of yearly mean water temperature at 0, 100 and 200*m* of the East Sea from Naganuma and Ichibashi(1985).

Data and Method of Analysis

Our analysis is based on the bimonthly seawater temperature data for 17 years (1967~1983) at the oceanographic stations shown in Fig. 2, which have been maintained by the National Fisheries Research and Development Agency of Korea (FRDA). The bimonthly (February, April, June, August, October and December) time series of seawater temperatures at standard depths (0, 10, 20, 30, 50, 75, 100, 125, 150, 200, 250, 300*m* and deeper ones) are available at those stations.

Since the water temperature in the surface layer of 0~100*m* are greatly influenced by the heat exchange across the sea surface, we used the temperature data mainly in the subsurface layer of 100~

200*m* depths in studying horizontal distribution and temporal changes of the UWL. The changes in the temperature in the subsurface layer are expected to be controlled mainly by the advections of heat associated with ocean currents. We generated the time series of heat content in the subsurface layer of 100 to 200*m* by employing the trapozoidal integration of the water temperatures at 100, 125, 150 and 200*m*, and the vertically averaged temperatures are obtained by dividing the heat content by the thickness of the layer. The time series of vertically averaged subsurface temperature (hereafter the vertically averaged temperature in the subsurface layer of 100～200*m* is simply referred to as the subsurface temperature) at 38 stations inside the dotted rectangle of Fig. 2 are used as the basic data set in studying the horizontal scale and locating the basic data set in studying the horizontal scale and locating the position of the UWL, and also in studying the temporal variability of the UWL.

The normals of subsurface temperature are computed by averaging the water temperatures in the same months during 17 years (1967～1983). For visual investigation of the UWL, we constructed 66 consecutive bimonthly maps of subsurface temperature for 11 years (1973～1983). From those maps we identified the location of the UWL, and counted the occurences of the center of the UWL within each of the half-degree rectangles in Fig. 6. In this paper we define the center of the UWL as the location with the maximum subsurface temperature, which is higher than the temperatures of its surroundings water.

The FRDA has been maintaining the bimonthly hydrocasts, almost without missing data, at stations inside of the dotted rectangle in Fig. 2. During the period of the Cooperative Study of the Kuroshio (CSK) in 1967～1969, the hydrographic casts along the Oceanographic Line 104 had been extended up to the Station 104～21 (see Fig. 2). The Oceanographic Line 104 passes approximately the center of the UWL. In this paper we present the vertical distributions of seawater temperature in the 0～300*m*

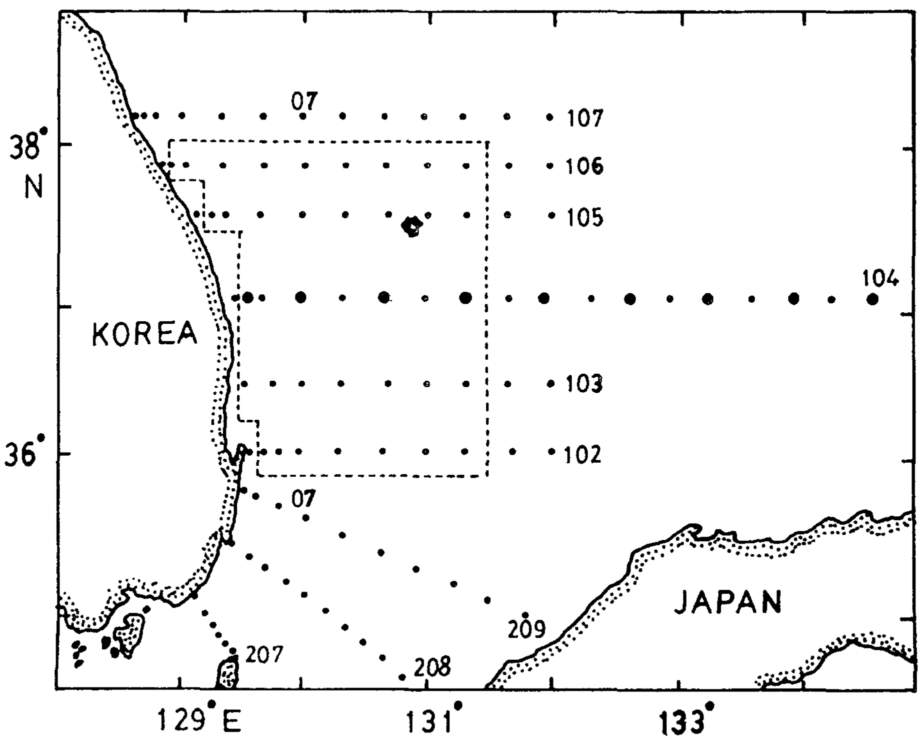


Fig. 2. Oceanographic stations of the FRDA in the study area.

layer along the Oceanographic Line 104. We inferred the vertical structure of the UWL from the vertical distributions of water temperature along the Oceanographic Line 104.

