Climate Variabilities of Sea Level around the Korean Peninsula

Yong-Hoon YOUN*[1], Im Sang OH [2], Young-Hyang PARK[3], and Ki-Hyun KIM[4]

[1] *Meteorological Research Institute, Korea Meteorological Administration, Seoul, Korea*

[2] *Research Institute of Oceanography, Seoul National University, Seoul, Korea*

[3] *Laboratoire d'Oceanographie Physique, Museum National d'Histoire Naturelle, Paris*

[4] *Department of Earth & Environmental Sciences, Sejong University, Seoul, Korea*

(Received 27 March 2003; revised 19 December 2003)

ABSTRACT

In order to study the climate variabilities of the sea level around the Korean Peninsula, tidal data observed at local stations in Korea were compared against those obtained using TOPEX/POSEIDON (T/P) altimetric sea level data. In the course of our study, the amount of sea level rise was estimated using the tidal data from 9 stations selected by an anomaly coherency analysis. The results indicated that the sea level has risen by $0.28\ \mathrm{cm\ yr^{-1}}$ around the Korean Peninsula over the past two decades. The extent of such a rise is about two times higher than that of the global increase (0.1–$0.2\ \mathrm{cm\ yr^{-1}}$). However, because most global warming effects occurred mainly over mid- and high-latitudes, this level of change appears to be realistic. According to the spectral analysis (at a spectral window of $k = 2$, k is the number of subdivisions), the decadal band of sea level variability is computed at 30% of the energy. Its spectral peak is found at 12.8 years. In the interannual band, the predominant sea level variability is in the 1.4–1.9-year band, with a sharp peak at 1.6 years. A secondary peak, although marginal, has a period of 2.2 years. Based on our estimates of sea level height from Topex/Poseidon, the quasi-biennial periodicity of 1.6 years is the representative interannual sea level variability in the seas adjacent to Korea. Trends vary greatly according to the geographical location, from a maximum of $1.0\ \mathrm{cm\ yr^{-1}}$ (the southern sector of the East Sea) to a minimum of $0.17\ \mathrm{cm\ yr^{-1}}$ (the northern sector of the East Sea). This is fairly consistent with the qualitative description already given with reference to the global map. As an analogue to the pattern seen in Korea, that of the Yellow Sea reveals practically the same trend as that of the adjacent seas ($0.56\ \mathrm{cm\ yr^{-1}}$). However, in the case of TOPEX/POSEIDON (T/P) data, there is no clear evidence of a linkage between the interannual sea level variability around the Korean Peninsula and ENSO.

Key words: sea level, tidal station, altimetry, TOPEX/POSEIDON, ENSO

1. Introduction

In recent years, there has been considerable scientific and societal interest in understanding and predicting the global climate change. This is particularly true with increasing greenhouse gases in the atmosphere and the associated global warming during the last century (IPCC, 1996). It has not yet been possible to unequivocally relate this warming to the increase of greenhouse gases (WCRP, 1995). New estimates of the climate response to natural and anthropogenic forcings are now available along with new detection techniques (IPCC, 2002). There is a great deal of research to detect and attribute an anthropogenic signal in the climate record of the past several decades. According to reconstructions of climate by current models, the warming over the past 100 years is unusual and is not entirely due to natural origins.

Sea level is determined by many factors that operate on a broad range of temporal and spatial scales. On the timescale of decades to centuries, sea level is influenced by the climate and climate-related processes. According to the proxy data analysis, thermal expansion is believed to be one of the major contributors to historical sea level changes. It is expected that thermal expansion will be one of the largest components raising sea levels over the next hundred years. Since deep ocean temperatures change slowly, thermal expansion would continue for many more centuries to come, even after the stabilization of the greenhouse.

---

*E-mail: yhyoun@metri.re.kr

It has been estimated that sea levels have risen about 10–20 cm in the last 100 years (IPCC, 2002). Processes that are not directly related to climate change also influence the sea level. On seasonal, interannual, and decadal timescales, changes of sea level can proceed in response to changes in atmospheric conditions and ocean dynamics. As one of the most striking examples, El Niño events can offer valuable insights into such dynamic changes on the earth's surface.

This study presents an empirical study carried out under CLIVAR without any international coordination. However, it aims to contribute to it with a description of the local climate variability of the sea level adjacent to Korea over the past century. The main purpose of the present study is to provide a basic description of the nature of interannual sea level variations to secular trends of the areas surrounding the Korean Peninsula. This study is also based on the systematic analysis of selected sea level data that have been collected over the last century. In fact, climate-related research activities are still in the infancy stage in Korea. Only a few recent studies have addressed this issue through the analyses of particular atmospheric variables (such as air temperature and/or rainfall data: e.g., Kang, 1998; Cha et al., 1999) or oceanic variables (such as SST: Park and Oh, 2000). Those previous studies have mainly focused on the relationships between the regional interannual variability and ENSO. In the present study, oceanic variables (sea surface height from conventional tide gauges and satellite altimetry) have been analyzed as the major parameter for the investigation. Such a basic empirical study should lay the foundations for understanding the mechanisms that determine the nature of the local climate variability, leading eventually to improved predictability.

2. Data and methods

2.1 *Data*

The oceanic parameters used in this study are the hourly tide data from 17 tidal stations of the National Oceanographic Research Institute (NORI) along the coast of Korea as well as altimetric sea level height data obtained by satellite altimetry from TOPEX/POSEIDON (T/P). Figure 1 shows the locations of the tidal and meteorological stations. Table 1 gives more detailed information on the datasets used in the present study.

