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Bifurcation Current Found along the Coast of the Kii Peninsula and Position of the Kuroshio Axis

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ABSTRACT

A bifurcation current is often observed along the southwest coast of the Kii Peninsula. The ADCP data taken in the period from 1988 to 1996 by the Wakayama Prefectural Fisheries Experimental Station were analyzed. The occurrence frequency of the bifurcation current is about 70% in the analyzed period. Current divergence along the line parallel to the coast, which roughly corresponds to the 100 m depth contour, was calculated. The divergence value averaged over the line is generally positive, and it is especially high when the bifurcation current occurs. Its value was small and negative in 1990 when the Kuroshio took a meandering path. The occurrence of the bifurcation current is shown to have a correlation with the position of the Kuroshio axis, and it is frequently observed when the Kuroshio is in a straight path and flows near the coast. The spatial current field and temporal variations of the bifurcation current were also analyzed using the data taken on board of the R/V Seisui-maru of Mie University.

(Key Words: Kuroshio, large meander, bifurcation, Kii Peninsula, Cape Shionomisaki)

INTRODUCTION

Along the southwest coast of the Kii Peninsula, a bifurcation current is often observed: one of the typical examples is shown in Fig.1 (June 28, 1991). We analyzed the ADCP data taken on board the R/V Wakayama of the Wakayama Prefectural Fisheries Experimental Station in the period from 1988 to 1996 (Takeuchi et al., 1998). Their main results will be summarized in Section 2. In order to clarify the structure and variability of the Bifurcation Current, we sent the R/V Seisui-maru of Mie University several times to the region under consideration. Some of the preliminary results will be given in Section 3.

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Occurrence frequency of the Bifurcation Current and its relation to the position of the Kuroshio Path

Most of the observation lines were selected so as to follow roughly along the 100 m depth contour that runs almost parallel to the coast, as shown in Fig. 1. The number of observations that covered at least from Cape Ichie (B in Fig. 1) to Cape Shionomisaki (F in Fig. 1) is 258. The time required to occupy the line is usually less than 2 hours, and tidal currents appear not to influence the flow pattern in this area.

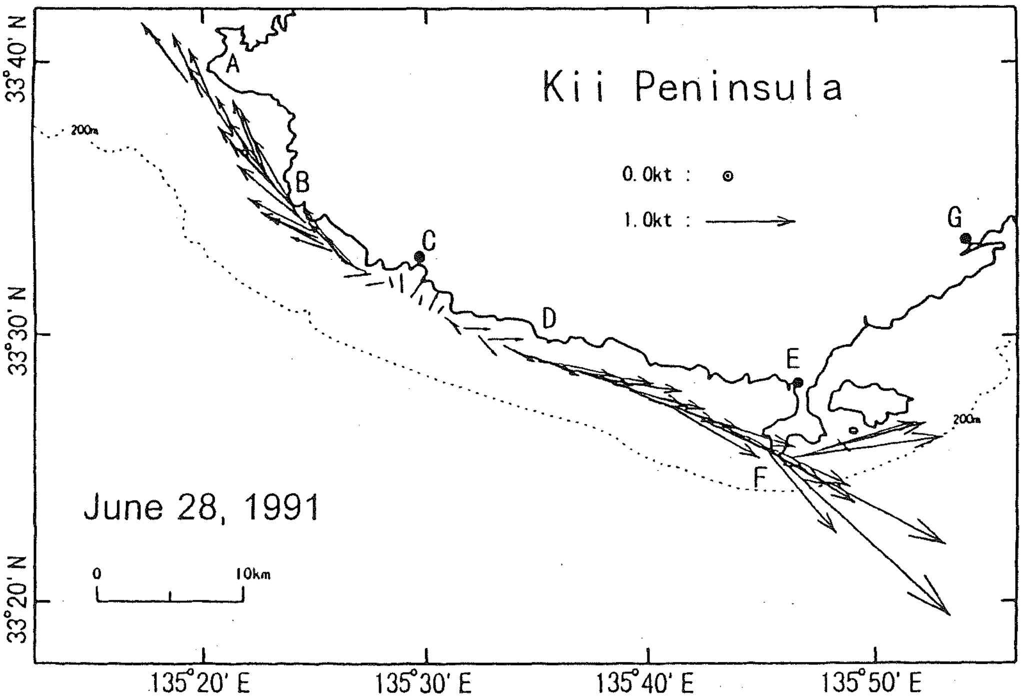

Fig. 1 An ADCP observation line along the southwest coast of the Kii Peninsula by the Wakayama Prefectural Fisheries Station: The observation line was usually selected so as to follow the 100 m depth contour that runs almost parallel to the coast. A current field measured at 5 m depth on June 28, 1991 is also shown. This gives a typical example of the Bifurcation Current (the Typical Bifurcation Current). Each current vector is given for the value averaged for 60 sec throughout this report. The current value averaged over each 1 min. interval is shown in each corresponding figure in this paper. A: Cape Seto, B: Cape Ichie, C: Susami, D: Cape Esu, E: Kushimoto, F: Cape Shiononmisaki, and G: Uragami. (Takeuchi et al., 1998).