Characteristics of the UWL

1. Normals of Subsurface Temperature

Maps of bimonthly normals of subsurface temperature for 17 years (1967~1983) are shown in Fig. 3. This figure shows that the isotherms of subsurface temperature in the coastal zone, within 100*km* from the coast, are almost parallel to the coast. In this coastal zone, the subsurface temperature generally increases with offshore distances. In other words, the subsurface (water) temperature in the vicinity of the coast is lower than that in the offshore region.

In the offshore region, at distances greater than 100*km* from the coast, the isotherms are not parallel to the coast. The subsurface temperatures in an area with a diameter of an order of 100*km* in the southern vicinity of the Ullung Island are relatively higher than those in the south or north of that area. This area with relatively warmer subsurface temperature than its surrounding temperature corresponds to the UWL area.

2. Temporal variation of the UWL

In order to demonstrate the temporal evolution of the UWL, we presented the successive bimonthly maps of subsurface temperature for 1 year in Fig. 4. The year of 1982 is chosen as an example in Fig. 4. From February to August in 1982, the centers of the UWL were located approximately 50 *km* south of the Ullung Island. In October and December of 1982, however, the centers were located in the west of the Ullung Island. The six successive maps of subsurface temperature in 1982, shown in Fig. 4, show that the location of the UWL change with time.

There arises a question whether the distribution of the subsurface water temperature repeats the same pattern with season or not. In order to answer this question, we present the maps of subsurface temperature in Augusts for 8 years from 1974 to 1981 in Fig. 5. According to this figure, the distribution of subsurface temperature in our study area does not repeat the same pattern with season. The location of the UWL in Augusts from 1974 to 1981 differs from year to year. In particular, the UWL was not found in our study area in August of 1979. On the other hand, the distirbution of the subsurface temperature in August of 1981 was characterized with ring-like distributions.

Fig. 5 also shows us that the magnitudes of subsurface temperature in Augusts in the central part of UWL differ from year to year. For example, the subsurface temperature at the center of UWL in August of 1975 reached up to 14℃, while only up to 7℃ in August of 1981.

3. Persistency of the UWL

The UWL is found almost all the time in the southern part of the Ullung Island. However, there were cases of no evident existence of UWL in our study area. Among 66 successive bimonthly maps of subsurface temperature from 1973 to 1983, we identified 57 cases with an existence of UWL in our study area (129~132°E, 36~38°N). This means that the probability of an existence of UWL in our study area is 86%.

For the cases with an existence of UWL in our study area, we visually determined the locations of the center of UWL and counted the occurence inside each half-degree squares. Fig. 6 shows the probability and frequency of the occurence of the center of the UWL in each of a half-degree squars. From this figure we learn that the center of the UWL in each of the UWL is scattered in an area of 150 by 150*km* in the southern vicinity of the Ullung Island. The hatched area in Fig. 6 indicates squares where the center of the UWL had been located more than 6 times (probability of 10%) during the 66 successive bimonths in years of 1973~1983. About 60% of the center of the UWL was located inside of 4 hatched squares of Fig. 6.

4. Thickness of the UWL

Fig. 7 shows the distribution of water temperature in the upper 300*m* layer along the Oceanographic Line 104, which passes approximately the center of the UWL. Fig. 7 yields the followings: The