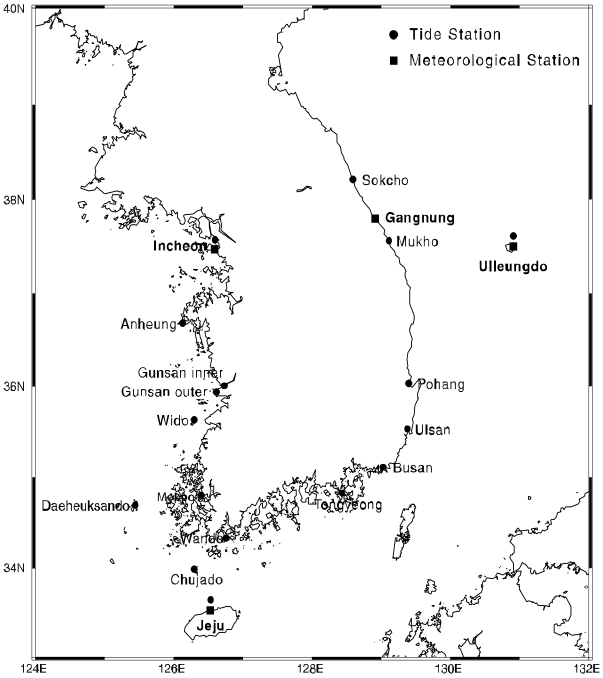

Fig. 1. A geographical map of 17 tidal stations (NORI) and four KMA meteorological stations (Incheon, Gangnung, Ulleungdo, and Jeju) used for investigation in the present study.

2.2 *Methods*

In this work, a number of methods were used to analyse the time series datasets, including both spectral and EOF analysis. Our analyses were basically made using the monthly time series that were initially converted from hourly tidal data, which have been averaged to monthly data. A linear trend over the record length of each time series is first calculated to study the secular trend. The time series were then decomposed into several period bands by applying a low-pass filter with different half-amplitude passing windows (1, 7, and 20 years) or a band-pass filter for different period intervals (1–20, 1–7, and 7–20 years). The basic filter we used is the Gaussian recursive filter of Park and Gambéroni (1995). Spectral analyses were made for those time series with a sufficiently long record length. This procedure was necessary to quantify any significant periodicity and to evaluate energy-containing period bands embedded in the time series. For altimetric data, EOF analyses were conducted to examine the spatio-temporal variability of the sea level in seas around Korea. More detailed information concerning our methodology is given below.

Table 1. Locations and data lengths from the 17 tide gauge stations of NORI used in the present study.

		Data length (year)		
Station	Location	Original	In this study	Used for Fig. 3
Sokcho	38°12′N, 128°36′E	28(1973–2000)	23(1978–2000)	20(1981–2000)
Mukho	37°33′N, 129°07′E	36(1965–2000)	30(1971–2000)	20(1981–2000)
Ulleungdo	37°30′N, 130°55′E	36(1965–2000)	23(1978–2000)	–
Pohang	36°01′N, 129°24′E	30(1971–2000)	22(1972–2000)	20(1981–2000)
Ulsan	35°31′N, 129°23′E	39(1962–2000)	36(1965–2000)	–
Busan	35°06′N, 129°02′E	45(1956–2000)	39(1962–2000)	20(1981–2000)
Tongyeong	34°49′N, 128°26′E	25(1976–2000)	25(1976–2000)	20(1981–2000)
Wando	34°19′N, 126°46′E	18(1983–2000)	18(1983–2000)	18(1983–2000)
Jeju	33°31′N, 126°32′E	37(1964–2000)	35(1966–2000)	–
Chujado	33°58′N, 126°18′E	18(1983–2000)	15(1986–2000)	12(1986–1997)
Daeheuksando	34°41′N, 125°27′E	36(1965–2000)	34(1967–2000)	16(1981–1996)
Mokpo	34°47′N, 126°24′E	45(1956–2000)	45(1956–2000)	–
Wido	35°37′N, 126°18′E	16(1985–2000)	15(1985–1999)	11(1985–1995)
Gunsan-in	35°58′N, 126°38′E	41(1960–2000)	35(1966–2000)	–
Gunsan-out	35°59′N, 126°43′E	21(1980–2000)	18(1983–2000)	–
Anheung	36°40′N, 126°08′E	15(1986–2000)	15(1986–2000)	–
Incheon	37°28′N, 126°36′E	42(1959–2000)	25(1976–2000)	–

3. Results

3.1 *Anomaly time series*

Each tidal station has its proper reference or benchmark relative to the actual measurement. If the reference level is different among different stations, as is the general case, the evaluation of sea level changes will not be realistic. In order to synchronize different time series (referring to different benchmarks) onto an identical reference line level that can be applicable to all stations, the 10-year mean sea levels for each station were calculated for the period between 1986-1995 and then subtracted from the corresponding time series. This last procedure can filter out most of the dominant seasonal variations embedded in each time series, making low-amplitude, low-frequency variations more easily detectable.

The resultant anomaly time series (low-pass filtered at intervals of 1 year) from all 17 tidal stations are shown in Fig. 2. There appears to be a great station-to-station disparity in sea level variations, which was especially pronounced prior to 1981. After that year, however, many stations exhibit a very coherent pattern, while some other stations (like Incheon, Gunsan (inner and outer ports), Mokpo, and Ulleungdo) still show very incoherent or spurious time series. These incoherent series, which are most distinctive after 1981, are also shown in Fig. 2. All of this information provides a useful lesson that should be kept in mind in treating tidal data for a certain area.

