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STUDY OF HYDRAULIC BEHAVIORS OF RIVER EFFLUENT AT CORIOLIS FORCE DOMINATING FIELD BY REMOTE SENSING

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SYNOPISIS

River effluents discharged into coastal water zones around Honshyu Islands in Japan are visualized by Landsat data with a view to observe those behaviors at extremely far field from river mouths. Landsat data indicate that the effluents in this sea area are affected significantly by oceanic currents such as the Branch of the Tsushima Current in the Sea of Japan and the Kuroshio Current in the Pacific Ocean. In the Sea of Japan, the river effluents at the extremely far field have tendency to flow north along the coastline. In the Pacific Ocean, large scale eddies, which are formed by interaction between various oceanic current systems, may entrain the coastal water masses in them.

INTRODUCTION

It is an important matter to know the hydraulic behaviors of effluents discharged from land to coastal water in evaluating the influences of human and industrial activities on the marine environment. The diffusion characteristics of river water and thermal effluents discharged into the sea are typical problems related to this matter and many results have been reported in this connection from the past. Most of those studies have been made on zones comparatively near the discharge outlets where inertia force or buoyancy of the water jet or plume are still predominant.

However, the flow characterictics in so-called " Coriolis force-dominating field" at an extreme distance from the outlet are important matter requiring study, since they comprise boundary conditions in analyzing the hydraulic behaviors of river effluents in the coastal water zones. Also, the flow characteristics at this extremely far field zone may become necessary to know, when evaluating influences on coastal water environment exerted by discharged water containing turbidity components, contaminants of non-damping nature or having long half-lives.

Next, as regards observation methods of the flow characteristics of such large scale, any conventional observation techniques from land or sea and application of remote sensing from aircraft are difficult to carry out, such a case, the much is expected of the application of remote sensing by satellites.

In view of the above, the authors carried out a study in the sea area off the shores of Fukushima and the Kii Peninsula by means of Landsat remote sensing and reported previously on one of the results obtained; the influences of large scale eddies generated off the shores on the movements of coastal water (1).

In this paper , the river effluents discharged into coastal water zones around the Honshyu Island in Japan are visualized by the Landsat remote sensing and some aspects of those hydraulic characteristics at the Coriolis force dominating field are discussed with taking account of results obtained by ship-borne observations.

DISTRIBUTION OF OCEANIC CURRENTS AROUND JAPANESE ISLANDS

Prior to going into analysis of the behaviors of water from individual rivers, the distribution of oceanic currents around Japanese Islands will be looked at, since these currents may controll movements of coastal waters directly receiving river waters. Figurel is a schema of the oceanic current systems around Japanese Islands, in which warm currents such as the Kuroshio and Tsushima Currents are shown by black solid lines and cold currents such as the Oyashio by white lines.