We classified the current pattern found in this coast into 6 groups: (1) the Typical Bifurcation Current as shown in Fig. 1; (2) the Bifurcation Current when the bifurcation tendency can be seen even if the bifurcation point is unclear (group (1) is also included); (3) the Eastward

Current as shown in B of Fig. 2; (4) the Westward Current as shown in C of Fig. 2; (5) the Converging Current as shown in D of Fig. 2; and (6) the Irregular Current as shown in E of Fig. 2. The occurrence frequencies of these current patterns were calculated and are shown in Fig.3. The Bifurcation Current is the most dominant current field, and its frequency reaches about 70%.

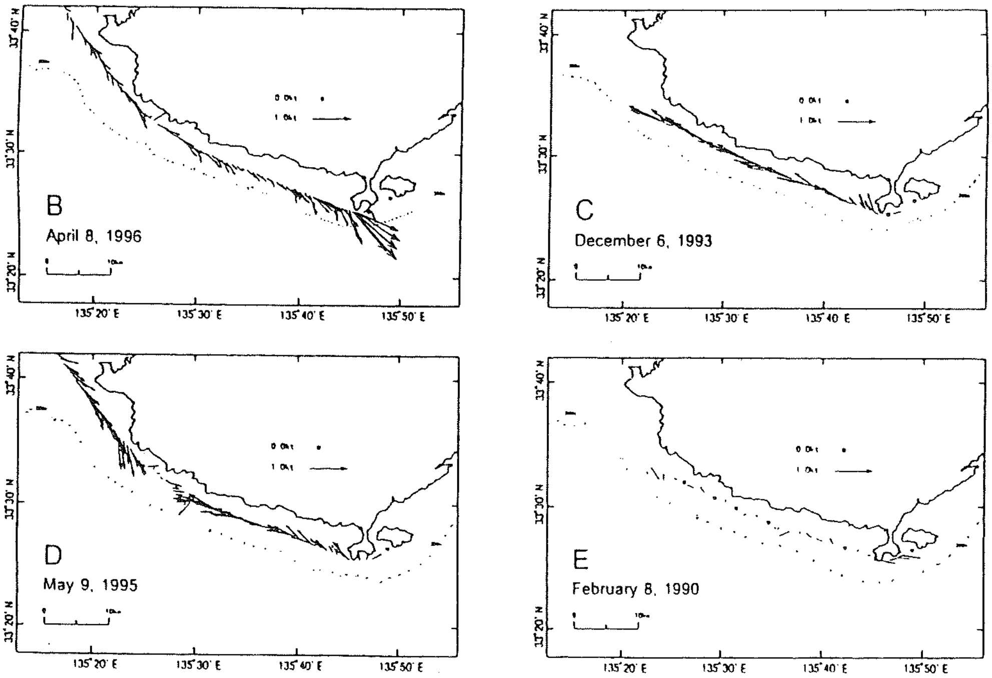

Fig. 2 Typical examples of the Eastward Current (top-left: April 8, 1996), the Westward Current (top-right: December 6, 1993), the Convergence Current (bottom-left: May 9, 1995), and the Irregular Current (bottom-right: February 8, 1990). The current fields measured at 5 m depth are shown. (Takeuchi et al., 1998).

It is said that the bifurcation usually occurs near Susami (C in Fig. 1). The distribution of the occurrence frequency shows a weak peak near Susami, but the bifurcation point can be found in a broad range from Cape Ichie near to Cape Shionomisaki. The bifurcation point may be shifted if there is an along-shore current of significant magnitude. Therefore, we calculated the divergence or the gradient of the along-shore current component and analyzed its statistical characteristics. In order to make a statistical analysis, each observation line was projected onto a standard line that runs roughly along a 100 m depth contour, and the velocity component along the line was calculated. As the observation points are not uniformly distributed, the divergence values were interpolated so as to obtain data at an equal interval of 1 km, and the resulting database is used to obtain various averages. The positive divergence is generally predominant in the analyzed area, and its magnitude does not show significant peaks at any specific location. Predominance of positive divergence suggests that the onshore currents prevail off the southwest coast of the Kii Peninsula.

