Long-Period Sea Level Variations around Korea, Japan, and Russia

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Monthly mean sea levels from 103 tidal stations in Korea, Japan, and Russia are analyzed to study long-period sea level variations. Barometric adjustment are done for all the sea level data, using monthly air pressures at sea levels from meteorological stations near tidal stations.

Seasonal variation is dominant in most of study area. It is the largest in the coasts along the Tsushima Current, and the smallest in the Russian coasts. The cross-correlations of seasonal variations are very high between the coasts along the Tsushima Current. In these marginal seas, seasonal variations seem to be related with the Tsushima Current. The phase of seasonal variations is generally getting late from south to north, and also from west to east. On the other hand, longer-period variations(longer than seasonal variation) have the largest amplitudes and the earliest phases in the coasts along the Pacific Ocean, which shows that they propagate from the Pacific Ocean. Shorter-period variations (shorter than seasonal variation) have generally lower cross correlations. Their values do not show any dictinct difference between areas, and show a common tendency that they are inversely proportional to distance. It implies that the shorter period waves are generated all over the study areas, and propagate in all the directions with faster dissipations.

The trends of sea levels in the study area are generally negative in the coasts along the Pacific Ocean and positive in the other areas during the period of 1965 to 1985. By the trends, the mean volume transport between Cheju and Sasebo can be reduced by about 1 *Sv* during the period. The seasonal variation of volume transport obtained by sea level difference is about 2 *Sv* in the Korea Strait. The values are comparable to previous reports.

Introduction

In the northwest marginal seas of the North Pacific Ocean, there are several oceanic phenomena showing long-period variations. These are the seasonal and secular variations of mass transport of the Tsushima Current (Yi, 1966; Toba *et al.*, 1982, Isobe; 1994), the southward extensions of the Yellow Sea Bottom Cold Waters in summer (Asoaka and Moriyasu, 1966; Nakao, 1977; Lie, 1984; Park, 1985, 1986; Kim *et al.*, 1991; Yoon *et al.*, 1991; Pang, *et al.*, 1992), the northward intrusion of the Yellow Sea Warm Current in winter (Uda, 1934; Byun *et al.*, 1988; Pang *et al.*, 1992) and the eastward movements of the Yangzee diluted coastal waters to the Cheju Strait in summer (Yu *et al.*, 1983; Beardley *et al.*, 1983; Zhao *et al.*, 1983; Kim, 1986; Pang *et al.*, 1992). These might be caused by a synoptic long-period variation, rather than by individual dynamics (Pang *et al.*, 1992, Pang, 1992).

Such synoptic long-period variations could be detected in sea level variations. It motivates us to study synoptic long-period sea level variation in this area.

Sea level variation is one of the most significant indications of the ocean dynamics. In this area, Nomitsu and Okamoto (1926) started to study long-period sea level variations along the Japanese coasts. Since then, there have been some studies, specially recently. Tomizawa *et al.* (1984) have analyzed them from Korea and Japan(coasts along the East Sea and the Pacific Ocean) and Oh *et al.* (1993) have analyzed them from Korea, Russia, and Japan(coasts along the East Sea). However, long-period sea level variations have not been studied synoptically in this whole area because of the difficulty of collecting data. For synoptic study in this whole area, we need data from South and North Koreas, China, Japan, and Russia. We might have to wait another decade for sufficient data. So, the more fundamental problem so far is how many data we have. In the present study, we still do not have data from North Korea and China, but we have a little more extensive data.

The collected data (from South Korea, Japan, and Russia) are still not sufficient to find the indications related to the oceanic phenomena mentioned above. However, we expect that they show us more of them. The analyses of cross-correlation and phase difference show us the propagation ranges and directions of long-period ocean waves and the variations of sea level difference show us those of volume transport. In this paper, we are specially interested in around seasonal variations. Such long-period variations can be accounted for by variations in the currents (LaFond, 1939). So, we want to group them into seasonal variations and longer and shorter periods variations. We will do it by Fourier spectral analysis. We are not interested in the meteorological influences, because only small portion can be related to them (Thompson, 1980).

In dealing with the sea level data from tidal stations, we should check the quality. Lots of data sets have missing data, and some of them have changes of reference levels. They are not chosen for spectral analysis. Even the selected data sets have different periods of observation. So, only the data sets which have a sufficiently long common period are chosen for cross-correlation analysis.

Data and Data Processing

The monthly mean tidal data from 103 tidal stations have been collected for analyzing the long-period sea level variations around Korea, Japan and Russia. As shown in Fig. 1, 21, 66, and 16 stations are located in Korea, Japan and Russia, respectively. The station names are alphabetized in Table 1. The numbers in Table 1 correspond to the station numbers in Fig. 1. The longest duration of data is 32 years from 1960 to 1991.

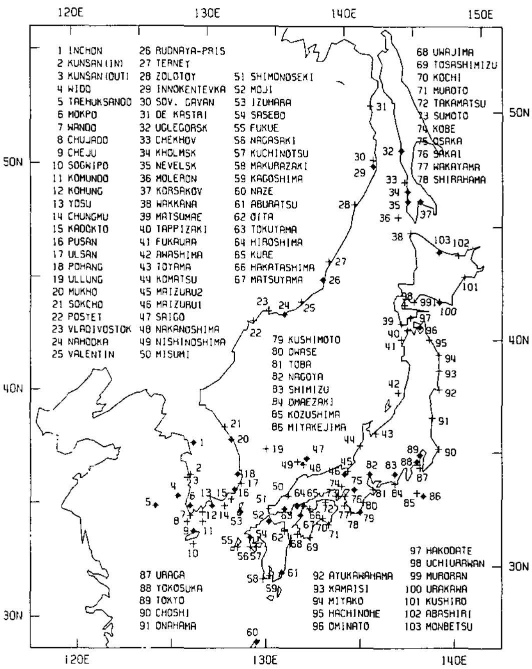

Fig. 1. Locations of stations. Stations for spectral analysis are marked with small circle.

The data at each tidal station have been first corrected by the subtraction of its mean sea level, and then, by the barometric adjustment with a factor of 1 *cm/mb* from the mean barometric pressure. Barometric correction has been made by using the monthly mean air pressures at sea surface from the meteorological stations near the tidal stations.

The air pressure data have been collected at 11 meteorological stations in Korea and Japan. The locations of meteorological stations are shown in Fig. 2. The sea level data in Russia have been corrected with the air pressure data at Urakawa and Monbetsu in Japan.

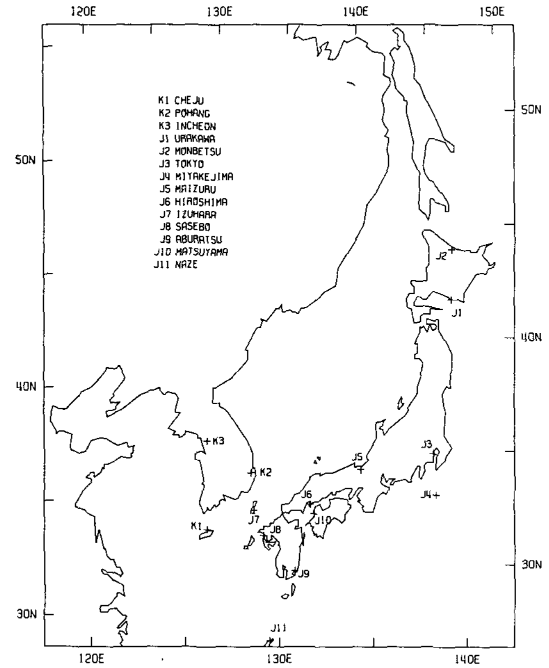

Fig. 2. Locations of meteorological stations.

Some basic statistical analyses such as mean annual difference, standard deviation, maximum deviation have been conducted for all tidal stations. However, for more advanced statistics, many data sets are not proper, because they have many missing values and changes of reference levels, and their data lengths are different from each other. About 37 stations have relatively good data for advanced process, and they have been analyzed by spectral analysis. These stations are marked with small circle in Fig. 1, and with asterisk in Table 1. For spectral analysis, small missing gaps of data (up to 5 values) are filled by the interpolation with neibouring values.

Cross-correlation analyses are conducted for only 16 selected staions. Even the data sets from the 37 stations are not good enough for cross-correlation since their data periods are different. The 16 stations have a relatively long common period from 1965 to 1985. The 16 stations are underlined in Table 1, and also shown in Fig. 3.

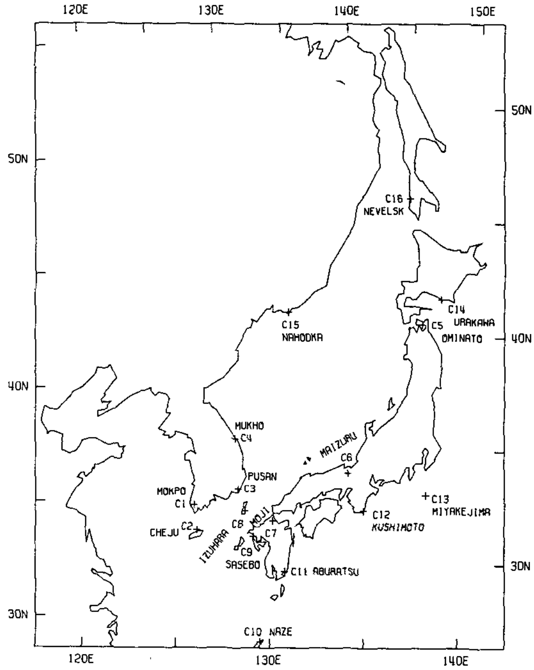

Fig. 3. 16 tidal stations for correlation analysis. They have data in a long common period from 1965 to 1985.

General Variations

Table 2 shows the ranges of mean annual variation, the standard deviations, and the maximum and minimum sea level records from the mean sea levels for 103 stations. The ranges of mean annual variation are the mean differences between the annual highest and the annual lowest sea levels. The mean annual variation ranges from 4.0 to 29.4 *cm* in the study areas. As shown in Fig. 4, the ranges are the smallest (< 10 *cm*) in the Russian coasts and the largest (> 25 *cm*) in the Japanese coasts along the Tsushima Current. It is interesting that the ranges in the Japanese coasts along the Paci-

Table 1. List of 103 tidal stations with station numbers shown in Fig. 1. The stations for spectrum and correlation are marked with asterisks and underlines, respectively. Underlined 16 ones are for correlation.

