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Variation in the Main Kuroshio Path South of Japan

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The time variation in the Kuroshio is studied by use of nine observed distances of the main Kuroshio axis from the Japanese coast. The observed distances over 1975 - 1995 are estimated from the Prompt Report of Oceanographic Conditions published by Hydrographic Department of the Maritime Safety Agency of Japan. It is shown that large sea level difference between Naze and Nishinoomote, which represents the volume transport of the southern inflow south of Kyushu, coincides with larger distance of the Kuroshio in the upstream area from off Kyushu to off eastern Kii Peninsula and smaller distance in the downstream area from off Omae-zaki to off Boso Peninsula. In contrast, large sea level difference between Nishinoomote and Aburatsu, which represents the volume transport of northern inflow south of Kyushu, corresponds to smaller distance in the upstream area and larger distance in the downstream area. Path dynamics of the Kuroshio is discussed with reference to the variation in Volume transport south of Kyushu.

Key words: Kuroshio, Bimodal kuroshio path, Tokara strait, Large meander

INTRODUCTION

The Kuroshio south of Japan has a bimodal path, fluctuating between a non-large meander path (nLMP) and a large meander path (LMP) (e.g. Ishii *et al.*, 1983; Kawabe, 1986). There have been various studies on the bimodal path dynamics of the Kuroshio. It is shown by some studies (Saiki, 1982; Kawabe, 1995; Akitomo *et al.*, 1996) using observational data that the volume transport of the Kuroshio is relatively larger in periods of LMP than in periods of nLMP. Furthermore, the path of the Kuroshio also depends on the topographic effect of the peninsula. Sekine (2000) generally discussed the topographic effect of a peninsula on a western boundary current. Both studies commonly show that the multi-steady state of the bimodal path covers a wide range of the in- and outflow velocity of the model.

In this context, detailed analysis of the variation in the observed main Kuroshio axis should be examined carefully with reference to the change in velocity and/or volume transport of the Kuroshio. In the present study, time variation in nine observed distances of the main Kuroshio axis from Japanese coast (Fig. 1) are examined during the period from 1975 to 1995. The distance is estimated along the south-north direction at 8 points, while the distance from Toi-misaki (TOI) is estimated in the south-eastward direction. The distance from Japanese coast is evaluated as the distance from tip of the peninsula to the center of the main Kuroshio path shown by the Prompt Report of Oceanographic Condition published by the Hydrographic Department of the Maritime Safety Agency of Japan, in which the main Kuroshio axis is estimated from the observed velocity and temperature during half of each month. If the main Kuroshio axis runs like multi-valued function (Fig. 1), all the possible distance with the maximum three distance value are evaluated. In all the data analyses, the largest distance is employed so that the characteristic features of the Kuroshio path are well represented by the largest distance, which also shows LMP or nLMP.

RESULTS

The time variations in the distances of the main Kuroshio path from nine Japanese coastal points are shown in Fig. 2. Here, the farthest distance is plotted and the shorter distances are shown by open and closed circles. In some cases, multiple crossings of north-south line by main axis of the Kuroshio are

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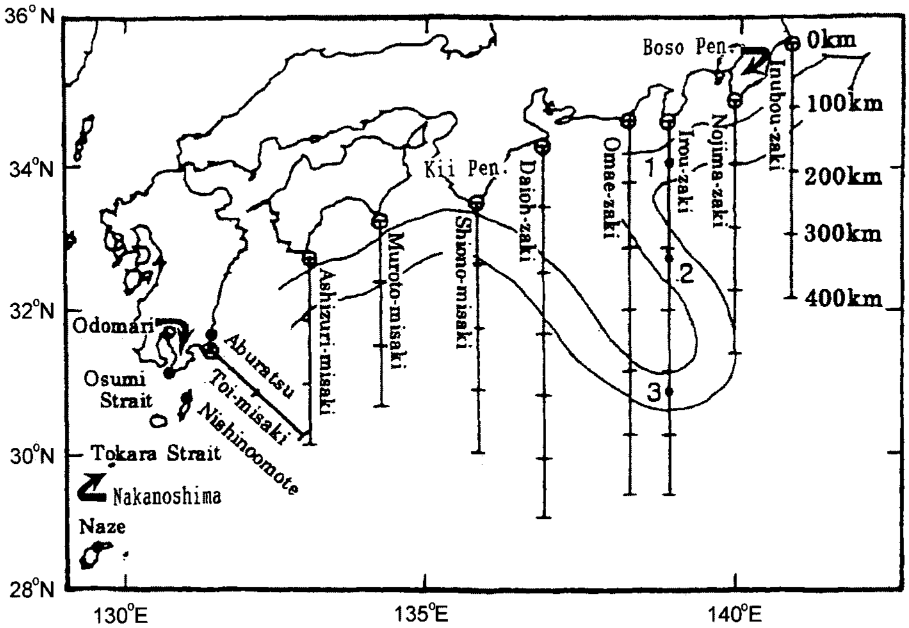

