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ON THE SEASONAL VARIATIONS OF SURFACE CURRENT IN THE EASTERN SEA OF KOREA (AUGUST 1979-APRIL 1980)

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ABSTRACT

The seasonal variations of surface current patterns in the Japan Sea were drawn out from the results of drift bottle experiments, current measurements and hydrographic observations during 1979~1980.

The North Korean Cold Current(NKCC) and the East Korean Warm Current(EKWC) were common features of circulation in the eastern sea of Korea. The intrusion of NKCC along the Korean coast became strong in summer(average velocity of 47.4cm/sec off Jumunjin and 23.4cm/sec near Jugbyeon) when the Tsushima Current was strong. But there was no indication of the NKCC in November 1979. Dynamic topography(August & November 1979) and satellite picture (November 1979) seemed to show the topographic steering of EKWC beginning off Janggigab. Drift bottles arrived at the Japanese coast were affected significantly by the strong Tsushima Current in summer and by the predominant northwesterlies in winter instead of weak current.

INTRODUCTION

Since Suda and Hidaka(1932) and Uda(1934) proposed the basic current pattern in the Japan Sea, Fukuoka(1957), Tanioka(1962), Moriyasu (1972) and others have studied the meandering of the Tsushima Current chiefly in the eastern part of the Japan Sea. Nishida(1932), Chang and Uda(1968), Tanioka(1968) and Lee and Bong(1968) studied the circulation in the western part of the Japan Sea. Many efforts have been devoted to understand the occurrence of the cold water mass around the southeastern coast of Korea in summer(Ann, 1974: Seung, 1974: Lee, 1978).

Local phenomena such as the upwelling off Ulsan may have close relations with large scale features of currents including the interaction between the Tsushima Current and the North Korean Cold Current. Therefore, the determination of current structure and its variation is an important problem of increasing interest to many disciplines of oceanography.

Simultaneous investigations of current measurements, hydrographic observations and drift bottle experiments were carried out in the eastern sea of Korea during August 1979 and April 1980. From these results we describe a study on the surface current in the Japan Sea. The coastal current flowing southward will be referred to as the North Korean Cold Current (NKCC) and the northward branch of the Tsushima Current as the East Korean Warm Current(EKWC). The purposes of the study are to identify the characteristics of the NKCC and to describe the seasonal variations of surface current in the Japan Sea.

METHODS

A. Drift bottle experiments

A total of 11,700 drift bottles were released

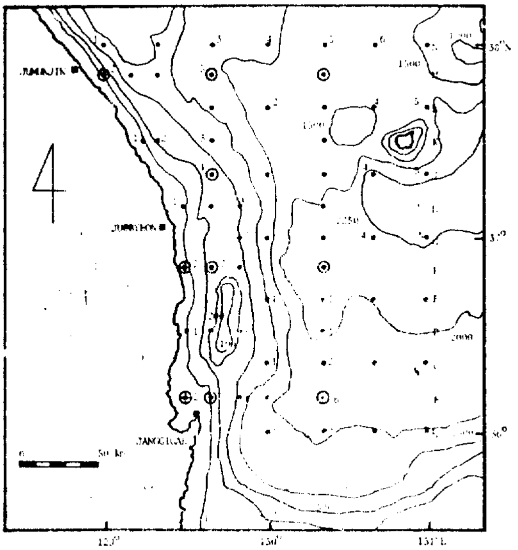


Fig. 1. Location chart showing positions of drift bottle release(circle), current measurement (cross) and hydrographic observation(dot).

in groups of 300 at 10 points(Fig. 1) during the four cruises(August & November 1979, February & April 1980). In order to determine the boundary between the NKCC and the EKWC, 3 points in the coastal regions, 3 points in the intermediate regions and 4 points in the offshore regions were selected. Release at J-1 was omitted in the first experiment.

Ballasted with sand, plastic drift bottles of 18cm in length, 6.7cm in diameter, 300 gr in weight were carefully prepared to reduce the direct influence of wind upon the bottle movements.

The authors divided the whole areas of recovery into 11 regions(Fig. 2) and sorted all the returned cards in accordance with the divisions for systematic analysis. When the cards in each division were more than 15, drift period was represented by the mean and standard deviation, if not, the range was recorded.