ABASHIRI	102	KUSHIRO	101	*SASEBO	54
*ABURATSU	61	*MAIZURU1	46	*SHIMIZU	83
AWASHIMA	42	MAIZURU2	45	SHIMONOSEKI	51
AYUKAWAHAMA	92	MAKURAZAKI	58	SHIRAHAMA	78
*CHEJU	9	MATSUMAE	39	SOGWIPO	10
CHEKHOV	33	*MATSUYAMA	67	SOKCHO	21
CHOSHI	90	MISUMI	50	SOV. GAVAN	30
CHUJADO	8	*MIYAKEJIMA	86	SUMOTO	73
CHUNGMU	14	MIYAKO	94	*TAEHUKSANDO	5
DE KASTRI	31	*MOJI	52	TAKAMATSU	72
FUKAURA	41	*MOKPO	6	TAPPIZAKI	40
FUKUE	55	MOLERON	36	TERNEY	27
HACHINOHE	95	*MONBETSU	103	TOBA	81
HAKATASHIMA	66	*MUKHO	20	*TOKUYAMA	63
HAKODATE	97	MURORAN	99	*TOKYO	89
*HIROSHIMA	64	MUROTO	71	TOSASHIMIZU	69
*INCHON	1	NAGASAKI	56	TOYAMA	43
*INNOKENTEVKA	29	*NAGOYA	82	UCHIURAWAN	98
*IZUHARA	53	*NAHODKA	24	*UGLEGORSK	32
KADOKTO	15	NAKANOSHIMA	48	ULLUNG	19
KAGOSHIMA	59	*NAZE	60	ULSAN	17
KAMAISI	93	*NEVELSK	35	URAGA	87
*KHOLMSK	34	NISHINOSHIMA	49	*URAKAWA	100
KOBE	74	OITA	62	UWAJIMA	68
KOCHI	70	OMAEZAKI	84	VALENTIN	25
KOHUNG	12	*OMINATO	96	VLADIVOSTOK	23
KOMATSU	44	ONAHAMA	91	WAKAYAMA	77
KOMUNDO	11	*OSAKA	75	WAKKANA	38
*KORSAKOV	37	OWASE	80	WANDO	7
KOZUSHIMA	85	*POHANG	18	*WIDO	4
KUCHINOTSU	57	POSYET	22	*YOKOSUKA	88
KUNSAN(IN)	2	*PUSAN	16	*YOSU	13
KUNSAN(OUT)	3	*RUDNAYA-PRIS	26	ZOLOTOY	28
*KURE	65	*SAIGO	47		
*KUSHIMOTO	79	SAKAI	76		

Table 2. Mean annual variation, standard deviations, and maximum and minimum sea level records from the mean sea levels for 103 stations

NO	ST. NAME	RANGE OF VARIATION	STANDARD DEVIATION	MAX. LEVEL	MIN. LEVEL	NO	ST. NAME	RANGE OF VARIATION	STANDARD DEVIATION	MAX. LEVEL	MIN. LEVEL
1	INCHON	24.6	10.4	28.3	-30.7	53	IZUHARA	26.6	10.3	24.6	-24.4
2	KUNSAN(IN)	29.4	15.2	35.7	-40.7	54	SASEBO	28.3	11.3	28.1	-23.2
3	KUNSAN(OUT)	26.7	10.0	24.2	-21.3	55	FUKUE	27.7	10.9	27.3	-18.3
4	WIDO	24.3	9.3	23.0	-17.5	56	NAGASAKI	28.1	11.1	26.1	-21.0
5	TAEHUKSANDO	20.6	13.1	29.8	-28.1	57	KUCHINOTSU	26.2	10.6	23.8	-20.7
6	MOKPO	24.8	13.7	36.4	-29.1	58	MAKURAZAKI	23.9	10.3	24.6	-19.0
7	WANDO	20.9	8.0	18.1	-13.8	59	KAGOSHIMA	25.8	11.0	28.6	-19.7
8	CHUJADO	18.9	7.8	17.3	-12.8	60	NAZE	23.3	10.5	24.9	-28.7
9	CHEJU	22.5	10.0	22.3	-30.2	61	ABURATSU	22.8	9.5	24.8	-19.0
10	SOGWIPO	21.4	8.9	19.6	-16.1	62	OITA	25.6	14.5	31.4	-40.5
11	KOMUNDO	19.0	7.8	19.3	-13.4	63	TOKUYAMA	26.5	11.1	26.1	-21.2
12	KOHUNG	24.9	9.1	19.3	-14.8	64	HIROSHIMA	25.4	11.0	26.7	-24.1
13	YOSU	24.8	9.6	24.8	-23.9	65	KURE	25.9	10.9	28.9	-22.7
14	CHUNGMU	20.6	7.7	20.2	-14.5	66	HAKATASHIMA	29.9	12.1	26.8	-47.1
15	KADOKTO	19.6	7.3	17.8	-14.9	67	MATSUYAMA	24.9	10.3	24.7	-29.1
16	PUSAN	17.1	6.9	21.0	-20.0	68	UWAJIMA	22.8	9.9	24.0	-19.2
17	ULSAN	17.5	6.6	22.9	-15.2	69	TOSASHIMIZU	21.4	9.4	26.2	-19.9
18	POHANG	17.6	6.5	18.0	-12.2	70	KOCHI	21.6	12.0	28.8	-24.7
19	ULLUNG	21.7	9.5	23.9	-21.3	71	MUROTO	23.4	10.1	32.4	-18.0
20	MUKHO	15.5	6.7	20.0	-23.3	72	TAKAMATSU	26.8	11.2	31.2	-21.3
21	SOKCHO	15.3	6.2	12.7	-22.7	73	SUMOTO	25.9	11.2	32.9	-23.1
22	POSYET	6.3	2.9	7.0	-13.7	74	KOBE	25.0	11.2	30.9	-22.1
23	VLADIVOSTOK	6.3	3.1	7.1	-13.6	75	OSAKA	26.4	19.3	41.3	-63.8
24	NAHODKA	5.7	2.8	6.7	-12.9	76	SAKAI	29.6	11.7	29.6	-21.2
25	VALENTIN	9.9	3.4	5.6	-12.3	77	WAKAYAMA	23.3	10.3	28.0	-21.4
26	RUDNAYA-PRIS	5.7	2.7	6.8	-11.9	78	SHIRAHAMA	21.7	9.9	26.5	-18.4
27	TERNEY	8.1	3.3	7.8	-9.2	79	KUSHIMOTO	21.8	9.6	25.6	-23.7
28	ZOLOTOY	5.3	2.8	8.1	-7.4	80	OWASE	21.2	9.5	26.5	-19.2
29	INNOKENTEVKA	6.3	2.9	7.4	-10.1	81	TOBA	23.9	11.8	32.0	-31.1
30	SOV. GAVAN	7.0	3.1	7.5	-9.9	82	NAGOYA	25.3	11.7	32.9	-27.1
31	DE KASTRI	4.0	2.7	9.6	-8.0	83	SHIMIZU	20.9	9.7	25.1	-24.0
32	UGLEGORSK	5.2	2.9	9.8	-9.9	84	OMAEZAKI	22.6	11.5	29.6	-25.9
33	CHEKHOV	9.4	3.4	6.0	-8.7	85	KOZUSHIMA	17.7	15.7	36.8	-42.1
34	KHOLMSK	6.0	3.2	11.4	-8.9	86	MIYAKEJIMA	20.6	16.8	40.5	-39.6
35	NEVELSK	5.8	2.9	9.3	-8.7	87	URAGA	22.7	9.8	27.4	-19.6
36	MOLERON	12.0	3.8	6.7	-5.3	88	YOKOSUKA	19.5	8.3	19.0	-20.8
37	KORSAKOV	6.4	3.0	9.6	-7.5	89	TOKYO	19.6	9.3	18.7	-29.1
38	WAKKANA	20.3	8.3	18.5	-18.1	90	CHOSHI	24.2	30.2	44.9	-47.2
39	MATSUMAE	19.6	7.7	14.7	-14.1	91	ONAHAMA	22.4	9.8	23.9	-22.7
40	TAPPIZAKI	22.1	8.5	15.3	-15.0	92	AYUKAWAHAMA	22.5	9.0	21.0	-18.8
41	FUKAURA	27.2	11.6	26.3	-28.1	93	KAMAISI	22.6	10.5	23.4	-28.0
42	AWASHIMA	23.2	10.0	22.1	-23.5	94	MIYAKO	23.1	8.8	18.6	-20.2
43	TOYAMA	27.3	11.0	25.4	-22.3	95	HACHINOHE	24.9	9.2	21.1	-17.7
44	KOMATSU	25.4	10.7	31.5	-24.0	96	OMINATO	22.8	9.4	22.0	-22.1
45	MAIZURU2	28.1	11.3	27.0	-23.0	97	HAKODATE	17.3	6.8	15.7	-14.2
46	MAIZURU1	28.0	11.4	26.5	-23.1	98	UCHIURAWAN	21.8	9.6	26.0	-19.2
47	SAIGO	27.8	11.1	23.4	-25.6	99	MURORAN	12.2	5.0	14.7	-14.8
48	NAKANOSHIMA	26.8	10.2	20.6	-23.8	100	URAKAWA	10.5	4.7	16.3	-15.9
49	NISHINOSHIMA	25.8	10.5	27.5	-23.3	101	KUSHIRO	9.8	7.7	16.5	-20.8
50	MISUMI	28.0	11.2	25.2	-21.2	102	ABASHIRI	16.0	6.5	27.3	-15.3
51	SHIMONOSEKI	28.0	11.1	27.5	-21.5	103	MONBETSU	13.0	6.5	15.0	-16.8
52	MOJI	27.9	11.0	25.3	-22.3						

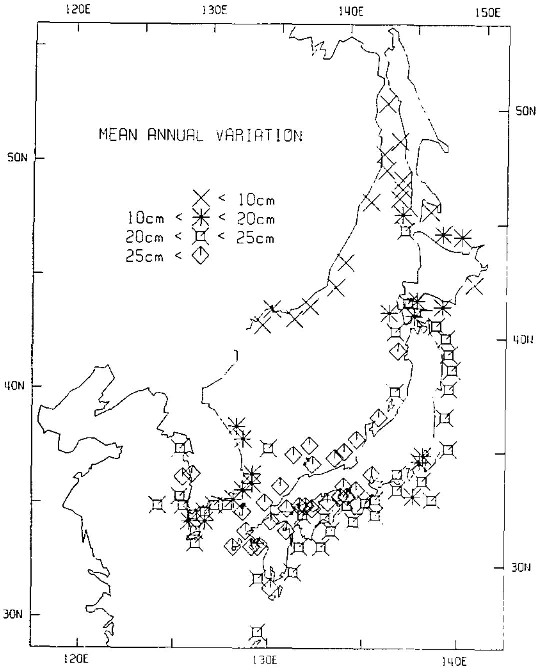

Fig. 4. Mean annual variations at 103 tidal stations.