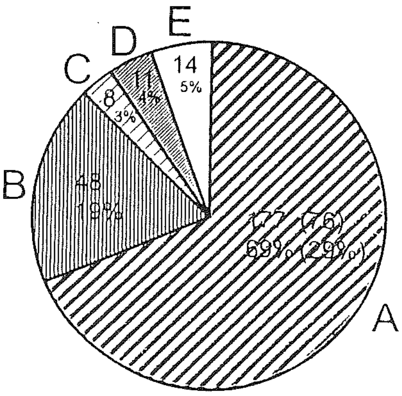

Fig. 3 Occurrence frequency of each flow pattern;
A: the Bifurcation Current,
B: the Eastward Current,
C: the Westward Current,
D: the Converging Current, and
E: the Irregular Current.
The occurrence number and frequencies in % are given in each corresponding section (numbers in parenthesis for A indicate the typical Bifurcation Current). (Takeuchi et al., 1998).

The current divergence averaged over the analyzed region and for each year is shown in Fig. 4. The value is small and negative in 1990. No typical Bifurcation Current occurs in this year. The variation of the position of the Kuroshio axis (the distance measured southward from Cape Shionomisaki to the Kuroshio axis) is shown in Fig. 5. The Kuroshio was flowing in a straight path, except when it took a large-meander path in 1990. The divergence averaged for the period of each current pattern group is calculated and shown in Fig. 6. The value is largest for the Typical Bifurcation Current. The magnitudes decrease in the following order: the Bifurcation Current, the Eastward Current, the Westward Current, the Irregular Current, and the Converging Current. The averaged divergence is negative only for the Converging Current. There is clear indication that the Bifurcation Current and the Eastward Current are often generated when the Kuroshio flows in a straight path, and that the Converging Current, the Westward Current, and the Irregular Current are generated when the Kuroshio flows in a large-meander path. The period of the Kuroshio Large Meander is relatively short in our analyzed period. This would be the reason that the occurrence frequency of the Bifurcation Current is high in our result.

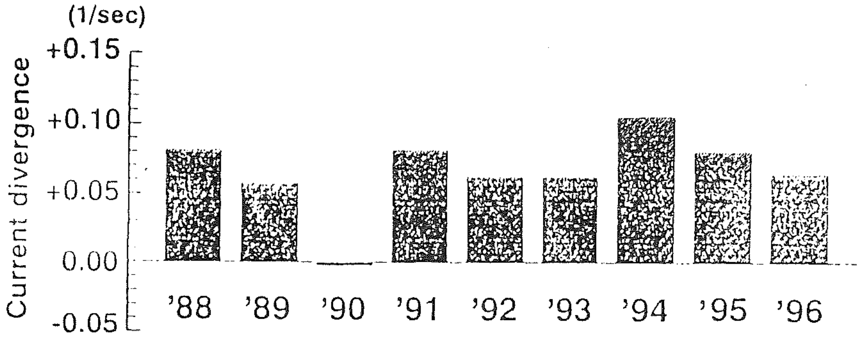

Fig. 4 Temporal variation of the current divergence (in 1/sec) averaged yearly over the line from off Cape Ichie to the point 5 km to the west of Cape Shionomisaki. A negative value occurred only in 1990. (Takeuchi et al., 1998)

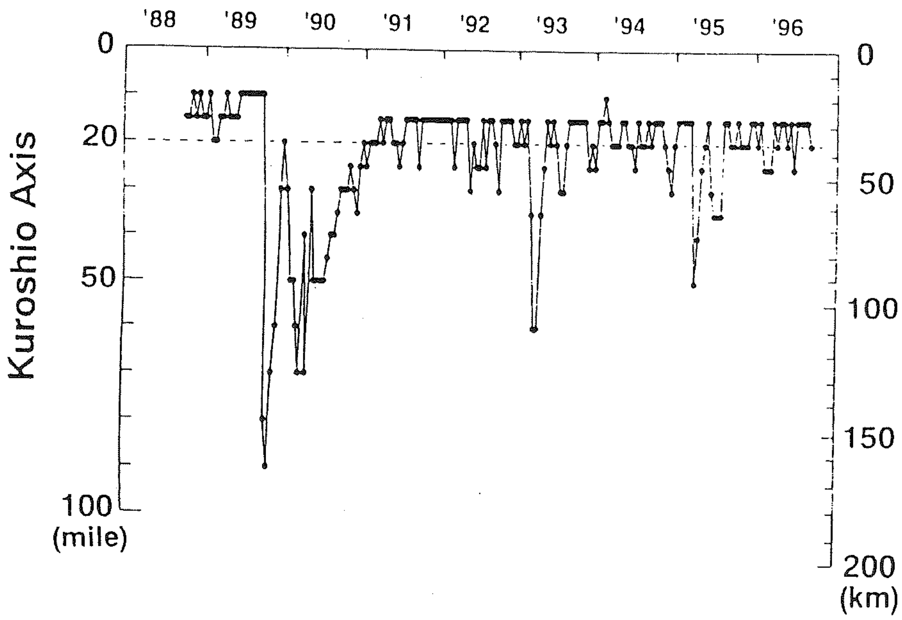

Fig. 5 Temporal variations of the position of the Kuroshio axis measured southward from Cape Shionomisaki (in nautical miles and in km) in our analyzed period. (Takeuchi et al., 1998)