B. Hydrographic observations

Temperature and salinity were observed using the Nansen bottle and a Plessey Model 9090 X-STD system to show the distributions of tem-

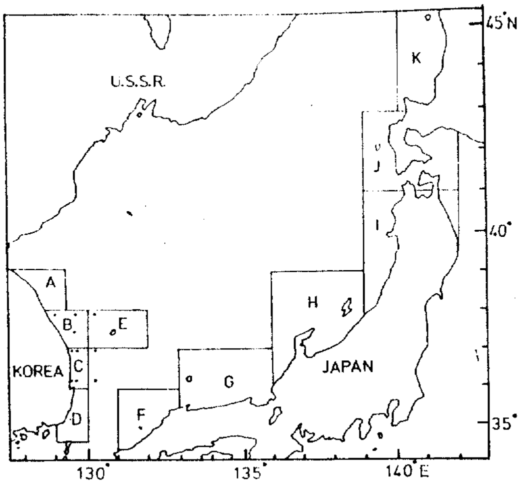


Fig. 2. Division of recovery areas

perature, salinity and dynamic topographies (Fig. 1).

C. Current measurements

It is very difficult to know the state of current in shallow region by the indirect methods such as dynamic technique. Therefore, currents of surface, intermediate and deep layers were measured at 3 stations (Fig. 1) in the coastal areas for 25 hours at the intervals of 10 minutes with CM-2 and Braystoke current meters.

Current vector stick diagrams and average velocities of the surface layers were compared with the results of drift bottle experiments.

RESULTS AND DISCUSSION

Surface current features were obtained by means of dynamic topographies. In order to extend the contour lines of dynamic height anomaly to the wide area of shallow water off Jugbyeon-Janggigab coast at the expense of accurate estimation of current velocity, 100 decibar surface was chosen as a reference level although Fukuoka(1957) suggested 300 decibar surface as a level of no motion. The reference

Table 1. Results of the drift bottle experiment in August 1979. The numbers in the brackets represent drift periods.

Release point	Release date	Areas of recovery											Total number
		A	B	C	D	E	F	G	H	I	J	K	
B-2	8/3	1 (24)	2 (16-42)	30 (11.0±6.0)	18 (5.1±2.7)			2 (208)	2 (235-336)				55
B-3	8/3			26 (9.2±4.2)	23 (6.0±4.1)	1 (53)							50
B-6	8/2		1 (71)					1 (178)	3 (136-239)	1 (171)			6
F-2	8/23		1 (1)	100 (2.0±1.3)									101
F-3	8/7								3 (185-237)	1 (168)			4
F-5	8/7						1 (90)	3 (56-132)	1 (152)	1 (138)			6
J-1	Omitted												Omitted
M-2	8/20	1 (35)	80 (1.8±1.5)	52 (4.1±3.0)									133
M-5	8/21	1 (59)	2 (44-45)	5 (39-59)	9 (39-53)			1 (61)	4 (78-220)				22
M-6	8/21		2 (40-41)	1 (40)	1 (145)				3 (117-202)	3 (86-144)			10

Recovery rate: 14.3%, Total: 387

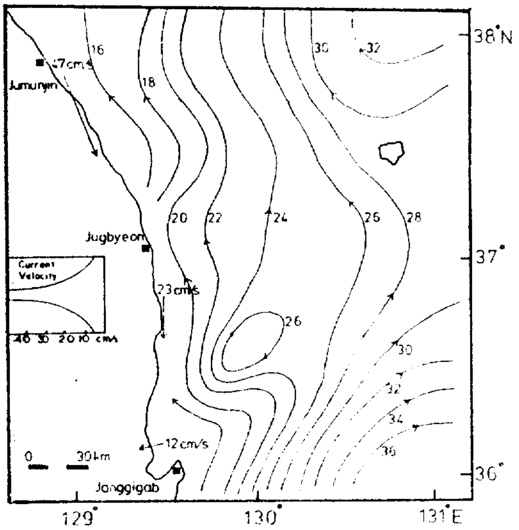
level of 100 decibar surface may be acceptable in the light of the following facts: Smith (1974) expected that the alongshore currents off the Oregon coast were mainly geostrophic. Halpern (1977) used dynamic topographies relative 50 and 100 decibar surfaces to describe the geostrophic surface currents in the Northwest Africa. General patterns of meandering motions around the Oki Islands as well as along the western coasts of Honshu and Hokkaido were referred to Fukuoka (1957), Maritime Safety Agency (1977) and Japan Hydrographic Association (1979).

