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A Relationship between the Sea Level Variations in the Korea Strait and the Tokara Strait in the Kuroshio region

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A relationship between sea level variations in the Korea Strait (the western and the eastern channels) and the Tokara Strait in the Kuroshio region is examined using daily-mean sea level data from 1966 to 1986. The seasonal variation of the sea level difference (SLD) between Izuhara and Pusan (the western channel) is most periodic: the positive anomalies appear from summer to autumn, and the negative anomalies from winter to spring year to year, whereas SLDs neither between Hakata and Izuhara (the eastern channel) nor between Naze and Nishinoomote (the Tokara Strait) show such a periodic variation. Much similarity has been found between SLDs in the eastern channel and the Tokara Strait, and in particular they were closely correlated in a special event of the Kuroshio region, such as a large meander of the Kuroshio. This paper shows that the periodic seasonal variation of the SLDs in the western channel should be less related to the Kuroshio region. This result also implies that the variation of SLD in the western channel is largely influenced by local factors, such as the bottom cold water in the western channel in summer, rather than from the Kuroshio region.

Key words: Korea Strait, western channel, eastern channel, Tokara Strait, SLD (sea level difference), Kuroshio region, local factors

Introduction

The Korea Strait has two channels called the western and the eastern channels, plays a role of a 'bridge' to connect the East China Sea to the East Sea (the Japan Sea), and is the entrance of the Tsushima Current flowing into the East Sea (Fig. 1). Since the past decades, it has been known that several oceanographic features appear in the western channel in summer: the volume transport of the Tsushima Current rapidly increases (Yi, 1974; Miida, 1976), and there exists bottom cold water less than 10℃ (Omura et al., 1994; Yun, 1996).

Figure 2 shows the sea level difference (SLD) between Izuhara and Pusan (IZ-PS; the western channel) and between Hakata and Izuhara (HK-IZ; the eastern channel) during 1966 to 1986. This has been incorporated from Kawabe (1982) and Hong et al. (1992). Their values are 5-days running means of SLDs, and the zero level of the ordinate represents an averaged SLD for the study period because the absolute values of the SLDs can not

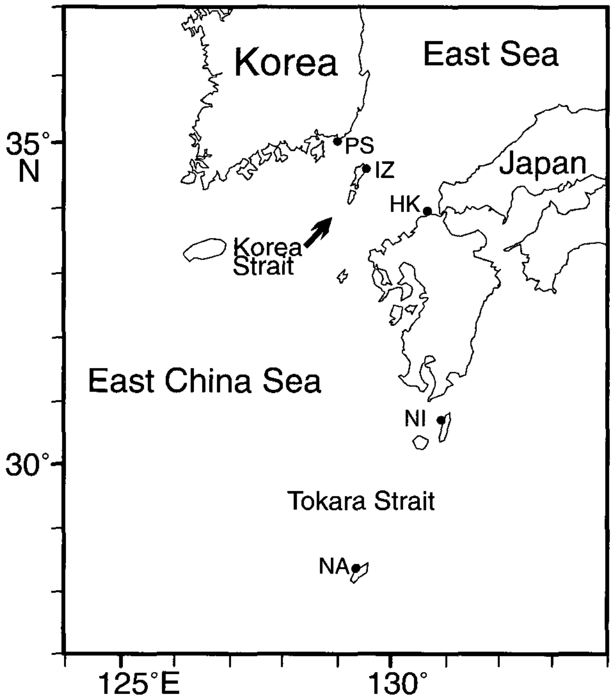

Fig. 1. Locations of tidal stations. PS, IZ, HK, NA, and NI represent Pusan, Izuhara, Hakata, Naze, and Nishinoomote, respectively.