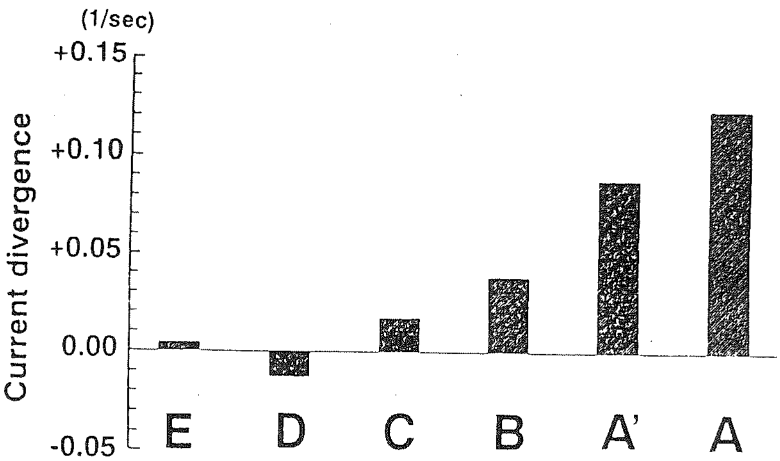

Fig. 6 Current divergence averaged for each flow pattern. A: the Typical Bifurcation Current, A': the Bifurcation Current, B: the Eastward Current, C: the Westward Current, D: the Converging Current and E: the Irregular Current. (Takeuchi et al., 1998)

Structure and variability of the Bifurcation Current

In order to clarify the structure and temporal variability of the Bifurcation Current, we conducted a series of ADCP and XBT observations on board the R/V Seisui-maru of Mie University in the regions under consideration: October 29-31, 1996, June 24-26, 1997, October 14-16, 1997, and December 3-4, 1997. Here, we shall introduce the preliminary results of the first two cruises.

The current field observed on June 24-25, 1997 is shown in Fig. 7, and temperature fields at 50 and 200 meter depths are shown in Fig. 8. The Typical Bifurcation Current is clearly seen along the northernmost line A, and the bifurcation trend can be recognized up to the fourth line D. The bifurcation nature is also seen in the temperature field at 200 m depth; a temperature zone higher than 13°C extends toward the northwest from the high temperature area of the Kuroshio Water at around 33° 22'N, 135° 37'E (lower figure of Fig. 8). Roughly along this high temperature zone, a warm water tongue extends towards the west at 50 m depth (upper figure of Fig. 8). As seen in these figures, the easternmost part of the Bifurcation Current appears to belong to the coastal portion of the current zone of the Kuroshio.

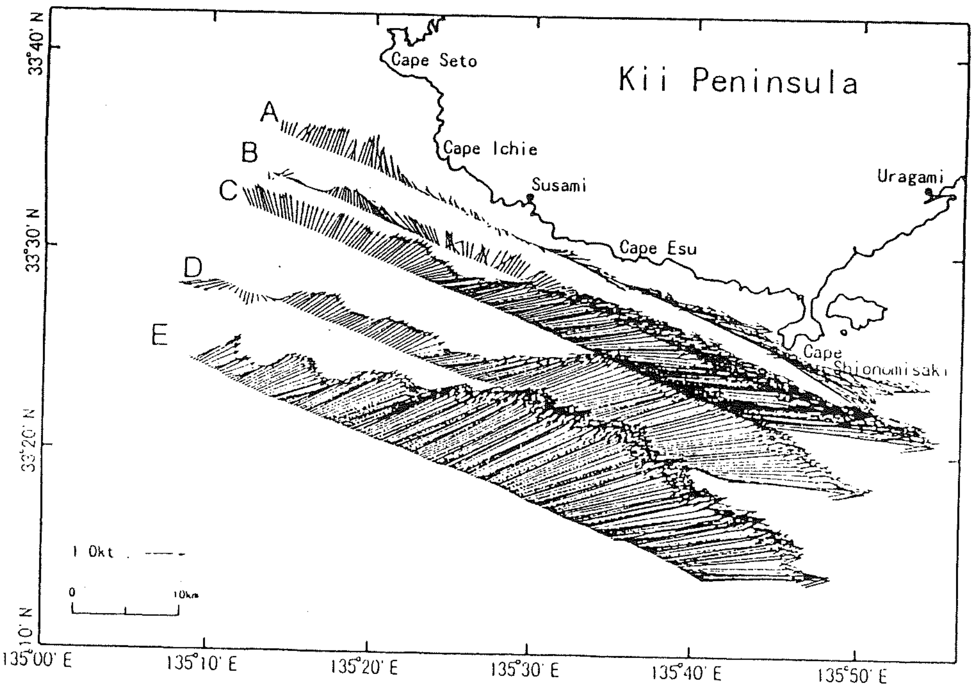

Fig. 7 Current field measured at 5 m depth on board the R/V Seisui-maru from 22:44 on June 24 to 15:45 on June 25, 1997. The northernmost observation line corresponds to the observation line of the R/V Wakayama, and we also call this A line. The observation lines will be called A line through E line outwards from coast.