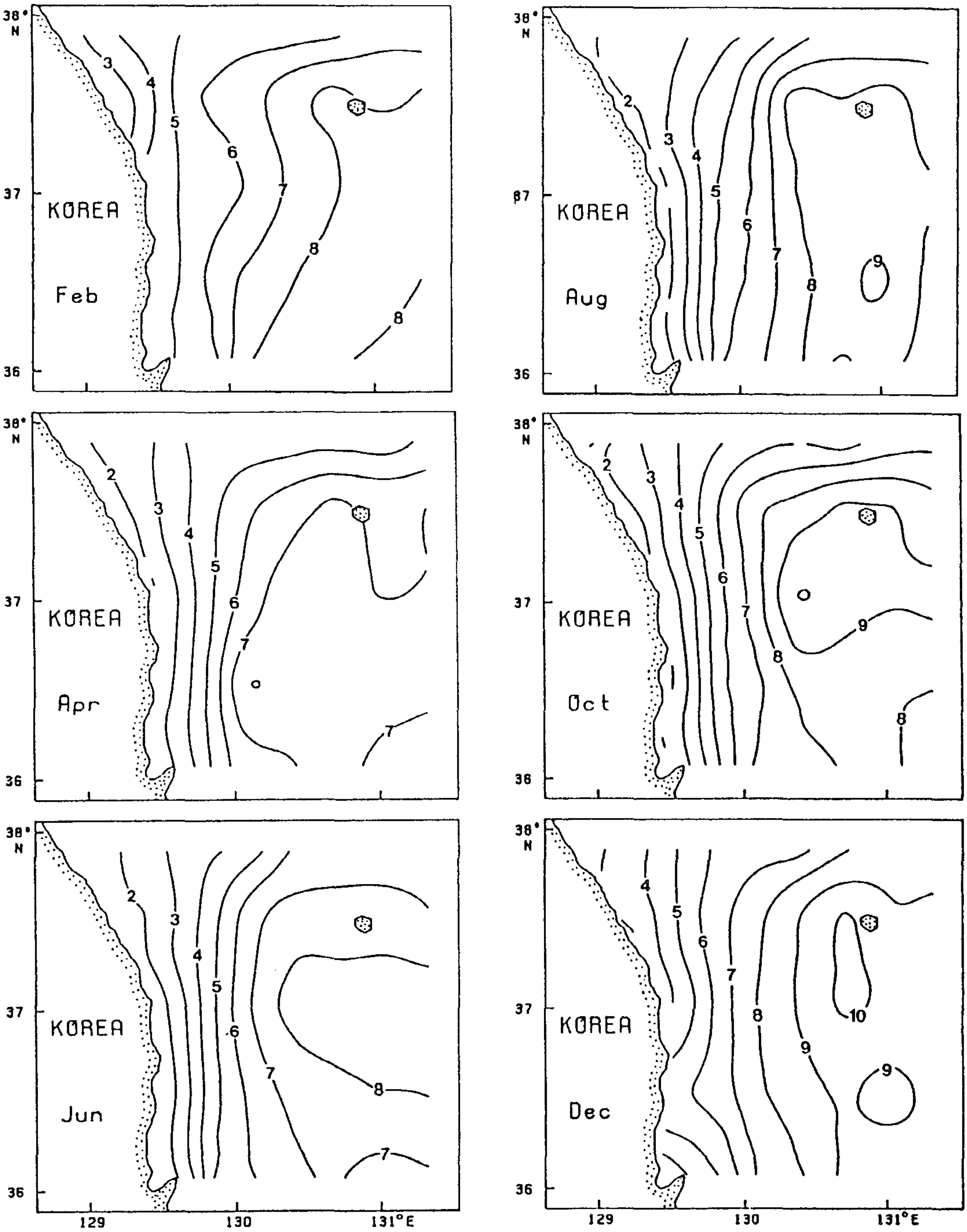


Fig. 3. Bimonthly normals of water temperature in the subsurface layer of 100 to 200*m*.