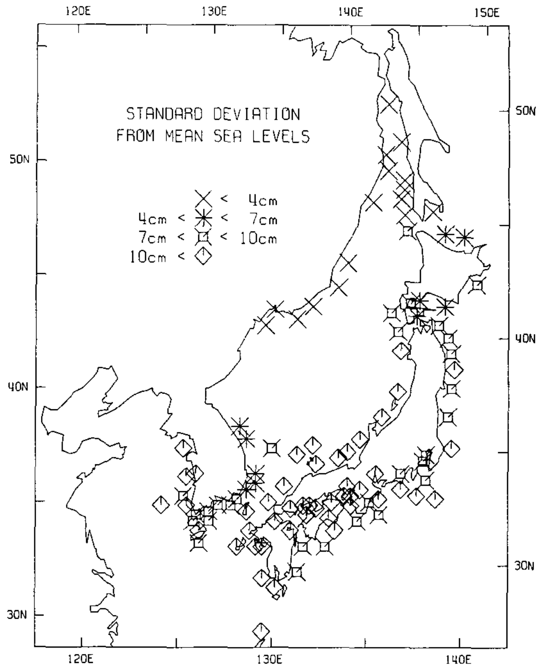

Fig. 5. Standard deviations at 103 tidal stations.

fic Ocean (20 to 25 *cm*) are smaller than in the Japanese coasts along the Tsushima Current. Around Hokkaido, they are small(10 to 20 *cm*). In Korea, they are small in the eastern coasts and large in the southern coasts. A similar pattern is shown in the distribution of the standard deviations as shown in Fig. 5. The standard deviation ranges from 2.7 to 16.8 *cm*. (The value of 30.2 at Choshi is due to the change of reference.) Such distributions suggests that the major annual variations are related in some way with the Tsushima Current in this area.

Fig. 6 shows the distribution of the maximum deviations. The maximum deviation is the greater one in absolute value out of the maximum and the minimum sea levels, which are shown in Table 2. Their pattern is generally similar to those of mean annual variation and standard deviation but they are a little larger in the Japanese coasts along the Pacific Ocean than in the Japanese coasts along the Tsushima Current. It tells us that the sea level along the Pacific Ocean is affected by somewhat irregular larger long-period waves.

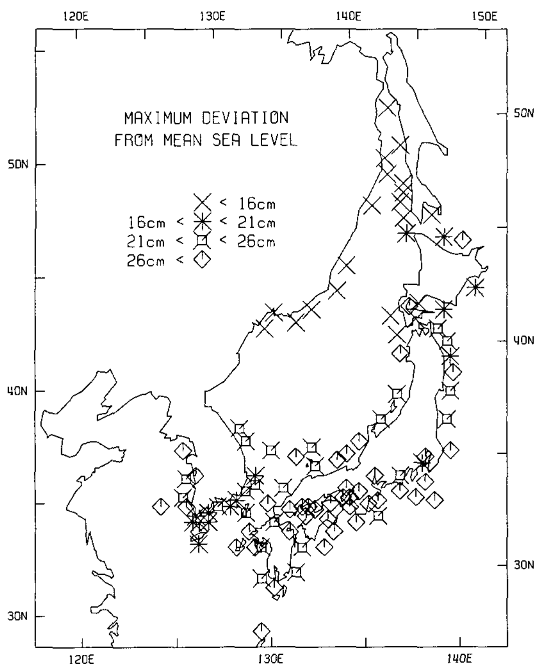

Fig. 6. Maximum deviations from mean sea level at 103 tidal stations.

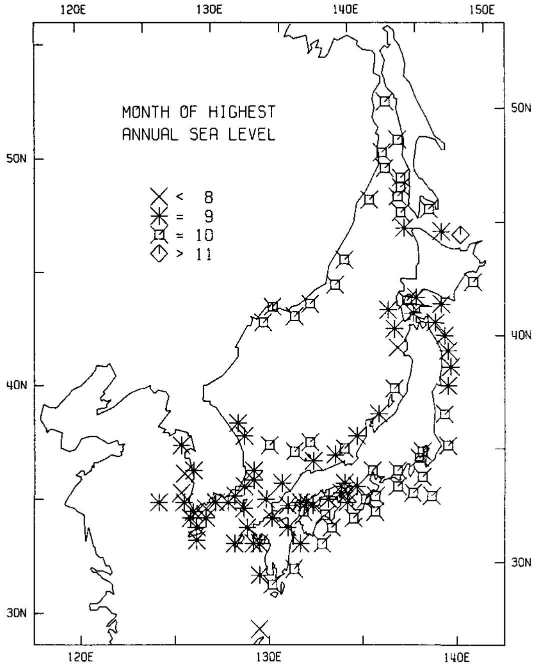

Fig. 7. Month of highest annual sea level at 103 tidal stations.

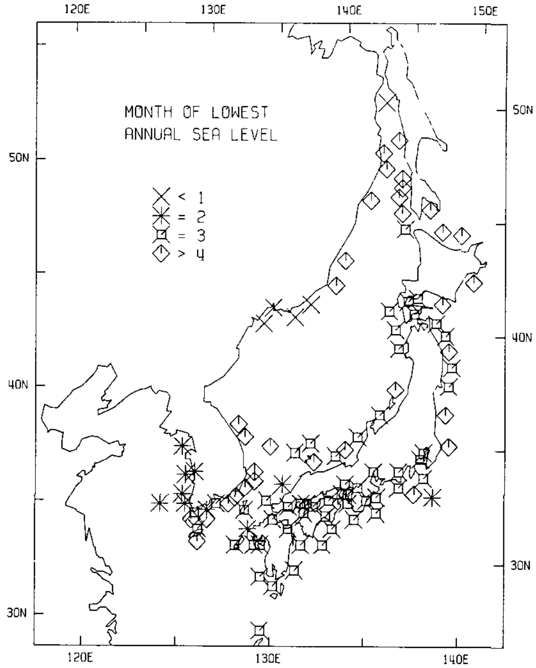

Fig. 8. Month of lowest annual sea level at 103 tidal stations.

Fig. 7 and 8 show the months of the annually highest and lowest sea levels. The sea level is the highest in September in the Korean coasts and the major part of Japanese coasts, and in October on the southern coasts of Japan and the Russian coasts. However, the sea level is the lowest in February on the western coasts of Korea and in March in the major part of Japanese coasts. On the southern and eastern coasts of Korea, most Russian coasts, and some of the eastern coasts of Japan, the sea level is the lowest in April or later. Generally, the highest or lowest month is getting late from south to north and also from west to east.

Fourier Spectral Analysis

Fig. 9 shows the monthly sea level variations of 16 stations shown in Fig. 3 during the period of 1965 to 1985, and Fig. 10 is the result of their spectral analysis. The Fourier Transform is used for spectral analysis. The energy of spectrum is calculated in amplitude directly from the results of the Fourier Transform, as shown in Appendix.

Because the mean values are subtracted from the sea level data used in spectral analysis, a general tendency of high energy (amplitude) in long periods (low frequencies) is not seen in the results of spectral analysis. However, in some areas such as Mokpo, such a tendency still remains due to their trends. (The high energy in long periods in Miyakesima is due to the long-period waves.)

Except the Russian coasts, seasonal variations are dominant in the study area. The amplitudes of seasonal variation at each tidal station are listed in Fig. 10. They are the largest (11~12 *cm*) in the Japanese coasts along the Tsushima Current (Sasebo, Izuhara, Moji, Maizuru) and the smallest (1~2 *cm*) in the Russian coast. In Russian coasts, seasonal variations are negligible. In Korea, they are larger in the southern coasts (8~9 *cm*) than in the eastern coasts (5~6 *cm*). The eastern coasts are less affected by the Tsushima Current. Generally, the Tsushima Current seems to make great

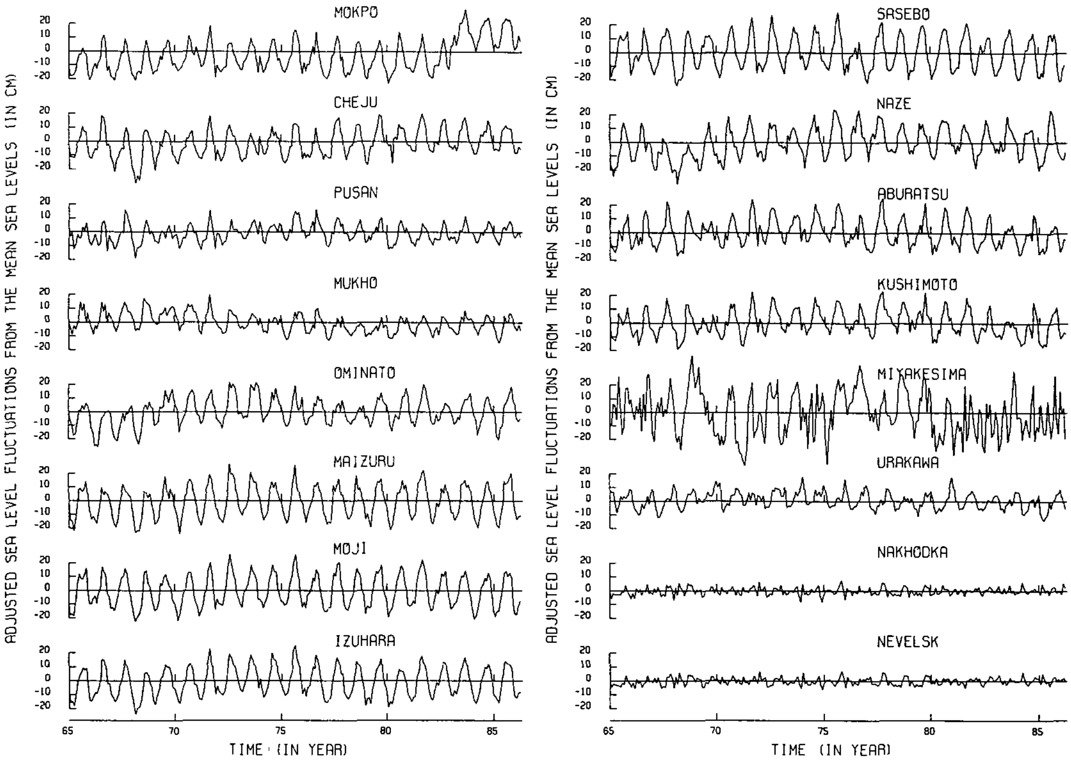

Fig. 9. Sea level variations of 16 tidal stations during the period of 1965 to 1985.