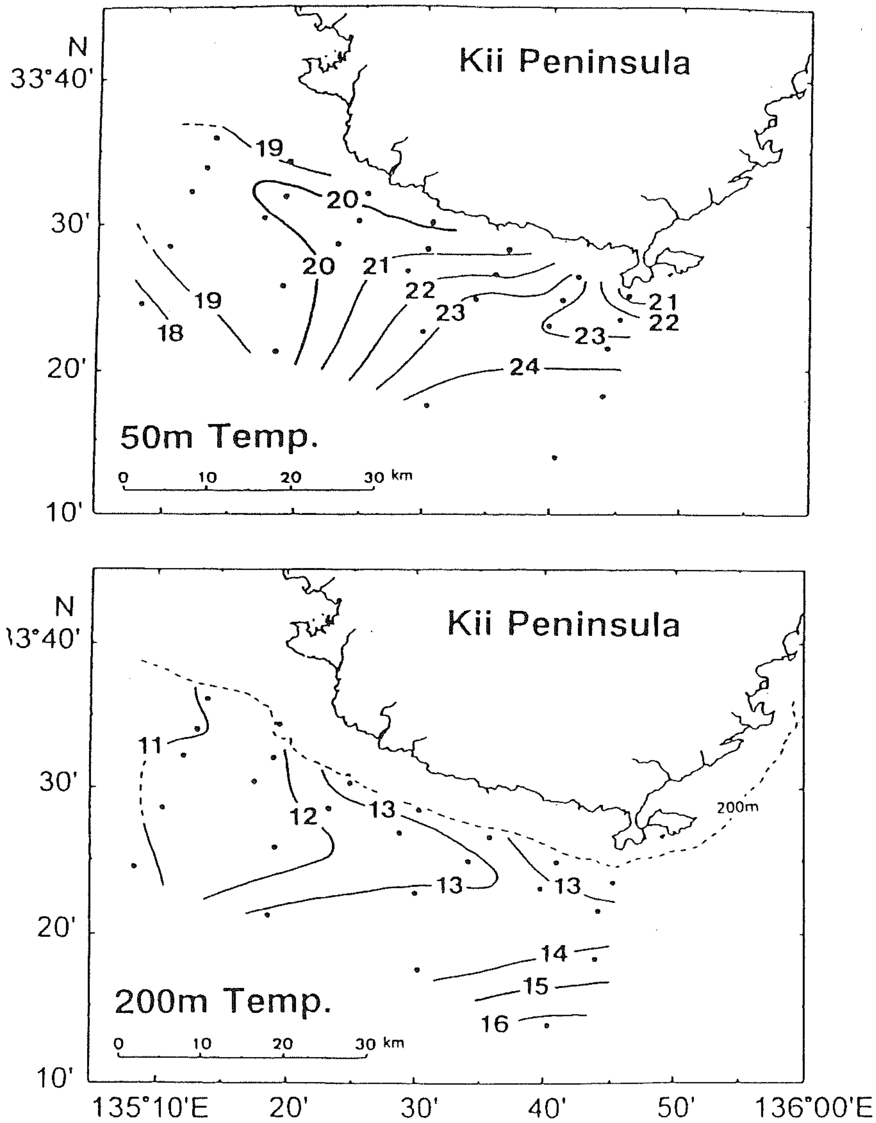

Fig. 8 Temperature fields at 50m and 200 m depths measured on board the R/V Seisui-maru from 22:44 on June 24 to 15:45 on June 25. Observation points are shown with dots.

We made repeated ADCP observations along the line A for a period from 17:11 on June 25 to 13:57 on June 26. The current field for each run is shown in Fig. 9. It takes only 2 to 3 hours to make each survey along the line. The observed current fields in Fig. 9 suggest that the tidal current is not so significant, and the current field is not changed significantly during the observation.