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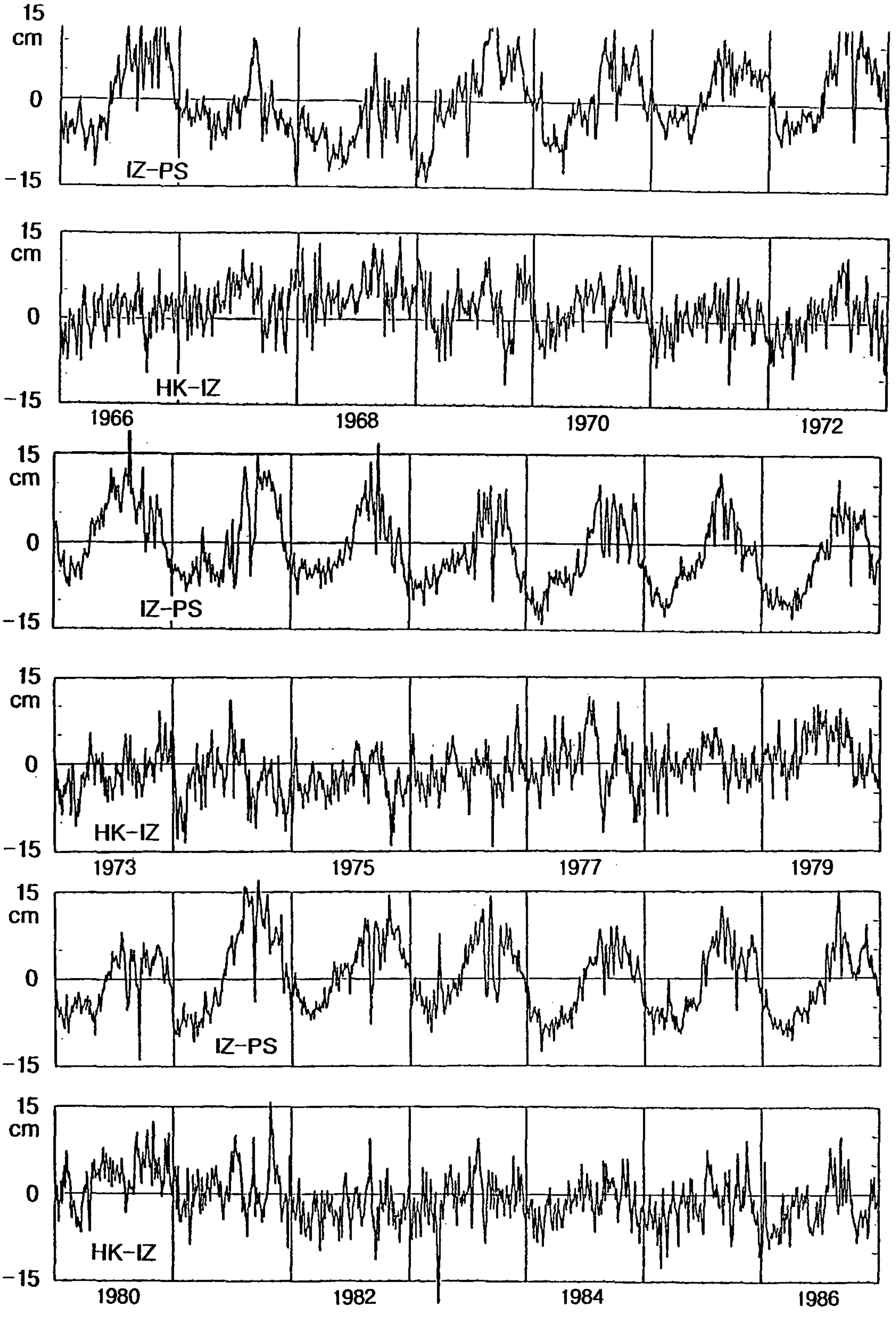


Fig. 2. Five-days running means of adjusted daily mean sea level differences (SLDs) between Izuhara and Pusan (IZ-PS), and between Hakata and Izuhara (HK-IZ) during 1966 to 1986. Reproduced from Kawabe (1982) and Hong et al. (1992).

be decided due to unknown datum line at tide gauges. In this figure we can find that the SLD in the western channel varies most seasonally, exhibiting the positive anomalies from summer to autumn and the negative anomalies from winter to spring. In the eastern channel, however, such a seasonal variation is not apparently identified.

Recently, Isobe (1994) reported that the seasonal variation of the surface current in the western channel is locally caused, and Isobe (1995) indicated that the bottom cold water may play an important role in the seasonal variation of SLD in the western channel. These features found in the straits, however, should not be simply explained due to unknown coupling effects between surrounding oceans, and thus for comprehensive understanding we need to extend the study area. In view of such aspect a comparison between sea level variations in the Korea Strait and the Kuroshio region would be meaningful to give an insight for that. Moreover, since the SLDs between some two stations can be used to estimate a geostrophical surface current crossing between these stations (Yosida, 1961; Konaga et al., 1973), this approach would give a speculation concerned with a dynamic relation between the two regions.

In this paper, the focus is to examine how the SLDs in the Korea Strait are related to the Kuroshio region, especially in terms of the differences between the western and the eastern channels of the Korea Strait. For the purpose examined are the SLDs of IZ-PS and HK-IZ (the Korea Strait) and between Naze and Nishinoomote (NA-NI, the Tokara Strait in the Kuroshio region) (see Fig. 1). Also a spectral analysis for the SLDs is given, and the time series are analyzed. In particular, the variation of the SLDs in the period of a special event of the Kuroshio, such as the large-meander of the Kuroshio is noted.