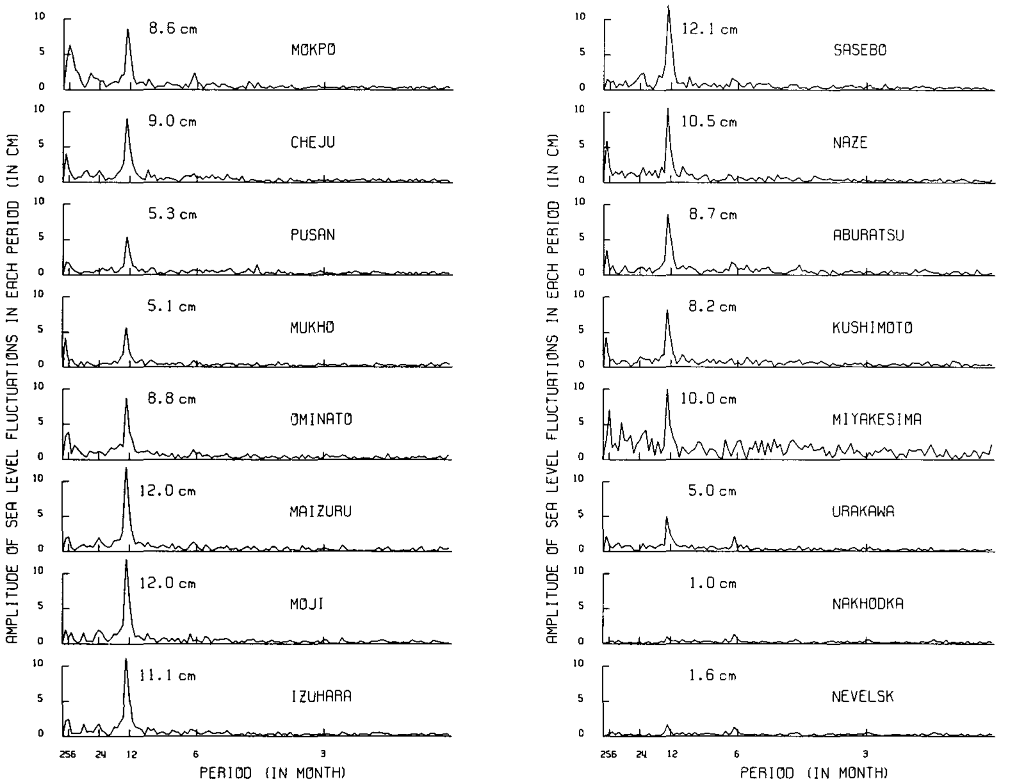

Fig. 10. Spectrums of sea level variation of 16 tidal stations during the period of 1965 to 1985. Energy of spectrum is converted to amplitude in *cm*. The values are the amplitudes of seasonal variation.

effects on seasonal variations in the study area. Ominato and Urakawa are close to each other, but their seasonal variations are a bit different. Their amplitudes are 8.9 *cm* and 4.9 *cm*, respectively. Ominato is in the passage of the Tsushima Current, while Urakawa is rather outside.

Fig. 11 and 12 show sea level variations with periods longer than one year and two years at 16 stations, respectively. Such variations do not seem to have any particular long-lasting regularity in time, while seasonal variations have a strong regularity. Specially, the variations in Miyakesima are very irregular, and also the largest. It seems to be because that Miyakesima is located nearer to the Pacific Ocean. Miyakesima is an island apart from the coast, and so easy to be affected by the waves from the Pacific Ocean. Generally, the coasts along the Pacific Ocean(Naze, Aburatsu, Kushimoto, Miyakesima, *et al.*) have the strongest variations. The coasts along the Tsushima Current(Sasebo, Izuhara, Moji, Maizuru, Ominato, *et al.*) have a little weaker variations, but their variations show a similar pattern. The patten seems to be maintained over those areas. So, such a pattern is also shown at Cheju. However, Pusan and Mukho, which are less affected by the Tsushima Current, show a little different patterns. The results suggest that longer-period variations come from the Pacific Ocean and propagate over the areas along the Tsushima Current. It agrees with the results in the next section that the phases of longer-period waves are the earliest in the Pacific Ocean, getting late along the Tsushima Current, and the latest in Russian coasts.

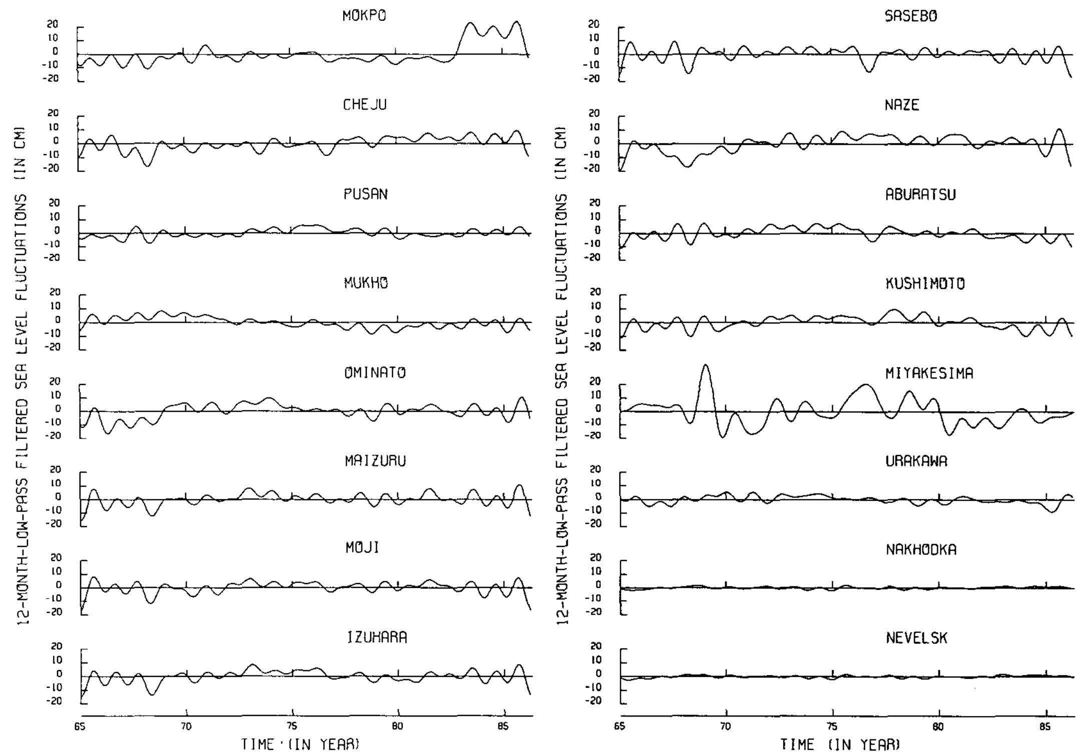

Fig. 11. 12-month low-pass filtered sea level variations at 16 tidal stations.

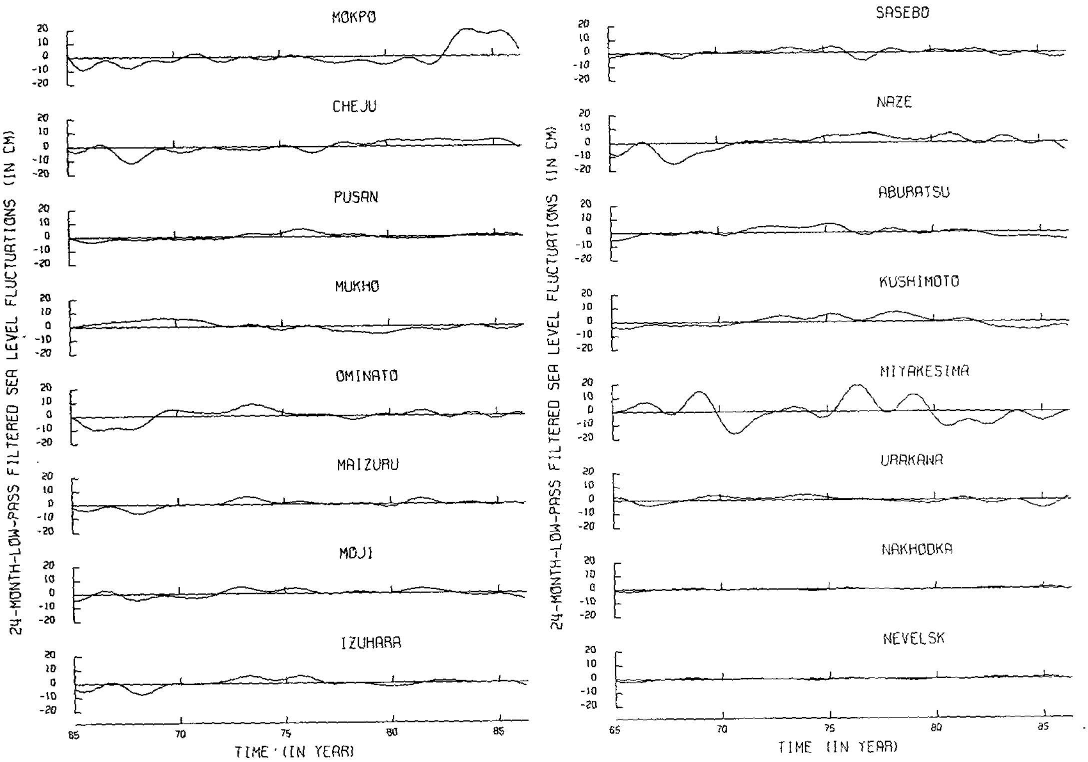

Fig. 12. 24-month low-pass filtered Sea level variations at 16 tidal stations.

Cross-correlations and Phase Differences

Cross-correlations are calculated between the 16 stations. The results are listed only for the periods of 3, 4, 6, 12 and 24 months, which are divisors or multiples of the period of seasonal variation (12 months). Because they have relatively significant energies. Tables 3~7 show the correlation coefficients and the phase differences (lags) for each period. The unit of phase is converted into month, and the positive (negative) means early (late). For example, -1.0 means that the phase is behind 1 month. The mean values of cross-correlation over the whole study area are 0.48, 0.51, 0.59, 0.60, 0.49 for the periods of 3, 4, 6, 12, and 24 months, respectively. It is the highest for seasonal variations.

For seasonal variations (period of 12 months), the Russian coasts are hardly correlated with other areas. Their cross-correlation values with other areas are no more than 0.3. Without the Russian coast, the mean value of the cross-correlation goes up to 0.74. High correlation occurs between the coasts along the Tsushima Current, specially between Sasebo, Izuhara, Moji, and Maizuru. It implies with the results of spectral analysis that a major part of seasonal variations in these areas is related to the Tsushima Current. The phases of seasonal variations are the earliest in Naze and the latest in Nevelsk. Generally, the phase is getting late from south to north, and also from west to east.

For longer-period variations (longer than seasonal variation, here only 24 months in Table), the coasts along the Pacific Ocean have earlier phases than the other coasts. It means that the waves of this period come from the Pacific Ocean. Specially, the coasts in Miyakesima and Urakawa have the

Table 3. Correlations and phase differences between 16 tidal stations for the 3 month-period variations.