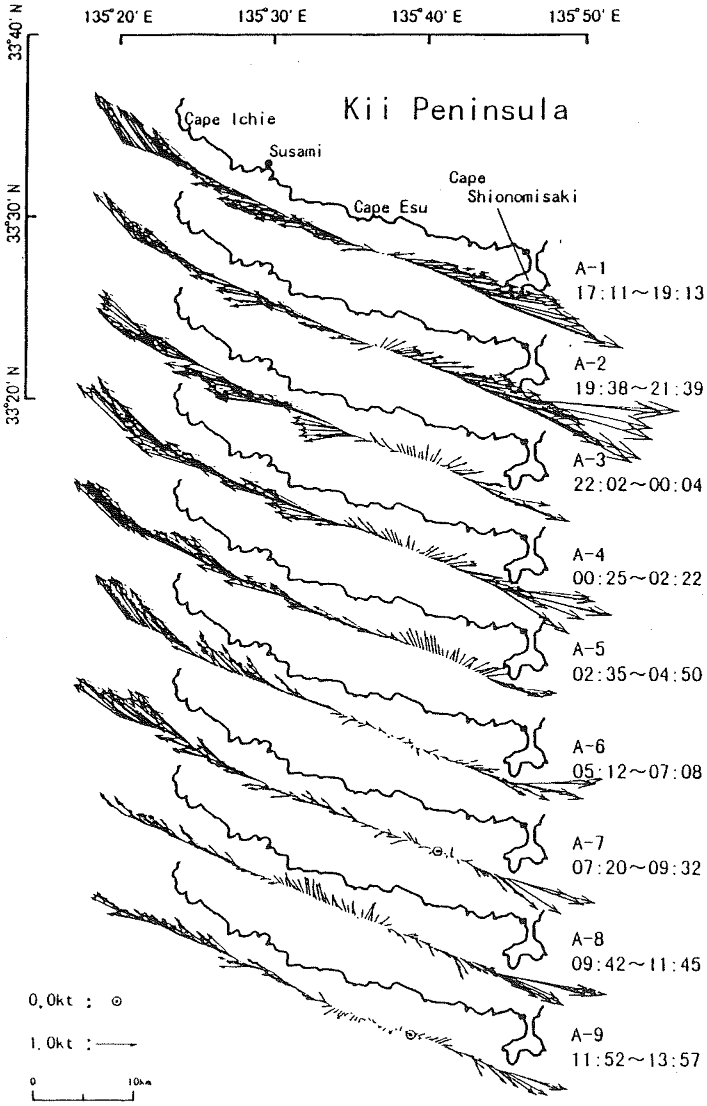

Fig. 9 Variation of the current field along line A. The line was occupied 9 times by the R/V Seisui-maru from 17:11 on June 25 to 13:57 on June 26 (A-1 through A-9). The period of each observation is shown to the right of each figure.

The variation in the sea level difference between Kushimoto and Uragami is shown in Fig. 10 for the period of our observation. This sea level difference is used by various investigators as a measure of the Kuroshio path patterns (e.g.: Kawabe, 1980). Fujita (1997) indicated that the Kuroshio flows in a straight path if the sea level difference exceeds 25 cm and in a meandering path if the difference is smaller than 25 cm; this value is shown with a horizontal dashed line in

Fig. 10. These results were derived from the comparison between the position of the Kuroshio given in the Prompt Report of Oceanographic Condition, which is published bimonthly by the Hydrographic Department of the Maritime Safety Agency, and the sea level difference averaged for the corresponding period. This criterion might not be directly applicable for hourly values. However, the sea level difference tends to decrease during our repeated observation, while the current speed just near to Cape Shionomisaki appears to continuously decrease. Though further elaborated studies are required, the sea level difference may be a measure of the position of the Kuroshio axis even for such short time-scale variations.