3.2 *Representative pattern of sea level variations*

The most coherent sea level variations observed at the nine stations since 1981 are, from the north and moving clockwise, Sokcho, Mukho, Pohang, Busan, Tongyeong, Wando, Chujado, Daeheuksando, and Wido. Note that the last three stations along the west coast have tended to exhibit somewhat different patterns in recent years (a slightly negative trend began to appear in 1995) compared to other stations. The datasets collected during those time periods are therefore excluded in the following analysis. The time series plot for sea level anomalies for all 9 coherent stations are illustrated in Fig. 3. The results of this analysis indicate that sea level anomalies with a coherent pattern exist in terms of phase and amplitude along all three sides of the Korean coast (east, south, west). This remarkable coherency permits the calculation of the mean values for drawing a representative sea level anomaly pattern for the Korean coast. The rms difference between this mean series and nine individual series is 2.6 cm. We were able to observe an upward trend of 0.28 cm yr^{-1} from the mean series for the period between 1981–2000.

The results of the 7-year low-pass filtered curve superimposed in Fig. 5, indicate that the sea level trend has not monotonically been increasing but rather has been modulated on a decadal timescale, rising in 1991 and falling in 1995. A much longer time series at Bu-

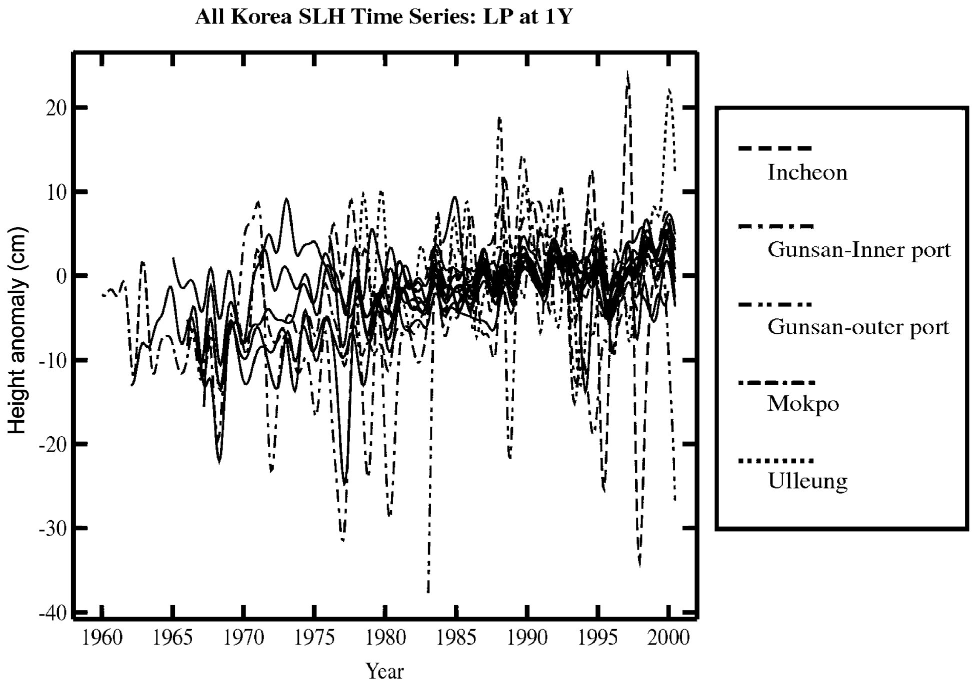

Fig. 2. Time series plots of sea level height anomalies at 17 tidal stations shown in Fig. 1.

san, one of the best matching results, confirms the modulation in terms of a decadal signal with two rising peaks (1965 and 1976) and two falling peaks (1970 and 1983) (Fig. 6). The sea level trend at Busan for the period of 1962–2000 is 0.25 cm yr^{-1}, which is not significantly different from the mean value of 0.28 cm yr^{-1} (1981–2000). It hence suggests that there has been no significant acceleration in sea level rise during the past 40 years along the coast of Korea. However, it is worth noting that the Korean sea level trend determined in this study is well beyond the upperbound value suggested for the global sea level trend for the past century (e.g., 0.1–0.2 cm yr^{-1}, IPCC, 1996). There is a possibility that previously reported global sea level trends were overestimated due to bias in geographical distribution of tidal stations than normal areas (Cabanes et al., 2001). However, the Korean sea level trend is likely to be at least twice as large as that of the global mean.

3.3 *Spectral analysis*

In order to quantify major periodicities and energy-containing period bands embedded in sea level variability around the Korean Peninsula, spectra time series are estimated. The time series used is the 1–20-year band-pass filtered one and contains interannual to decadal variability.

Smoothed spectral estimators are calculated using the Turkey window with different lag window widths: $M = T/k$, where T is the record length and k is the number of subdivisions (Jenkins and Watts, 1968). The basic idea underlying the smoothed spectral analysis can be best understood by considering the rectangular window case, which divides the record into k series of length M, evaluates a sample spectrum for each sub-series, and averages k sample spectra to yield smoothed spectra. Instead of a box function, $w(u) = 1$ for $|u| \leqslant M$, for the rectangular window, the Turkey window uses a cosine function defined by $w(u) = (1 + \cos \pi u/M)/2$ for $|u| \leqslant M$. We tried three different subdivision numbers $k(= 2, 4, 6)$ for the Turkey window. We see an increasing smoothing effect with increasing subdivision number k, as expected, but the positions of major spectral peaks remain unchanged with k greater than 4. The degree of freedom that determines the confidence range of spectral estimators is given by $2.667k$ (Jenkins and Watts, 1968), yielding approximately 5, 11, and 16 for $k = 2, 4$, and 6. The higher the degree of freedom, the lower the variance in spectral estimators is expected, but at the price of a lower frequency resolution.