Data

Daily-mean sea level data at five tidal stations (Pusan, Izuhara, Hakata, Naze, and Nishinoomote) during 1966 to 1986 are used. The data at Pusan were obtained by the Hydrographic Office of Korea, and the others by the Japan Maritime Safety Agency of Japan. The SLDs are obtained from IZ-PS (the western channel), HK-IZ (the eastern channel), and NA-NI (the Tokara Strait). The missing data at each station in the study periods were linearly interpolated. A pressure correction for the data was carried out to barometrically adjust the sea levels. The SLDs between two stations used here represent the differences between anomalies of the sea level at each station, which were obtained by subtracting the sea levels from the interannual mean because of unknown absolute values of SLDs between two stations, as mentioned above.

The spectral analysis of the sea level data at each station is given by a fast Fourier transform method (degrees of freedom = 8). The power spectra of SLDs in the two straits are compared in the periods of both non-large meander (1966 to 1975) and large meander (1975 to 1979) of the Kuroshio, respectively.

Results

1. Interannual variations of SLDs in the western and the eastern channels

The power spectra of the SLDs of IZ-PS (upper) and HK-IZ (lower) given in Fig. 3 show that the amplitude of the annual component in the western channel (IZ-PS) is much larger than that in the eastern channel (HK-IZ). This indicates that the seasonal variation of the SLDs in the western channel is more dominant, as previously pointed out in Fig. 2. At each channel the components with the period of 1.8-year seem to be significant within 90 % confidence level.

The monthly mean SLDs of the two channels averaged from 1966 to 1986 (Fig. 4) show that the annual range of SLD is larger in the western channel (about 14 cm; solid line) than in the eastern channel (about 5 cm; broken line) as pointed out by Kawabe (1982), implying that the seasonal range of the surface current velocity is larger in the western channel. Note that there exists a time lag with one month between the maximum SLDs of these channels, i.e., the peak reaches in July at the eastern channel and in August at the western channel. It should be noted that the value in the western channel suddenly drops in September. This is caused by frequently passing of typhoons in summer as early indicated by Yi (1974) and numerically examined by Hong et al. (1992). Historical studies of the surface current in the Korea Strait listed in Table 1 show that the annual ranges of SLDs and surface velocity in the

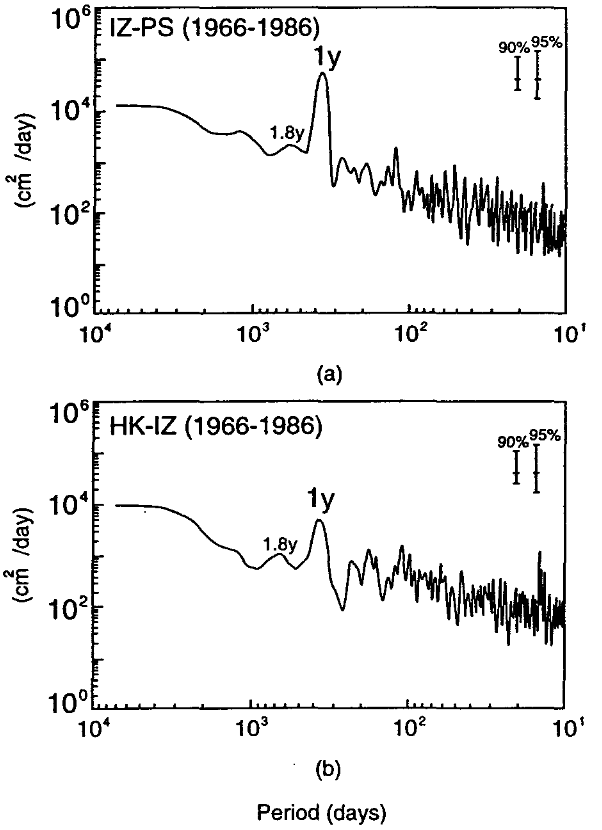


Fig. 3. Power spectra in a) IZ-PS, and b) HK-IZ during 1966 to 1986.

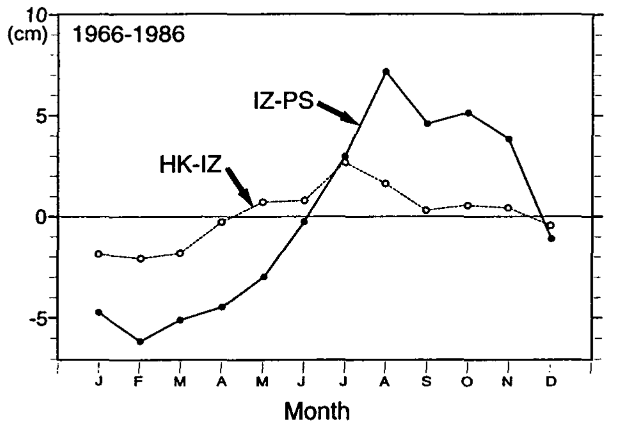


Fig. 4. Interannual monthly mean SLDs of IZ-PS (solid) and HK-IZ (broken).