A. Summer 1979.

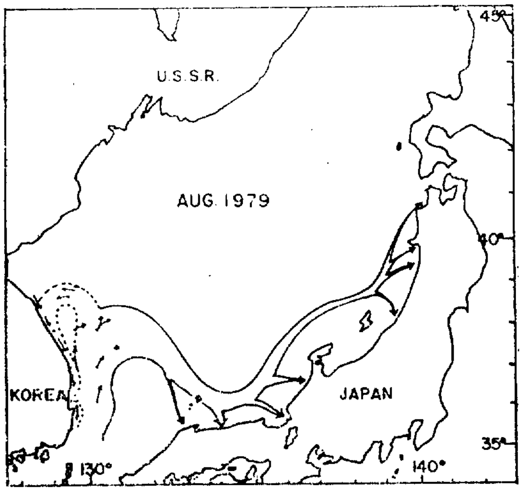
Figure 3-a shows that the EKWC is separated from the Tsushima Warm Current. It is remarkable that the EKWC turns westward off Janggigab and flows northward along the coast. As can be seen in Figure 1, water depth increases rapidly off Janggigab. It is well known that if depth increases, current usually turns cyclonically and makes topographic steering to satisfy the conservation of potential vorticity (Pond and Pickard, 1978).

The NKCC was strong and persistent. Vector-averaged velocity of 25 hours data was 47.4cm/sec in SSE direction at M-2 and 23.4cm/sec southward at F-2. It is difficult to know whether the variations of current at F-2 and B-2 are periodic because the durations of current measurements were too short (Fig. 3-b).

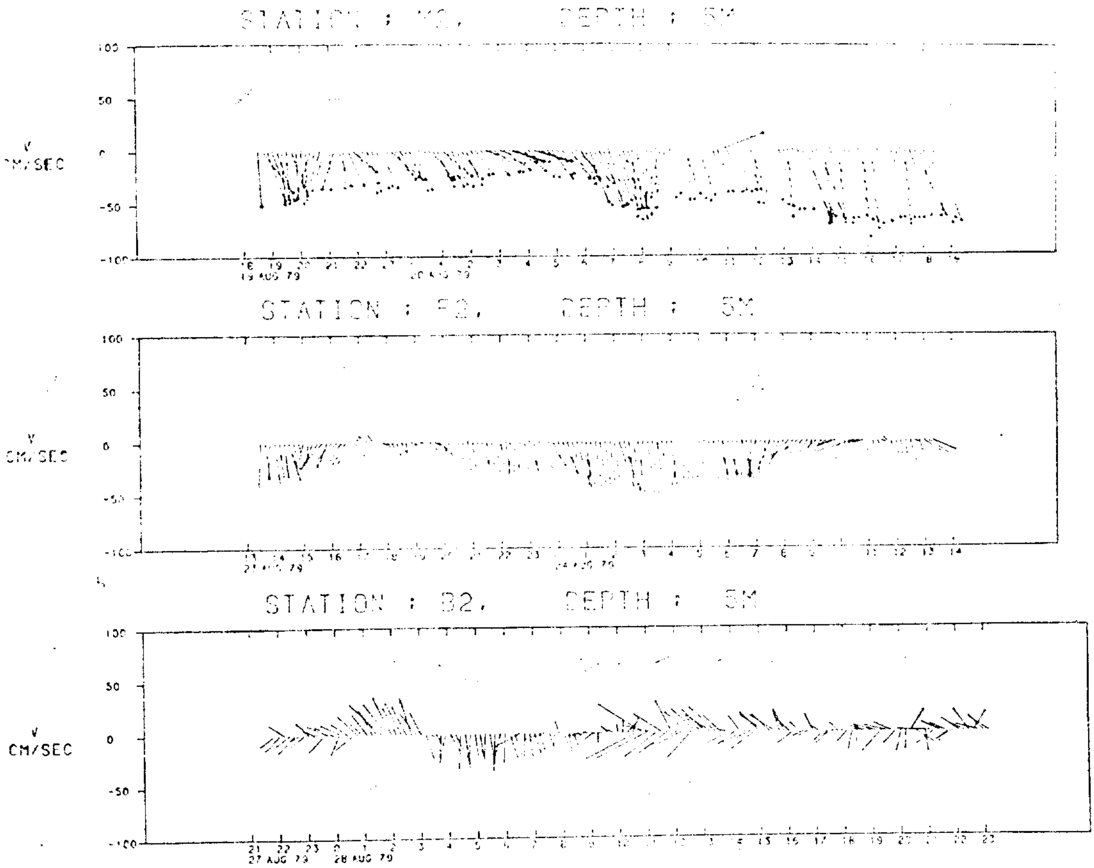
A violent typhoon (Irving) passed over the Japan Sea during 16~18 August. However, it didn't seem to have significant influence on the results of the bottles drifted, because bottles released in the coastal regions (B-3, B-3, F-2, M-2) were mostly recovered along the Korean coast regardless of that event. Most of the bottles released at off-shore stations (B-6, F-3, F-5) were recovered at the western coast of Japan. Meanwhile, many bottles released at M-5 and M-6 were drifted to the Korean coast and some of them were found in the southern areas. It may be explained that they moved northward