CROSS-CORRELATIONS

		C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16
C1	MOKPO	1.0	.7	.4	.8	.2	1.0	.3	.9	.5	.5	.4	.8	.5	.4	.6	.9
C2	CHEJU	.7	1.0	.5	.9	.1	.7	.2	.7	.4	.6	.3	.6	.7	.6	.4	.7
C3	PUSAN	.4	.5	1.0	.5	.1	.3	.1	.4	.2	.8	.2	.3	.8	.9	.2	.3
C4	MUKHO	.8	.9	.5	1.0	.1	.7	.2	.8	.4	.6	.3	.7	.6	.5	.5	.7
C5	OMINATO	.2	.1	.1	.1	1.0	.2	.7	.2	.4	.1	.4	.2	.1	.1	.3	.2
C6	MAIZURU1	1.0	.7	.3	.7	.2	1.0	.3	.9	.6	.4	.5	.9	.4	.4	.6	1.0
C7	MOJI	.3	.2	.1	.2	.7	.3	1.0	.3	.5	.1	.6	.3	.1	.1	.5	.3
C8	IZUHARA	.9	.7	.4	.8	.2	.9	.3	1.0	.5	.5	.4	.8	.5	.4	.6	.9
C9	SASEBO	.5	.4	.2	.4	.4	.6	.5	.5	1.0	.2	.8	.6	.3	.2	.9	.6
C10	NAZE	.5	.6	.8	.6	.1	.4	.1	.5	.2	1.0	.2	.4	1.0	.9	.3	.4
C11	ABURATSU	.4	.3	.2	.3	.4	.5	.6	.4	.8	.2	1.0	.5	.2	.2	.7	.5
C12	KUSHIMOTO	.8	.6	.3	.7	.2	.9	.3	.8	.6	.4	.5	1.0	.4	.3	.7	.9
C13	MIYAKEJIMA	.5	.7	.8	.6	.1	.4	.1	.5	.3	1.0	.2	.4	1.0	.8	.3	.4
C14	URAKAWA	.4	.6	.9	.5	.1	.4	.1	.4	.2	.9	.2	.3	.8	1.0	.2	.4
C15	NAHODKA	.6	.4	.2	.5	.3	.6	.5	.6	.9	.3	.7	.7	.3	.2	1.0	.6
C16	NEVELSK	.9	.7	.3	.7	.2	1.0	.3	.9	.6	.4	.5	.9	.4	.4	.6	1.0

MEAN=.48 for whole area (.46 except the Russia Coasts)

PHASE DIFFERENCE IN MONTH

		C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16
C1	MOKPO	.0	-1.4	-.4	-.3	-1.7	-2.0	-1.3	-1.1	-1.7	-2.0	-.5	-.3	-.7	.2	-2.2	-2.2
C2	CHEJU	1.4	.0	1.0	1.1	-.3	-.6	.1	.3	-.3	-.5	1.0	1.1	.8	1.6	-.8	-.8
C3	PUSAN	.4	-1.0	.0	.1	-1.3	-1.6	-.9	-.7	-1.3	-1.5	-.0	.1	-.2	.6	-1.8	-1.8
C4	MUKHO	.3	-1.1	-.1	.0	-1.3	-1.7	-1.0	-.8	-1.4	-1.6	-.1	.0	-.3	.5	-1.9	-1.8
C5	OMINATO	1.7	.3	1.3	1.3	.0	-.3	.4	.6	-.0	-.3	1.2	1.4	1.0	1.8	-.5	-.5
C6	MAIZURU1	2.0	.6	1.6	1.7	.3	.0	.7	.9	.3	.1	1.6	1.7	1.4	2.2	-.2	-.2
C7	MOJI	1.3	-.1	.9	1.0	-.4	-.7	.0	.2	-.4	-.6	.9	1.0	.7	1.5	-.9	-.9
C8	IZUHARA	1.1	-.3	.7	.8	-.6	-.9	-.2	.0	-.6	-.8	.7	.8	.5	1.3	-1.1	-1.1
C9	SASEBO	1.7	.3	1.3	1.4	.0	-.3	.4	.6	.0	-.2	1.3	1.4	1.1	1.9	-.5	-.5
C10	NAZE	2.0	.5	1.5	1.6	.3	-.1	.6	.8	.2	.0	1.5	1.7	1.3	2.1	-.3	-.2
C11	ABURATSU	.5	-1.0	.0	.1	-1.2	-1.6	-.9	-.7	-1.3	-1.5	.0	.2	-.2	.6	-1.8	-1.7
C12	KUSHIMOTO	.3	-1.1	-.1	-.0	-1.4	-1.7	-1.0	-.8	-1.4	-1.7	-.2	.0	-.4	.5	-1.9	-1.9
C13	MIYAKEJIMA	.7	-.8	.2	.3	-1.0	-1.4	-.7	-.5	-1.1	-1.3	.2	.4	.0	.8	-1.6	-1.5
C14	URAKAWA	-.2	-1.6	-.6	-.5	-1.8	-2.2	-1.5	-1.3	-1.9	-2.1	-.6	-.5	-.8	.0	-2.4	-2.3
C15	NAHODKA	2.2	.8	1.8	1.9	.5	.2	.9	1.1	.5	.3	1.8	1.9	1.6	2.4	.0	.0
C16	NEVELSK	2.2	.8	1.8	1.8	.5	.2	.9	1.1	.5	.2	1.7	1.9	1.5	2.3	-.0	.0

Table 4. Correlations and phase differences between 16 tidal stations for the 4 month-period variations.

CROSS-CORRELATIONS

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16
C1 MOKPO	1.0	.2	.7	.6	.6	.5	.3	.2	.3	.8	.7	.9	.6	.8	.4	.4
C2 CHEJU	.2	1.0	.2	.4	.4	.5	.8	.8	.8	.3	.2	.2	.1	.3	.6	.6
C3 PUSAN	.7	.2	1.0	.4	.4	.3	.2	.1	.2	.5	1.0	.7	.9	.5	.3	.3
C4 MUKHO	.6	.4	.4	1.0	1.0	.7	.5	.3	.5	.8	.4	.6	.4	.7	.7	.7
C5 OMINATO	.6	.4	.4	1.0	1.0	.7	.5	.3	.5	.8	.4	.6	.4	.8	.7	.7
C6 MAIZURU1	.5	.5	.3	.7	.7	1.0	.7	.4	.6	.6	.3	.4	.3	.5	.9	.9
C7 MOJI	.3	.8	.2	.5	.5	.7	1.0	.6	1.0	.4	.2	.3	.2	.4	.7	.7
C8 IZUHARA	.2	.8	.1	.3	.3	.4	.6	1.0	.7	.2	.1	.2	.1	.2	.5	.5
C9 SASEBO	.3	.8	.2	.5	.5	.6	1.0	.7	1.0	.4	.2	.3	.2	.3	.7	.7
C10 NAZE	.8	.3	.5	.8	.8	.6	.4	.2	.4	1.0	.5	.7	.5	.9	.5	.5
C11 ABURATSU	.7	.2	1.0	.4	.4	.3	.2	.1	.2	.5	1.0	.7	.8	.6	.3	.3
C12 KUSHIMOTO	.9	.2	.7	.6	.6	.4	.3	.2	.3	.7	.7	1.0	.6	.8	.4	.4
C13 MIYAKEJIMA	.6	.1	.9	.4	.4	.3	.2	.1	.2	.5	.8	.6	1.0	.5	.2	.2
C14 URAKAWA	.8	.3	.5	.7	.8	.5	.4	.2	.3	.9	.6	.8	.5	1.0	.5	.5
C15 NAHODKA	.4	.6	.3	.7	.7	.9	.7	.5	.7	.5	.3	.4	.2	.5	1.0	1.0
C16 NEVELSK	.4	.6	.3	.7	.7	.9	.7	.5	.7	.5	.3	.4	.2	.5	1.0	1.0

MEAN=.51 for whole area (.50 except the Russia Coasts)

PHASE DIFFERENCE IN MONTH

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16
C1 MOKPO	.0	.2	.2	-.2	-.7	2.0	1.1	.4	.9	2.8	.6	.7	.9	-.2	.8	.8
C2 CHEJU	-.2	.0	.0	-.4	-.9	1.8	.9	.2	.7	2.5	.4	.4	.7	-.4	.6	.6
C3 PUSAN	-.2	.0	.0	-.4	-.9	1.8	.9	.2	.7	2.5	.4	.4	.7	-.4	.6	.6
C4 MUKHO	.2	.4	.4	.5	-.5	2.2	1.3	.6	1.1	2.9	.8	.8	1.1	.0	1.0	1.0
C5 OMINATO	.7	.9	.9	.5	.0	2.7	1.8	1.1	1.6	3.4	1.3	1.3	1.5	.5	1.5	1.5
C6 MAIZURU1	-2.0	-1.8	-1.8	-2.2	-2.7	.0	-.9	-1.6	-1.1	.8	-1.4	-1.3	-1.1	-2.1	-1.2	-1.1
C7 MOJI	-1.1	-.9	-.9	-1.3	-1.8	.9	.0	-.7	-.2	1.7	-.5	-.4	-.2	-1.3	-.3	-.3
C8 IZUHARA	-.4	-.2	-.2	-.6	-1.1	1.6	.7	.0	.5	2.4	.2	.3	.5	-.6	.4	.4
C9 SASEBO	-.9	-.7	-.7	-1.1	-1.6	1.1	.2	-.5	.0	1.9	-.3	-.2	.0	-1.0	-.1	-.0
C10 NAZE	-2.8	-2.5	-2.5	-2.9	-3.4	-.8	-1.7	-2.4	-1.9	.0	-2.2	-2.1	-1.9	-2.9	-2.0	-1.9
C11 ABURATSU	-.6	-.4	-.4	-.8	-1.3	1.4	.5	-.2	.3	2.2	.0	.1	.3	-.8	.2	.2
C12 KUSHIMOTO	-.7	-.4	-.4	-.8	-1.3	1.3	.4	-.3	.2	2.1	-.1	.0	.2	-.8	.1	.2
C13 MIYAKEJIMA	-.9	-.7	-.7	-1.1	-1.5	1.1	.2	-.5	.0	1.9	-.3	-.2	.0	-1.0	-.1	-.0
C14 URAKAWA	.2	.4	.4	-.0	-.5	2.1	1.3	.6	1.0	2.9	.8	.8	1.0	.0	1.0	1.0
C15 NAHODKA	-.8	-.6	-.6	-1.0	-1.5	1.2	.3	-.4	.1	2.0	-.2	-.1	.1	-1.0	.0	.0
C16 NEVELSK	-.8	-.6	-.6	-1.0	-1.5	1.1	.3	-.4	.0	1.9	-.2	-.2	.0	-1.0	-.0	.0

Table 5. Correlations and phase differences between 16 tidal stations for the 6 month-period variations.

