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# Warming Trend of Coastal Waters of Korea during Recent 60 Years (1936~1995)

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Recent changes in the coastal sea surface temperatures (SST) in Korea are studied by time series analysis of daily SST data during the last 60 years (1936~1995) at 18 coastal observation stations of the National Fisheries Research and Development Institute. The climate of coastal SST in Korea are rapidly changing in recent years. General trends of coast SST changes in Korea are as follows. The annual averages of SST are increasing. The annual ranges of SST variation are decreasing. The winter SST are increasing while the summer SST have a decreasing tendency. Climatic changes in coastal SST in recent 30 years (1965~1995) are more pronounced than those in the last 60 years (1936~1995). The observed trend of coast SST implies that the climate in Korea shows a tendency to shift from temperate zone to subtropical zone.

Key words: SST (sea surface temperature), Coastal SST, Warming trend, Climate change, Subtropical shift, Temperate zone, Subtropic zone

## Introduction

Sea water temperature is one of the most important factors affecting fisheries and aquacultures. Changes of sea water temperature are also important in determining the atmospheric climate. Recent warming of sea surface temperatures (hereafter referred to as SST) at coastal waters around Korea was investigated by pioneering works by Hahn (1994, 1997a, 1997b). He carefully compared the SST values in the marine atlases published in the past and those values of recent observations. He compared 5 data set of 15 years SST normals from 1882 to 1990. He read SST data in 1881~1910 from Marine Meteorological Chart (Hydrographic Office, 1913), that for 1911~1925 from the data by Suda and Seki (1930). The 15 year SST normals for 1926~1940, 1961~1975 and 1976~1990 were computed from hydrographic observations data file by the Fisheries Research and Development Institute of Korea. From those SST normal data set at 1 by 1 degree grids, he concluded that the SST in February and August in the neighbouring seas of Korea have been increased approximated 2℃ and 1℃, respectively, during the last century (Hahn, 1994). In the region between 32~38N and 124~132E, the linear trends of February SST $T_{Feb}$ and August SST $T_{Aug}$ in the last century are (Hahn, 1997a)

$$T_{Feb}=0.023(Yr-1880)+8.72$$
$$T_{Aug}=0.013(Yr-1880)+24.49$$

where $Yr$ is the calendar year. Under the assumption that the trend of SST increase at present is maintained, he estimated the expected SST distributions of Korean waters in 2100 (Hahn, 1997b). He claimed that the climate of SST around Korea will be changed from temperate zone to subtropical zone in 2100 of present trend of SST increase is maintained.

Gradual shift of ocean climate around Korea toward subtropical climate is more evident in the daily observations of SST at coastal stations. According to Hahn (1998), the annual averages of SST at Jangigab (St.10 in Fig. 1) has been increased by 1.9℃ and the annual range of SST variation is decreased by 3.7℃ during the last century. At the Symposium

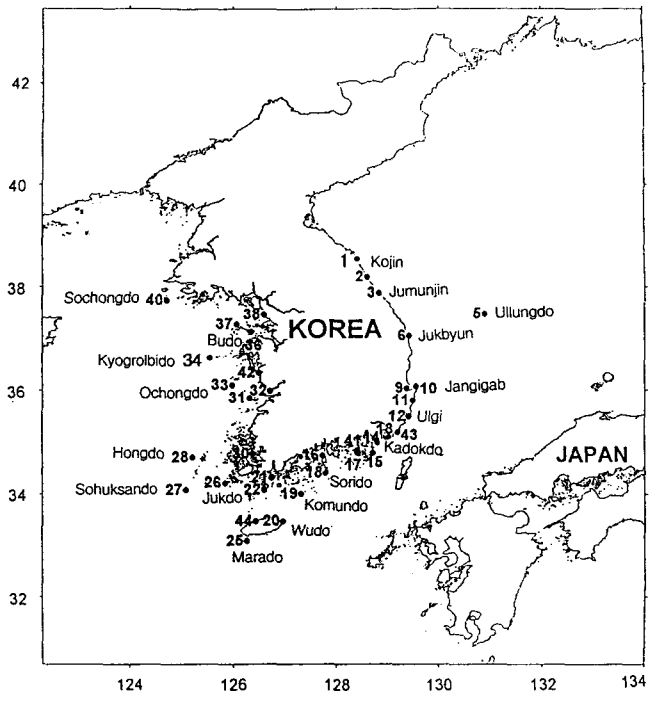


Fig. 1. Locations of coastal stations.

on "Global Warming and Ecological Disturbance" held at Seoul in October 1998, Dr. Hahn reported about the changes of coastal water temperature in recent 80 years (1916~1995) at 9 stations as shown in Table 1 (Personal communication). According to him, the average SST has been increased while the annual range of SST has been decreased. The winter SST have been increased while the summer SST has been slightly decreased.

