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The Kuroshio Fronts and Cold Eddies off Northeastern Taiwan Observed by NOAA-AVHRR Imageries

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ABSTRACT

Over a hundred AVHRR-HRPT thermal imageries of NOAA satellites which covered dimensions 350Km (columns) × 280Km (rows) with center point at 26°N and 123°E, period from October 1989 to December 1990, had been derived to observe the surface features of waters off northeasern Taiwan.

The patterns of Kuroshio fronts in this water (KEEP area) can be generalized to three types: (A) front extending away from northeastern Taiwan northeastwardly, (B) front extending away from northeastern Taiwan northeastwardly, then turning into an anticlockwise frontal eddy, and (C) front extending westward along coast of northern Taiwan then away with an arcuate curve and turning to east. The locations of cold eddies, another major phenomenon in this area, can also be generalized to three types related to Kuroshio fronts: (A) eddy formed with no Kuroshio fronts around, (B) eddy located on cool (west) side of fronts, and (C) eddy located on warm (east) side of fronts.

Front Type-A is the dominant and most stable pattern in summer. On the contrary, in other seasons, all three front types are variable and have different degrees of intrusion onto shelf waters. Regarding the cold eddies, the most common is Type-B, probably existing in each season. The next most common is Type-A, which prevails in summer. The least common is Type-C, which usually appears in winter. Regarding the relationship between front types and eddy types, the most prevailing composition is the cold eddy Type-B associated with the front Type-A.

1. INTRODUCTION

The Kuroshio, a steady boundary current, originates in the west Philippine Sea, then flows by Taiwan Island, East China shelf, east of Japan, and into the sub-polar region of the North Pacific ocean. Generally speaking, the Kuroshio flows along the continental edge between the Asiatic plate and the Pacific plate. When reaching southern area of Taiwan, the Kuroshio divides into two currents: the main current flows along the east of Taiwan and the

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branch flows through Taiwan Strait. After flowing away from the east of Taiwan, the main current passes the Suao Ridge and enters the Okinawa Trough area. It is blocked by the East China shelf and so generates upwelling and cyclonic cold eddies (Chern and Wang, 1989; Su, 1991).

Meanwhile, the upwelled subsurface water intrudes northwestwardly onto shelf and into the East China Sea to form a source of the Taiwan Warm Current (Chern and Wang, 1989). Moreover, the China Coastal Water flows down to the Taiwan Strait, and branches to the north coast of Taiwan. The upwelling and the Kuroshio fronts are much more variable, owing to the effect of topography, current meander, monsoon and other atmospheric disturbances (Yin, 1973; Fan, 1980; Lin and Shyu, 1990). From the past studies on the water chemistry and geology, it is known that the Kuroshio affects the composition and distribution of sediments (Shyu and Chen, 1984) and promotes circulation of nutrients (Liu and Pai, 1987; Liu *et al.*, 1988). The temperature and salinity of main Kuroshio current have less seasonal variation (Chern and Wang, 1989). Kuroshio fronts were formed by the warm and salt Kuroshio water mixing with the relatively cold and fresh shelf water of the East China Sea (Liu and Pa, 1987). However, there are few data that are adequate for monitoring synoptically these phenomena.

Remote sensing is a technique which can be used to identify characteristics of objects by detecting reflections and radiations of targets. Furthermore, satellite remote sensing can offer us realtime and large-scale information about the sea surface property. In this study, detailed and broad range surface features in this area will be analyzed and discussed by using long-period and continuous thermal infrared imageries and data from limited ship cruises. A large amount of NOAA satellite imageries, with high spatial resolutions, were derived to study the hydrographic phenomena, Kuroshio fronts and cold eddies, in waters off northeastern Taiwan.

2. MATERIALS AND METHODS

AVHRR (Advanced Very High Resolution Radiometer) imageries through HRPT (High Resolution Picture Transmission) unit were received and their MCSST (Multichannel Sea Surface Temperature) maps were generated by a NOAA statellite ground station in Taiwan Fisheries Research Institute. That installation locked digital signals from satellites NOAA-9, NOAA-10 and NOAA-11, then received, transferred and stored data automatically at least 6 times everyday (Lin and Shyu, 1990). In total, 405 available imageries of passes from 457 days (cross marks in Figure 1), October 1989 to December 1990, had been selected, and image processes were conducted. Those days without data are due to hardware malfunctions or clouds. Imageries of NOAA-10 were abandoned because of its low accuracy of calculated MCSST, owing to the channels characteristics. KEEP area, defined with central point 26°N 123°E and 320 pixels (350Km) $\times$ 256 pixels (280Km), then was sliced from the whole rectangle original image (Figure 2). Most of in-situ survey stations named P-Box, one of the sea truth data source, are included in our defined area. CTD data from two cruises (no. 254 and 260) surveys were used to draw thermal contours to compare with satellite MCSST maps.

Some image processing steps were taken in order to get the final MCSST map. These processes such as channels selecting, albedo ratio and brightness temperature calculating, missing lines interpolating, navigation error adjusting, atmospheric moisture model correcting, clouds and lands screening, and geographic correcting were processed by UNIX computer software packages and some C shell procedures. The accuracy of MCSST is about 0.6°C

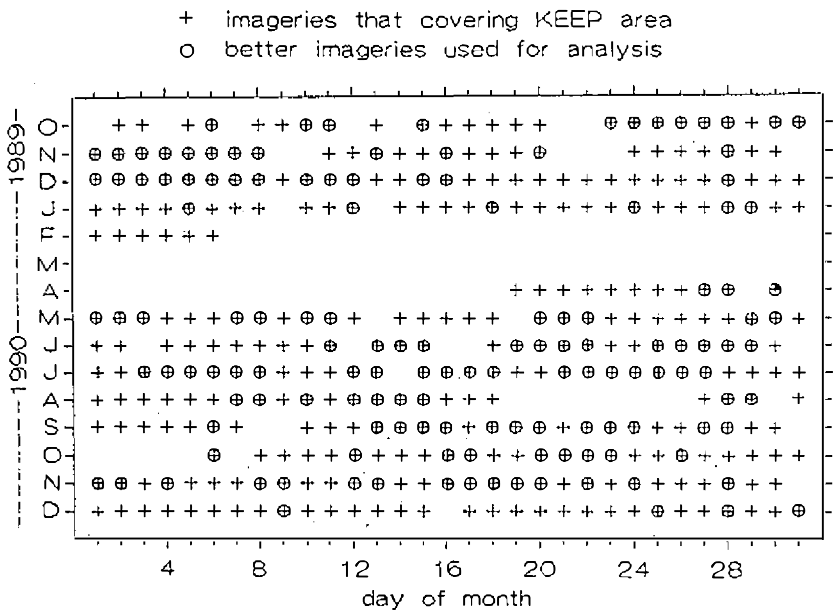


Fig. 1. The day distribution of imageries from Oct. 1989 to Dec. 1990 that cover KEEP area and are used for analysis.