(a) Dynamic topography (in dyn. centimeter) relative to 100 db. Arrows at near-shore represent the average velocities of measured currents



(c) Schematic chart showing the approximate drift paths of bottles.



(b) Current vector stick diagram of surface layer.

Fig. 3. Current data in Augst 1979

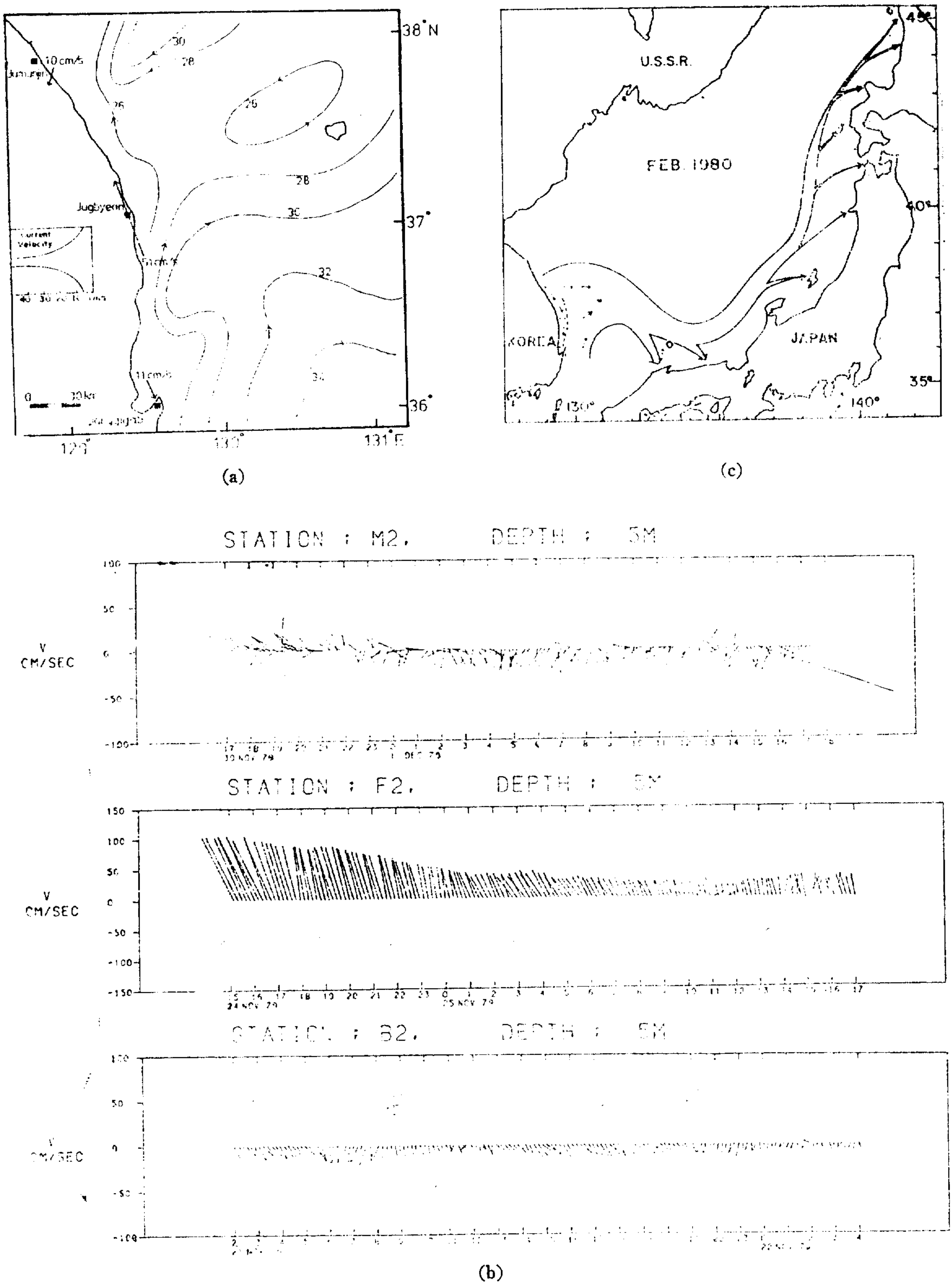


Fig. 4. Current data in November 1979

Table 2. Results of the drift bottle experiment in November 1979

Release point	Release date	Areas of recovery											Total number
		A	B	C	D	E	F	G	H	I	J	K	
B-2	11/21								8(64-129)				8
B-3	11/22								6(92-104)				6
B-6	11/22						24(40.0±22.0)	34(50.4±33.7)	2(55-57)				60
F-2	11/25							2(98)	3(79-128)				5
F-3	11/25					1(25)		5(48-55)	7(54-240)				13
F-5	11/25						3(20-52)	4(41-350)	3(58-102)				10
J-1	12/5					1(22)	2(30-44)	1(86)	3(115-118)				7
M-2	12/1							4(107-209)	6(48-202)				10
M-5	12/2					3(12-45)		3(54-173)	4(85-102)				10
M-6	12/3					1(44)	1(48)	1(55)	8(53-295)				11

Recovery rate: 4.7%, Total: 140

at first and met the strong NKCC near 39°N (Fig. 3-c, Table 1). It is interesting to note that a bottle released at M-6 was found at the northern tip of Tsushima Island 145 days after the release. This may be an evidence that the southward flow of NKCC could be extended to the southernmost part of Japan Sea as Nishida (1932) suggested.