In this paper I re-examine the daily SST data for 60 years (1936~1995) at 18 coastal stations of Korea. Previous works by Hahn were based on 15 year normals of offshore SST and 5 years averages of monthly SST. Instead of extracting informations from 5 years interval average data, I analysed the daily observations data themselves. In this paper I present results on the recent warming trend of coastal SST, which are revealed by an objective analysis of daily observations.

## Data and Method of Analysis

The data of daily SST at 18 stations, shown in Fig. 1, are used for a study of long-term change of SST climate during the last 60 years (1936~1935). Among the data at 43 coastal stations, which are available through Internet service by Korea Ocean Data Center (Internet address: http://www.nfrda.re.kr), I chose 18 representative stations: 6 from the east, 6 from the south and 6 from the west part of Korea. The years of data availability at the selected stations are shown in Table. 2.

I made time series of daily normals of SST for 20 years (1976~1995) at each stations. The period of SST normal is identical for all stations. I smoothed daily normal series of SST by applying low-pass filter (Hamming, 1977; Kim and Kang, 1984). The time series of daily SST anomalies are generated by substracting daily normals from the observed SST data. I did not make any interpolation on missing data. Subsequent time series analyses are applied for available data only. From the daily data I made pentad (5-days interval) time series by averages of available data belonging to the 5-day period. The pentad time series thus generated are used as a basic data set for the subsequent study.

Table 1. Changes of coastal SST during the last 80 years (1916~1995) at coastal stations of Korea by S.D. Hahn (1998, personal communication)

| Station | Winter SST | Summer SST | Annual averge | Annual range |
|---|---|---|---|---|
| Jumunjin | 0.20℃ Increase | 0.17℃ Decrease | 0.06℃ Increase | 0.37℃ Decrease |
| Jukbyun | 0.18℃ Increase | 0.01℃ Decrease | 0.11℃ Increase | 0.19℃ Decrease |
| Jangigab | 0.34℃ Increase | 0.03℃ Decrease | 0.19℃ Increase | 0.39℃ Decrease |
| Yongdo | 0.07℃ Increase | 0.01℃ Decrease | 0.05℃ Increase | 0.08℃ Decrease |
| Komundo | 0.25℃ Increase | 0.02℃ Decrease | 0.10℃ Increase | 0.27℃ Decrease |
| Jukdo | 0.14℃ Increase | 0.06℃ Decrease | 0.02℃ Increase | 0.21℃ Decrease |
| Ochongdo | 0.10℃ Increase | 0.11℃ Decrease | 0.03℃ Increase | 0.20℃ Decrease |
| Kyogrolbido | 0.15℃ Increase | 0.08℃ Decrease | 0.03℃ Increase | 0.24℃ Decrease |
| Sochongdo | 0.12℃ Increase | 0.10℃ Decrease | 0.03℃ Increase | 0.21℃ Decrease |
| Average | 0.17℃ Increase | 0.07℃ Decrease | 0.07℃ Increase | 0.24℃ Decrease |

Table 2. Availability of data at each station (A: data available, N: data not available)

| No | Station | 36 | 38 | 40 | 41 | 43 | 45 | 46 | 48 | 50 | 51 | 53 | 55 | 56 | 58 | 60 | 61 | 63 | 65 | 66 | 68 | 70 | 71 | 73 | 75 | 76 | 78 | 80 | 81 | 83 | 85 | 86 | 88 | 90 | 91 | 93 | 95 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 01 | Kojin | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| 03 | Jumunjin | N | N | N | N | N | N | N | N | N | N | N | N | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| 05 | Ullungdo | N | N | N | N | N | N | N | N | N | N | N | N | A | A | A | A | N | N | N | N | A | A | N | A | A | A | A | A | A | A | A | A | A | A | A | A |
| 06 | Jukbyun | N | N | N | N | N | N | N | N | N | N | N | N | A | A | A | A | N | N | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| 10 | Jangigab | A | A | A | A | A | A | N | N | N | N | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| 12 | Ulgi | N | N | N | A | A | A | N | N | N | N | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| 14 | Kadokdo | A | A | A | A | A | A | N | N | N | N | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| 18 | Sorido | A | A | A | A | A | A | N | N | N | N | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| 19 | Komundo | A | A | A | A | A | A | N | N | N | N | A | A | N | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| 20 | Wudo | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| 25 | Marado | A | A | A | A | A | A | N | N | N | N | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| 26 | Jukdo | A | A | A | A | A | A | N | N | N | N | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| 27 | Sohuksando | A | A | A | A | A | A | N | N | N | N | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| 28 | Hongdo | N | N | N | N | N | N | N | N | N | N | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| 33 | Ochongdo | A | A | A | A | A | N | N | N | N | N | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| 34 | Kyogrolbido | A | A | A | A | A | A | N | N | N | N | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | N |
| 36 | Budo | A | A | A | A | A | A | N | N | N | N | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| 40 | Sochongdo | A | A | A | A | A | A | N | N | N | N | N | N | N | N | N | N | N | N | N | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |