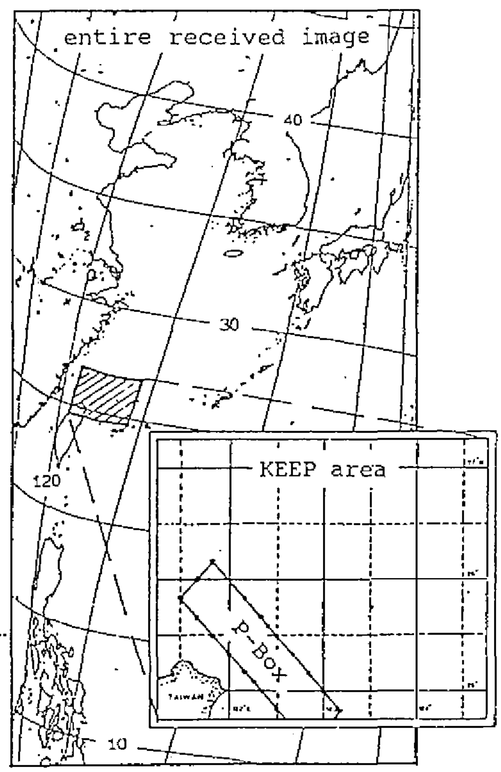


Fig. 2. Selection of the geographic domain from entire NOAA satellite pass data for KEEP. The frame with dots showing the P-Box survey area.

(Liu and Liu, 1986) and the resolution is 0.1°C (Lauritson, 1979). Brightness temperature is calculated from thermal infrared measurements (channels 3,4,5) based on black body (Stefan-Boltzmann) theory. And MCSST is computed from the former with multichannels empirical equations that were developed by Strong and McClain (1984) and distributed by NOAA (US National Oceanic and Atmospheric Administration):

$$daytime : MCSST = a + b(T4) + c(T4 - T5),$$

$$night : MCSST = a + b(T4) + c(T3 - T5),$$

where T3,T4,T5 are brightness temperature of channels 3,4,5 and a,b,c are constants for each NOAA satellite.

Visible measurements (channels 1,2) can be calculated to obtain albedo (sunlight reflection) ratio value of each pixel (Lauritson, 1979). The equation is as follows:

$$R = a(C) - b,$$

where R is albedo ratio value (ranges from 0 to 100%), C is measurement of channels 1,2 by radiometer and a,b are constants for each NOAA satellite.

Two methods, threshold value setting (1st) and 3×3 pixels mask filtering (2nd), are carried out to clean clouds and lands in one time, but, there are different tasks between daytime and nocturnal images (SeaSpace, 1989). Regarding the former, a threshold value of albedo ratio (channel 2) and a difference between values of central pixel and mean of other 8 neighboring pixels (channel 4) are given. The latter are also processed with same methods, but albedo are replaced by subtractive value of brightness temperature of channels (3 minus 4) because there are only blank data of visible channels (1 and 2) at night. Therefore, each pixel can be recognized as a good pixel if its contents fit the setting conditions that its value (channel 2 or channels 3 minus 4) is less than the 1st setup and value (channel 4) more than the 2nd setup.

Next, the coastal line was manually matched. Based on orbit elements data in the near time, the actual scene displayed with visible channel image was used to adjust navigational error of NOAA satellites due to Earth's asymmetric gravity fields and unequal poises of satellite. Same orbit elements were also used to calculate and correct geographic distortion of image affected by geoid and poises of satellite.

After above image processing, the cleaned and normalized MCSST imageries are visualized to format maps for analysis by displaying, ranging, painting and dividing into 0.5°C per color. Finally, a total of 141 (about 31% to overall available imageries) good MCSST maps (1 map for 1 day) were chosen (circle marks in Figure 1) to analyze the dynamics of currents in this area.

3. RESULTS

3.1 Comparisons between observations of in-situ and satellite data

In-situ hydrographic surveys of P-Box stations in Keep area had been taken for two cruises during September 18-23 (no. 254) and November 3-7 (no. 260). It is found from the 10m-depth temperature contours (Figure 3), that the cold eddy seems to exist northeast of Taiwan in both cruises. However, the surveyed area of 5 day cruises is not big enough to cover the whole eddy to detennine the scale and intensity. On the other hand, a synoptic view was acquired from NOAA satellites imageries (Plate 1), which roughly match the in-situ survey results in eddy position and its magnitude. For cruise 254, the magnitude of cold eddy in NOAA-11 image on September 19 is estimated to be about 110 Km east-west and 55 Km south-north, and SST gradient is 4.5°C (Plate 1A). The NOAA-11 image at November 8, for cruise 260, shows that the intensity of cold eddy is lower with 2.5°C SST gradient (Plate 1B).

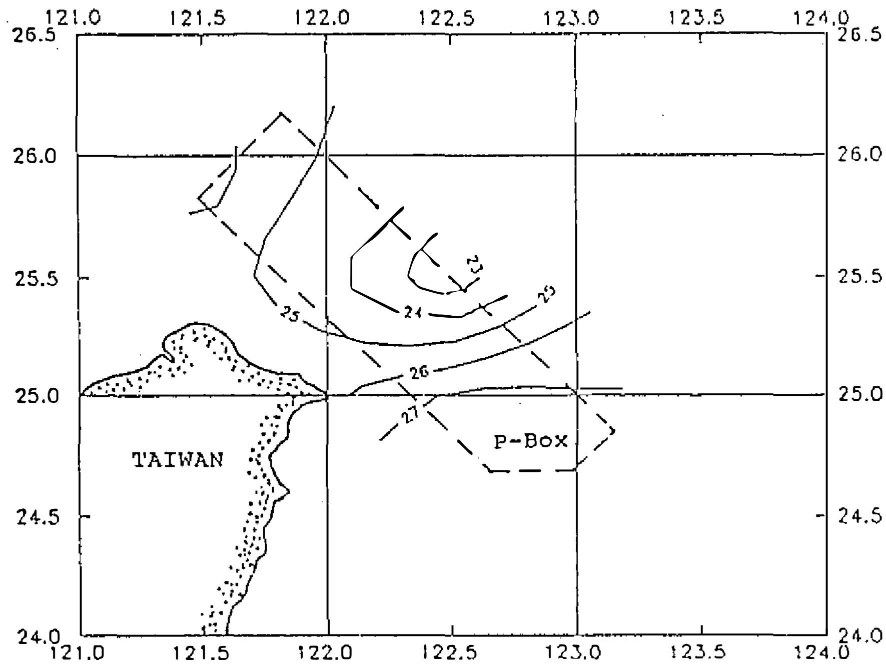


Fig. 3A. Isotherms (°C) in 10m depth, from 18th Sep. 1990 to 23th Sep. 1990 (cruise 254).

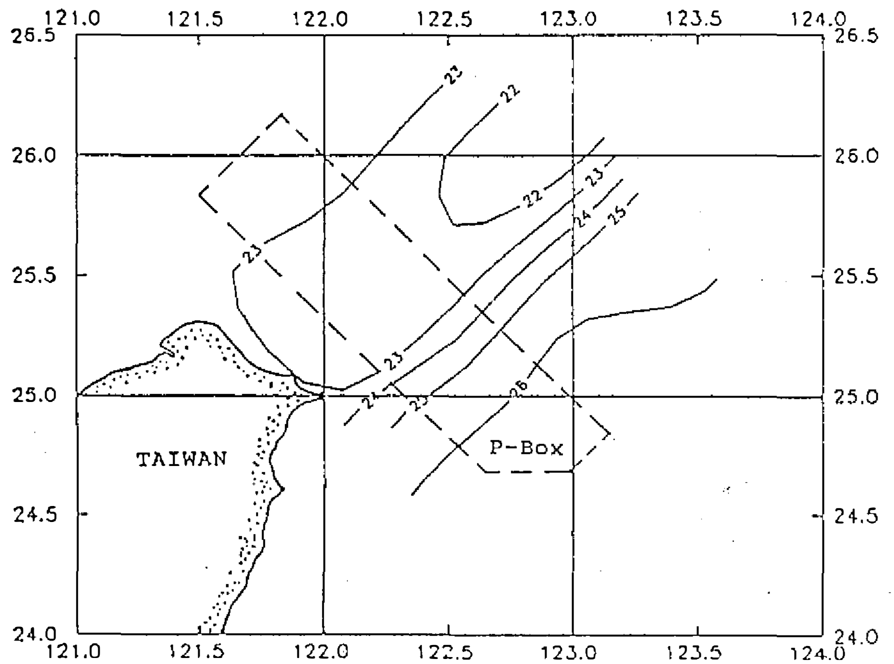


Fig. 3B. Isotherms (°C) in 10m depth, from 3th Nov. 1990 to 7th Nov. 1990 (cruise 260).