Table 1. Annual ranges of the amplitude of SLDs at IZ-PS (WC) and HK-IZ (EC), and the surface velocity based on the SLDs at each channel

Authors	Study periods	Elevation (cm)		Surface velocity (cm/s)	
		WC	EC	WC	EC
Yi (1970)	1962~1967	20	5	55	5
Kawabe (1982)	1966~1976	15	5	36	5
The present study	1966~1986	13.7	5	33	5

eastern channel are constant with 5 cm and 5 cm/s, respectively. In the western channel, however, the longer the study periods, the smaller their values.

The time series of the annual mean SLDs at the two channels as shown in Fig. 5 gives that since early 1970s, a phase lag with about two-year period seems to be found between these channels. On the other hand, the squared coherences (Fig. 6) shows that these components with two-year period at the channels should be closely related to each other within 95% confidence level.

2. A relationship between the SLDs in the Korea Strait and the Tokara Strait

According to Kawabe (1988), the seasonal variation of SLDs may be more apparently exhibited by a manipulation of the sea level data: two-month and one-year running means for the SLDs at three places (i.e., IZ-PS, HK-IZ, and NA-NI) have been carried out, and the residuals (i.e., the former minus the latter) have been analyzed. This process corresponds to using a band-pass filter as depicted in Fig. 7, in which the amplitudes are decreased to less than 70 % in the periods over 1.3-year and under 5.5-months.

The residual at each place is compared in Fig. 8. The one at the Tokara Strait (NA-NI) has been reproduced from Kawabe (1988). In the western channel (IZ-PS, Fig. 8a) the residuals appear most periodically every year: the positive ones occupy from July to December, and the negative ones from January to June, while both the eastern channel (HK-IZ; Fig. 8b) and the Tokara Strait (NA-NI; Fig. 8c) (hereafter ECTS) do not show such a periodic variation but rather tend to be irregular. The power spectra (Fig. 9) has been obtained from the same data as used in Fig. 8 except for extending the data period to 1986 in the Tokara Strait. Note that in ECTS the components with periods shorter

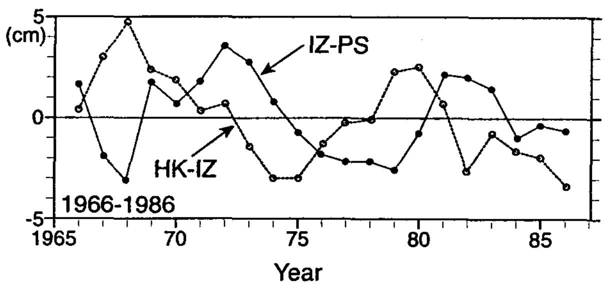


Fig. 5. Same as Fig. 4 but for the annual mean SLDs.

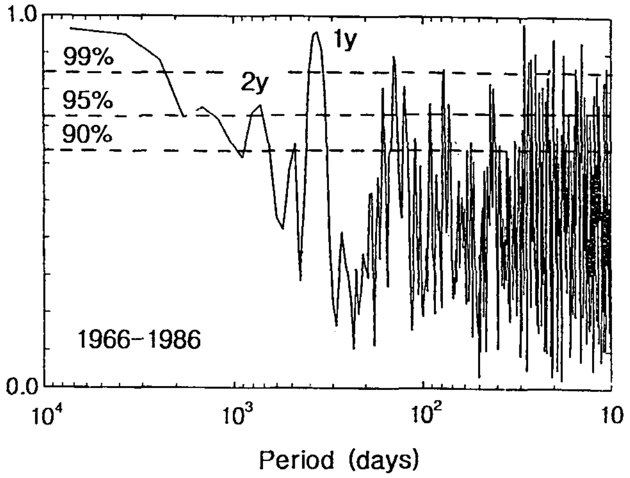


Fig. 6. Squared coherences between SLDs of IZ-PS and HK-IZ. The broken abscissas represent confidence levels.