The annual mean and annual range of SST of each year are obtained by harmonic fitting of the pentad SST by

$$T(t) = T_0 + T_1 \cos(\omega t - \phi_1) + T_2 \cos(2\omega t - \phi_2)$$

where $t$ is the time in pentads, $T_0$ is annual average, $T_1$ and $T_2$ are annual and semi-annual amplitudes, respectively, $\omega$ is annual angular frequency, $\phi_1$ and $\phi_2$ are annual and semi-annual phases, respectively. The harmonic fitting is applied for the year with more than 60 valid pentad data among 73 pentads per year. If valid pentad data are less than 60, that year is regarded as data-missing year in the harmonic fitting. Table 3 shows the averages and standard deviations of harmonic constants ($T_0$, $T_1$, $T_2$, $\phi_1$, $\phi_2$) of the SST variation for the years with available data in the last 60 years (1936~1995). The years with available data are shown in Table 2. In Table 3. *Fit* (%) is the percentage of SST variance explained by harmonic fit, and $\delta T$(℃) is the magnitude of the difference between the observed SST and the harmonic fit SST.

Long-term changes of SST climate are studied as follows. Linear trends of annual averages and annual amplitudes of SST at each station, estimated by harmonic analysis, are fitted to a linear regression curve by

$$F(Year) = a(Year - Year_0) + b,$$

where $F(Year)$ is annual average or annual amplitude of the calendar year *Year*, $a$ is annual increase rate, and $b$ is a constant. Linear regression is applied to data of the past 60 years (1936~1995) and to that of more recent 30 years (1966~1995). I applied similar regression fitting to the pentad series of SST anomalies for 60 years and 30 years. The trends in the winter SST and summer SST are studied by linear regression of the winter (February 1 to March 10) and summer (August 1 to September 10) SST, respectively.

## Climatic Change of SST

### Mean SST

Trends of annual means of SST during the last 60 years (1936~1995) and 30 years (1966~1995) are shown in Table 4. During the last 60 years the mean SST have been increased at 9 stations among 12 stations with average increase rate of 0.007℃/Year. During recent 30 years the mean SST have been increased at all of 18 stations, and average increase rate is 0.024℃/Year.

Similar results are found on the trends of SST anomalies, shown in Table 5. The SST anomalies during the last 60 years have been increased at 9 stations among 12 stations with average increase rate of 0.008℃/Year. In recent 30 years the SST