In the spectral decomposition of a time series, the variance (or energy) within a frequency interval df is given by:

$$\text{variance} = S(f)df = fS(f)d(\log f)\ ,$$

where $S(f)$ is the spectral density at a central frequency f, having an interval df. A spectral density diagram in log-log coordinates, i.e., $\log S(f)$ versus $\log f$,

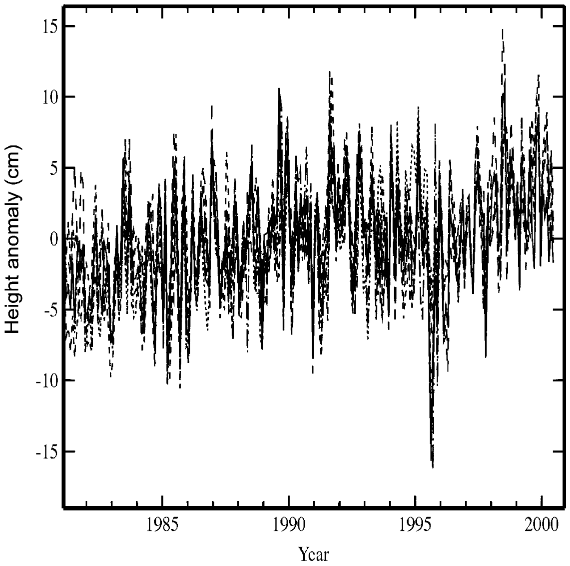

Fig. 3. Sea level height anomalies from the most coherent 9 tidal stations along the Korean coast.

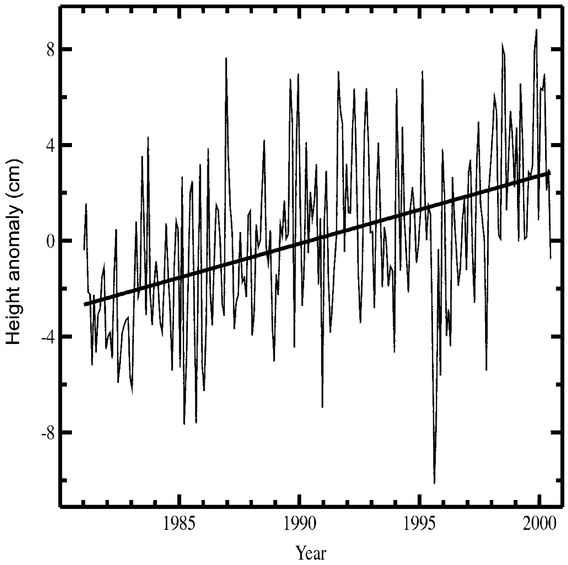

Fig. 4. Mean series obtained from the 9 most coherent series shown in Fig. 3.

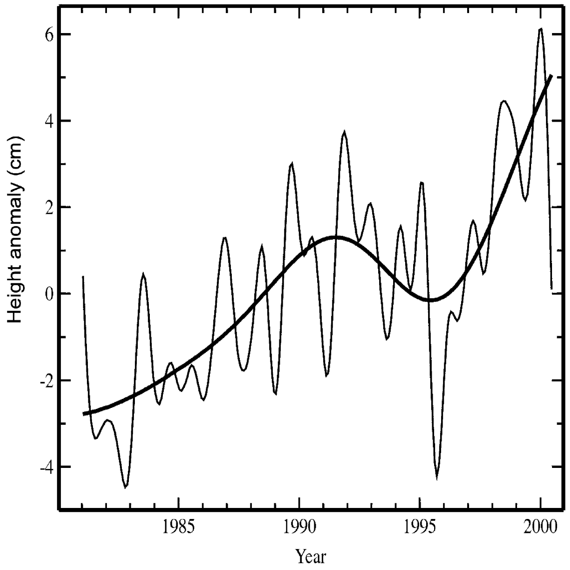

Fig. 5. Same as Fig. 4, except for low-pass filtered at 1 year. The 7-year low-pass filtered curve is superimposed.

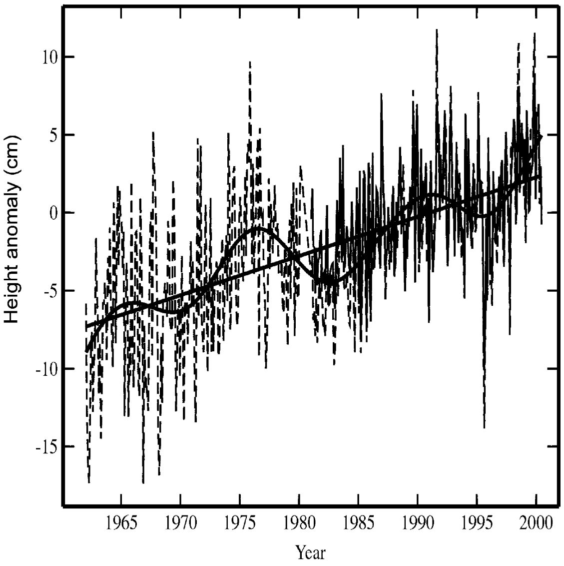

Fig. 6. Sea level height anomalies at Busan (dashed line) and the mean series (solid line) shown in Fig. 4. Superimposed are the 7-year low-pass filtered curve and linear trend line at Busan.

as in the classical representation of spectra such as seen in Fig. 7, does not say anything about the proportion of energy contained in a given frequency interval. Figure 8 is the energy-conserving spectra of the same time series, in which the $fS(f)$ distribution versus log$f$ is presented in semi-log coordinates. For ease of practical interpretation, the ordinate of the spectra is labelled in terms of period ($= 1/f$), instead of frequency. This form of spectral representation ensures that the area between the ordinate and the spectral curve for a given period band is proportional to the energy (or variance) contained in that band.