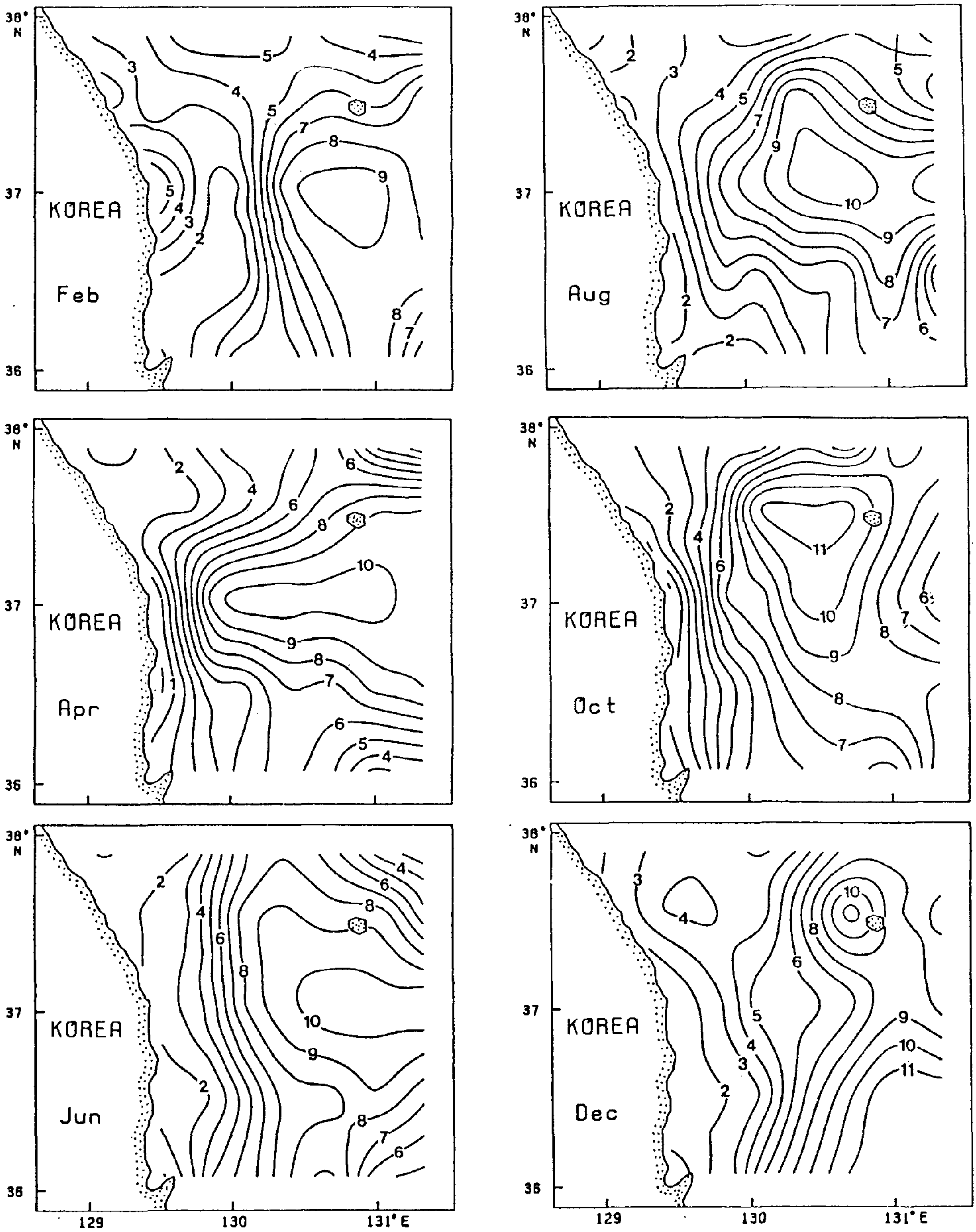


Fig. 4. Temporal variation of subsurface water temperature at successive bimonths in 1982.