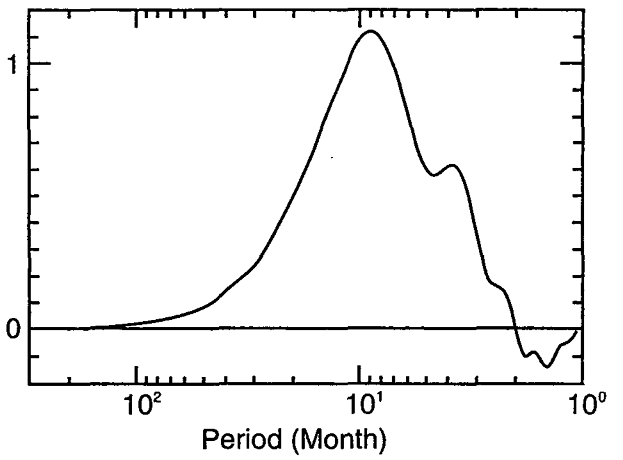
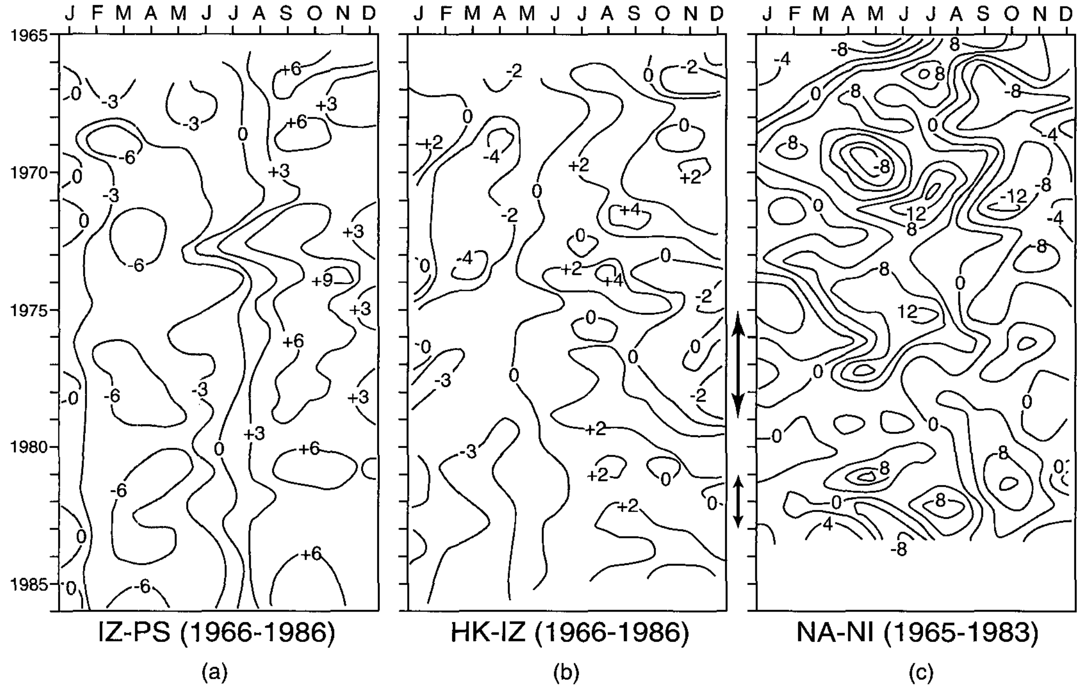


Fig. 7. A relative amplitude obtained by a band-pass filter for processing two-months running means minus one-year running means of the SLDs.

than one-year component are fairly dominant so should not be neglected. Actually they should cause to make such a irregularity in ECTS as shown in Fig. 8. In the spectra of ECTS given in Fig. 9, similar periods (e.g., 225 or 110 days) are found even if their significances are low. A comparison between monthly mean SLDs in the three places (Fig. 10) may in part show some differences (this was made by adding one in the Tokara Strait to Fig. 4). The peaks in ECTS appear in July (the western channel in August), and the increasing patterns of the SLDs from winter to spring and a temporary decrease in June are slightly similar, even though the decreasing patterns after July are largely different from each other. Also a comparison between the SLDs in the period of a special event in the Kuroshio region, such as a large meander of the Kuroshio, would show some differences of the SLDs in the three places. During



(a) (b) (c)

Fig. 8. An interannual variation of the residuals of the two-months running means minus the one-year running means of SLDs in a) IZ-PS, b) HK-IZ c) NA-NI. NA-NI has been reproduced from Kawabe (1988).