Because of the significantly strong coherence between Busan and other stations, Busan's sea level anomaly time series (Fig. 6) have been used to represent sea level variations along the Korean coast since 1962. A spectral analysis is done using the Turkey window, but with the subdivision number k limited to 4 because of the relatively short record length (Figs. 8 and 9). The spectral density is more or less monoton-

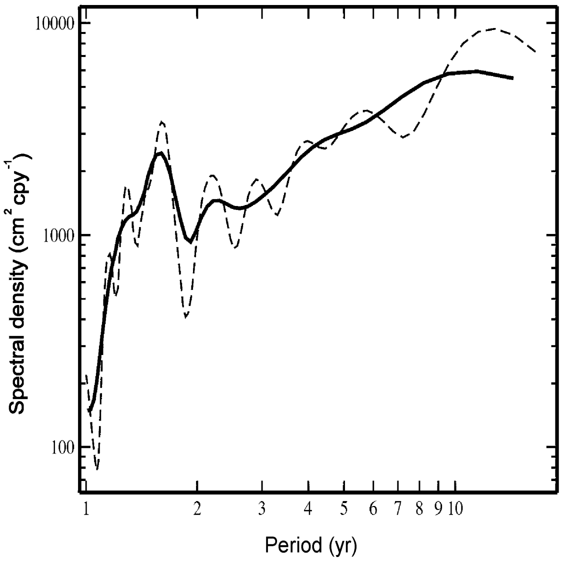

Fig. 7. Spectra of sea level height anomalies at Busan. The Turkey window with two subdivision numbers k is used as: $k = 2$ (dashed line), $k = 4$ (solid line).

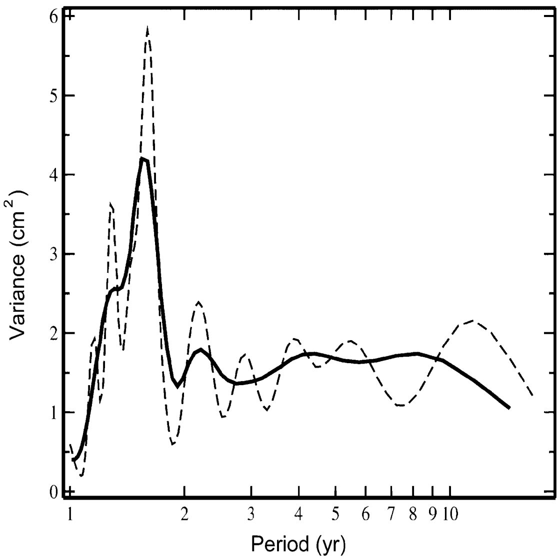

Fig. 8. Same as Fig. 7, except for energy-conserving spectra.

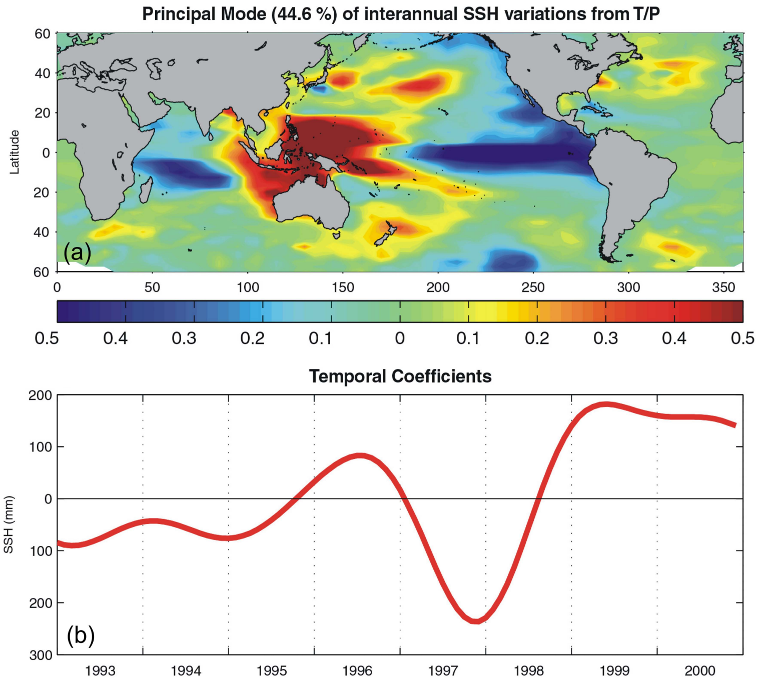

Fig. 9. Spatial pattern and temporal coefficients of the first EOF mode of T/P sea level height anomalies over the world's oceans. Cited from Park (2001).

ically increasing with increasing period, especially for periods longer than 3 years. The spectra with $k = 2$ (dashed line) indicates a gap of around 7 years, separating the decadal band (7–20 years) from the interannual band (1–7 years). However, this spectral gap disappears with $k = 4$ (solid line) because the record length (39 years) is not long enough with such a subdivision number to finely resolve the harmonics of periods longer than 3 years.