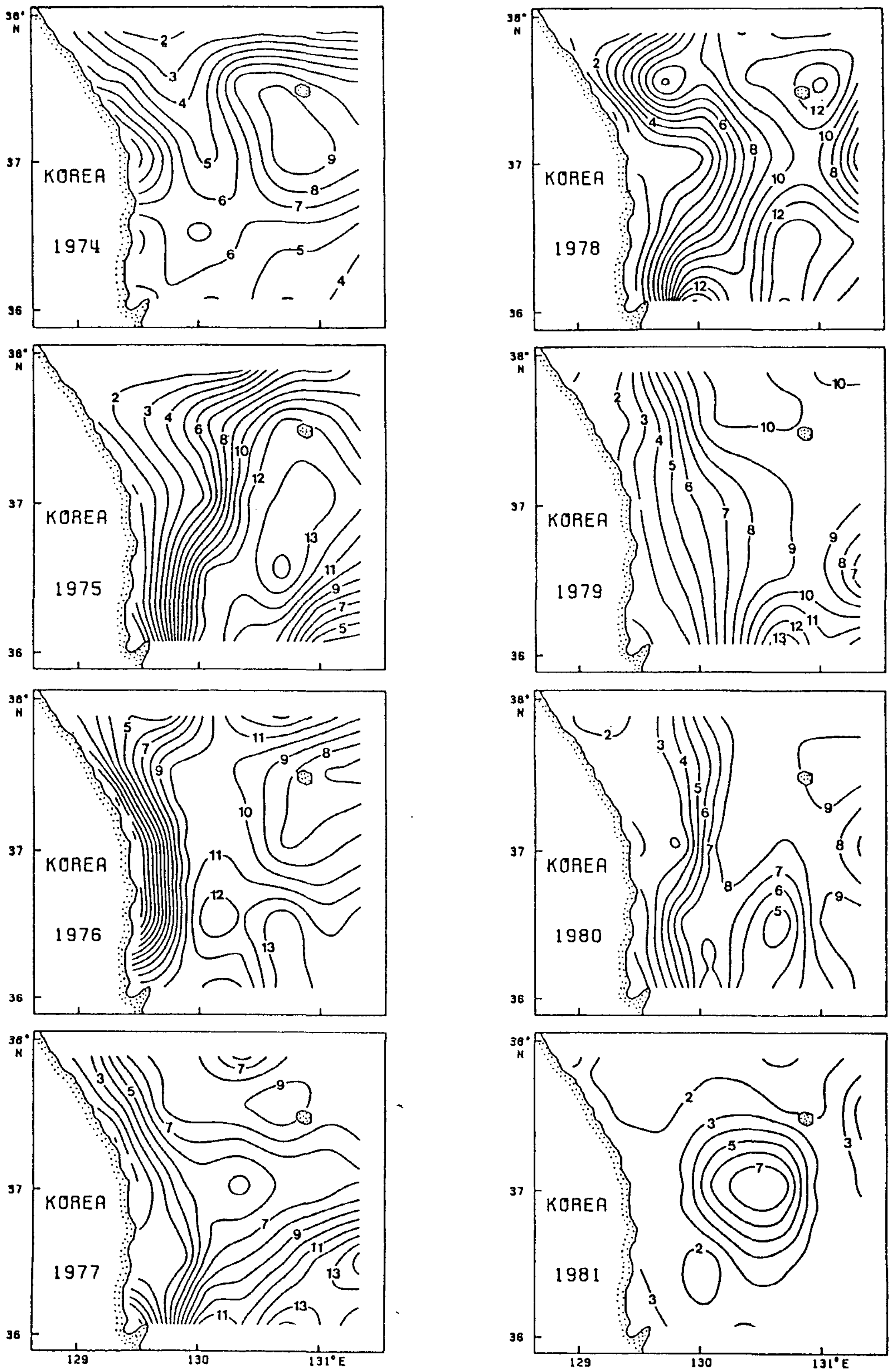


Fig. 5. Distribution of subsurface water temperatures in eight Augusts from 1974 to 1981.

UWL is characterized by a relatively warmer subsurface temperature than that in the surrounding at the same depths. The symptom of the UWL is not apparent from the distribution of sea surface temperatures. That is, the distritution of the sea surface temperature does not distinctively indicate the existence of the UWL in the subsurface layer. Along the vertical section of the Oceanographic Line 104, the UWL was usually found in the subsurface layer of 100 to 300*m*, but in August of 1969 it was found in the subsurface layer of 100 to 250 *m*. The horizontal extent of the UWL along the Oceanographic Line 104 was 160*km* from Station 7 (130°00′E) to Station 13 (131°53′E).

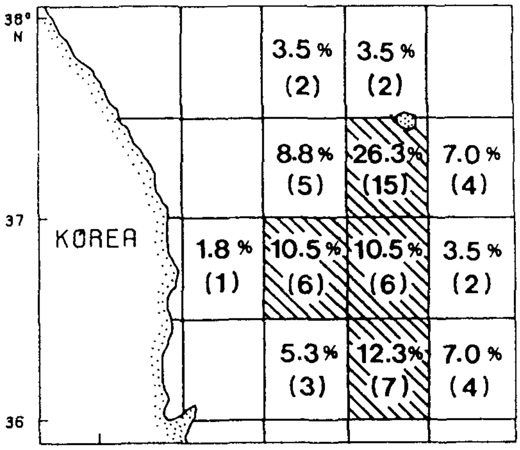


Fig. 6. Frequencies of occurences of the center of UWC in half-degree squares during 1973 to 1983.