Strength of the Tsushima Current at the northern section of the Korea Strait is maximum(about 1.5 knot) in August and minimum (about 0.2 knot) in February(Lee and Jung, 1977). The bottles released in August are expected to pass the Japanese coast in late fall when the northward current are rather weak. As the results, bottles didn't reach the northern regions of Japan(Fig. 3-c).

B. Autumn 1979.

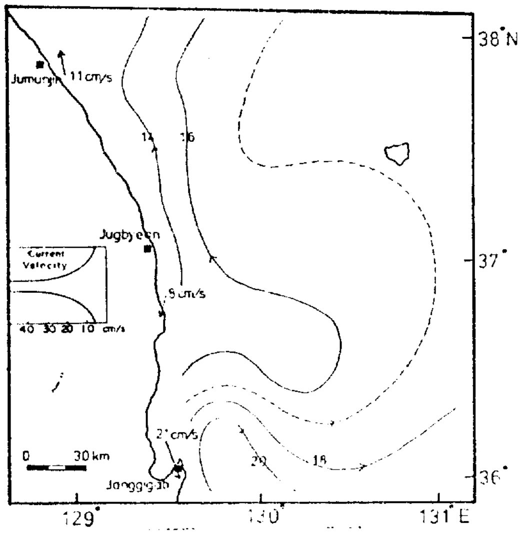
All of the bottles drifted eastward and most of them were dispersed near F-H regions of Japan(Table 2). This might indicate that the NKCC was very weak or absent. At M-2 current was variable but southward component was dominant in general. Very weak southward current less than 10cm/sec persisted at B-2 throughout the whole period. But extraordinarily strong current(average velocity of 51cm/sec) flowing northwestward was recorded at F-2(Fig. 4-b). The approach of the intensified current to the coastline(Fig. 4-a) implies the possibility of such a strong northward flow. At the same time, meandering motion around Janggigab is also noted.

The satellite picture(Plate 1) showed the aspects more vividly. Very weak EKWC meandering off Janggigab produced a cyclonic eddy which seemed to support the arguments in the preceding section. The brightest band along the coast could be considered as the results of cooling effect by land and run-off by the Hyungsan River.