According to the spectra with $k = 2$, a decadal band of sea level variability can contain 30% of the energy with its spectral peak at 12.8 years. In the interannual band, the predominant sea level variability is in the 1.4–1.9-year band, with a sharp peak at 1.6 years. A secondary peak, albeit marginal, has a period of 2.2 years.

3.4 *Sea level height from TOPEX/POSEIDON*

3.4.1 *Global sea level variations*

A highly accurate assessment of sea level (2-cm levels on a monthly basis) at a given time can be obtained from the satellite altimetry of T/P (Cheney et al., 1994; Park and Gambéroni, 1995; Verstraete and Park, 1995). Figure 9 presents the spatial pattern and temporal coefficients for the first EOF mode of T/P data (Park, 2001). This mode alone can explain about 45% of the interannual sea level variance, but only in the areas where elevated spatial coefficients are physically meaningful. The corresponding temporal coefficients show very similar variations with SOI (Southern Oscillation Index), indicating that this first mode represents the dominant ENSO-related pattern of sea level variations, especially in the tropical Pacific and Indian Oceans.

3.4.2 *Sea level variations in adjacent seas of Korea*

In order to more closely examine the local sea level variations around Korea, we calculated the area-mean, sea level time series for the following four areas: the Yellow Sea, southern East Sea south of 40°N, northern East Sea north of 40°N, and the entire adjacent seas (Fig. 10). The methods used here are the same as those of Park (2001). Both south and north regions of the East Sea exhibit two extremes in terms of interannual variability. The sea level in the former area varied from 5 (in early 1996) to +10 cm (in late 1999), while that in the latter mostly fluctuated between –2 and +2 cm, without any noticeable extended trend. The sea level time series of the Yellow Sea shows an intermediate pattern with the two extreme cases but is very close to the mean series of the entire adjacent seas. Another noticeable feature is the existence of a quasi-biennial variability. Although the short record length of T/P may not be adequate for spectral analysis, a simple inspection of the time series can easily distinguish 5 waves in the 8-year records, roughly yielding a periodicity of 1.6 years. Although fortuitous, this value is exactly the same as the most dominant interannual periodicity seen in the Busan tidal data. It can hence be inferred that the quasi-biennial periodicity of 1.6 years is the representative interannual sea level variability within the whole of the seas adjacent to Korea.

Figure 11 shows the T/P sea level trend lines for the four areas mentioned above. The trends derived from the T/P data vary greatly according to the geographical location, from a maximum of 1.0 cm yr^{-1} (in the southern East Sea) to a minimum of 0.17 cm yr^{-1} (in the northern East Sea), which is consistent with the qualitative description provided in reference to the global map. As in the case of interannual variability, the Yellow Sea also reveals practically the same trend as that of the whole of the adjacent seas, which is 0.56 cm yr^{-1}. It is found that these values do not represent climatic trends of the areas but indicate a short-term tendency during a rising phase of sea level on a decadal timescale. In fact our T/P period mostly coincides with the second half of the latest decadal signal seen in Fig. 6. Determination of climatically useful sea level trends from T/P data sets is therefore limited, possibly for at least another decade.

According to the global EOF analysis shown in Fig. 9, the ENSO-related interannual sea level variations are prominent, especially in the tropical areas. In this figure, the seas surrounding Korea have spatial coefficients much smaller than those of the tropical Pacific; this result thus suggests that the direct ENSO effects in our study area, if any, should be only marginal. In order to get more definitive information on this matter, an EOF analysis was performed using T/P data obtained from the coastal areas of Korea only. The results of the first EOF mode can explain 36% of the local interannual variability, as shown in Fig. 12. The overall spatial pattern is similar to the global map, while the detailed patterns are quite different. For example, a number of mesoscale eddy-like features appear, especially in the southern East Sea. However, such a pattern does not exist in the global map. This is not astonishing because the global map was made using T/P crossover point data previously averaged on a 5°lat×10°lon grid (Y.-H. Park, personal communication, 2002). Hence, it should suppress any mesoscale features. On the other hand, our local map uses the original T/P crossover point data. Very interestingly, four alternating positive and negative eddies are depicted along the east coast of the Korean Peninsula. Mesoscale eddies are also present along a line connecting Ulleungdo Island and the Tsugaru Strait. In previous work, a number of eddies have been mapped at similar locations in observationally based schematics of surface circulation or in high-resolution numerical model studies (e.g., Hogan and Hurlburt, 2000; and references therein). The corresponding temporal coefficient time series (lower panel) shows a general upward trend that is modulated by a superimposed interannual variability. Obviously, there is no apparent relationship between this curve and the SOI-like curve seen in Fig. 9. In Korea's case, the sea level is lowest near the end of 1995 and highest near the end of 1999.