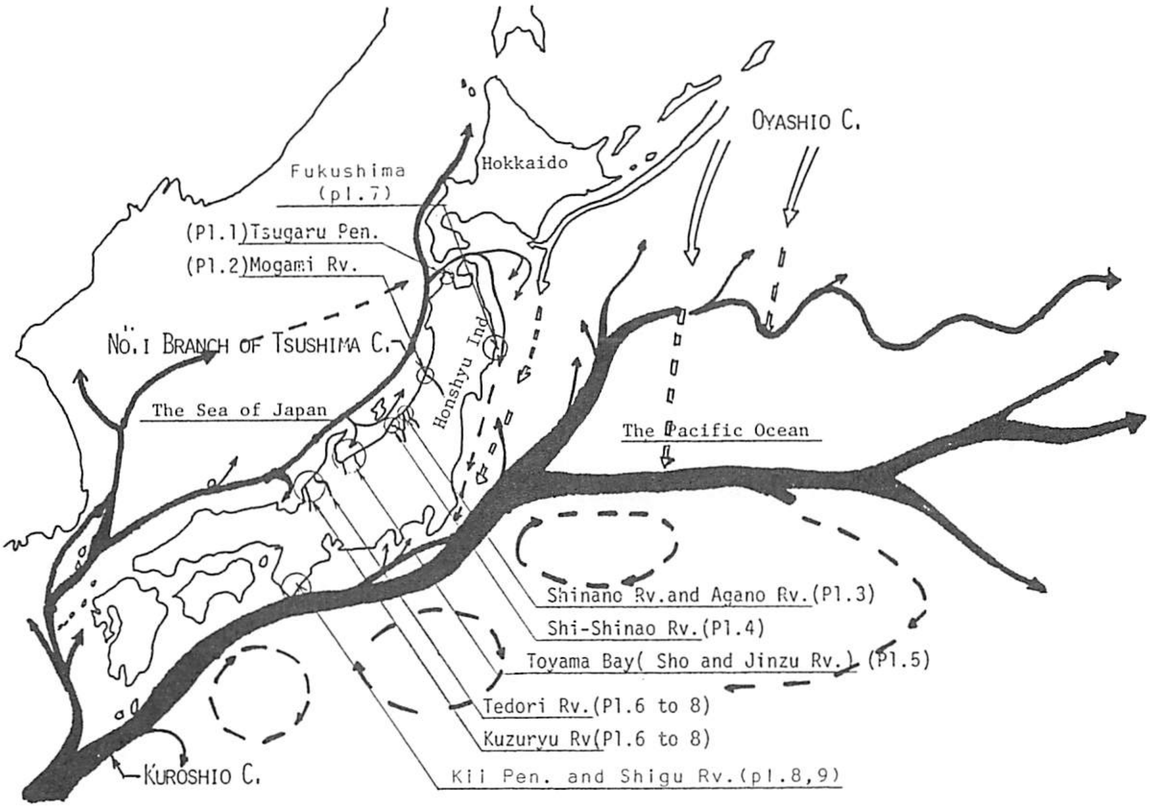

Fig. 1 Oceanic current systems aroumd Japanese Islands

Offshore of the northeastern Tohoku Region of Japan facing the Pacific Ocean, the Kuroshio and Oyashio interact with each other and produce perturbed water areas containing many eddies of various sizes (2). The Kuroshio on the south of the Japanese Islands changes its path periodically in frequencies of several years. The Tsushima Current, on entering the Sea of Japan, is divided into three branches, one of which takes a course along Honshu and sometimes called the No.1 Branch of the Tsushima Current.

HYDRAULIC CHARACTERICTICS OF RIVER EFFLUENTS AT EXTREMELY FAR FIELD OBTAINED BY LANDSAT DATA ANALYSIS

landsat data of the coastal water areas around Honshyu Island in Japan were analyzed in an attempt at visualization of the distributing condition of river water discharged into the sea. The obtained results are shown in Plates 1 to 8, in which the north points upwards. And locations of analyzed areas are shown in

Figure 1.

Plate 1 is a 4th band image obtained from MSS data in the vicinity of Tsugaru Peninsula on May 15, 1982. A water mass containing muddying substances released from Lake Jusan is distributed over the sea area of width approximately 5 km along north side from the mouth of the Lake, and flows past Cape Kodomari with the tip reaching as far as Cape Tappi. It may also seen that a wake zone is formed behind the Cape Kodomari. A similar flow pattern was also recognized in the Lansat data obtained on April 23, 1983.

Plate 2 shows a MSS image of the coast from Akita Prefecture to Yamagata Prefecture on April 23, 1981. Water discharged from the Mogami river deviates in the northeast direction approximately 15 km offshore from the river mouth, and at about 25 km north, it reaches land again in the vicinity of Misaki. In other words, it may be considered that the coast from the river mouth to Misaki comprises a large eddy zone isolated from the outer sea. The width of the river effluent at the extremely far field is more or less constant. This trend is different in aspect from the conventional jet theory that the width of jet increases with distance from its exit. Furtheremore, the distribution of the concentration of turbidity substances in the river effluent differs from the continuously diminishing deduced from the conventional theory, and it is seen that high turbidity ware masses are distributed discontinuously.

Plate 3 is an image of the vicinity of Niigata city on July 12, 1983. The river effluents thought to have increased their turbidities due to sediment supplied from the Shinano and Agano rivers are bent eastward at approximately 5 km offshore from the river mouths to reach the shoreline around Muramatsuhama northeast of Higashi-Kogyo-ko of Niigata port.

Plate 4 is a MSS 4th band image showing the condition of effluent discharged from the Shin-Shinano river on October 23,1979. The effluent from this river flows along the shoreline, and in area contacting the shoreline there are distributions of water zones containing comparatively high concentration of suspended sediment. It may be learned from this that is a tendency for this beach area as a whole to become a sedimentary shore owing to the sediment suppied from the Shin-Shinamo river. It can be seen in this image that the tip of the water plume from this river is bifurcated, and that the front between the coastal and offshore water zones at the sea area south of the river mouth is destabilized and there are vortices rotating in a counter-clockwise direction.