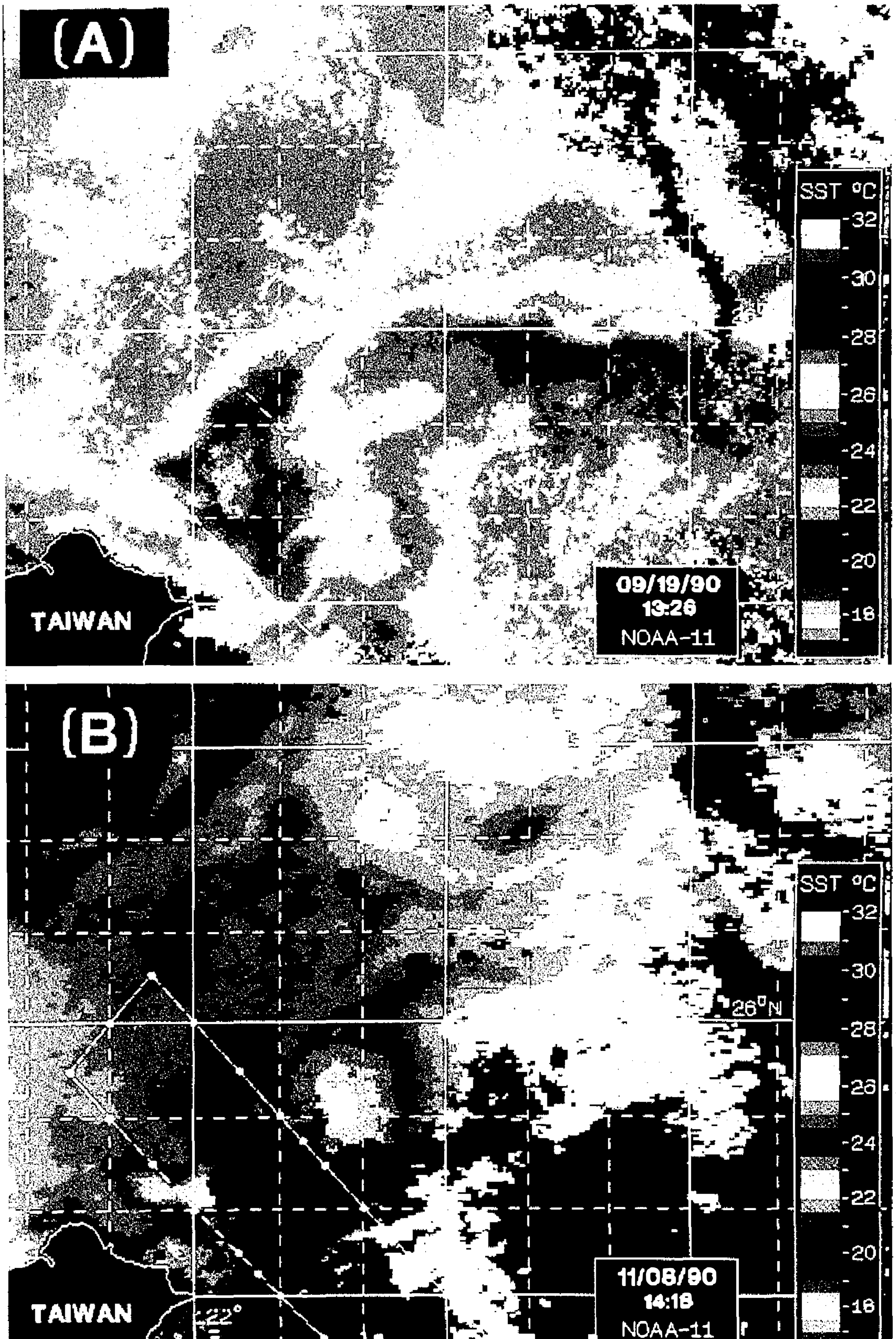


Plate 1. Satellite thermal images on Sep. 19, 1990 (A) and Nov. 8, 1990 (B), used to compare with the observations by R/V Ocean Research I in figure 3.

3.2 Kuroshio fronts and their progression

3.2.1 Types of Kuroshio fronts

Various forms of Kuroshio fronts are found in the whole year except summer, the only season that fronts are not significant (21.88% out of 141 samples) (Table 1). Three types of Kuroshio fronts are generalized from all of the imageries based on their extended directions, as sketched in Figure 4. Front Type-A (Figure 4A), which extends away from northeastern Taiwan northeastwardly, can occur in any season with unequal gradient scales. About 38.4% of all observed imageries belongs to this type (Table 1). Front Type-B (Figure 4B), which extends away from northeastern Taiwan northeastwardly about a hundred kilometers and then turns into an anticlockwise frontal eddy, is dominant in every month except July, August and September. This type of front has a stronger SST gradient and occupies 31.2% of all imageries (Table 1). Front Type-C (Figure 4C), which begins at northeastern Taiwan and extends along the coast of northern Taiwan, and then away with an arcuate curve and turns to the east , is dominant in the winter time, especially in December and January. This type of front has the strongest SST gradient among the three front types, but only occupies 9.4% of all imageries (Table 1).

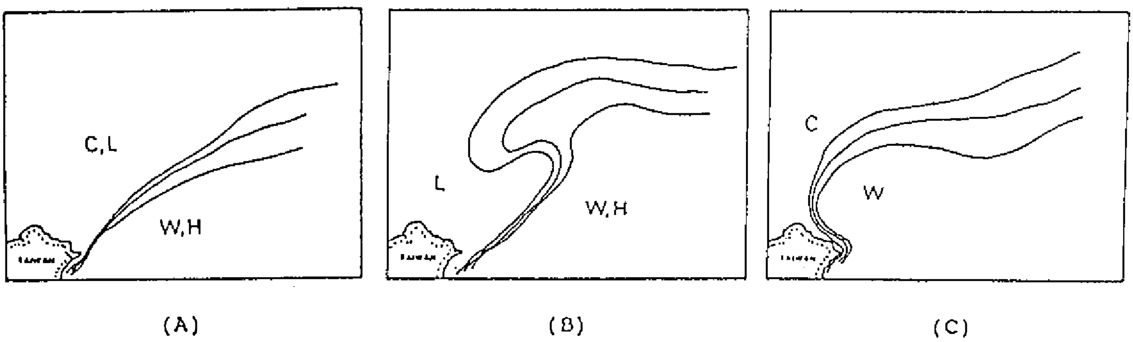


Fig. 4. Three main front types of Kuroshio in Keep area off northeastern Taiwan observed from NOAA-HRPT satellite IR imageries. (marks H:hot, W:warm, L:cool, C:cold) (A): northeastwardly with a simple curve. (B): direction same as (A), but with counter-clockwise meanders. (C): with an arcuate curve that turns northwest, north, then northeast; also front is close to coast of northern Taiwan.