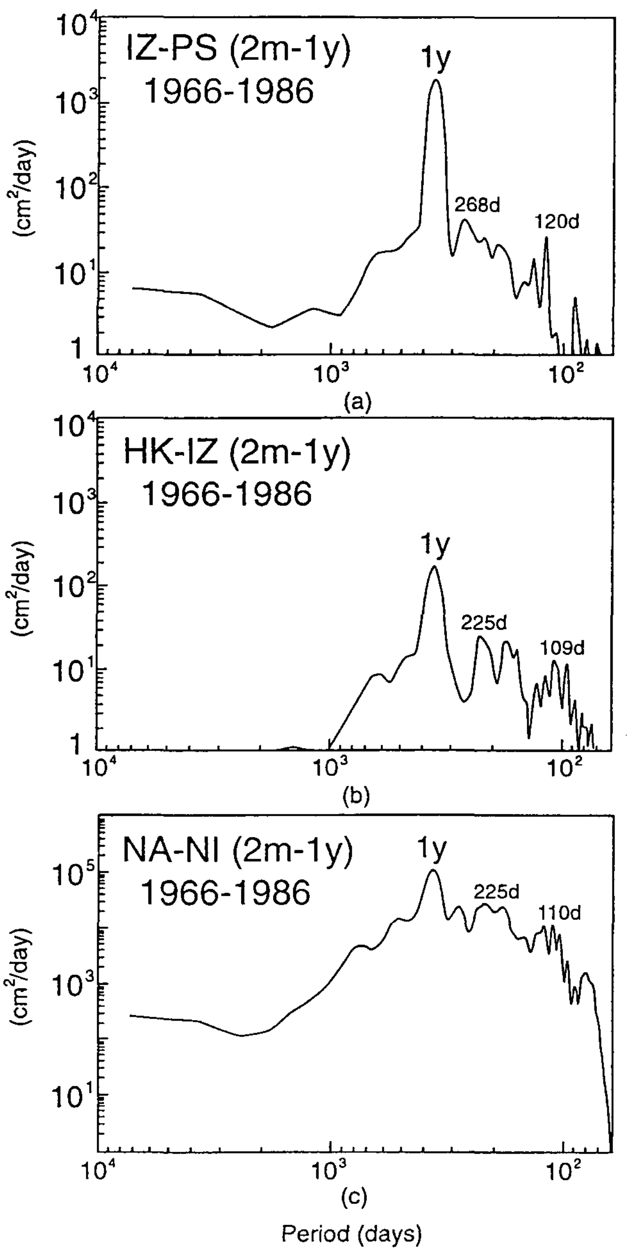


Fig. 9. Power spectra in a) IZ-PS, b) HK-IZ c) NA-NI in the same data as Fig. 8.

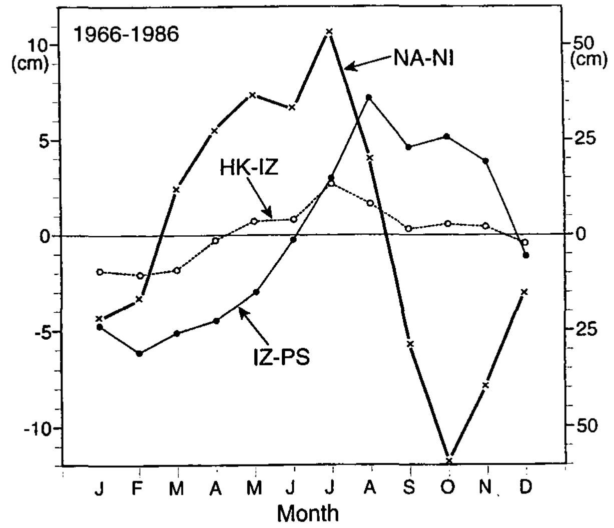


Fig. 10. A comparison of interannual monthly mean SLD at the three places during 1966 to 1986. The left ordinate is measured for IZ-PS and HK-IZ, and the right ordinate for NA-NI.

this period, the Kuroshio experiences the variation of the path, the velocity, and the volume transport (Taft, 1972; Kawabe, 1995), thus the large meander of the Kuroshio has been known as one of the most striking features in the Pacific Ocean.

Figure 11 gives the power spectra of SLDs in the three places in the non-large meander period of April 1965 to August 1975. The periods of the data at NA-NI are slightly short because it has been reproduced from Kawabe (1988). In this period, there should be a few of any special differences except that components with similar periods (e.g., about 180 or 115 days) still exist in ECTS within low confidence levels, as previously pointed out. A striking feature, however, has been found in the large meander period of October 1975 to December 1979 as illustrated in Fig. 12: in ECTS not only the most dominant components within 95 % confidence level are found in a shorter period, i.e. about 110 days, but also their powers are comparable to the annual component. In the western channel, however, only the annual component is still most dominant as before. This should be an evidence to reveal that the SLDs of ECTS are correlated to each other and that the shorter period variation of the SLDs in the Kuroshio region plays an important role in the sea level variation in the eastern channel. In addition, it should be noted that the negative residuals, as shown in Fig. 8 (see the arrows), have been dominant in the eastern channel during these periods.

Conclusions and Discussion

A relationship between the sea level variations in the Korea Strait (the western and the eastern channels) and the Tokara Strait in the Kuroshio region was examined using daily-mean sea level data during 1966 to 1986. The conclusions are as follows:

1) The seasonal variation of the SLDs in the western channel (IZ-PS) is most periodic every year, whereas it is not apparently found both in