Plate 5 is a MSS 4th band image of Naoetsu to Toyama Bay on October 23,1979. In this plate, it can be seen how the waters from the Sho and Jinzu rivers discharged into the Toyama Bay flow toward Niigata from offshore, and continue on outside the bay. There is distribution of a coastal water band approximately 10 km in width longshore, and the movement of river effluent is limited to inside this coastal water band.

Plate 6 shows the distribution of water discharged from the Kuzuryu river on May 13,1981 obtained from MSS 4th band data. Similarly to the case of Plate 3, the river effluent either flows longshore or flows to approach the coastline, and its width is more or less uniform.

Plate 7 is a MSS 4th band image of sea surface off the coast of Fükushima facing the Pacific Ocean on April 26,1982. In this sea area the interactions between the Kuroshio Current and the Oyasho Current produce a confused water circulation containing many large eddies. In this plate, we can see that meso scale eddy with diameter on the order of tens of kilometers, located approximately 30 km offshore from the coastline, entrains the coastal water mass into it.

Plate 8 is a MSS 5th band image of the sea surface off the Kii Peninsula on October 10, 1982. Plate 9 is a closer view indicating distribution of the effluent from the Shingu river. One can see that the coastal water mass containing the river effluent is entrained into a large scale eddy at approximately 60 km offshore the tip of the peninsular. S.Onishi (1,3) discussed how such large scale eddies as seen in Plates 7 and 8 influence the mixing between the coastal and oceanic water masses.

HYDRAULIC CONSIDERATIONS REGARDING IMAGES OBSERVED BY LANDSAT

A) Influence of the No.1 Branch of Tsushima Current on river effluents.

The following features were recognized in the images of river effluents discharged into the Sea of Japan from Wakasa to the tip of the Tsugaru Peninsula.

a). There are distinct fronts demarcating coastal and oceanic water zones which run roughly parrarel to the shoreline at distance offshore of the order of ten kilometers.

b). River effluents deviate to the right as they move farther away from the river mouths, and after becoming parrarel to the shoreline, they have tendency to veer further and try to reach the shore. In such case, the width of river effluent is roughly constant at the extremely far field from the river mouth, and the concentration of suspended substances varies discontinuosly(Plate 3 for Mogami river and Plate 6 for Kuzuryu river).

c). River effluents in the Sea of Japan in all cases shown in Plates 1 to 6 flow up through the belt on the land side of the above mentioned fronts in the direction toward the Tsugaru Peninsula .

All of the above features are thought to suggest that the movements of coastal waters are significantly affected by the No.1 Branch of the Tsushima Current and have geostrophic nature at the extremely far field.

As shown in Figure 1, both the Kuroshio Current off the southern Japanese Islands and the No.1 Branch of the Tsushima Current flow along land. However, it is considered that in the Coriolis force dominating field the effects of existence of land on the behaviors of those two currents as well as the coastal water masses directly adjacent to the land are essentially different from each other.