CROSS-CORRELATIONS

		C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16
C1	MOKPO	1.0	.5	.3	.4	.6	.6	.2	.4	.6	.2	.7	.2	.7	.9	.6	.5
C2	CHEJU	.5	1.0	.6	.8	.9	.9	.4	.7	.9	.3	.8	.3	.8	.6	.9	1.0
C3	PUSAN	.3	.6	1.0	.8	.6	.6	.6	.9	.6	.5	.5	.5	.5	.4	.6	.6
C4	MUKHO	.4	.8	.8	1.0	.7	.7	.5	.9	.7	.4	.6	.4	.6	.4	.7	.7
C5	OMINATO	.6	.9	.6	.7	1.0	1.0	.3	.6	1.0	.3	.9	.3	.9	.6	1.0	.9
C6	MAIZURU1	.6	.9	.6	.7	1.0	1.0	.3	.6	1.0	.3	.8	.3	.8	.6	1.0	1.0
C7	MOJI	.2	.4	.6	.5	.3	.3	1.0	.5	.3	.8	.3	.9	.3	.2	.3	.3
C8	IZUHARA	.4	.7	.9	.9	.6	.6	.5	1.0	.6	.4	.5	.5	.5	.4	.6	.7
C9	SASEBO	.6	.9	.6	.7	1.0	1.0	.3	.6	1.0	.3	.8	.3	.8	.6	1.0	1.0
C10	NAZE	.2	.3	.5	.4	.3	.3	.8	.4	.3	1.0	.2	.9	.2	.2	.3	.3
C11	ABURATSU	.7	.8	.5	.6	.9	.8	.3	.5	.8	.2	1.0	.2	1.0	.7	.9	.8
C12	KUSHIMOTO	.2	.3	.5	.4	.3	.3	.9	.5	.3	.9	.2	1.0	.2	.2	.3	.3
C13	MIYAKEJIMA	.7	.8	.5	.6	.9	.8	.3	.5	.8	.2	1.0	.2	1.0	.8	.9	.8
C14	URAKAWA	.9	.6	.4	.4	.6	.6	.2	.4	.6	.2	.7	.2	.8	1.0	.6	.6
C15	NAHODKA	.6	.9	.6	.7	1.0	1.0	.3	.6	1.0	.3	.9	.3	.9	.6	1.0	.9
C16	NEVELSK	.5	1.0	.6	.7	.9	1.0	.3	.7	1.0	.3	.8	.3	.8	.6	.9	1.0

MEAN=.59 for whole area (.56 except the Russia Coasts)

PHASE DIFFERENCE IN MONTH

		C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16
C1	MOKPO	.0	.5	-.2	-1.6	-2.1	-2.1	.6	-.2	.7	.3	.5	.6	-4.1	-1.5	.8	.9
C2	CHEJU	-.5	.0	-.7	-2.1	-2.6	-2.6	.1	-.7	.2	-.2	.0	.2	-4.6	-2.0	.3	.4
C3	PUSAN	.2	.7	.0	-1.4	-1.9	-2.0	.8	-.0	.9	.5	.7	.8	-3.9	-1.3	1.0	1.1
C4	MUKHO	1.6	2.1	1.4	.0	-.5	-.5	2.2	1.4	2.3	1.9	2.1	2.3	-2.5	.1	2.4	2.5
C5	OMINATO	2.1	2.6	1.9	.5	.0	-.0	2.7	1.9	2.8	2.4	2.6	2.8	-1.9	.6	2.9	3.0
C6	MAIZURU1	2.1	2.6	2.0	.5	.0	.0	2.7	1.9	2.8	2.4	2.6	2.8	-1.9	.6	3.0	3.0
C7	MOJI	-.6	-.1	-.8	-2.2	-2.7	-2.7	.0	-.8	.1	-.3	-.1	.1	-4.6	-2.1	.2	.3
C8	IZUHARA	.2	.7	.0	-1.4	-1.9	-1.9	.8	.0	.9	.5	.7	.9	-3.8	-1.3	1.0	1.1
C9	SASEBO	-.7	-.2	-.9	-2.3	-2.8	-2.8	-.1	-.9	.0	-.4	-.2	-.0	-4.8	-2.2	.1	.2
C10	NAZE	-.3	.2	-.5	-1.9	-2.4	-2.4	.3	-.5	.4	.0	.2	.4	-4.4	-1.8	.5	.6
C11	ABURATSU	-.5	.0	-.7	-2.1	-2.6	-2.6	.1	-.7	.2	-.2	.0	.2	-4.6	-2.0	.3	.4
C12	KUSHIMOTO	-.6	-.2	-.8	-2.3	-2.8	-2.8	-.1	-.9	.0	-.4	-.2	.0	-4.7	-2.1	.2	.2
C13	MIYAKEJIMA	4.1	4.6	3.9	2.5	1.9	1.9	4.6	3.8	4.8	4.4	4.6	4.7	.0	2.6	4.9	5.0
C14	URAKAWA	1.5	2.0	1.3	-.1	-.6	-.6	2.1	1.3	2.2	1.8	2.0	2.1	-2.6	0	2.3	2.4
C15	NAHODKA	-.8	-.3	-1.0	-2.4	-2.9	-3.0	-.2	-1.0	-.1	-.5	-.3	-.2	-4.9	-2.3	.0	.1
C16	NEVELSK	-.9	-.4	-1.1	-2.5	-3.0	-3.0	-.3	-1.1	-.2	-.6	-.4	-.2	-5.0	-2.4	-.1	.0

Table 6. Correlations and phase differences between 16 tidal stations for the 12 month-period variations.

CROSS-CORRELATIONS

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16
C1 MOKPO	1.0	1.0	.6	.7	1.0	.7	.7	.8	.7	.8	1.0	1.0	.9	.6	.1	.2
C2 CHEJU	1.0	1.0	.6	.6	1.0	.7	.7	.8	.7	.9	1.0	.9	.9	.6	.1	.2
C3 PUSAN	.6	.6	1.0	.9	.6	.4	.4	.5	.4	.5	.6	.6	.5	.9	.2	.3
C4 MUKHO	.7	.6	.9	1.0	.6	.5	.5	.5	.5	.5	.7	.7	.6	.9	.2	.3
C5 OMINATO	1.0	1.0	.6	.6	1.0	.7	.7	.8	.7	.8	1.0	.9	.9	.6	.1	.2
C6 MAIZURU1	.7	.7	.4	.5	.7	1.0	1.0	.9	1.0	.9	.7	.7	.8	.4	.1	.1
C7 MOJI	.7	.7	.4	.5	.7	1.0	1.0	.9	1.0	.9	.7	.7	.8	.4	.1	.1
C8 IZUHARA	.8	.8	.5	.5	.8	.9	.9	1.0	.9	.9	.8	.7	.9	.5	.1	.1
C9 SASEBO	.7	.7	.4	.5	.7	1.0	1.0	.9	1.0	.9	.7	.7	.8	.4	.1	.1
C10 NAZE	.8	.9	.5	.5	.8	.9	.9	.9	.9	1.0	.8	.8	1.0	.5	.1	.2
C11 ABURATSU	1.0	1.0	.6	.7	1.0	.7	.7	.8	.7	.8	1.0	.9	.9	.6	.1	.2
C12 KUSHIMOTO	1.0	.9	.6	.7	.9	.7	.7	.7	.7	.8	.9	1.0	.8	.6	.1	.2
C13 MIYAKEJIMA	.9	.9	.5	.6	.9	.8	.8	.9	.8	1.0	.9	.8	1.0	.5	.1	.2
C14 URAKAWA	.6	.6	.9	.9	.6	.4	.4	.5	.4	.5	.6	.6	.5	1.0	.2	.3
C15 NAHODKA	.1	.1	.2	.2	.1	.1	.1	.1	.1	.1	.1	.1	.1	.2	1.0	.6
C16 NEVELSK	.2	.2	.3	.3	.2	.1	.1	.1	.1	.2	.2	.2	.2	.3	.6	1.0

MEAN=.60 for whole area (.74 except the Russia Coasts)

PHASE DIFFERENCE IN MONTH

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16
C1 MOKPO	.0	.3	1.0	1.2	1.6	.5	-.1	.1	-.2	-.3	.4	.6	1.1	3.1	2.0	3.0
C2 CHEJU	-.3	.0	.7	.9	1.2	.2	-.4	-.2	-.5	-.6	.1	.3	.8	2.8	1.7	2.7
C3 PUSAN	-1.0	-.7	.0	.2	.6	-.5	-1.1	-.8	-1.2	-1.3	-.6	-.4	.1	2.1	1.0	2.0
C4 MUKHO	-1.2	-.9	-.2	.0	.3	-.7	-1.3	-1.1	-1.4	-1.6	-.8	-.7	-.1	1.8	.8	1.8
C5 OMINATO	-1.6	-1.2	-.6	-.3	.0	-1.0	-1.7	-1.4	-1.8	-1.9	-1.2	-1.0	-.5	1.5	.4	1.5
C6 MAIZURU1	-.5	-.2	.5	.7	1.0	.0	-.6	-.4	-.7	-.8	-.1	.0	.6	2.5	1.5	2.5
C7 MOJI	.1	.4	1.1	1.3	1.7	.6	.0	.3	-.1	-.2	.5	.7	1.2	3.2	2.1	3.1
C8 IZUHARA	-.1	.2	.8	1.1	1.4	.4	-.3	.0	-.3	-.5	.2	.4	.9	2.9	1.8	2.9
C9 SASEBO	.2	.5	1.2	1.4	1.8	.7	.1	.3	.0	-.1	.6	.8	1.3	3.3	2.2	3.2
C10 NAZE	.3	.6	1.3	1.6	1.9	.8	.2	.5	.1	.0	.7	.9	1.4	3.4	2.3	3.4
C11 ABURATSU	-.4	-.1	.6	.8	1.2	.1	-.5	-.2	-.6	-.7	.0	.2	.7	2.7	1.6	2.6
C12 KUSHIMOTO	-.6	-.3	.4	.7	1.0	-.0	-.7	-.4	-.8	-.9	-.2	.0	.5	2.5	1.4	2.5
C13 MIYAKEJIMA	-1.1	-.8	-.1	.1	.5	-.6	-1.2	-.9	-1.3	-1.4	-.7	-.5	.0	2.0	.9	1.9
C14 URAKAWA	-3.1	-2.8	-2.1	-1.8	-1.5	-2.5	-3.2	-2.9	-3.3	-3.4	-2.7	-2.5	-2.0	.0	-1.1	-.0
C15 NAHODKA	-2.0	-1.7	-1.0	-.8	-.4	-1.5	-2.1	-1.8	-2.2	-2.3	-1.6	-1.4	-.9	1.1	.0	1.0
C16 NEVELSK	-3.0	-2.7	-2.0	-1.8	-1.5	-2.5	-3.1	-2.9	-3.2	-3.4	-2.6	-2.5	-1.9	.0	-1.0	.0

Table 7. Correlations and phase differences between 16 tidal stations for the 24 month-period variations.