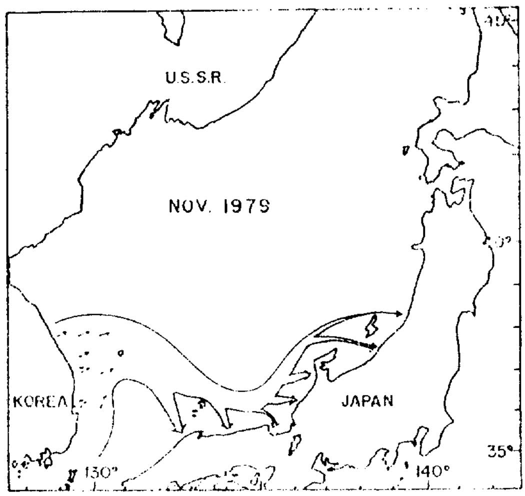
Bottles recovered in F-G regions had relatively short drift periods. The strength of the Tsushima Current is minimum in Winter, nevertheless, predominant northwesterly seasonal winds may accelerate the drifting speeds. Actually, the continental high pressure system of 1038-1054 mb developed frequently in November-December 1979(Central Meteorological Office, 1980).

C. Winter 1980.

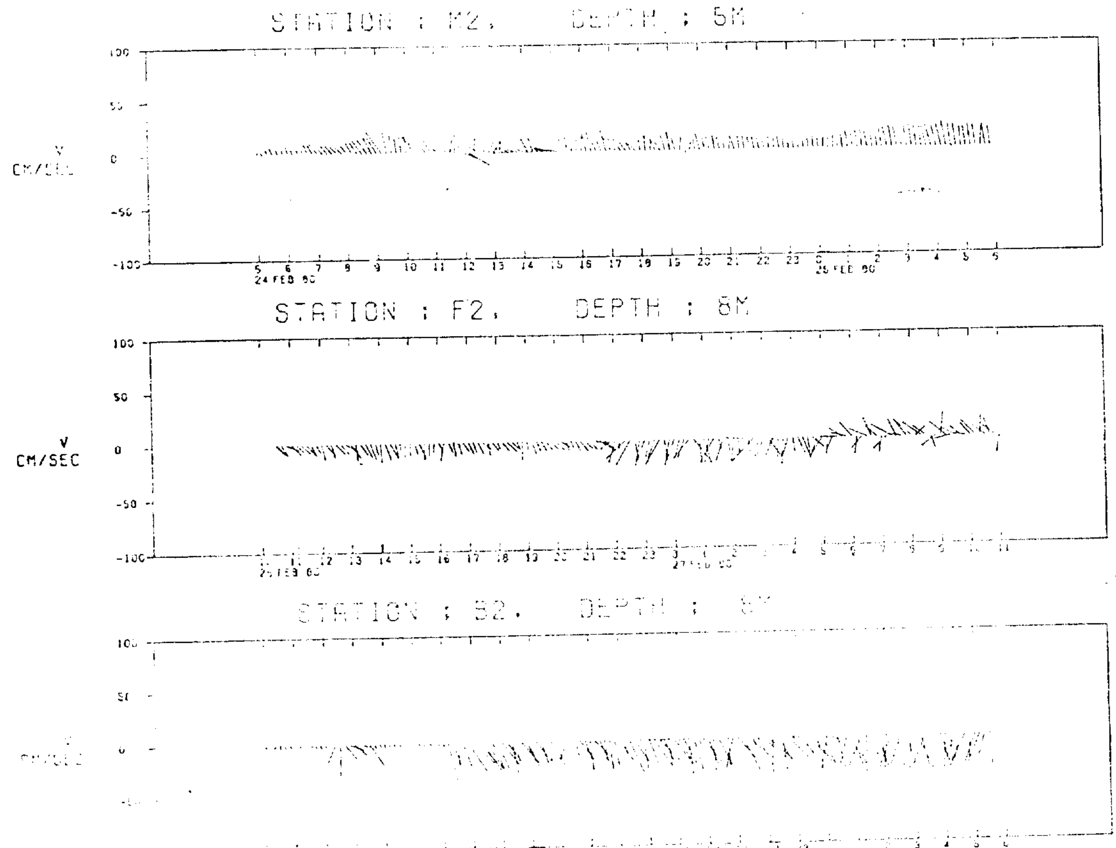
The result of drift bottle experiment is noted for its very low recovery rate(2.1%). The fact that bottles released at F-2, F-3, J-1 and M-6 were recovered in C-D regions suggests there was weak southward flow along the Korean