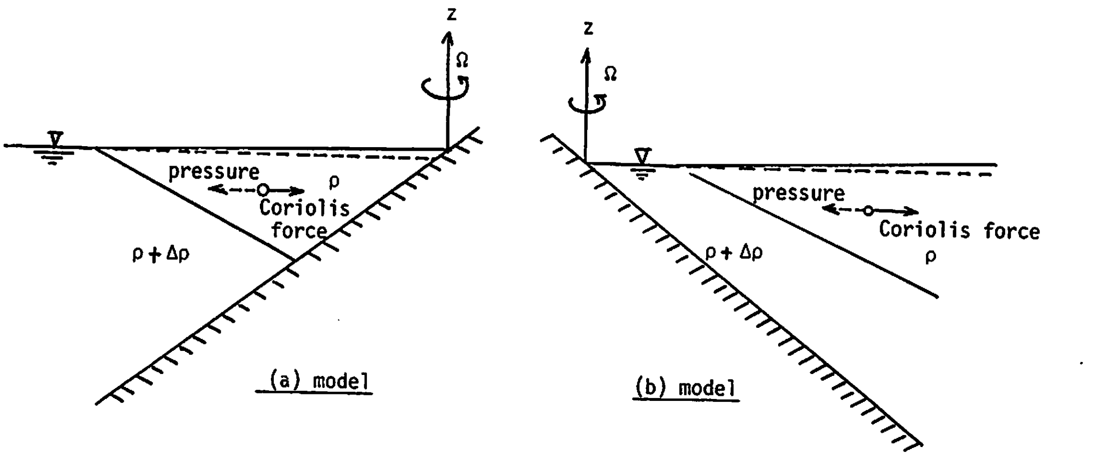

Fig. 2 Two different models of geostrophic current along land

Figure 2 indicates schematically two different models of currents along land in the Coriolis force dominating field. In the model (a) which corresponds to the case of the No.1 Branch of the Tsushima Current, the land is located to the right of the current when facing in the flow direction. Under this condition, the Coriolis force acting on the current takes a direction toward the land, and therefore, the current has a tendency to approach the land and hence the water level at the shore side next to the current becomes higher than on the offshore side in order to maintain geosrophic balance. In the model (b), corresponding to the Küroshio Current, the land exists to the left side of the current. The

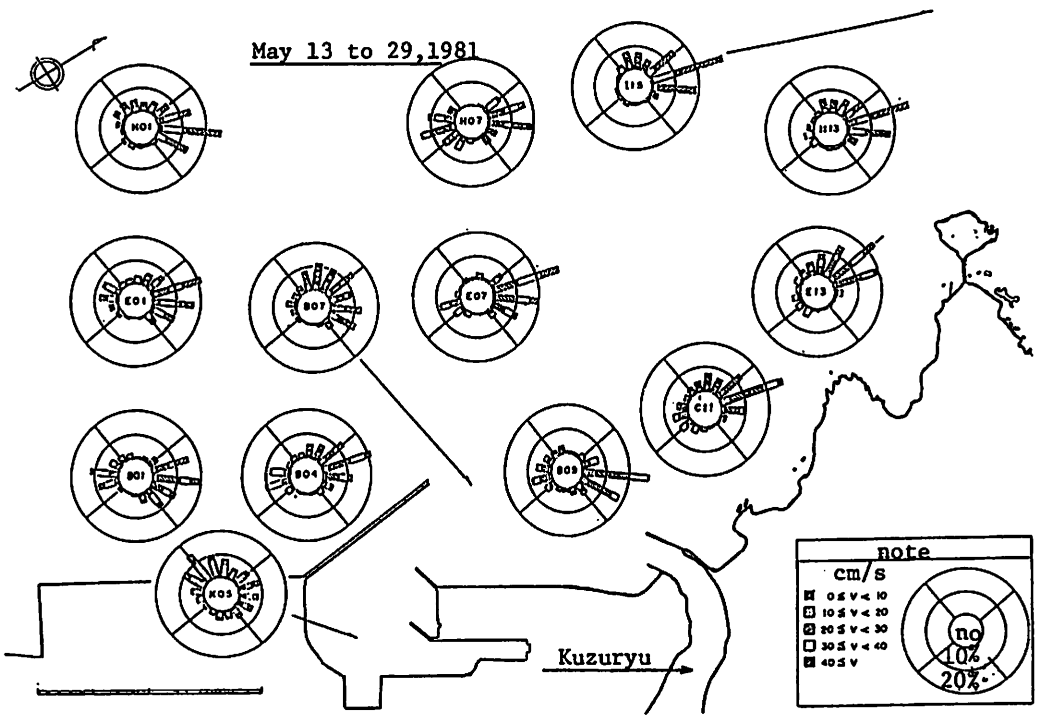

Fig. 3 Occurence frequency of current velocity at estuary of Kzuryu river , May 13 to 29, 1981.