Examples of the three types of Kuroshio fronts are shown in Plate 2. In the first map (July 15, 1990) (Plate 2A), the warm Kuroshio current (29-32°C), marked by deep orange to yellow, flows away from the coast of Taiwan in a northeastward direction. The front, a boundary with cool coastal water (27-29°C) of purple red, is classified as Type-A. The Kuroshio water does not appear to intrude onto shelf break.

The second map (October 27, 1989) (Plate 2B) clearly indicates a large-scale anti-clockwise frontal eddy, colored yellow, and might be Kuroshio upwelled water. Both the northeastward front and the eddy have 2.5-4°C gradient boundary with cooler shelf water colored green.

In the third map (December 3, 1989) (Plate 2C), a 18.5-21°C cold branch of China Coasal Water (purple and cyan color) intrudes into coastal zone of northern Taiwan. On the other hand, water of Kuroshio current also intrudes onto shelf to form a large-scale Kuroshio water (green color). Between the two different waters, a high thermal gradient (about 6°C) front Type-C is formed.

Table 1. Cross tabulation analysis between front types of Kuroshio and position types of cold eddies in KEEP area off northeastern Taiwan

		none	front types of Kuroshio			Total
			type A	type B	type C	
position types of cold eddies	type A	2 1 21.88%t 100.00%f 100.00%e	0	0	0	2 1 21.88%
	type B	0	4 5 46.88%t 66.18%f 97.83%e	2 3 23.96%t 33.82%f 92.00%e	0	6 8 70.83%
	type C	0	1 1.04%t 14.29%f 2.17%e	2 2.08%t 28.57%f 8.00%e	4 4.17%t 57.14%f 100.00%e	7 7.29%
Total		2 1 21.88%	4 6 47.92%	2 5 26.04%	4 4.17%	9 6 ** 100.00%

notes: %t ratio to overall total
%f ratio to all front types (horizontial)
%e ratio to all eddy types (verticle)
** is about 81.3% out of 113 cases that could be used to recognize existence of cold eddies.

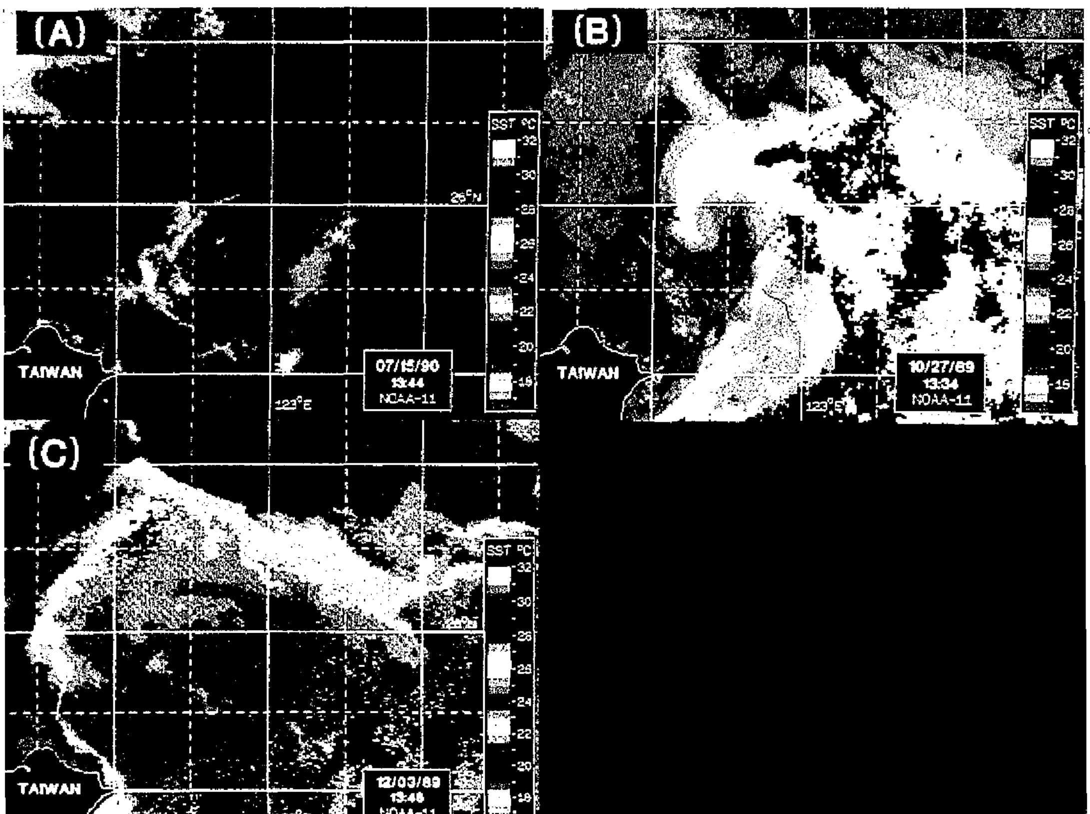


Plate 2. Examples of types A, B, C of Kuroshio fronts.

3.2.2 Progression of Kuroshio fronts

Figure 5 shows detailed status of progression of Kuroshio fronts in KEEP area from daily figure of front boundary. The left axis of each monthly diagram shows latitude. Note that interval of day is also equal to 1 degree distance in longitude (122-123°E). Figure 5 indicates that almost all of the south part (25-26°N) of Kuroshio fronts is located at 122-123°E and has fewer fluctuations.

In late October 1989, there was a rapid transformation from front Type-A to front Type-B. The frontal wave was formed, moving northward and reducing its magnitude. To the end of the month, the frontal wave of Kuroshio water had become a lathy configuration. In early November, the front seemed to change back to Type-A. In early December, another strong front Type-C existed and turned to become Type-B in middle of the month. From early January to 2 May 1990, few data were available. From later on, in summer time (May-July), Type-A was the dominant feature. Furthermore, fronts Type-B in middle August, Type-A in September and Type-C in October could also be identified. November 1990 was a variable period that front Type-B changes to Type-A and then back to Type-B in the first twenty days. In conclusion, front Type-A is dominant and more stable in summer. In other seasons, all three front types are more variable and have different degrees of intrusion onto the shelf.