CROSS-CORRELATIONS

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16
C1 MOKPO	1.0	.7	.4	.1	.5	.8	.9	.8	1.0	.5	.6	.4	.7	.1	.1	.1
C2 CHEJU	.7	1.0	.7	.1	.8	.8	.7	.8	.7	.8	.9	.7	.5	.2	.2	.2
C3 PUSAN	.4	.7	1.0	.2	.8	.5	.5	.6	.4	.8	.8	1.0	.3	.3	.3	.3
C4 MUKHO	.1	.1	.2	1.0	.2	.1	.1	.1	.1	.2	.2	.2	.1	.7	.8	.8
C5 OMINATO	.5	.8	.8	.2	1.0	.7	.6	.7	.5	1.0	.9	.8	.4	.2	.2	.2
C6 MAIZURU1	.8	.8	.5	.1	.7	1.0	.9	1.0	.8	.6	.7	.5	.6	.2	.1	.1
C7 MOJI	.9	.7	.5	.1	.6	.9	1.0	.9	.9	.6	.6	.5	.7	.1	.1	.1
C8 IZUHARA	.8	.8	.6	.1	.7	1.0	.9	1.0	.8	.7	.7	.6	.6	.2	.2	.2
C9 SASEBO	1.0	.7	.4	.1	.5	.8	.9	.8	1.0	.5	.6	.4	.7	.1	.1	.1
C10 NAZE	.5	.8	.8	.2	1.0	.6	.6	.7	.5	1.0	.9	.8	.4	.2	.2	.2
C11 ABURATSU	.6	.9	.8	.2	.9	.7	.6	.7	.6	.9	1.0	.8	.4	.2	.2	.2
C12 KUSHIMOTO	.4	.7	1.0	.2	.8	.5	.5	.6	.4	.8	.8	1.0	.3	.3	.3	.3
C13 MIYAKEJIMA	.7	.5	.3	.1	.4	.6	.7	.6	.7	.4	.4	.3	1.0	.1	.1	.1
C14 URAKAWA	.1	.2	.3	.7	.2	.2	.1	.2	.1	.2	.2	.3	.1	1.0	.9	.9
C15 NAHODKA	.1	.2	.3	.8	.2	.1	.1	.2	.1	.2	.2	.3	.1	.9	1.0	1.0
C16 NEVELSK	.1	.2	.3	.8	.2	.1	.1	.2	.1	.2	.2	.3	.1	.9	1.0	1.0

MEAN=.49 for whole area (.55 except the Russia Coasts)

PHASE DIFFERENCE IN MONTH

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16
C1 MOKPO	.0	2.4	-.4	2.0	.5	-.6	-1.4	-1.0	-1.4	-3.3	-.6	-1.3	-13.7	-13.6	4.2	4.1
C2 CHEJU	-2.4	.0	-2.8	-.4	-1.9	-3.0	-3.8	-3.4	-3.8	-5.7	-3.1	-3.7	-16.1	-16.0	1.8	1.7
C3 PUSAN	.4	2.8	.0	2.4	.9	-.2	-1.0	-.6	-1.0	-2.9	-.2	-.9	-13.2	-13.2	4.6	4.5
C4 MUKHO	-2.0	.4	-2.4	.0	-1.5	-2.6	-3.4	-3.0	-3.4	-5.3	-2.7	-3.3	-15.7	-15.6	2.2	2.1
C5 OMINATO	-.5	1.9	-.9	1.5	.0	-1.1	-1.9	-1.5	-1.9	-3.8	-1.2	-1.8	-14.2	-14.1	3.7	3.6
C6 MAIZURU1	.6	3.0	.2	2.6	1.1	.0	-.8	-.4	-.8	-2.7	-.1	-.7	-13.1	-13.0	4.8	4.7
C7 MOJI	1.4	3.8	1.0	3.4	1.9	.8	.0	.4	.0	-1.9	.7	.1	-12.3	-12.2	5.6	5.4
C8 IZUHARA	1.0	3.4	.6	3.0	1.5	.4	-.4	.0	-.4	-2.3	.3	-.3	-12.7	-12.6	5.2	5.1
C9 SASEBO	1.4	3.8	1.0	3.4	1.9	.8	-.0	.4	.0	-1.9	.7	.1	-12.3	-12.2	5.5	5.4
C10 NAZE	3.3	5.7	2.9	5.3	3.8	2.7	1.9	2.3	1.9	.0	2.6	2.0	-10.4	-10.3	7.5	7.3
C11 ABURATSU	.6	3.1	.2	2.7	1.2	.1	-.7	-.3	-.7	-2.6	.0	-.6	-13.0	-12.9	4.8	4.7
C12 KUSHIMOTO	1.3	3.7	.9	3.3	1.8	.7	-.1	.3	-.1	-2.0	.6	.0	-12.4	-12.3	5.5	5.3
C13 MIYAKEJIMA	13.7	16.1	13.2	15.7	14.2	13.1	12.3	12.7	12.3	10.4	13.0	12.4	.0	.1	17.8	17.7
C14 URAKAWA	13.6	16.0	13.2	15.6	14.1	13.0	12.2	12.6	12.2	10.3	12.9	12.3	-.1	.0	17.7	17.6
C15 NAHODKA	-4.2	-1.8	-4.6	-2.2	-3.7	-4.8	-5.6	-5.2	-5.5	-7.5	-4.8	-5.5	-17.8	-17.7	.0	-.1
C16 NEVELSK	-4.1	-1.7	-4.5	-2.1	-3.6	-4.7	-5.4	-5.1	-5.4	-7.3	-4.7	-5.3	-17.7	-17.6	.1	.0

earliest phases. However, their cross-correlation values with the other areas are very low (mostly less than 0.3) in Urakawa, while generally higher (0.4~0.7 with the coasts along the Pacific Ocean and along the Tsushima Current) in Miyakesima. It means that the longer-period waves are significantly weaken around Urakawa. Between the coasts along the Pacific Ocean and the coasts along the Tsushima Current, cross-correlations are higher and phase differences are smaller. On the other hand, the Russian coasts have the lowest cross-correlation values with the other coasts(mostly less than 0.3) and the latest phases. The longer-period waves seem to arrive there with being weakened after long times. The phase difference says that they arrive there through the areas of the Tsushima Current.

For shorter-period variations (shorter than seasonal variation, here only 3, 4, and 6 months in Table), the correlation values do not show any dictinct difference between areas. Therefore, the mean cross-correlation values without the Russian coasts do not increase, while they increase for seasonal and longer-period variations. The cross-correlation values rather show a common tendency that they are inversely propotional to distance. They are also generally lower for shorter period. It implies that the waves of shorter periods are generated all over the areas and propagate in all the directions, and their energies decay more rapidly for shorter period.

Sea Level Difference

Table 8 shows the trends of sea level difference between 16 stations during the period of 1965 to 1985. The unit is *cm*/month. They have significant trends for the period. For example, the sea level difference between Cheju and Sasebo (sea level of Cheju minus sea level of Sasebo) has a trend of 0.043 *cm*/month, which means about 5 *cm* rising of the sea level in Cheju compared with the sea level in Sasebo for the period. It corresponds to about 1 *Sv* reduction of mean transport between Cheju and Sasebo (that of Tsushima Current) for the period.

Compared to the sea levels in other areas, the sea levels are rising in the Korean coasts and falling in the coasts along the Pacific Ocean for the period. Such trends are also shown in individual sea levels. Table 9 shows the trends of sea level variation in each station. They are positive(which

Table 8. Trends of sea level difference (cm/month) between 16 tidal stations during the period of 1965 to 1985.

		C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16
C1	MOKPO	.000	.026	.054	.097	.045	.051	.059	.055	.068	.026	.073	.065	.093	.076	.059	.059
C2	CHEJU	-.026	.000	.028	.071	.019	.025	.034	.029	.043	.000	.047	.039	.067	.050	.034	.034
C3	PUSAN	-.054	.028	.000	.043	-.009	-.003	.005	.001	.014	-.028	.019	.011	.039	.022	.005	.005
C4	MUKHO	-.097	.071	-.043	.000	-.052	-.046	-.037	-.042	-.028	-.071	-.024	-.032	.004	-.021	-.037	-.037
C5	OMINATO	-.045	.019	.009	.052	.000	.006	.015	.010	.024	-.019	.028	.020	.048	.031	.015	.015
C6	MAIZURU1	-.051	.025	.003	.046	-.006	.000	.008	.004	.017	-.025	.022	.014	.042	.025	.008	.008
C7	MOJI	-.059	.034	-.005	.037	-.015	-.008	.000	-.005	.009	-.034	.013	.005	.034	.017	-.000	.000
C8	IZUHARA	-.055	.029	-.001	.042	-.010	-.004	.005	.000	.014	-.029	.018	.010	.038	.022	.005	.005
C9	SASEBO	-.068	.043	-.014	.028	-.024	-.017	-.009	-.014	.000	-.043	.004	-.004	.025	.008	-.009	-.009
C10	NAZE	-.026	.000	.028	.071	.019	.025	.034	.029	.043	.000	.047	.039	.067	.050	.034	.034
C11	ABURATSU	-.073	.047	-.019	.024	-.028	-.022	-.013	-.018	-.004	-.047	.000	-.008	.020	.003	-.014	-.013
C12	KUSHIMOTO	-.065	.039	-.011	.032	-.020	-.014	-.005	-.010	.004	-.039	.008	.000	.028	.011	-.006	-.005
C13	MIYAKEJIMA	-.093	.067	-.039	.004	-.048	-.042	-.034	-.038	-.025	-.067	-.020	-.028	.000	-.017	-.034	-.034
C14	URAKAWA	-.076	.050	-.022	.021	-.031	-.025	-.017	-.022	-.008	-.050	-.003	-.011	.017	.000	-.017	-.017
C15	NAHODKA	-.059	.034	-.005	.037	-.015	-.008	.000	-.005	.009	-.034	.014	.006	.034	.017	.000	.000
C16	NEVELSK	-.059	.034	-.005	.037	-.015	-.008	.000	-.005	.009	-.034	.013	.005	.034	.017	-.000	.000

means rising) in the Korean coasts and negative (which means falling) in the coasts along the Pacific coasts. We do not know why such trends over a long period were made in this area, but we guess they should be eventually related to the variations of the Kuroshio and the Tsushima Currents in some way.

Fig. 13 is the spectrum of sea level differences between Cheju and Sasebo. There is the largest energy in long period, which corresponds to the long period trend. Except the trend, the seasonal variation is also prominent, and its amplitude is 4.2 *cm*. It means that the sea level differences between two stations seasonally vary up to 8.4 *cm*. It corresponds to the seasonal variation of 1.5 *Sv* in volume transport with the width of 270 *km* and the mean depth of 150 *m* between Cheju and Sasebo.

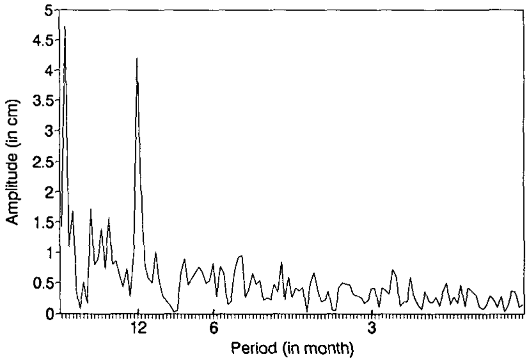

Fig. 13. Spectrum of sea level differences between Cheju and Sasebo.