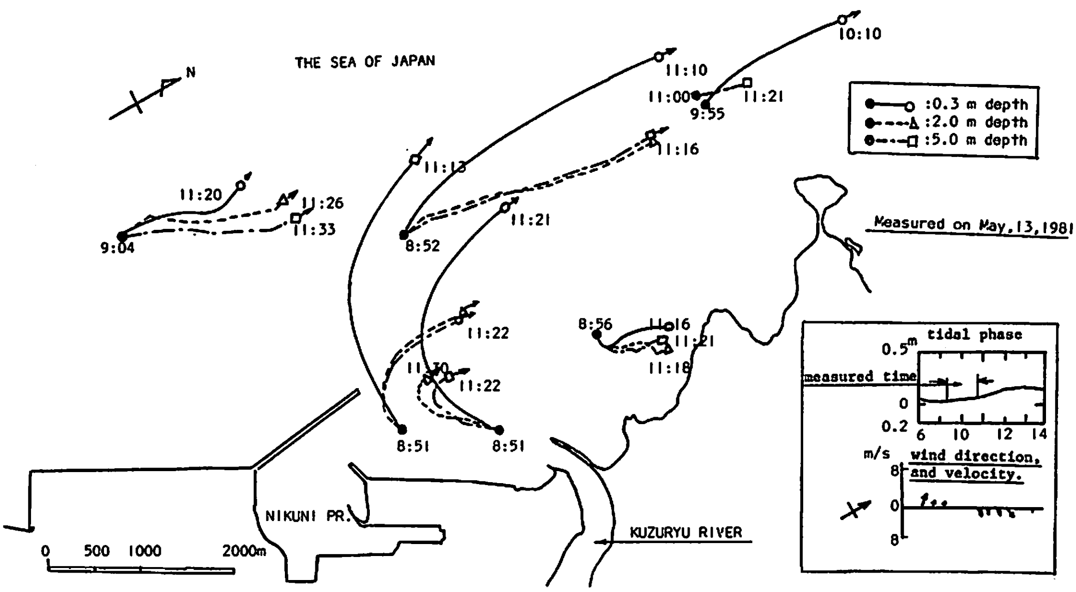

Fig. 4 Tide, wind direction and paths of floats at estuary of Kuzuryu river ,May 13, 1981.

Coriolis force acting on the current takes a direction away from the shore and the current can not touch the land.

B) Boundary between the oceanic and coastal currents.

Simultaneously with the Landsat remote sensing (Plate 6), ship-borne observations of the current velocity were carried out at the sea area around the mouth of Kzuryu river in a period of May 13 to 29, 1981. The measurement results of occurrence frequencies of the flow direction, tidal change, wind direction and time -averaged velocity are shown in Figures 3 and 4, respectively. From these results one can see that although north-eastward current shall be dominant at this sea area, the currents at the coastal area adjacent to the shoreline change the directions rather periodically. Namely, it is considered that there may exist boundary,inside of which periodic coastal currents can be dominant. Then , an interest is stimulated to know the extents where either of the periodic coastal current or the oceanic current be donimant. Look into this problem, the Landsat TM data of the sea area around the mouth of Kuzuryu river were analyzed.

Plate 10 and Plate 11 show TM 2nd band image (indicating difference of turbidity in the water) and 6th band (infrared) image of the sea surface on October 8, 1984, respectively. Furthermore, Plate 12 shows a closer view of the TM 2nd band image of the same area.

In these plates, one can see that the turbid water masses released from the Tedori river at approximately 55 km north-east of the Kuzuryu river, are transported along the shoreline by south-westward coastal current and then turns its direction offshore and finally becomes to flow reversely about 15 km off the Tojimbo coast. As seen in Plate 11, the water mass issued from the Kuzuryu river, temperature of which is lower than that of surrouding sea water, extedds all over off the river mouth, forming definite thermal fronts with the surrounding warmer water. Those thermal fronts (in Plate 11) are well lain on the fronts due to the difference of turbidity (in Plate 10), as indicated in Figure 5.

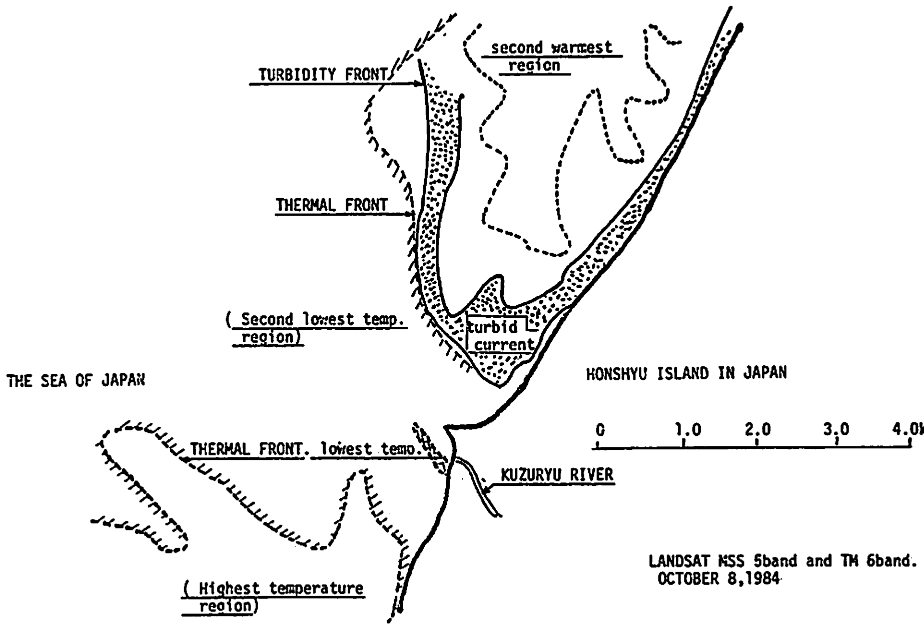

Fig. 5 Fronts caused by differences of water temperature and turbidity

From the above analysis of the Landsat TM data, we can understand that at the coastal sea area in the distance less than approximately 15 km from the shoreline, the periodic coastal currents may exist, but at the sea area more than about 20 km far away the land, the north-eastward geosrophic current, that is, No.1 Branch of the Tsushima Current is predominant in this particular area.