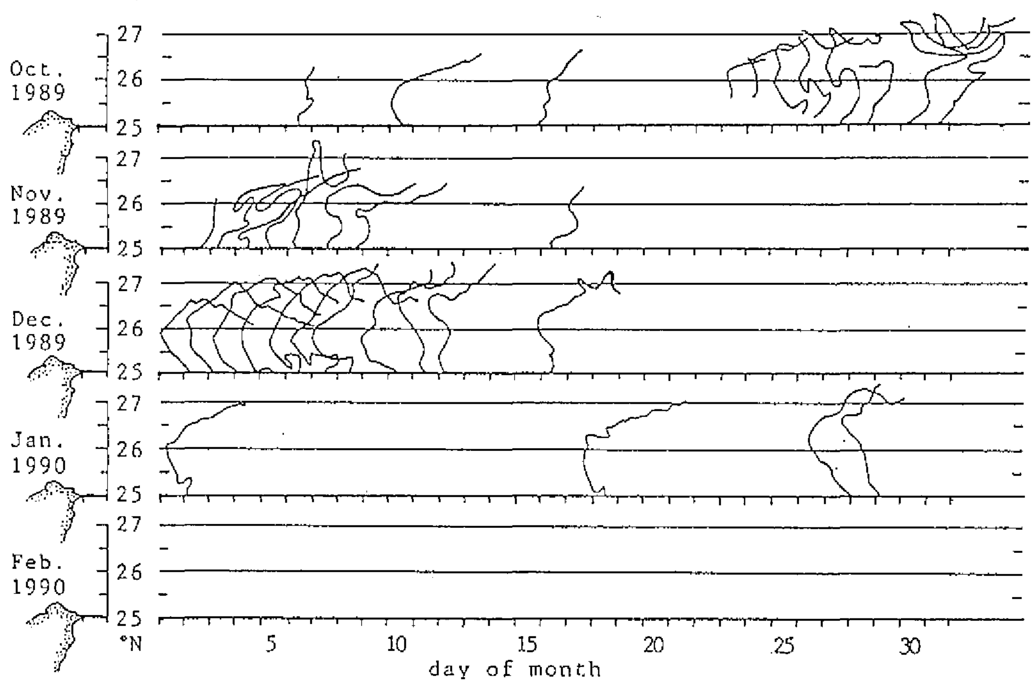
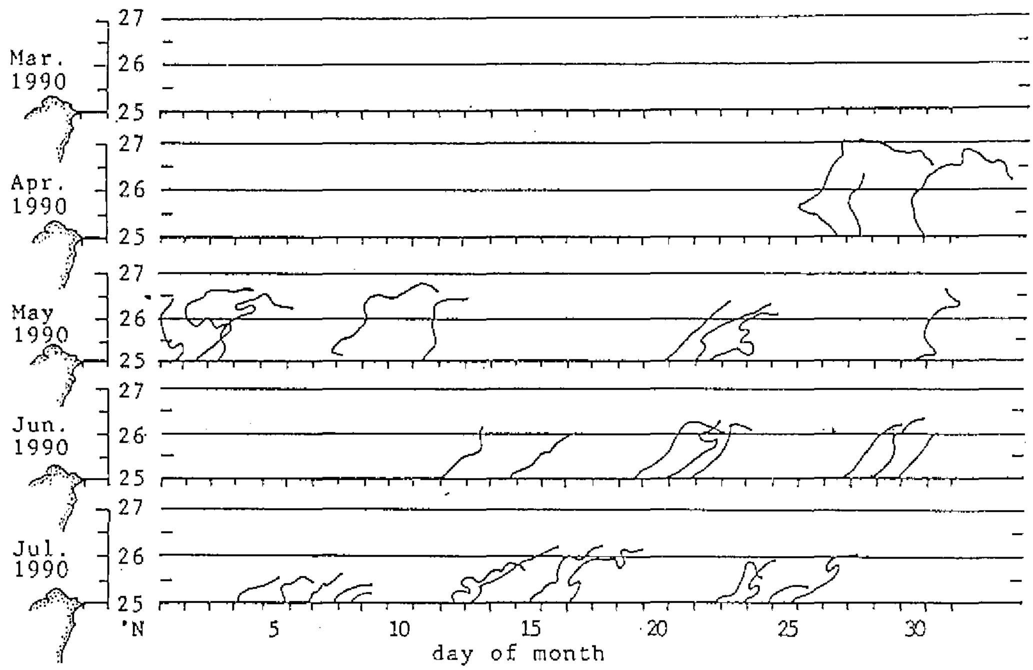


Fig. 5. Daily variation of front feature of Kuroshio in KEEP area based on NOAA-HRPT satellite imageries from Oct. 1989 to Dec. 1990. (note: data are missing in Feb. and Mar. 1990, and vertical axis shows the latitude)



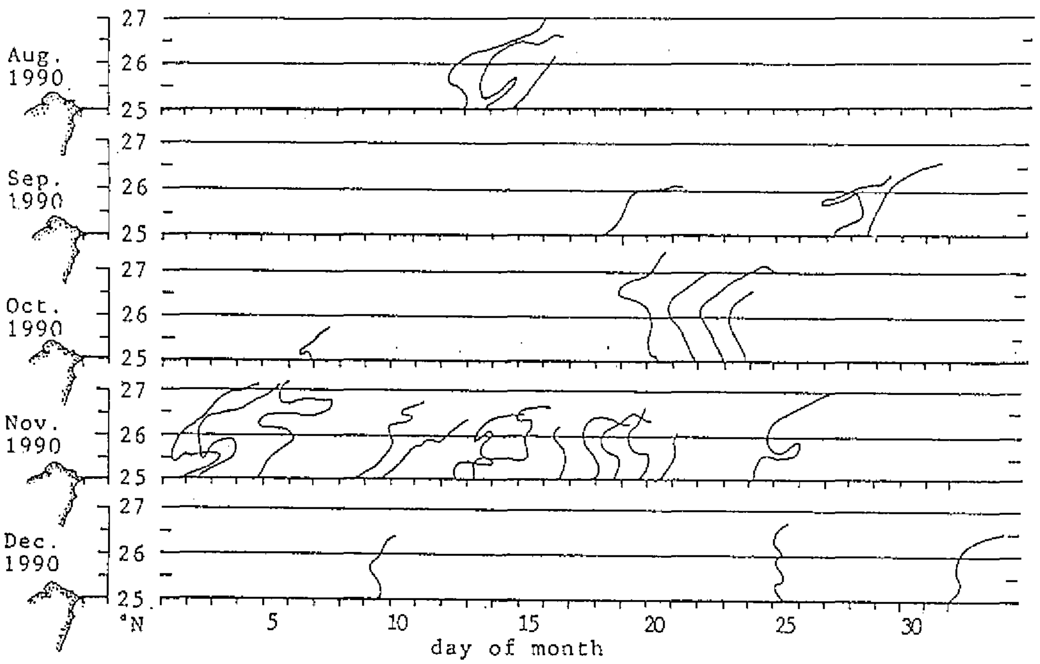


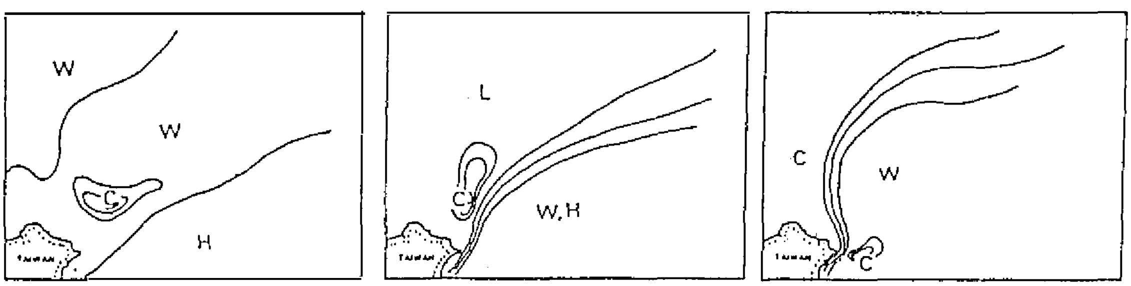
Fig. 5. (Continued)

3.3 Cold eddies and their life cycle

3.3.1 Types of cold eddies

Based on satellite data, 118 MCSST maps are extracted from the original 141 passes, because there are 23 maps seriously contaminated by the clouds. The cold eddies can be identified in 96 maps (81.3% out of the available 118 ones). The eddies off northeastern Taiwan seem to exist all year round. A vigorous eddy can occupy over $3700Km^2$ area on the sea surface and reach a 6°C difference from its coldest center to its surrounding water. Moreover, the eddies also have a life cycle, from outcropping the sub-surface water to a vigorous stage, and then disappearing. In other words, the scale, configuration, and temperature distribution of the eddy vary with time.