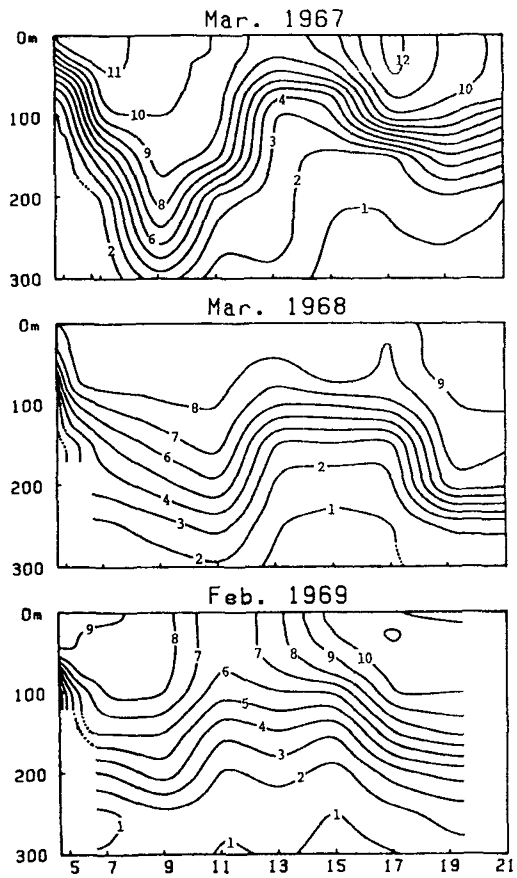


Fig. 7a. Distribution of water temperatures along vertical section of the Oceanographic Line 104 in winters of 1967, 1968 and 1969.

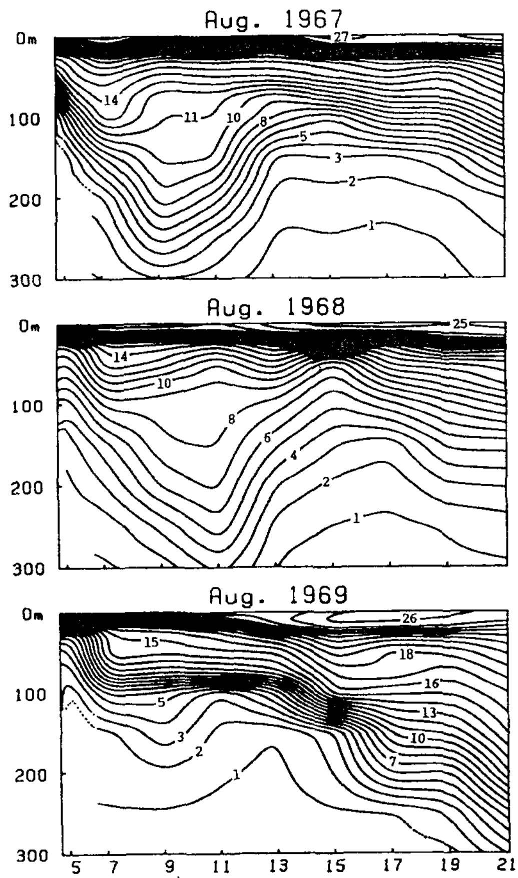


Fig. 7b. Distribution of water temperatures along vertical section of the Oceanographic Line 104 in summers of 1967, 1968 and 1969.

Discussion and Conclusions

In this paper, through analysis of the historical oceanographic data by the National Fisheries Research and Development Agency of Korea, we presented the spatio-temporal characteristics of the UWL. The major features of the UWL are as follows.

The UWL has relatively higher water temperature than its surrounding waters. the UWL is found almost all the time in the subsurface layer (100~300*m*) in the southern part of the Ullung Island in the East Sea. According to the successive bimonthly data for 11 years (1973~1984), the chance for the existence of the UWL in the strudy area (the dotted rectangle area in Fig. 2) was 86%. The typical size of the UWL is of an order of 100 *Km*. The UWL is basically a subsurface phenomenon found in the 100 to 300*m* depths layer, and its existence is not well posed in the distribution of the sea surface temperature. The location of the UWL center is not fixed in space: the position of the center migrates in the region of 150 by 150 *Km* in the south of the Ullung Island. Apparently, the spatial distribution of the UWL does not repeat the same pattern with an annual cycle.

The water temperature in the UWL is higher than its surrounding, and this feature suggests that the waters in the UWL are originated from the Tsushima Warm Current. The northern boundary of the UWL is confronted with the Polar Thermal Front in the East Sea. Geostrophic balance associated with the thermal distribution of the UWL indicates that the currents around the UWL are anticyclonic (clockwise) flows.

Numerical model study by Seung et al. (1990) showed that a combined effects of differential cooling and bottom topography is responsible for the formation of the UWL. Rotary tank experiments by Na and Kim (1990) suggests that the bottom topography is one of the important factors for the formation of the UWL. The mechanisms for the temporal variability of the UWL should be further explored.

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