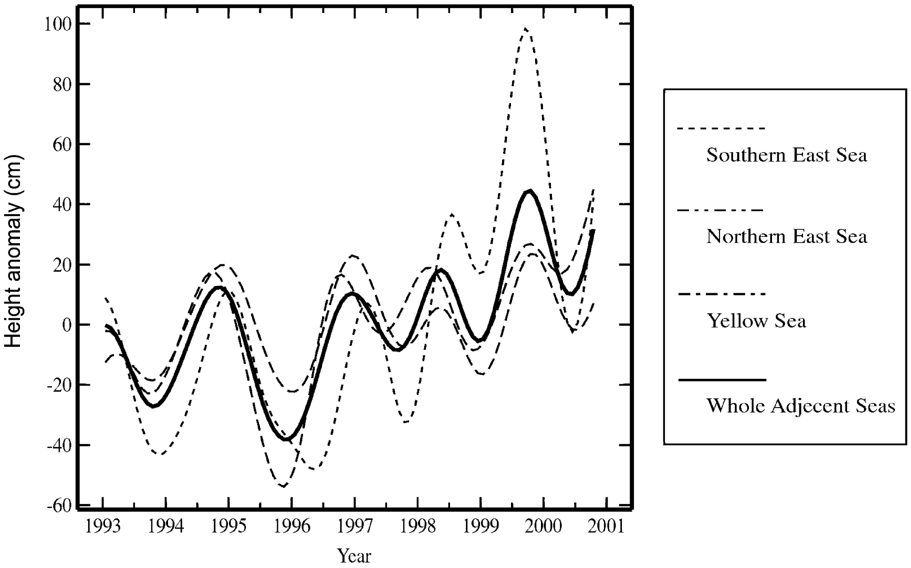

Fig. 10. Area-mean T/P sea level time series in the southern East Sea, northern East Sea, Yellow Sea, and the entire adjacent seas.

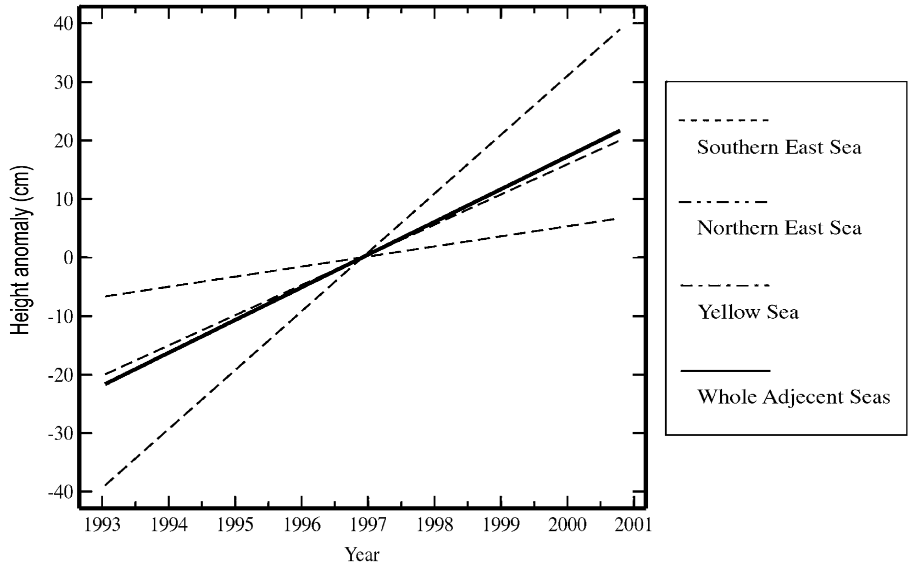

Fig. 11. T/P sea level trends of the southern East Sea, northern East Sea, Yellow Sea, and entire adjacent seas.

During the 1997/1998 ENSO period, Korea's sea level was near normal, in great contrast to the extreme sea level variations in the equatorial and tropical Pacific, i.e., a positive maximum in the central to eastern equatorial Pacific and a negative maximum in the western Pacific warm pool area. Moreover, we do not find any extreme events in 1995 and 1999 from SOI. It may therefore be concluded that no clear evidence appears for a linkage in the T/P data set between the interannual sea level variability around the Korean Peninsula and ENSO.

4. Discussions and conclusions

In this study, the monthly averaged tide data from 17 tidal stations around the Korean Peninsula were compared against those of T/P altimetric sea level data to discover the climate variabilities of sea level around Korea over the past century.

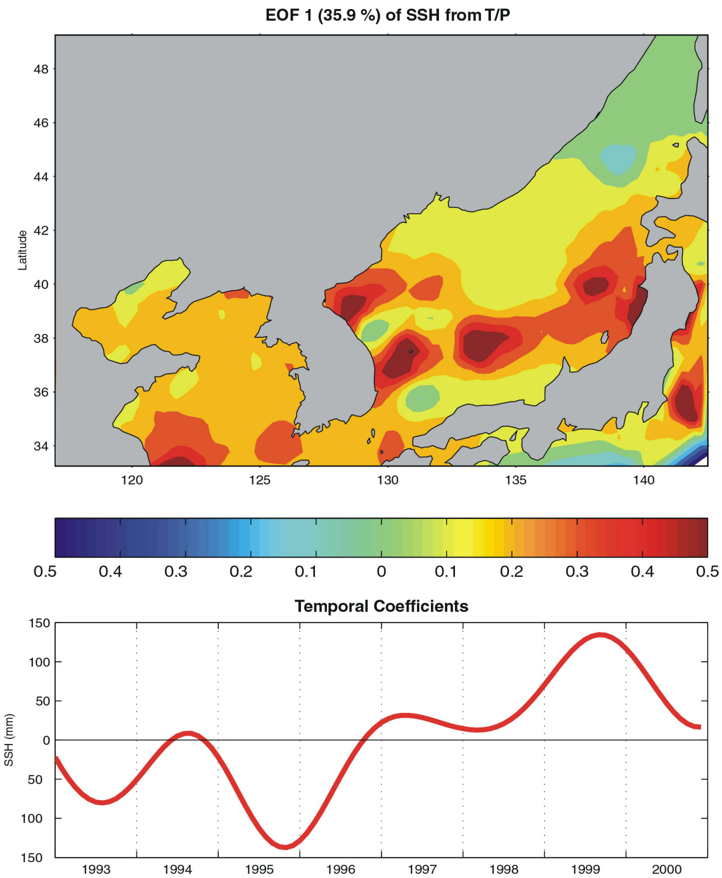

Fig. 12. Spatial pattern and temporal coefficients of the first EOF mode of T/P sea level height anomalies in the oceanic regions surrounding the Korean Peninsula.