CONCLUSION

In the foregoing, distributions of river effluents discharged into the coastal water zones of Honshyu Island in Japan were visualized by the Landsat data and it has been shown that effect of the No.1 Branch of Tsushima Current on behaviors of the river effluents discharged into the Sea of Japan can not be ignored and also that the river effluents in this sea have a tendency to flow north along the coastline, and in addition, at the extremely far field, the effluents keep the widths approximately constant and the concentration of substances suspended in the effluents from the Mogami and Kuzuryu rivers distribute discontinuosly. Such features at the extremely far field suggest that the coastal currents flow under the geostrophic balance.

In the coastal area adjacent to the shoreline, generally there exist coastal currents generated by various causes such as tide, wind, wave ond others. Ship-borne observations carried out at the sea area around the mouth of Kuzuryu river indicate that the directions of the coastal currents may be changed periodically. And the Landsat TM data of the water area show that at the coastal sea area in the distance less than approximately 15 km from the shoreline, the periodic coastal currents could be dominant, but at the sea area further far away the land, the north-eastward oceanic currents becomes dominant in this particular area.

In some coastal water areas facing the Pacific Ocean, large scale eddies far offshore produced by the oceanic currents may entrain the coastal water masses in it, which suggest that such large scale eddies influence the mixing between the coastal and oceanic waters sigificantly.

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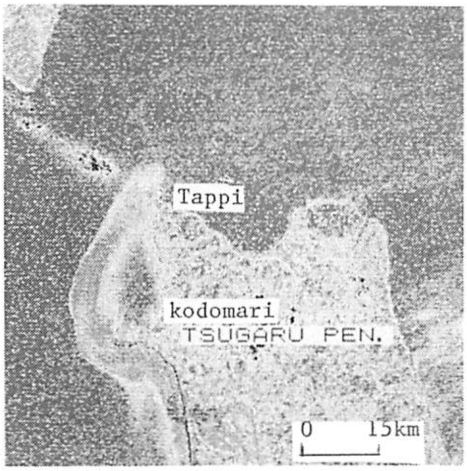