Table 10 shows the amplitudes of seasonal variation of sea level difference between stations. The

Table 9. Trends of sea level (cm/month) at 16 tidal stations during the period of 1965 to 1985.

MOKPO	.064	CHEJU	.039	PUSAN	.010	MUKHO	-.032
OMINATO	.020	MAIZURU1	.013	MOJI	.005	IZUHARA	.010
SASEBO	-.004	NAZE	.039	ABURATSU	-.008	KUSHIMOTO	-.000
MIYAKEJIMA	-.028	URAKAWA	-.012	NAHODKA	.005	NEVELSK	.005

Table 10. Amplitudes of seasonal variation of sea level difference (cm) between 16 tidal stations.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16
C1 MOKPO	.0	1.5	4.8	5.3	6.8	4.3	3.4	2.6	3.7	2.4	1.8	2.5	5.3	10.0	8.2	8.8
C2 CHEJU	1.5	.0	4.4	4.7	5.6	3.2	3.8	2.3	4.2	3.5	.5	1.4	3.9	9.6	8.4	8.8
C3 PUSAN	4.8	4.4	.0	.7	3.9	7.0	8.1	6.7	8.4	7.2	3.9	3.2	4.6	5.3	4.5	4.8
C4 MUKHO	5.3	4.7	.7	.0	3.3	7.0	8.5	7.0	8.8	7.7	4.2	3.5	4.3	4.9	4.8	4.9
C5 OMINATO	6.8	5.6	3.9	3.3	.0	6.3	9.1	7.4	9.6	9.1	5.1	4.3	2.5	6.3	7.8	7.7
C6 MAIZURU1	4.3	3.2	7.0	7.0	6.3	.0	3.8	2.4	4.5	5.1	3.4	3.8	3.8	11.8	11.3	11.7
C7 MOJI	3.4	3.8	8.1	8.5	9.1	3.8	.0	1.8	.6	2.1	4.3	5.1	7.0	13.3	11.6	12.2
C8 IZUHARA	2.6	2.3	6.7	7.0	7.4	2.4	1.8	.0	2.3	2.7	2.8	3.6	5.2	11.9	10.6	11.1
C9 SASEBO	3.7	4.2	8.4	8.8	9.6	4.5	.6	2.3	.0	1.8	4.7	5.6	7.5	13.7	11.8	12.4
C10 NAZE	2.4	3.5	7.2	7.7	9.1	5.1	2.1	2.7	1.8	.0	4.0	4.8	7.3	12.4	10.1	10.8
C11 ABURATSU	1.8	.5	3.9	4.2	5.1	3.4	4.3	2.8	4.7	4.0	.0	.9	3.6	9.1	8.0	8.5
C12 KUSHIMOTO	2.5	1.4	3.2	3.5	4.3	3.8	5.1	3.6	5.6	4.8	.9	.0	3.0	8.4	7.5	7.9
C13 MIYAKEJIMA	5.3	3.9	4.6	4.3	2.5	3.8	7.0	5.2	7.5	7.3	3.6	3.0	.0	8.5	9.1	9.2
C14 URAKAWA	10.0	9.6	5.3	4.9	6.3	11.8	13.3	11.9	13.7	12.4	9.1	8.4	8.5	.0	4.2	3.4
C15 NAHODKA	8.2	8.4	4.5	4.8	7.8	11.3	11.6	10.6	11.8	10.1	8.0	7.5	9.1	4.2	.0	.9
C16 NEVELSK	8.8	8.8	4.8	4.9	7.7	11.7	12.2	11.1	12.4	10.8	8.5	7.9	9.2	3.4	.9	.0

large amplitudes are shown between the coasts along the Tsushima Current and the Russian coasts. It is because of the largest seasonal variations in the coasts along the Tsushima Current and the smallest seasonal variations in the Russian coasts. From the seasonal variations of sea level difference, we can estimate the seasonal variations of volume transport. They are 0.3 *Sv* in the Cheju Strait (between Mokpo and Cheju) and 2 *Sv* in the Korea Strait(between Pusan and Moji). Sea level differences, distances between the stations, and mean depths used in the calculation are 3 *cm*, 120 *km* and 80 *m* for the Cheju Strait, and 16.2 *cm*, 200 *km* and 100 *m* for the Korea Strait. The results are comparable to the previous reports of Yi(1966) and others.

Summary

Monthly mean sea levels from 103 tidal stations in Korea, Japan, and Russia are analyzed to study long-period sea level variations. Barometric adjustments are done for all the sea level data, using monthly air pressures at sea levels from meteorological stations near tidal stations. With some basic statistical analyses for all the stations, Fourier spectral analyses are done for 37 stations having relatively good data for spectral analysis. Out of them, 16 stations have a relatively long common period of 1965 to 1985. For the 16 stations, cross-correlations and phase differences are analyzed. Finally, sea level differences between the 16 stations are analyzed to see the variations of volume transport.

Seasonal variation, which is dominant in most of study areas, is the largest in the coasts along the Tsushima Current and the smallest in the Russian coasts. The cross-correlations of seasonal variations are very high between the coasts along the Tsushima Current, and very low between the Russian coasts and the other coasts. The Russian coasts are hardly affected by the Tsushima Current. In the eastern coasts of Korea, which are less affected by the Tsushima Current, the seasonal variations are small and their cross-correlation values with other areas are a little low. In these marginal seas, the seasonal variations seem to be related to the Tsushima Current. The phase of seasonal variations is generally getting late from south to north, and also from west to east.

Longer-period variations (longer than seasonal variation) have the largest amplitudes and the earliest phases in the coasts along the Pacific Ocean. Cross-orrelations are high and phase differences are small between the coasts along the Pacific Ocean and the coasts along the Tsushima Current. The Russian coasts have the lowest cross-correlation values with the other coasts and the latest phases. It suggests that longer-period variations are generated in the Pacific Ocean, and propagate to the study areas, and eventually arrive at the Russian coasts with being very weakened. On the other hand, shorter-period variations(shorter than seasonal variation) have generally low cross-correlations, and the cross-correlation values do not show any dictinct difference between areas. The cross-correlation values show a common tendency that they are inversely propotional to distance. They are also generally lower for shorter period. It implies that the waves of shorter periods are generated all over the study areas and propagate in all the directions, and the energies decay more rapidly for shorter period.

Sea levels in the study area show significant trends for the period of 1965 to 1985. The trends are generally negative in the Pacific coasts and positive in other areas. By the trends, the mean volume transport between Cheju and Sasebo can be reduced about 1 *Sv* during the period. The seasonal variation of volume transport obtained by sea level difference is about 1.5 *Sv*, 0.3 *Sv*, and 2 *Sv* across the section between Cheju and Sasebo, the Cheju Strait, and the Korea Strait, respectively. The values are comparable to previous reports.

Appendix

Suppose that we have N consecutive sampled values h_k, $k=0, 1, 2, 3, \cdots\cdots, N-1$, and the sampling interval is 1 for simplicity. Then, the discrete values of frequency f_n for the discrete Fourier

Transform are:

$$f_n = n/N, \quad n = -N/2, \cdots\cdots, N/2.$$

The extreme values of n in the above correspond to the lower and upper limits of the Nyquist critical frequency range, and the frequency $-f_n$ corresponds to the frequency f_{N-n}. The formulas for the discrete Fourier Transform H_n of the N points h_k and the discrete inverse Fourier Transform h_k, which recovers the set of h_k's exactly from H_n's are:

$$H_n(f_n) = \sum_{k=0}^{N-1} h_k \cdot \exp(i2\pi kn/N)$$

$$h_k = \frac{1}{N} \sum_{n=0}^{N-1} H_n \cdot \exp(-i2\pi kn/N)$$

If the time series h_k contains $A\cos(2\pi kn/N + \theta)$ at a frequency f_n, where A and θ are the amplitude and the phase lag, respectively, and $k = 0, \cdots, N-1$, then,

$$\begin{aligned} H(\pm f_n) &= \sum_{k=0}^{N-1} h_k \cdot \exp(\pm i2\pi kn/N) \\ &= \sum_{k=0}^{N-1} A\cos(2\pi kn/N + \theta) \cdot \exp(\pm i2\pi kn/N) \\ &= \sum_{k=0}^{N-1} A\{\cos(2\pi kn/N)\cos\theta \\ &\quad - \sin(2\pi kn/N)\sin\theta\} \cdot \exp(\pm i2\pi kn/N) \\ &= A(N/2)\,(\cos\theta \mp i\sin\theta) \end{aligned}$$

$$\therefore A = \sqrt{2(|H(f_n)|^2 + |H(f_{N-n})|^2)/N^2}$$

Here we use the summation relation $\sum_{k=0}^{N-1} \cos^2 x = \sum_{k=0}^{N-1} \sin^2 x = N/2$ and the frequency $-f_n = f_{N-n}$.

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우리나라 근해의 장기적인 해수면변화

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해수면의 장주기변동을 알기 위하여 우리나라, 일본, 러시아의 103개 조위관측점의 월평균 해수면을 분석하였다. 기압보정에는 조위관측점 부근의 기상관측점에서 관측된 월평균 해수면기압을 사용하였다.

계절변화는 대부분의 해역에서 지배적이며, 대마해류역 해안에서 가장 크고 러시아 해안에서 가장 작다. 계절변화의 상호상관관계는 대마해류역 해안 사이에서 가장 크다. 이 부속해에서는 계절변화가 대마해류와 관계를 갖고 있는 것으로 보인다. 계절변화는 남쪽에서 북쪽 뿐만 아니라 서쪽에서 동쪽으로도 전파되고 있다. 반면에, 계절변화보다 장주기의 변화는 태평양 연안에서 가장 큰 진폭과 가장 빠른 위상을 보여, 장주기의 변화는 태평양에서 부터 전파되어 오는 것을 보여준다. 계절변화보다 짧은 주기의 변화는 일반적으로 상관관계가 낮다. 이들의 상관관계 값들은 해역사이에 특별한 차이를 보이지 않으며, 거리에 반비례하는 공통적인 경향을 보이고 있다. 이것은 짧은 주기의 파들이 전 해역에 걸쳐 발생하여 모든 방향으로 전파되고 있으며 빨리 소멸한다는 것을 의미한다.

1965 부터 1985년 동안 이 해역에서 해수면변화의 경향은 일반적으로 태평양연안에서 음의 기울기를 다른 해역이 양의 기울기를 갖는다. 이러한 경향으로 인해 제주와 Sasebo 사이의 평균 해수수송량은 이 기간동안 약 1 *Sv*의 유량이 줄어들 수 있다. 해수면 차이로부터 계산한 수송량의 계절변화는 대한해협에서 2 *Sv* 정도로 이미 발표된 다른 연구 보고와 비슷하다.