Fig. 1. Schematic view showing the distance of the main Kuroshio path from Japanese coast shown by open marks. Locations of tidal stations, straits and islands are also shown by closed marks.

found downstream from Daioh-zaki (DAI) on the eastern side of the Kii Peninsula (Fig. 1). It is shown from Fig. 2 that multiple crossings from DAI to Irou-zaki (IRO) are confined to the period of the LMP formed in 1975, while those from IRO to Inubou-zaki (INU) are confined to the periods of LMP formed after 1981. On the whole, the Kuroshio is relatively close to the coast upstream from the Kii Peninsula, and far from the coast in the downstream area. Note that the vertical scales in Fig. 2 are different between the upper four panels and the lower five panels.

It is also shown from Fig. 2 that the LMP formed in 1975 has a relatively larger distance in the upstream area from off Ashizuri-misaki (ASH) to off DAI, while LMPs formed after 1981 have a larger distance in the downstream area from off Omae-zaki (OMA) to off INU. Mean farthest distances during each meander period are show in Fig. 3. A clear difference of the path pattern is detected. In particular, it is noted that the mean path of LMP formed 1975 path runs through the gate area over the Izu Ridge, while those formed after 1981 run in southern area to the gate region and a larger topographic effect of the Izu Ridge is indicated. Namely, the LMP formed 1975 matches the zonal scale of the Shikoku Basin, but the LMP formed after 1981 does not match the zonal scale, which causes the shorter lifetime of the LMPs formed after 1981 show by the black bands in Fig. 2.

Lagged correlation between nine distances of the main Kuroshio axis from Japanese coast (Fig. 2) and the sea level differences between Naze and Nishinoomote (SLD:NA-NI) and between Nishinoomote and Aburazu (SLD: NI-AB) are shown in Fig. 4. It is shown by Nakano and Kaneko (1990) and Nakano *et al.* (1994) that the Kuroshio flow in the Tokara Strait is branched into a southern flow and a northern flow. The volume transport of the northern flow can be estimated by the sea level difference between Nishinoomote and Aburatu (Ichikawa *et al.*, 1982; Ishii, 1978; Ichikawa, 1990). The volume transport of the southern flow should be estimated from the sea level difference between Naze and Nakanoshima (Fig. 1), the sea level data at Nakanoshima is available after 1985. However, the sea level difference between Naze and Nakanoshima is well correlated with that between Naze and Nishinoomote (Sekine and Chen, 2002) and the volume transport of the southern flow is estimated by the sea level difference between Naze and Nishinoote. Namely, SLD: NI-AB (SLD: NA-NI) represents the volume transport of the northern (southern) flow of the Kuroshio through the Tokara Strait.

It is shown from Fig. 4 that a significant negative correlation is found between the distances from TOI (Fig. 1) and MUR and the SLD: NI-AB. The negative correlation is weakened downstream, and disappears at off DAI. Conversely, a significant positive correlation is found between the SLD:NI-AB and the distances of the Kuroshio from the coast from OMA to NOJ. The positive correlation in the downstream