Plate 1 Tsugaru Peninsula,MSS 4, May 15, 1982

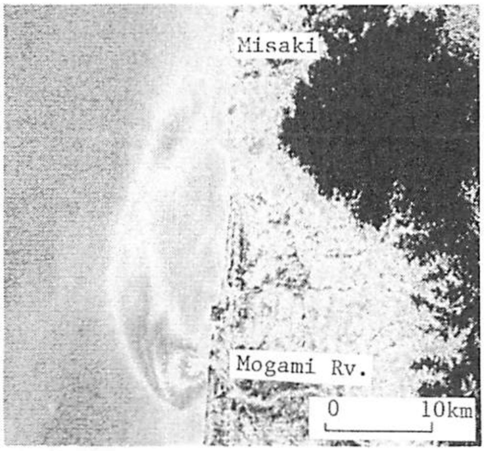

Plate 2 Mogami river, MSS 5, April 23, 1981

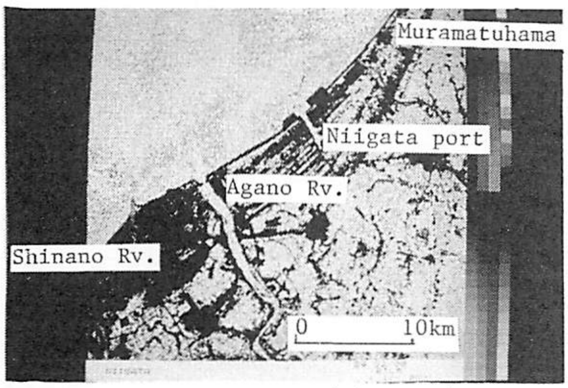

Plate 3 Shinano and Agano rivers MSS 5, July 12, 1983

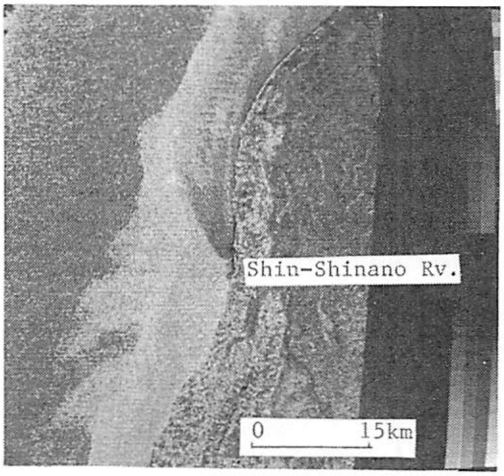

Plate 4 Shin-Shinano river MSS 4, Oct.23,1979

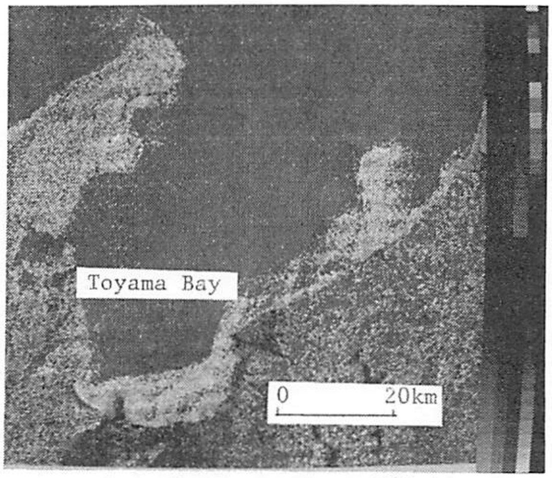

Plate 5, Toyama bay, MSS 4, October 23, 1979

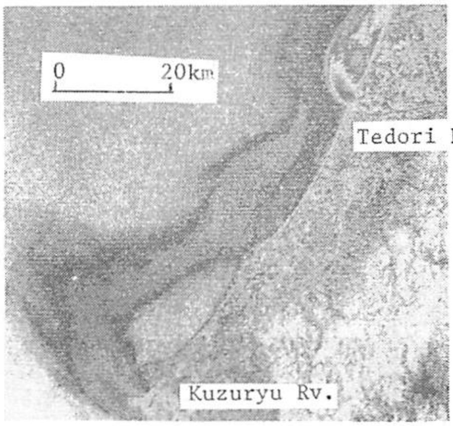

Plate 6 Kuzuryu river , MSS 4, May 13, 1981

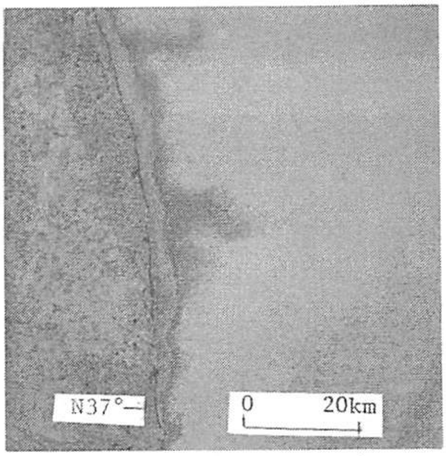