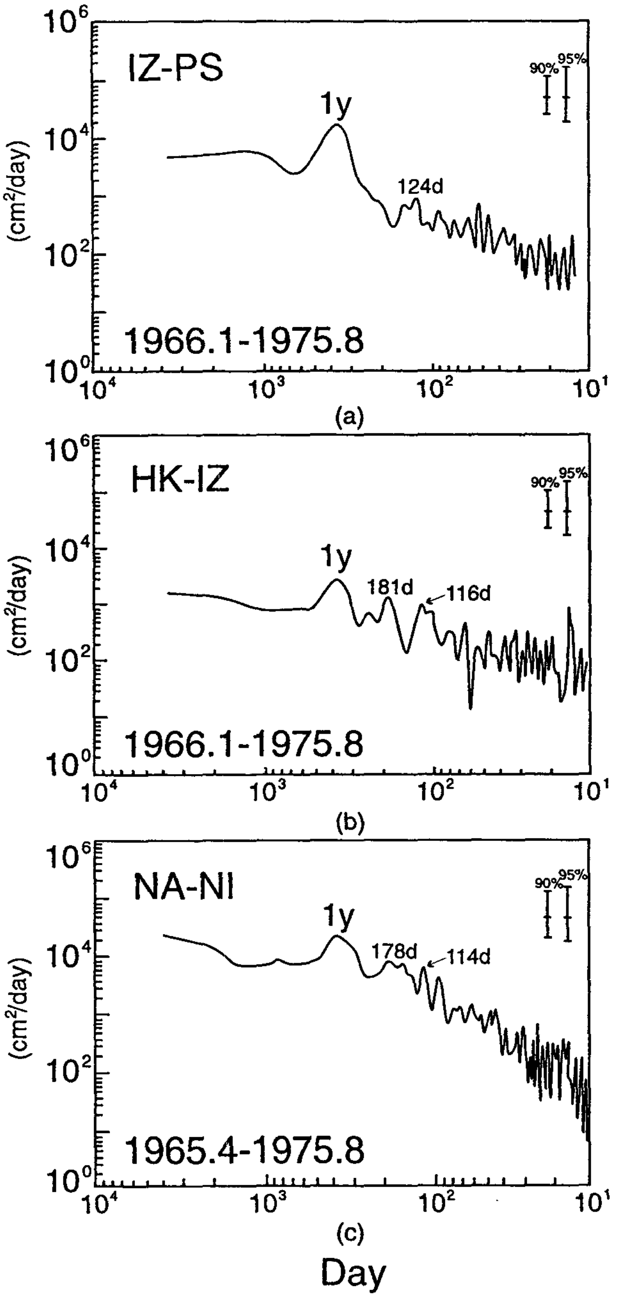


Fig. 11. Power spectra of the SLDs in the three places in the non-large meander period of April 1965 to August 1975. NA-NI has been reproduced from Kawabe (1988).

the eastern channel (HK-IZ) and the Tokara Strait (NA-NI) (ECTS).

2) The SLDs in the ECTS are correlated each other, especially in the period of the large meander events of the Kuroshio.

3) This study implies that the periodic seasonal variation of the SLDs in the western channel should be less related to the variation of the SLDs in the Kuroshio region.

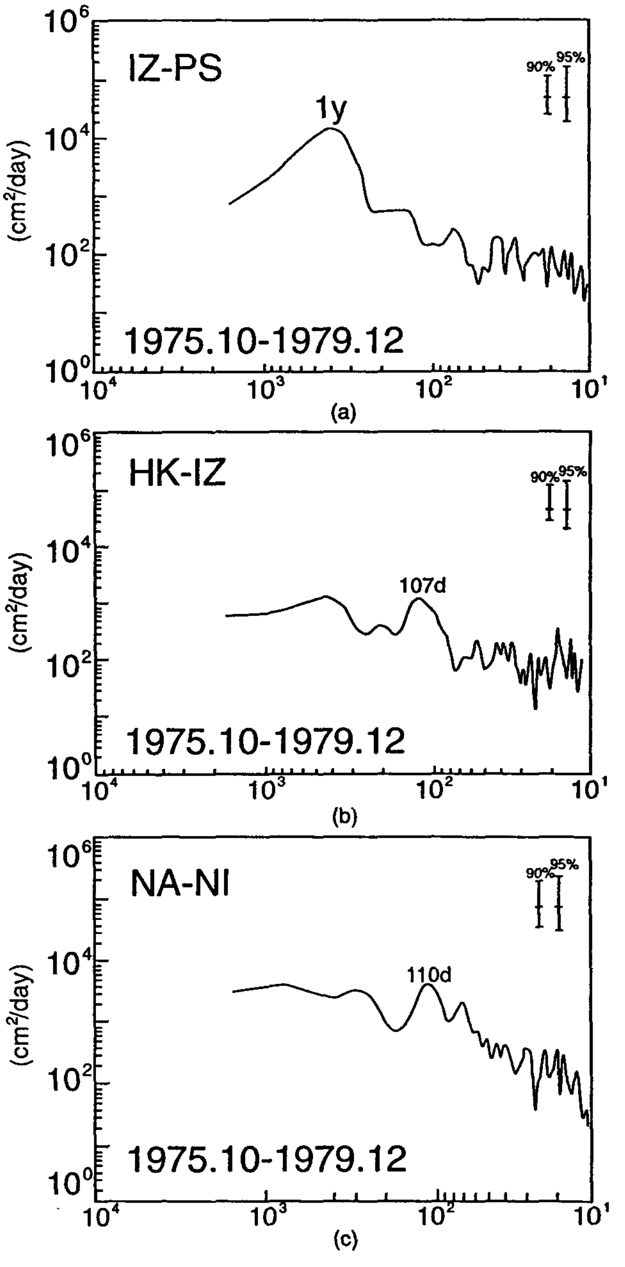


Fig. 12. Same as in Fig. 11 but for the large meander period of October 1975 to December 1979.