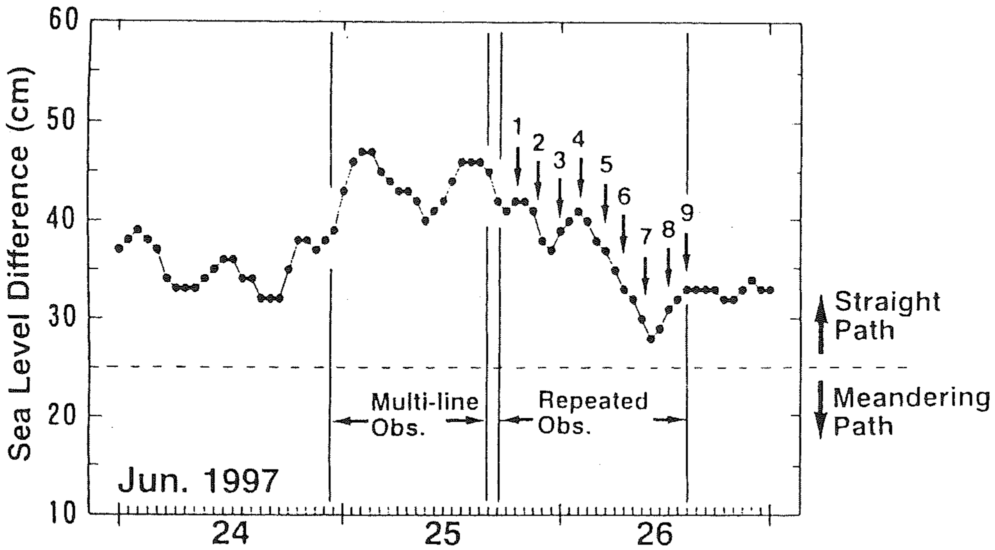

Fig. 10 The variation of the sea level difference between Kushimoto and Uragami (see Fig. 1 for these locations) from June 24 to 26, 1997. This sea level difference is often used for monitoring the position of the Kurosio path off the Kii Peninsula. The observation time for each section is indicated by an arrow with a numeral indicating the serial number of the observation. According to Fujita's criterion, the sea level difference indicates that the Kuroshio was flowing in a straight path during our observation, but it tends to decrease during our repeated observation.

The current fields observed in October 1996 were quite different from those in June 1997 and were very changeable. Current fields observed at 5 m depth and 50 m depth on October 29 (A line, 20:38-22:42) are shown in Fig. 11, and those observed along two lines at 5 m depth on October 30-31 (A line, 19:19-21:24 and B line, 21:53-00:00) are in Fig. 12. The current pattern on October 29 was the Westward Current, while that on October 30-31 was the Eastward Current. Usually, the current at 50 m depth is almost identical to that at 5 m, but in this case the current field at 50 m was considerably different from that at 5 m. For example, the current near Cape Esu was towards the shore at 5 m, but at 50 m it was away from the shore. The current field along A line on October 30-31 was quite different from that taken along B line; this difference is hard to understand as a variation in space and would be attributed to temporal variation. The variation of the sea level difference between Kushimoto and Uragami is shown in Fig. 13. The difference was around or below 25 cm at the time of our observation. A satellite image taken in this period indicates that a small-scale meander of the Kuroshio passed by Cape Shionomisaki at this time. The short-time variation of the sea level also appears to indicate the passage of the small eddy by Cape Shionomisaki. The large variability of the current field both in time and space on October 29-31 would be attributed to such complex oceanic conditions.

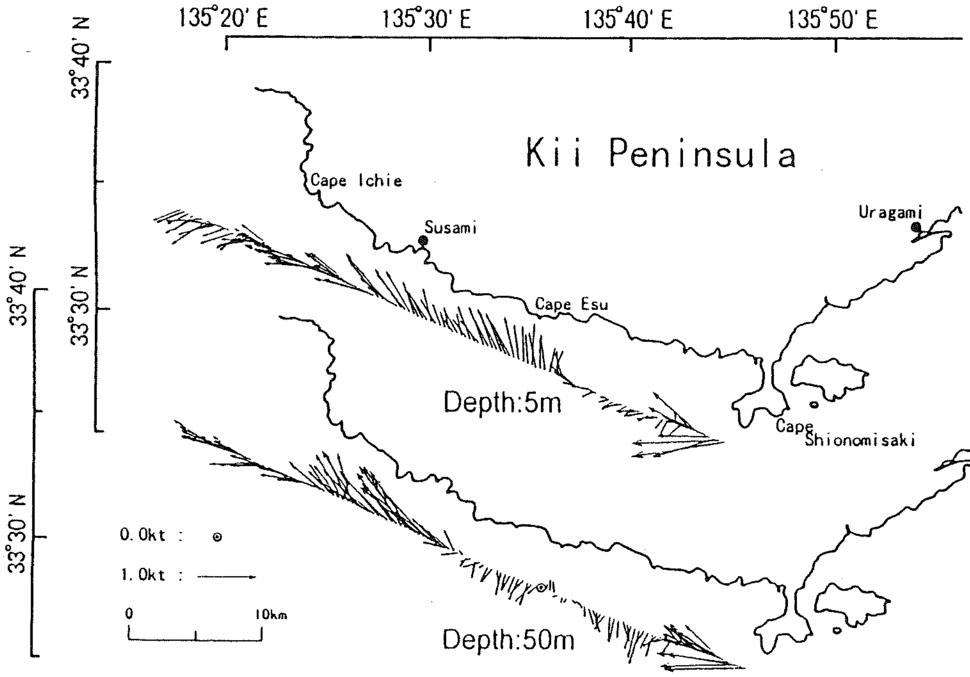

Fig. 11 Current fields observed at 5 m depth and 50 m depth on October 29 (A line, 20:38-22:42), 1996.