Plate 7 Fukushima , MSS 4,
April 26, 1982

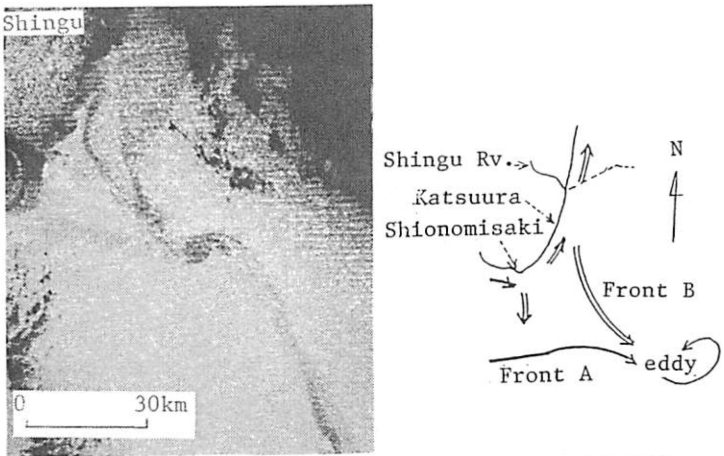

Plate 8 Off the Kii peninsula , MSS 5, October 10,1982

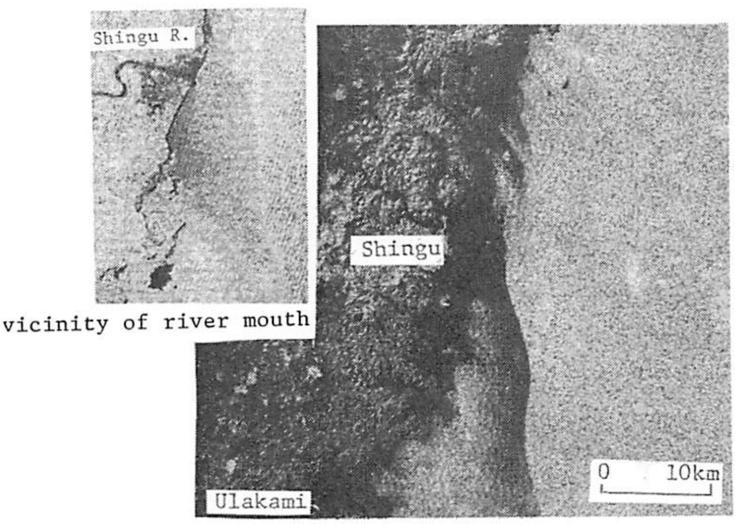

Plate 9 Off the Shingu river, MSS 5, October 10, 1982

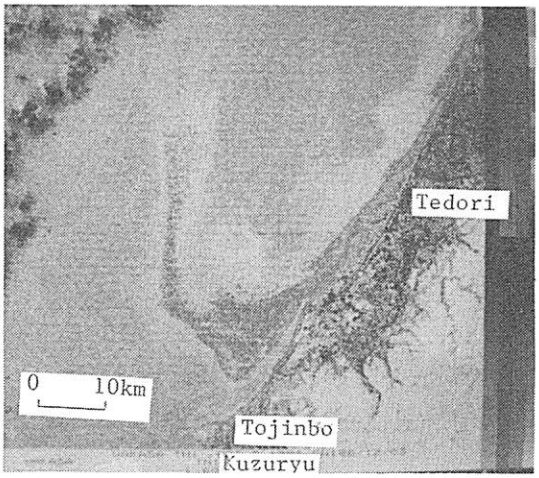

Plate 10 Kuzuryu and Tedori rivers, TM 2, October 8,1984

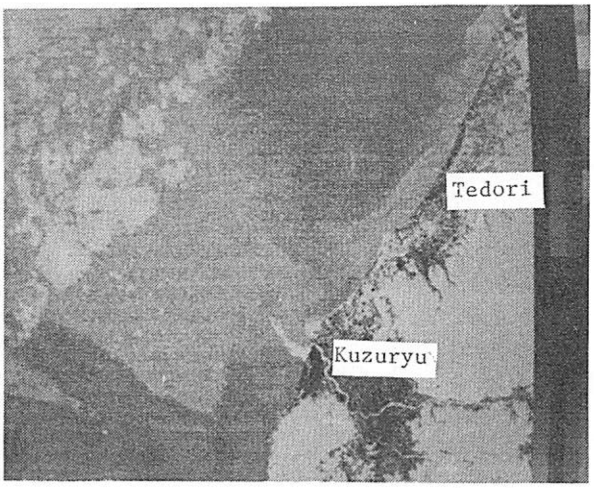

Plate 11 Kuzuryu and Tedori rivers, TM 6, October 8,1984

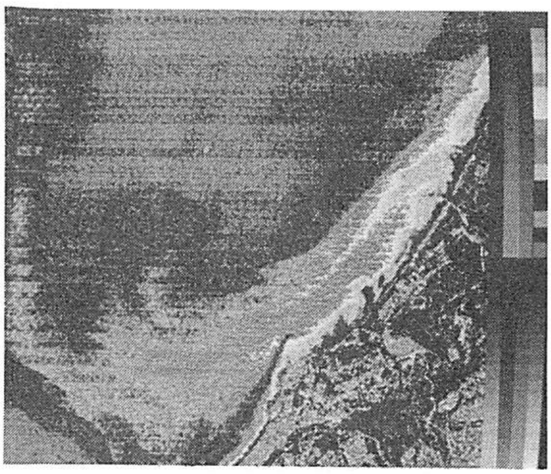

Plate 12 Coastal current in vicinity to Tedori river
(closer view of Plate 10)