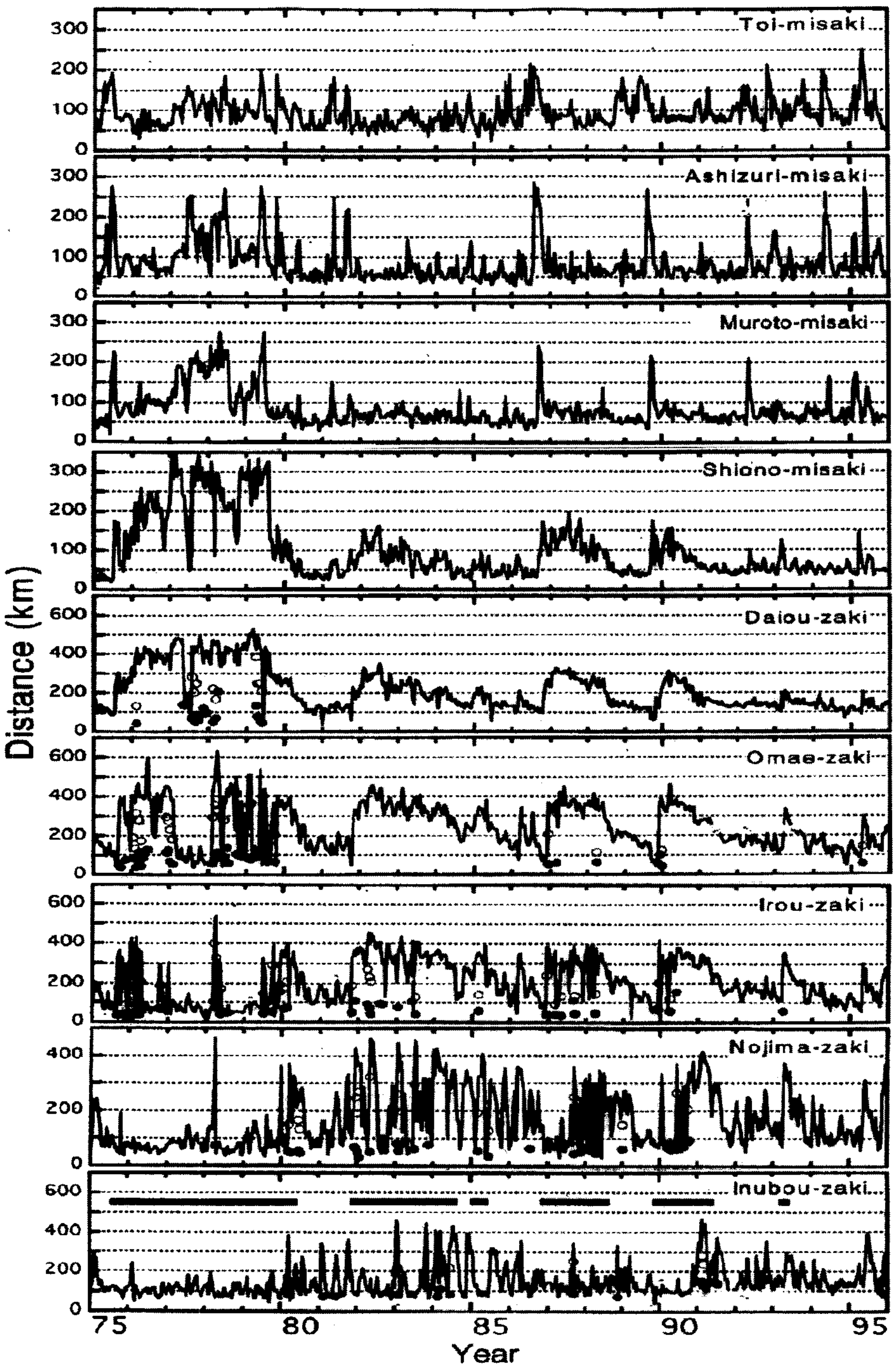

Fig. 2. Time variations in the monthly mean farthest distance of the main Kuroshio axis from the Japanese coast shown in Fig. 1. In the multi-distance cases, the first distance and the second distance (Fig. 1) are shown by closed circles and open circles, respectively. Black bands in the bottom panel show the periods of the large meander path.

area is clearly different from the negative correlation in the upstream area, which indicates that the large volume transport of the northern inflow induces small distance of the Kuroshio in the upstream area and large distance in the downstream area.

It is also shown in Fig. 4 that the positive correlation between the SLD: NA-NI and the distance of the Kuroshio in the upstream area is found from off ASH to off DAI, conversely a negative correlation in the downstream area from off OMA to off IRO. This change is the opposite tendency to the correlation of the SLD: NI-AB, which implies that variations in volume transports of the northern inflow and southern inflow have a different effect on the path dynamics of the Kuroshio.

Because the northern inflow south of Kyushu flows over the shallow region, and its depth contour continues to the continental slope east of Kyushu, large

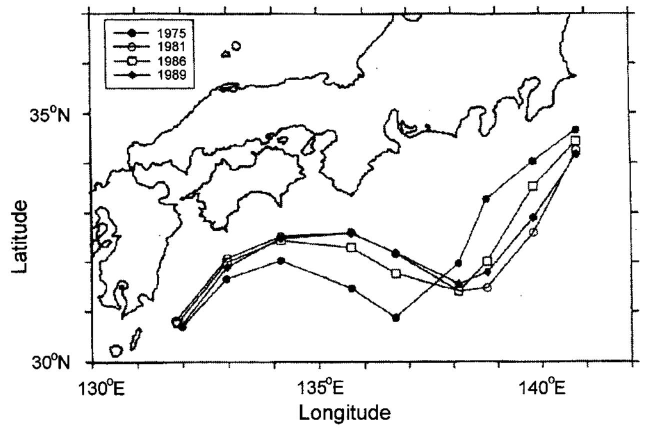

Fig. 3. Mean farthest distance of the main Kuroshio axis from Japanese coast in periods of large meander path. Symbols shown at top left correspond to the year of the formation of each large meander path. Periods of each large meander path are shown by black bands in Fig. 2.

volume of the northern flow suppresses the separation of the current path from the continental slope in the upstream area by the conservation of potential vorticity.