One of the oceanographic features in the western channel is to rapidly increase in the volume transport of the Tsushima Current during summer to autumn as early indicated by many authors (e.g., Yi, 1974; Miida, 1976). The other is the existence of the bottom cold water (under 10℃) in summer every year (Lim et al, 1969; Omura et al. 1994, Yun, 1996). Recently, Isobe (1995) indicated that the bottom cold water in the western channel plays an important role in the seasonal variation of the

SLD using observed data and a simple two-dimensional model (horizontally one-dimensional) in the Korea Strait. Isobe (1994) reported that the bottom cold water may generate a baroclinic motion in the western channel using sea level and CTD data. Their results imply that the seasonal variation of the SLDs in the western channel may be due to the existence of the bottom cold water. In fact many results in this paper (e.g., Figs. 2, 8, and 12) showed that the SLDs in the western channel have most periodically varied every year regardless of a special event in the Kuroshio region, such as the large-meander of the Kuroshio. The SLDs in the eastern channel, however, have been largely affected from the Kuroshio region. In other word, this shows that the regular seasonal variation of the SLDs in the western channel should not be related to the Kuroshio region. Therefore, as indicated by Isobe (1995), this paper also implies that the SLDs in the western channel should be mainly governed by local factors, e.g., the bottom cold water, at least in a short period variation. However, it must be elucidated by more observations.

Kang (1985) reported that anomalies of annual-mean sea surface temperature at Izuhara are correlated to that at Naze and Ishigakijima in the Kuroshio region although he did not examine in the western channel. Tawara (1984) found a component with about 2-year period in the spectrum of long-term period temperature data in the eastern channel (Fig. 13), and Kutsuwada (1988) obtained the component with the similar period (1.8-year) in the power spectra of the SLDs in the Tokara Strait (Fig. 14). We also obtained such a component of the SLD both in the western and the eastern channels (e.g. Figs. 3 and 6). These results indicate that the Kuroshio region influences both channels as long as the long-term variation of the SLDs is concerned.

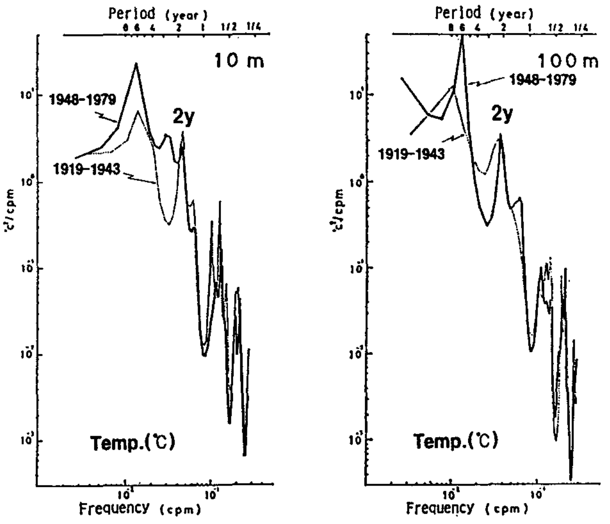


Fig. 13. Power spectra of the temperature field in long-term periods. (after Tawara, 1984).

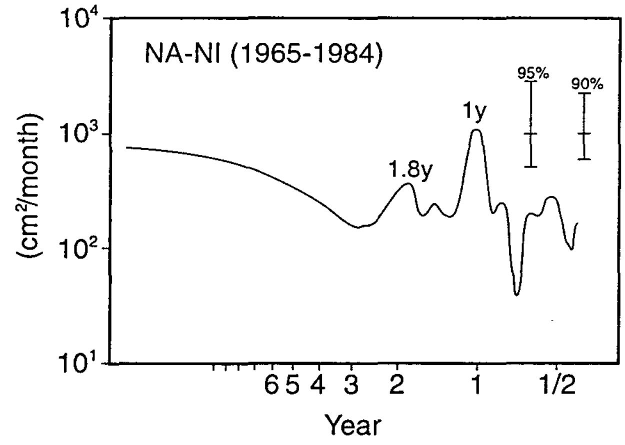


Fig. 14. Power spectra of SLDs at the Tokara Strait during 1965 to 1984. Reproduced from Kutsuwada (1988).

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