(a)



(c)



(b)

Fig. 5. Current data in February 1980

Table 3. Results of the drift bottle experiment in February 1980

Release point	Release date	Areas of recovery											Total number
		A	B	C	D	E	F	G	H	I	J	K	
B-2	2/3			1(2)			2(15-26)	6(14-135)		1(135)			10
B-3	2/3						4(15-21)	15(26.5±13.8)					19
B-6	2/12						4(9-34)	5 (18-215)					9
F-2	2/13			2(36-41)		1(66)			1(172)				4
F-3	2/13			1(179)	1(50)			1(21)		2(138-168)			5
F-5	2/18						2(29-65)	1(42)	1(127)			1(159)	5
J-1	2/18			1(39)				1(104)					2
M-2	2/25					1(24)					3(203-209)		4
M-5	2/20						1(21)				2(228-262)		3
M-6	2/20			1(32)							1(230)	1(249)	3

Recovery rate: 2.1%, Total: 64

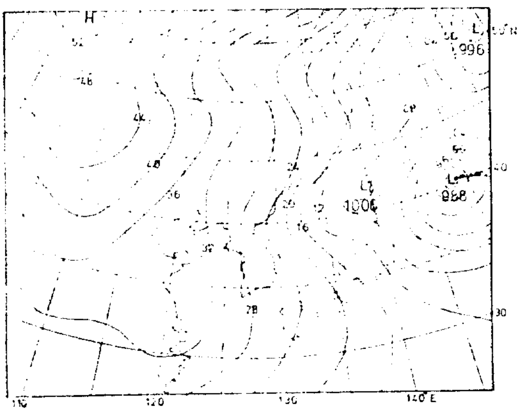


Fig. 6. A Typical weather map in February 1980 (0603i)

coast(Table 3). Southward components of the currents were dominant at F-2 and B-2(Fig.5-b). satellite picture(plate 2) shows an intrusion of NKCC reaching the Jugbyeon area. The currents were quite weak in the open sea(Fig. 5-a).

In about 30 days many bottles reached F-G regions due to the strong northwesterly winds which have been predominant in the whole period of February(Fig. 6). But as they continued to drift, the residual bottles were arrived at the northern part of Hokkaido with the help of the growing Tsushima Current(Fig. 5-c).

Table 4. Results of the drift bottle experiment in April 1980.

Release point	Release date	Areas of recovery											Total number
		A	B	C	D	E	F	G	H	I	J	K	
B-2	4/16		8(8-11)	37(1.2±0.5)									45
B-3	4/16										1(185)		1
B-6	4/9								1(219)				1
F-2	4/17			11(1-11)									11
F-3	4/18					1(22)			1(90)		2(85-103)		4
F-5	4/28			1(101)				1(277)			1(267)	3(163-170)	6
J-1	4/28								1(151)		3(64-151)		4
M-2	4/23		112(2.0±1.5)										112
M-5	4/24								1(108)	1(73)			2
M-6	4/25					1(16)			1(23)		4(74-199)		7