Three types of cold eddies (Type-A, Type-B and Type-C) can be identified based on the locations relative to the Kuroshio fronts (Figure 6). Eddy Type-A is defined as the eddy which appears with no distinct Kuroshio front (Figure 6A). The eddy Type-A, which occupies 21.88% of all eddies (Table 1), is most prevalent in summer. Eddy Type-A can last for half a month and interval of recurrence takes only two or thee days. The eddy Type-B is defined as the eddy which appears on the cool (west) side of the Kuroshio front (Figure 6B). The eddy Type-B, which have the highest ratio (70.83%) (Table 1), probably exists in all seasons. Its interval of recurrence is similar to that of eddy Type-A. The eddy Type-C is defined as the eddy which appears on the warm (east) side of the Kuroshio front (Figure 6C). The eddy Type-C, which has only 7.29% out of the all eddies identified (Table 1), is most prevalent in winter. Eddy Type-C may last only 4-5 days. The interval of recurrence was unknown because of the scarcity of data.



(A) (B) (C)

Fig. 6. Three main position types of cold eddies in Keep area off northeastern Taiwan observed from NOAA-HRPT satellite IR imageries. (marks H:hot, W:warm, L:cool, C:cold) (A): with no distinct Kuroshio fronts in whole area. (B): west (cool) side of distinct Kuroshio fronts. (C): east (warm) side of distinct Kuroshio fronts.

Examples of each type of eddy are demonstrated by three MCSST maps of NOAA-9 or NOAA-11 satellites (Plate 3). Plate 3A shows an eddy Type-A (July 23 1990), colored with yellow. The cold eddy was enveloped by the warmer water, while no distinct Kuroshio front appeared. About a 3°C difference was generated by the cold eddy such that its center was 25°C (the sienna region) and its outside water was about 28°C (the purple region around the eddy. And, the cold eddy seemed to extend northeastwardly, judging from its elongated shape. The second map (Plate 3B) shows an eddy Type-B (November 3 1990), colored with blue. The eddy is located on the west side of the Kuroshio front which is the boundary between the Kuroshio water (the yellow region) and the eddy water (green region). This eddy covered large area of about 3700Km^2 and had a high temperature difference of 6°C (21°C-27°C). Meanwhile, the eddy was partially-enclosed by a Kuroshio front Type-B formed by anticlockwise frontal eddy. The eddy Type-B can also co-exist with a front Type-A. Plate 3C shows an eddy Type-C (December 6 1989) which is near the northeast coast of Taiwan. The eddy Type-C is located in the warm Kuroshio water (colored with green) and has a small scale of about 185Km^2 with a temperature gradient of 2°C. The eddy Type-C appeared with all Kuroshio front types.

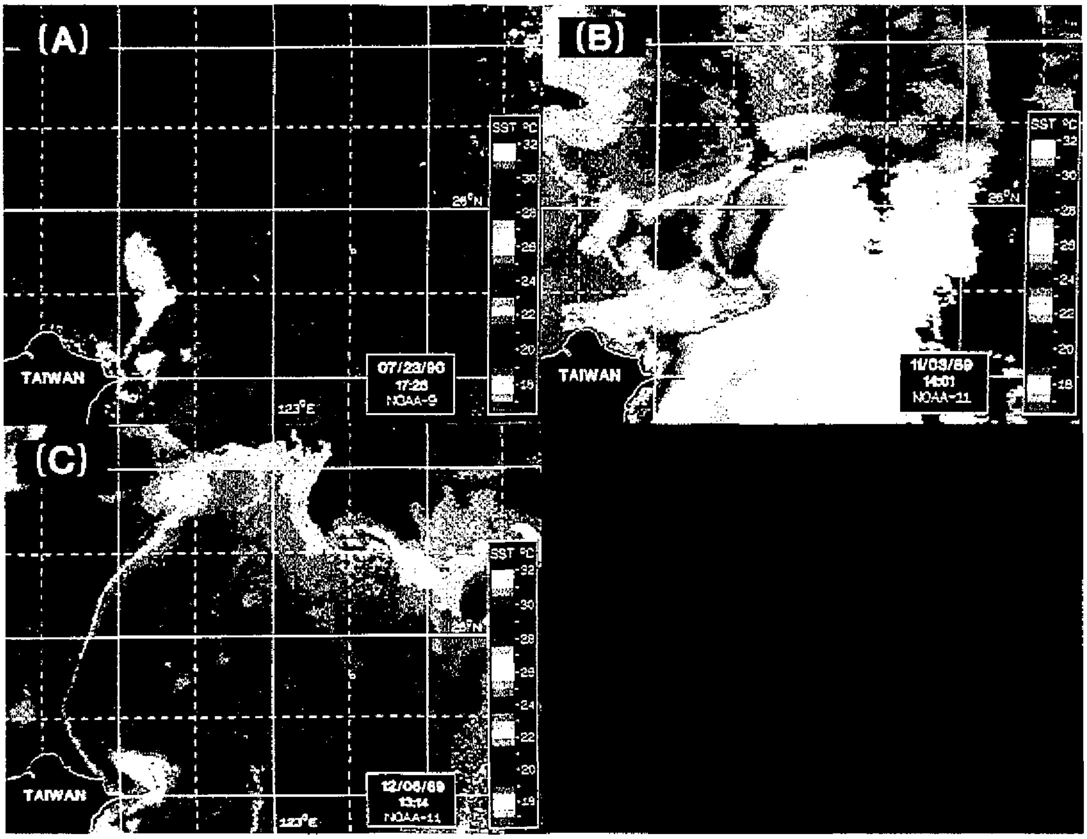


Plate 3. Examples of types A, B, C of cold eddies.

3.3.2 Life cycle of cold eddies

For the life cycle of a cold eddy, an entire sequence of an eddy Type-B and the formation of an eddy Type-C are described.

3.3.2.1 Life cycle of an eddy Type-B

There are 8 sequential MCSST maps to demonstrate the life cycle of an eddy Type-B (Plate 4). The maps are obtained from satellite NOAA-9 and NOAA-11 during October 26 - November 6, 1989. At the beginning, the eddy (Plate 4-1, the reseda region off northeasten Taiwan) outcropped the surface layer on the west side of the warm Kuroshio water, colored with purple and yellow, and generated a front Type-B. It occupied only a small area with just about 1°C difference from its coldest center (22°C) to the outside water. The eddy was blocked by the anticlockwise frontal wave of Kuroshio water, clearly marked with yellow.

The eddy gradually grew. Two days later (October 28, Plate 4-2), the eddy enlarged both in the scale and in the temperature gradient. Its location also apparently moved northwardly. On October 30 (the 5th day, Plate 4-3), the center temperature was about 21°C with a 2°C difference in the outside water. The eddy had changed to an elliptical shape. On November 1 (the 7th day, Plate 4-4), the temperature of the eddy continued to decrease. On November 2 (the 8th day, Plate 4-5), the eddy had reached the most vigorous stage. Its center had the lowest temperature (20°C) for the life cycle of the eddy. Its temperature gradient also reached the maximum of 3°C from its center to the outside water. Its scale also reached the maximum size. After the most vigorous stage, the eddy gradually decayed both in its size and temperature gradient. The temperature rose in the center and became near that of the outside water. On the 12th day (November 6), the eddy almost disappeared. One other important feature was that the eddy traveled northwardly with the Kuroshio frontal wave from bout 56Km to 110Km off Taiwan. It lasted about 12 days. The shape of this eddy (Type-B) was constantly changing, being affected by the anticlockwise frontal wave of Kuroshio water. It takes about twice of the time in the growing stage compared with the decaying stage. A cold eddy Type-B also can be associated with Kuroshio front Type-A. But there are no sequential maps for demonstration.