DISCUSSION

The above results indicate that if the northern inflow over the shallower bottom in south to Kyushu is large, a flow has a strong tendency to flow along geostrophic contours of f/h and the offshore distance of the main Kuroshio axis from Japanese coast is decreased in the upstream area. Although quantitative discussion is needed on this problem, this gives an important information for the path dynamics of the Kuroshio.

It is thus suggested that the horizontal distribution of the volume transport south of Kyushu is an important factor for the path dynamics of the Kuroshio. Although the multi-steady state of the bimodal path has been numerically discussed as for the total volume transport of the in- and outflow, the horizontal velocity distribution varies even if the volume transport is constant. The multi-steady state should be analyzed in terms of the horizontal distribution of the inflow velocity as well as the total volume transport.

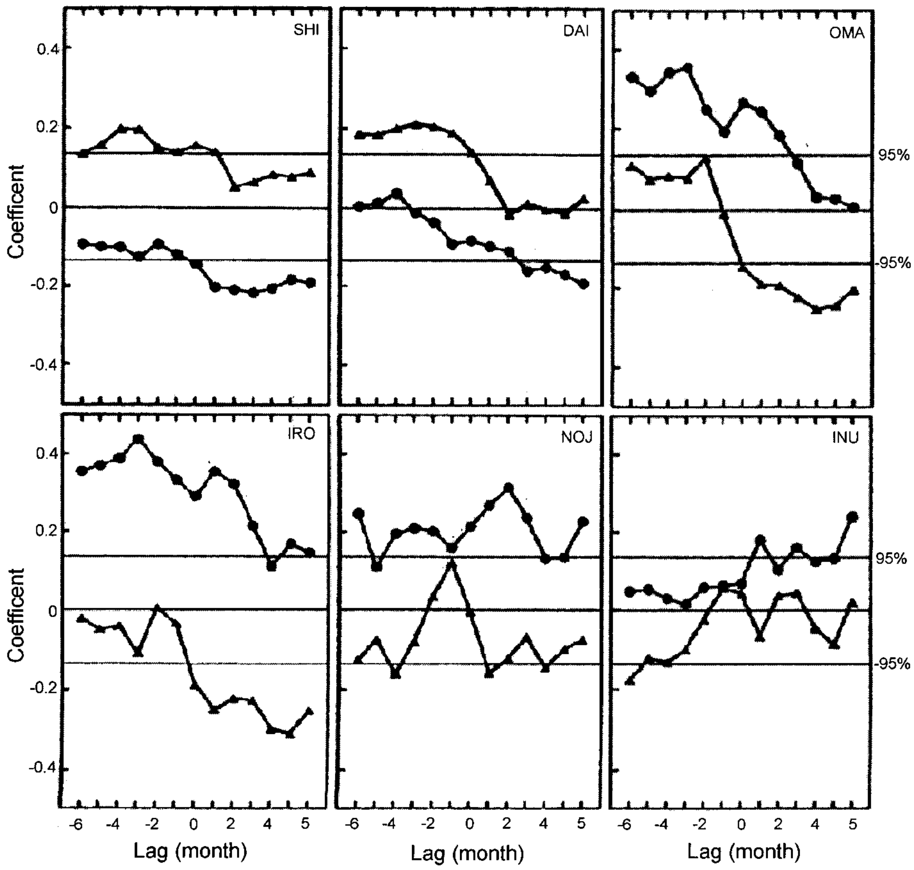

Fig. 4. Lagged correlations between the distances of the main Kuroshio axis from the Japanese coast (Fig. 1) and sea level difference anomaly between Naze and Nishinoomote which corresponds to the volume transport of the southern inflow of the Kuroshio through Tokara Strait south of Kyushu (▲) and between Nishinoomote and Aburatsu (●) which corresponds to the volume transport of the northern inflow of the Kuroshio. Plus (minus) lag means that the sea level difference lags (leads) to the distance of the main Kuroshio axis.

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