Recovery rate: 6.4%, Total: 193

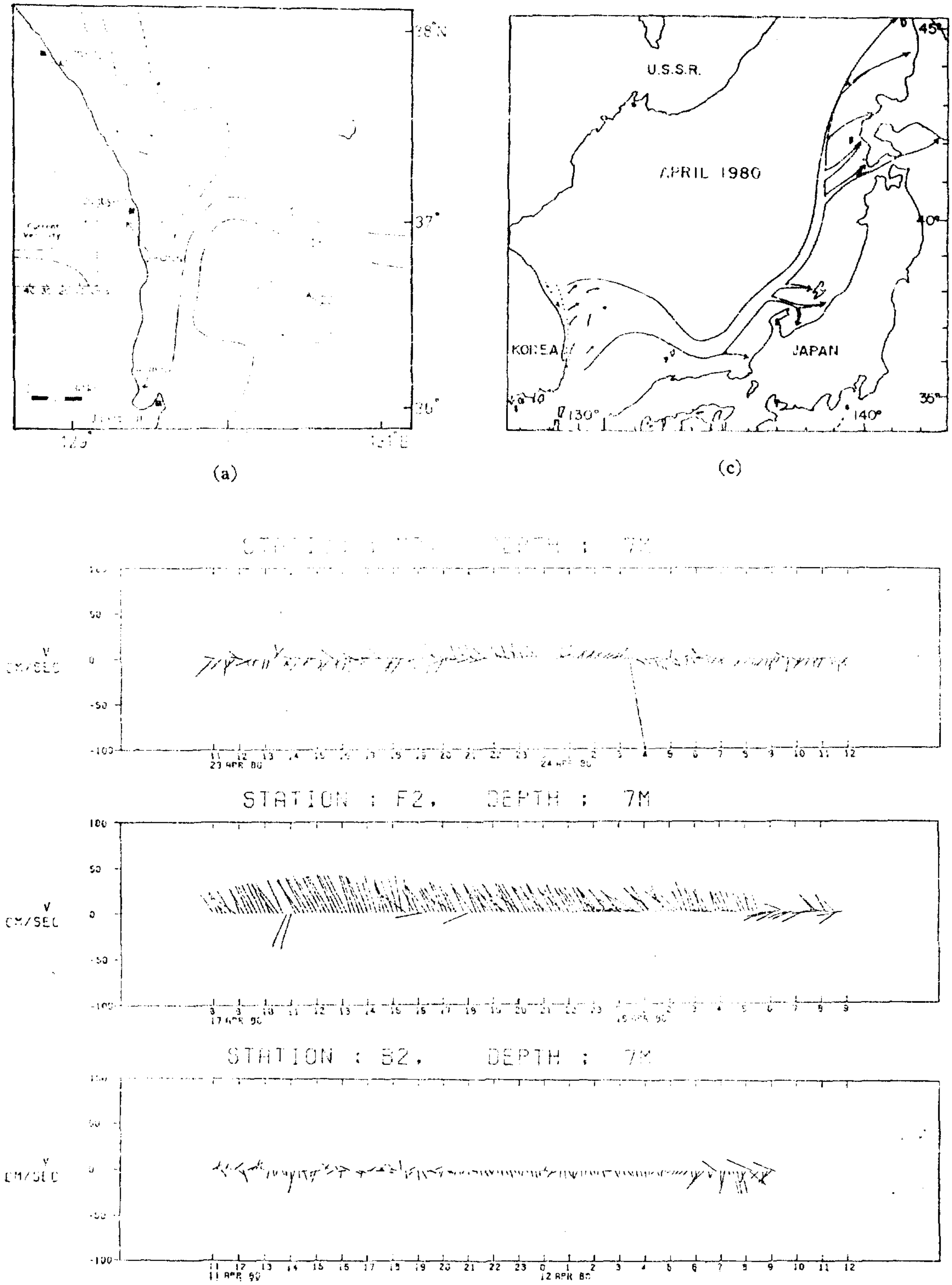


Fig. 7. Current data in April 1980.

Plate 1. Thermal Infrared Picture in 19 November 1979. 0616Z, TIROS-N, ORBIT 5667, AVHRR CHANNEL 4. Dark area represents the warm region.

Plate 2. Thermal Infrared Picture in 27 February 1980. 2310Z, NOAA-6, ORBIT 3487, AVHRR CHANNEL 4.

D. Spring 1980

Currents at M-2 and B-2 were variable, but at F-2, northwestward current was dominant (Fig. 7-b). However, the result of drift bottle experiment suggests the presence of KNCC. Bottles released at F-2 and F-5 were recovered in C region and all the bottles released at M-2 were recovered in the vicinity of B region (Table 4).

Most of the bottles recovered along the Japanese coast reached Hokkaido owing to the intensification of the Tsushima Current in summer (Fig. 7-c).

CONCLUSIONS

It was reported that the North Korean Cold Water Mass characterized by low salinity and high dissolved oxygen content could be traced to the southeastern coast of Koera in summer (Kim, 1979). Drift paths of bottles inferred from the drift bottle experiments and other data seemed to prove the existence of NKCC except for the case in November 1979. This current was persistent and strong in August when EKWC became also strong. But the periods of current measurements were somewhat short to understand the detailed properties of currents.

Distributions of the recovered bottles along the Japanese coast had close similarities with those of Uda (1934) and Lee and Bong (1968). Drift bottles released in August and November didn't reach the northern area of Japan due to the weakened current during the winter season. In winter, predominant northwesterly winds reduced the drifting periods of bottles in spite of the weak currents.

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