3.3.2.2 The formation of an eddy Type-C

Plate 5 demonstrates the forming process of an eddy Type-C which happened in winter. The 4-day MCSST maps are derived from the satellite NOAA-11 on December 3-6, 1989. All four maps have similar hydrographic distribution so that a Kuroshio front Type-C was clearly formed by the Kuroshio water (the green region) interacting with the China Coastal Water (the blue region located in the west side of the Kuroshio water). On December 3 (Plate 5-1), no eddy was observed near Taiwan. Some of the China Coastal Water seemed to flow along the northeast coast of Taiwan to I-Lan Bay. In the second map (December 4, plate 5-2), the flow of the China Coastal Water into the I-Lan Bay seemed to be interrupted by the Kuroshio water. By the third day (December 5, Plate 5-3), part of the water of the I-Lan Bay flowed northeastwardly into the region of Kuroshio water. It also seemed to be intercepted by the interleaving of the Kuroshio water. On the fourth day (December 6, Plate 5-4), the cold water left I-Lan Bay and became a separate cold eddy. The cold eddy occupied a area of about $185Km^2$ with only 2°C difference from its coldest center (21.5°C) to the outside water. In the following days, the eddy could not be tracked, owing to the effect of the clouds. The eddy Type-C also appears with the front Type-A and front Type-B. However, it is not clear about the forming process when eddy exists with front Type-A or Type-B, because of the scarcity of data.

3.4 Relationship between the Kuroshio fronts and cold eddies

The relationship between cold eddies and Kuroshio fronts can be summarized by utilizing the cross tabulation (Table 1). The numerical totals of eddies that were ever found during the study period are 96 days total. The cold eddy Type-A only appears when there is no front. The cold eddy Type-B occupies the highest ratio (70.83%) and appears with front Type-A or Type-B, but not with front Type-C. The eddy Type-C appears with all three front types, and most often with front Type-C.

4. DISCUSSION AND CONCLUSIONS

4.1 Characteristics of Kuroshio fronts

The dynamics of Kuroshio fronts have greatly fascinated the ocean researchers, because of their importance to physical and chemical characteristics of the West Pacific Ocean and

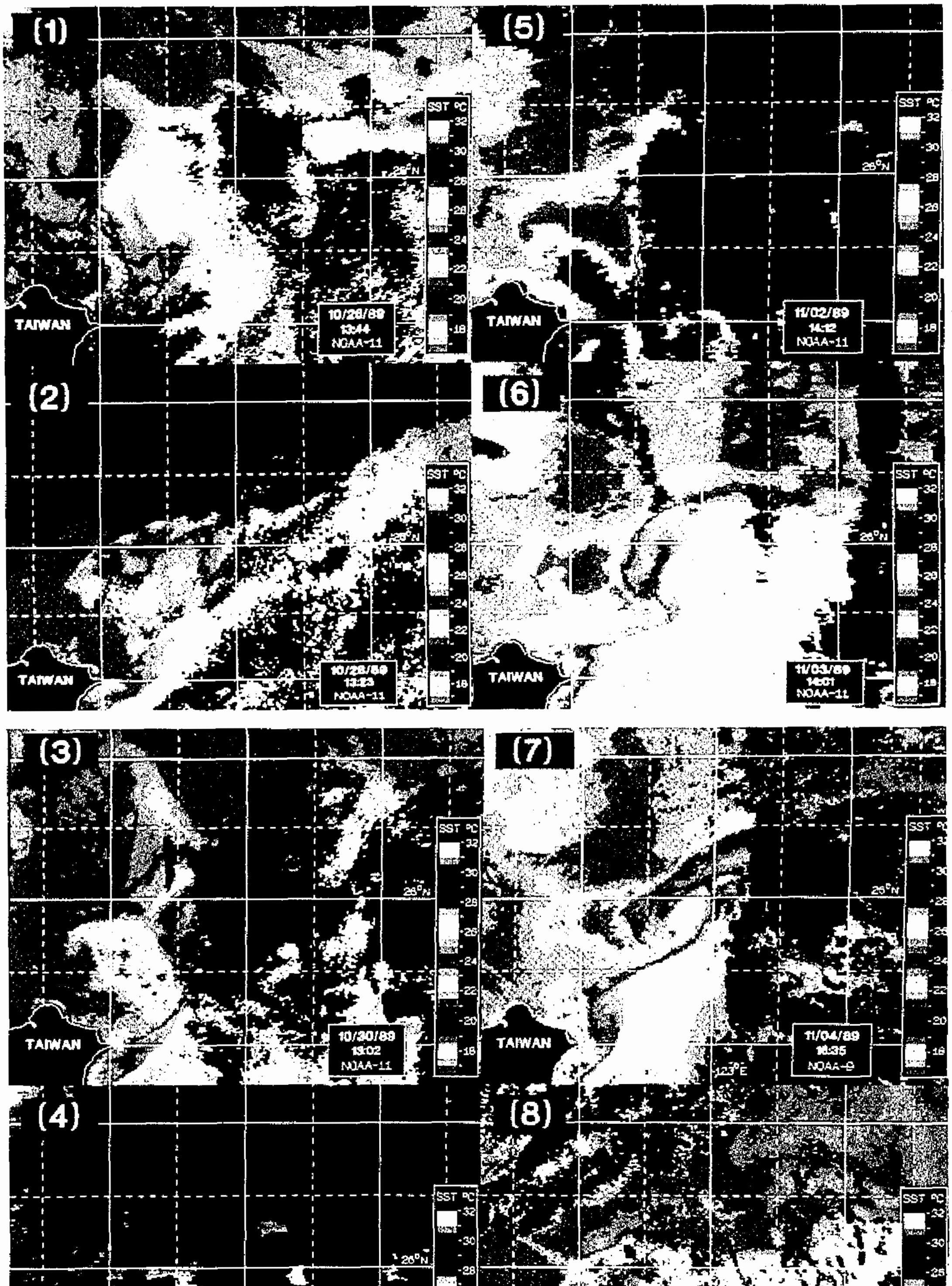


Plate 4. Eight serial images showing the progression of cold eddy Type-B between Oct. 26 to Nov. 6, 1989.

