Unusual Behavior of the Kuroshio Current System from Winter 1996 to Summer 1997 Revealed by ADEOS-OCTS and Other Data (Continued): A Study from Broad External Conditions with Bottom Topography

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In the previous paper (Toba and Murakami, 1998) we reported on an unusual path of the Kuroshio Current System, which occurred in April 1997 (April 1997 event), using the Ocean Color and Temperature Scanner (OCTS) data of the Advanced Earth Observing Satellite (ADEOS). The April 1997 event was characterized by the flow of the Kuroshio along the western slope (northward) and the eastern slope (southward) of the Izu-Ogasawara Ridge, a very southerly turning point at about 32°N, followed by a straight northward path up to 37°N of the Kuroshio Extension along the eastern flank of the Izu-Ogasawara and the Japan Trenches. Overlaying of depth contours on ADEOS-OCTS chlorophyll-a images at the April 1997 event demonstrates the bottom topography effects on the current paths. A new finding based on TOPEX/Poseidon altimeter data is that the sea-surface gradient across the Kuroshio/Kuroshio Extension diminished greatly in the sea area southeast of the central Japan, as a very temporary phenomenon prior to this event. This temporary diminishing of the upper-ocean current velocity might have caused a stronger bottom effect along the Izu-Ogasawara Ridge, and over the Izu-Ogasawara Trench disclosed a weak background, barotropic trench-flank current pattern, which existed otherwise independently of the Kuroshio Extension. The very southerly path of the Kuroshio Extension from winter 1996 to autumn 1998 corresponded, with a time lag of about 1.5 years, to the previous La Niña tendency with weaker North Equatorial Current. The April 1997 event occurred in accordance with its extreme condition.

Keywords:
- Kuroshio,
- Kuroshio Extension,
- April 1997 event,
- ADEOS-OCTS,
- bottom topography effect,
- Izu-Ogasawara Ridge and Trench,
- Japan Trench,
- La Niña tendency,
- TOPEX/Poseidon, altimeter.

1. Introduction

In the previous paper (Toba and Murakami, 1998), we reported that the Kuroshio and the Kuroshio Extension exhibited unusual behavior from the winter of 1996 to the summer of 1997. That report was based on a time series of satellite observation images of sea-surface temperature (SST) and ocean color obtained by the Advanced Earth Observing Satellite (ADEOS), and also SST images obtained by the Advanced Very High Resolution Radiometer (AVHRR) of the National Oceanic and Atmospheric Administration (NOAA) satellites, together with some hydrographic observation data.

The particular behavior included (1) a long-lasting very southerly path of the Kuroshio Extension, and (2) a Kuroshio path very distant from Japan with the following alternating-jet-like north-south flow pattern of the Kuroshio Extension at this event. The event occurred twice independently, once in February and again in April 1997. The event in April was more conspicuous, and we will call it hereafter the "April 1997 event." It was conjectured that this event was affected by the bottom topography of the Izu-Ogasawara Ridge and Trench, and

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the Japan Trench. A mechanism was also suggested for the formation of the alternating-jet-like flow pattern of the Kuroshio Extension: a topographically forced alternating-jet instability (AJI).

In order to investigate the cause of this unusual behavior of the Kuroshio/Kuroshio Current System in this period from the viewpoint of broad external conditions, as well as local dynamics, we conducted further studies in two ways. First we used available TOPEX/Poseidon altimeter data. Second, we more closely investigated the relation between the current paths and the bottom topography.

By using the altimeter data, we found that the unusual behavior was related primarily to the temporary diminishing of the upper ocean current component in the sea area southeast of central Japan. This will be discussed in Section 2. In order to investigate the relation between current paths and the bottom topography precisely, the bottom contours were overlaid on the OCTS chlorophyll-a images. The figures will demonstrate that the current path was then greatly affected by the bottom topography all the way to the sea surface as displayed in Section 3.

By comparing the El Niño Monitoring Indices (at NINO3) with the position in the latitude of the Kuroshio Extension as revealed by the altimeter data, we were able to infer that the very southerly position of the Kuroshio Extension was a link of the larger scale La Niña–El Niño phenomena, with a time lag of 1.5 years. This result supports former studies by Yamagata et al. (1985) and Qiu et al. (1991). The above-mentioned diminishing of the upper ocean current prior to the April 1997 event occurred in accordance with the extreme condition of the La Niña tendency with 1.5-year lag, and it can be inferred to be related to these large-scale phenomena. This will be discussed in Section 4.

2. External Conditions of the April 1997 Event Revealed by TOPEX/Poseidon Altimeter Data

External conditions, which might have caused the previously mentioned unusual behavior of the Kuroshio and the Kuroshio Extension, were investigated using TOPEX/Poseidon altimeter data. The altimeter data of TOPEX/Poseidon, distributed from NASA, were processed by using an algorithm developed in JAMSTEC (JAMSTEC Project Team, 1996). The ground tracks of the TOPEX/Poseidon altimeter around Japan are shown in Fig. 1. We analyzed the data during 1993 and 1998. In order to express the sea-surface height variation of this region from the data of limited years, the anomaly from the mean of three years from 1993 to 1995 was obtained first, and then the anomaly was added to the mean sea-surface dynamic height (the reference level: 1000 db). The latter is referred to Levitus (1982), which are shown in Fig. 2. For obtaining the anomaly, a co-linear method (Cheney et al., 1983) was used together with a median filter with 50-km width, removal of the bias, a moving average and a low-pass filter, each with 150-km width.

Figure 3 presents a time series of the thus obtained along-track sea-surface dynamic height for six descending passes (112 to 238) that crossed the Main Island of Japan. The data of descending passes 010, 086 and 162 had a special characteristic feature for the nominal dates of April 6 or April 15, 1997, as shown by thick curves labeled with bold letters: (970406) and (970415). Since these nominal dates in Fig. 3 are entered by the Package Data Start Time, the dates when the satellite passed around Japan are several days after these nominal dates. This special characteristic feature appeared just prior to the April 1997 event at the Kuroshio/Kuroshio Extension, around 34 degrees North. Figure 4 shows an enlargement of this vicinity in Fig. 3. This feature is distinguished by very flat parts of curves, indicating that the sea surface gradient across the Kuroshio/Kuroshio Extension was very small for this short period, from the west to the east of the Izu-Ogasawara Ridge. A similar tendency is seen for the February 1997 event, but only in the 010 (see the curve labeled 970215).

Since these three passes covered a considerably wide sea area southeast of the central Japan, the diminishing of the sea-surface slope indicated by the altimeter data cannot be regarded as caused by the shift of the current direction. In order to examine the fact, similar data from ascending passes: 101, 177 and 253 (cf. Fig. 1) indicating some similar flat parts of curves at the positions of the Kuroshio Current System, or between 30°N and 35°N, are summarized in Fig. 5.

Figure 6 shows a time series of the two-dimensional