In the course of our study, both spectral and EOF analyses were applied to the time series data and their derived variables (such as high- and low-band pass filtered data). These analyses enable us to provide basic and unique descriptions of interannual and decadal sea level variations on both interannual and decadal scales and the local climate over a long-term scale on the Korean Peninsula. The amount of sea level rise around the Korean Peninsula was also estimated in this study using the tide data from 9 tidal stations selected by an anomaly coherency analysis. The mean series of the coherently-varying 9 tide stations showed a sea level increase at a rate of 0.28 cm yr^{-1} between the period of 1981–2000. The trend of sea level change over the decadal period is estimated to be 2 times larger than that of the global mean, so that the rate of sea level change in Korea is consistent with that of surface air temperature.

There generally exists a good coherent relationship between interannual and interdecadal variabilities of sea surface temperature in the Eastern Asian Marginal Sea and Equatorial Pacific Ocean with different phase lags (Park and Oh, 2000). However, correlations between sea level anomalies around the Korean Peninsula and the strength of ENSO are in fact found to be weak. This implies that the relationship between ENSO and Korean climate is merely marginal, if anything, as already studied in a number of previous works (e.g., Kang 1998 and Ahn and Park 2000). In spite of the TOGA-type (Tropical Ocean Global Atmosphere) influences of ENSO on global climate, its impact does not appear to be significant on the climate of Korea.

As confirmed by the EOF analysis of T/P satellite altimetry data, the first EOF mode, explaining 45% of the total variance related to the ENSO pattern of sea level variation, shows a marginal amplitude around the Korean Peninsula. This result thus suggests that there is little correlation between ENSO and the sea level variability in Korea.

Acknowledgments. This paper would not have been possible without the support and helpful advice of Prof. Jong Yul Chung, Prof. Hui-Soo An, and Dr. Sang-Kyung Byun. Tide gauge data were obtained from the National Oceanography Research Institute (NORI). Thisstudy was carried out as a part of "A Study on the Monitoring of the Global Ocean Variability with ARGO Program" at the Meteorological Research Institute/KMA (Korea Meteorological Administration).

REFERENCES

Ahn, J. B., and J. Y. Park, 2000: A study on a statistical long-term prediction model using global sea-surface temperature anomalies. *Journal of the Korean Meteorological Society*, **36**(2), 179–188.

Cabanes, C., A. Cazenavé, and C. Le Provost, 2001: Sea level rise during past 40 years determined from satellite and in situ observations. *Science*, **294**, 840–842.

Cha, E. J., J. G. Jhun, and H. S. Chung, 1999: A study on characteristics of climate in South Korea for El Niño/La Niña years. *Journal of the Korean Meteorological Society*, **35**(1), 98–117. (in Korean)

Cheney, R. E., L. Miller, R Agreen, N. Doyle, and J. Lillibridge, 1994: TOPEX/POSEIDON: The 2-cm solution. *J. Geophys. Res.*, **99**, 24555–24564.

Hogan, P. J., and H. E. Hurlburt, 2000: Impact of upper ocean-topographical coupling and isopycnal outcropping in Japan/East Sea models with 1/8 to 1/64 resolution. *J. Phys. Oceanogr.*, **30**, 2535–2561.

IPCC, 1996: *Climate Change 1995: The Science of Climate Change*. J. T. Houghton, Ed, Cambridge University Press, Cambridge, United Kingdom, and New York, NY, 572pp.

IPCC, 2002: *Climate Change* 2001: *The Scientific Basis*. J. T. Houghton et al., Eds., Cambridge University Press, Cambridge, United Kingdom, and New York, NY, 572pp.

Jenkins, G. M. and D. G. Watts, 1968: *Spectral Analysis and Its Applications*. Holden-Day, San Francisco, 525pp.

Kang, I. S., 1998: Relationship between El-Niño and Korean climate variability. *Journal of the Korean Meteorological Society*, **34**(3), 390–396. (in Korean)

Park, Y. H., 2001: Interannual sea level variability in the Southern Ocean within the context of global climate change. *The AVISO Newsletter*, **8**, 95–96.

Park, Y. H., and L. Gambéroni, 1995: Large-scale circulation and its variability in the South Indian Ocean from TOPEX/POSEIDON altimetry. *J. Geophys. Res.*, **100**, 24911–24929.

Park, W. S., and I. S. Oh, 2000: Interannual and interdecadal variations of sea surface temperature in the East Asian Marginal Seas. *Progress in Oceanography*, **47**, 191–204.

Verstraete, J.-M., and Y.-H. Park, 1995: Comparison of TOPEX/POSEIDOM altimetry and in situ sea level data at Sao Tome island, Gulf of Guniea. *J. Geophys. Res.*, **100**, 25129–25134.

WCRP, 1995: *A study of climate variability and predictability*. WCRP Publ., WMO/TD-No. 690, 157pp.