CONCLUDING REMARKS

The Bifurcation Current is predominant along the southwest coast of the Kii Peninsula at least when the Kuroshio takes its straight path. The eastward flow of the Bifurcation Current near Cape Shionomisaki may be considered as a part of the Kuroshio current. The westward current of the western portion of the Bifurcation Current appears to be related to the anti-clockwise eddy usually existing in the Kii Channel (Fujita et al., 1998). The current pattern, such as the Bifurcation Current, usually appears to be stable, but is very changeable when the short time fluctuation of the Kuroshio occurs near Cape Shionomisaki. However, we would need to make further investigations in order to confirm these conclusions.

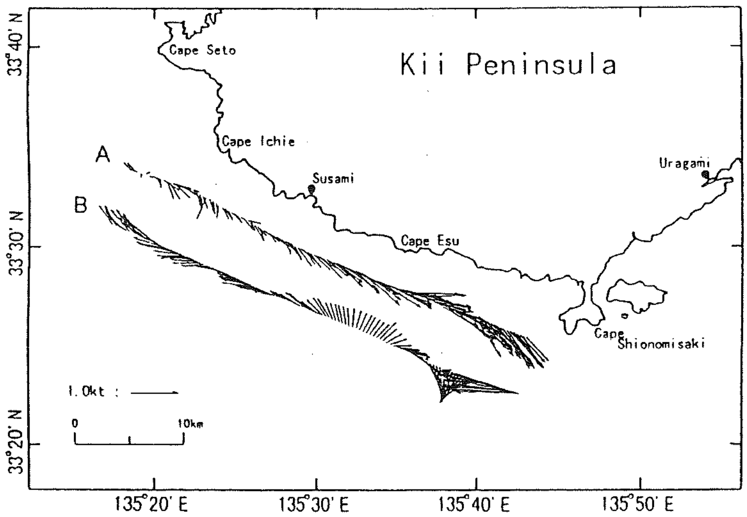

Fig. 12 Current fields at 5 m depth along line A (19:19-21:24 on October 30) and line B (21:53-00:00 on October 30).

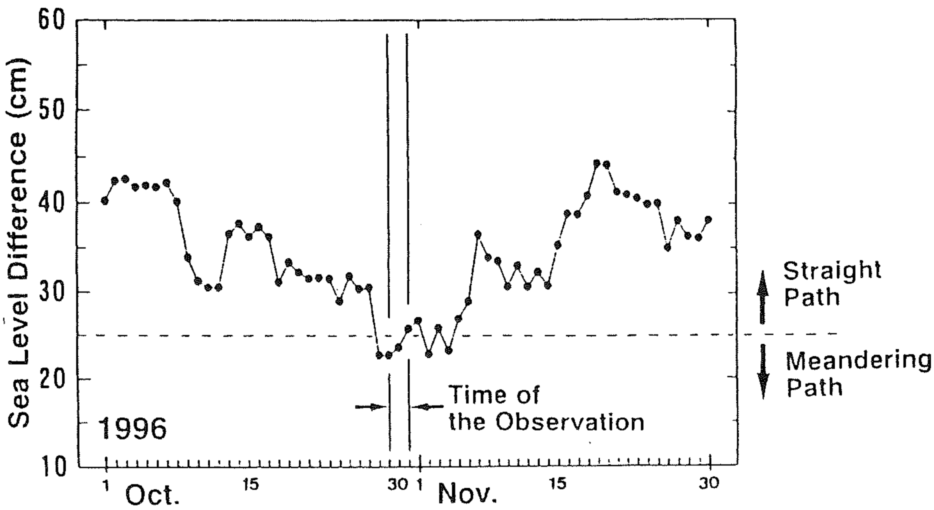

Fig. 13 The variation of the sea level difference between Kushimoto and Uragami from October 1 to November 30. This sea level difference is often used for monitoring the position of the Kuroshio path off the Kii Peninsula. The sea-level difference fluctuated around 25 cm at the time of our observation, indicating a small-scale eddy passed by Cape Shionomisaki in this period.

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紀伊半島沿岸的分叉流與黑潮軸心的位置

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摘　要

紀伊半島西南岸常發現分叉流。在 1988~1996 期間，由和歌山縣水產試驗場的剖流儀資料分析得知，分叉流的發生率約爲 70%。沿著幾個平行海岸的 100m 等深線所推算出的海流輻散值顯示，其平均值通常爲正，當分叉流發生時，正値特大。1990 年當黑潮蛇行時，其輻散值是較小的負値。分叉流發生的時機與黑潮軸心位置相關，當黑潮貼岸直行時，常常觀測到分叉流。本文也使用了三重大學 Seisui-maru 研究船的資料，分析分叉流的時序變化及流場的空間分佈。

(關鍵詞: 黑潮、大蛇行、分叉、紀伊半島、鹽野岬)

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