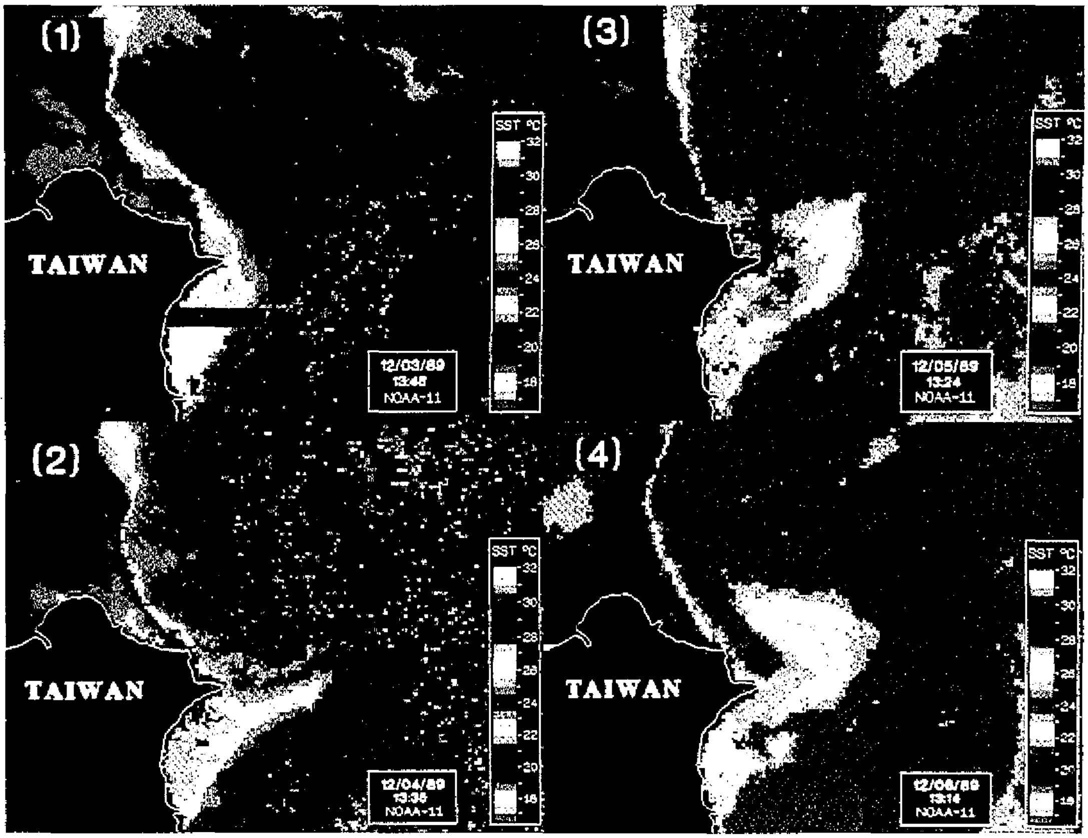


Plate 5. Four serial images showing the progression of cold eddy Type-C between Dec. 3 to Dec. 6, 1989.

fishery productivities in the adjacent waters. In this area, past efforts, which mostly utilized ship observations, already had a basic knowledge about the seasonal variation of the Kuroshio fronts (Yu and Miao, 1991; Su and Pan, 1990). Hence, for those months when satellite data were not available (February and March), past studies are supplemented for the following discussion.

Kuroshio front in January was clearly illustrated from a case study of NOAA satellite IR image by Liu and Pai (1987). In the same paper, the location of Kuroshio front about 10-20 miles off northern Taiwan was described by the result of ship's survey that crossed the front in March. The water on the east side of the front is considered to be the Kuroshio water and that on the west is the shelf water. It's obvious that the front in that report is Type-C. Moreover, Chern and Wang (1989) suggested that the continental shelf water in February sinks due to its higher density, so that the surface Kuroshio water intrudes the shelf. Furthermore, the investigation in February and March by Tseng (1972), from the distributions of 50m-depth temperature and chlorinity, reveals that Kuroshio water intrudes onto shelf. Other past studies also described the similar hydrographic conditions in waters off northern Taiwan in winter time (Su and Pan, 1990; Pan *et al.*, 1990, 1991; Yu and Miao, 1991). Therefore, it seems that the Kuroshio fronts mainly keep Type-C or Type-B in winter.

From summer to autumn (June-September), the types of Kuroshio fronts are Type-A or Type-B , or no thermal front is observed because the surface temperature is almost uniform. According to MCSST maps, the locations of fronts in these seasons are further offshelf than in other season. This feature is similar to Yu and Miao (1991) who identified the location of the front by using hydrographic data of several years. The reason may be due to the variation of Kuroshio axis. According to Yuan *et al.* (1991), axis of the Kuroshio in summer is further offshelf than in winter. The shelf water is mixed by water of Taiwan Strait, Yangtze River and intruding Kuroshio water to form warm water with low salinity. The density of this mixing water is similiar to the Kuroshio surface water, which may prevent the Kuroshio surface water from intruding into the shelf (Pan *et al.*, 1990).

4.2 The forming mechanism of the cold eddy

The cold eddy off northeastern Taiwan is an important hydrographic feature. Some researchers have reported the existence of cold eddies (Yin,1973; Fan, 1980; Liu, 1983). The forming mechanism of cold eddy also has been widely discussed (Chern and Wang, 1989; Chern *et al.* 1990). It was suggested that the cold eddy is the upwelling of the Kuroshio subsurface water which impinges on the shelf break off northeastern Taiwan. Moreover, the hydrographic study during KEEP (Gong and Liu, 1991) reveals the upwelling of Kuroshio subsurface water on the shelf all year round. Type-A and Type-B could be the upwelling of the Kuroshio subsurface water. They seemed to be enveloped by the warmer water without the intrusion of cold water, although the China Coastal Water sometimes appears in the northwest of this observed area. On the other hand, the eddy Type-C which appears in winter might be formed by the horizontal mixing between the Kuroshio water, the China Coastal Water and the coastal water of I-Lan Bay.

So far, little is known about the factors that affect the variation of the eddies on the surface layer. The eddies exist all year round in the deep layer (Chern and Wang, 1989). However, the surface eddies are constantly changed and complicated by the variation of currents and the monsoon wind (Chern and Wang, 1989). During December to March, the eddies which are not discovered on the surface layer may be overflown by the surface Kuroshio water. During June to September, the eddies which usually appear as a northeast-southwest oriented elliptical feature, may be affected by the water from the Taiwan Strait flowing into East China Sea. And during May and November, the surface eddies travel northeastwardly with the anticlockwise front of the Kuroshio water (Plate 4), which suggests that the Kuroshio has a very significant impact on the eddies.

4.3 Conclusions

The synoptic-view MCSST imageries derived from AVHRR data of NOAA satellites helped to discover some features in waters off northeastern Taiwan. For the first time, features like fronts and eddies are classified. Because there are some missing data on cloudy days, further observations are needed by using the satellite remote sensing data to study and describe more detailed variations of the types of Kuroshio fronts and cold eddies in the KEEP area.

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以NOAA衛星AVHRR影像觀測臺灣東北海域黑潮鋒面及冷水團之研究

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摘要

自1989年10月至1989年12月間，共選用百餘張AVHRR-HRPT衛星水溫影像，用以觀測和分析臺灣東北海域之表層水文動態（以北緯26度，東經123度爲中心，東西約350公里，南北約280公里），以下爲結果摘要：

在本觀測海域（KEEP海域），黑潮鋒面型態可歸納爲三型：(A)黑潮鋒面自臺灣東北一帶沿岸向東北方向延伸。(B)黑潮鋒面自臺灣東北一帶沿岸往東北方向前進，而後形成一反時鐘方向之曲折渦流。 (C)黑潮鋒面順著北臺灣沿岸往外海先向西繞了一個圓弧形後再轉向東方。另外，臺灣東北外海的冷水團也是一主要之水文現象，在本海域的冷水團亦依其相對於黑潮鋒面之關係而劃分爲三種型式：(A)冷水團形成於無明顯鋒面時。(B)冷水團形成於黑潮鋒面之冷水側(西側)。 (C)冷水團形成於黑潮鋒面之暖水側(東側)。

黑潮鋒面A型主要盛行於夏季時，至於其他三個季節，三種鋒面均有可能發生且有所變動 ， 而其侵入陸棚之程度亦有所不同。至於冷水團，最常出現的是B 型，於各季節均有可能發生；其次是A型，較盛行於夏季；最少出現的是 C 型，較常出現於冬季。對黑潮鋒面和冷水團之關係，最常出現的情形是冷水團 B型伴隨著黑潮鋒面A型。