Table 3. Mean and standard deviations of harmonic constants of SST variations

| No. | Station | $T_0$(℃) | $T_1$(℃) | $\phi_1$(deg) | $T_2$(℃) | $\phi_2$(deg) | *Fit*(%) | $\delta T$(℃) |
|---|---|---|---|---|---|---|---|---|
| 01 | Kojin | 12.9 ± 1.0 | 8.4 ± 1.1 | 231.5 ± 4.4 | 0.8 ± 0.4 | 164.8 ± 100.3 | 96.3 | 0.86 |
| 03 | Jumunjin | 13.9 ± 1.1 | 7.9 ± 1.0 | 230.6 ± 4.5 | 0.9 ± 0.3 | 117.5 ± 74.7 | 96.1 | 0.84 |
| 05 | Ullungdo | 15.9 ± 0.8 | 6.8 ± 0.8 | 235.8 ± 4.1 | 0.9 ± 0.4 | 96.1 ± 81.3 | 97.0 | 0.62 |
| 06 | Jukbyun | 14.7 ± 0.8 | 6.2 ± 0.8 | 238.4 ± 6.5 | 0.9 ± 0.4 | 141.7 ± 51.0 | 93.1 | 0.87 |
| 10 | Jangigab | 15.1 ± 0.8 | 7.3 ± 0.9 | 221.5 ± 5.7 | 1.1 ± 0.6 | 131.0 ± 45.7 | 94.4 | 0.96 |
| 12 | Ulgi | 15.9 ± 0.8 | 5.1 ± 1.2 | 239.2 ± 7.5 | 1.1 ± 0.5 | 152.3 ± 36.2 | 88.2 | 0.93 |
| 14 | Kadokdo | 15.9 ± 0.5 | 6.5 ± 1.1 | 228.4 ± 8.2 | 0.8 ± 0.3 | 129.9 ± 48.7 | 96.8 | 0.62 |
| 18 | Sorido | 16.0 ± 0.6 | 7.2 ± 0.6 | 229.8 ± 3.8 | 1.1 ± 0.4 | 119.8 ± 31.2 | 97.2 | 0.65 |
| 19 | Komundo | 16.6 ± 0.6 | 5.8 ± 0.8 | 236.5 ± 5.6 | 1.6 ± 0.4 | 107.4 ± 18.8 | 94.8 | 0.74 |
| 20 | Wudo | 18.3 ± 0.5 | 4.9 ± 0.5 | 241.8 ± 4.9 | 1.2 ± 0.4 | 96.3 ± 24.7 | 95.4 | 0.57 |
| 25 | Marado | 18.8 ± 0.5 | 5.8 ± 0.6 | 237.9 ± 6.2 | 1.3 ± 0.4 | 91.2 ± 18.1 | 95.2 | 0.72 |
| 26 | Jukdo | 14.0 ± 0.7 | 5.6 ± 0.7 | 235.1 ± 6.7 | 0.8 ± 0.4 | 134.4 ± 50.5 | 93.8 | 0.76 |
| 27 | Sohuksando | 15.3 ± 0.7 | 6.9 ± 0.8 | 236.6 ± 5.7 | 1.7 ± 0.5 | 87.2 ± 18.2 | 95.3 | 0.84 |
| 28 | Hongdo | 14.0 ± 0.8 | 7.9 ± 0.9 | 235.7 ± 5.6 | 1.5 ± 0.6 | 93.6 ± 30.3 | 96.4 | 0.80 |
| 33 | Ochongdo | 13.1 ± 0.8 | 9.1 ± 0.7 | 236.6 ± 4.9 | 1.2 ± 0.6 | 91.1 ± 45.6 | 97.6 | 0.73 |
| 34 | Kyogrolbido | 13.0 ± 0.8 | 9.9 ± 0.7 | 235.9 ± 4.5 | 1.1 ± 0.4 | 82.2 ± 28.8 | 98.1 | 0.70 |
| 36 | Budo | 12.6 ± 0.9 | 10.2 ± 0.6 | 235.4 ± 2.3 | 0.8 ± 0.4 | 190.6 ± 43.6 | 98.2 | 0.50 |
| 40 | Sochongdo | 11.3 ± 0.6 | 8.2 ± 0.7 | 232.8 ± 4.3 | 1.1 ± 0.4 | 109.6 ± 52.5 | 97.5 | 0.71 |

Table 4. Linear trends in annual means of SST during the last 60 and 30 years (in ℃)

| No | Station | 60 Years (1936~1995) | 30 Years (1966~1995) |
|---|---|---|---|
| 01 | Kojin | | 0.047 × (Year-1965) + 12.12 |
| 03 | Jumunjin | | 0.040 × (Year-1965) + 13.27 |
| 05 | Ullungdo | | 0.043 × (Year-1965) + 15.00 |
| 06 | Jukbyun | | 0.041 × (Year-1965) + 14.08 |
| 10 | Jangigab | 0.025 × (Year-1935) + 14.28 | 0.027 × (Year-1965) + 14.96 |
| 12 | Ulgi | 0.005 × (Year-1935) + 15.73 | 0.009 × (Year-1965) + 15.79 |
| 14 | Kadokdo | 0.014 × (Year-1935) + 15.39 | 0.029 × (Year-1965) + 15.51 |
| 18 | Sorido | 0.013 × (Year-1935) + 15.60 | 0.028 × (Year-1965) + 15.69 |
| 19 | Komundo | 0.005 × (Year-1935) + 16.43 | 0.001 × (Year-1965) + 16.64 |
| 20 | Wudo | | 0.007 × (Year-1965) + 18.06 |
| 25 | Marado | 0.006 × (Year-1935) + 18.65 | 0.018 × (Year-1965) + 18.63 |
| 26 | Jukdo | 0.001 × (Year-1935) + 13.96 | 0.010 × (Year-1965) + 13.77 |
| 27 | Sohuksando | −0.004 × (Year-1935) + 15.42 | 0.008 × (Year-1965) + 15.02 |
| 28 | Hongdo | | 0.032 × (Year-1965) + 13.46 |
| 33 | Ochongdo | −0.002 × (Year-1935) + 13.21 | 0.013 × (Year-1965) + 12.88 |
| 34 | Kyogrolbido | −0.003 × (Year-1935) + 13.07 | 0.032 × (Year-1965) + 12.25 |
| 36 | Budo | 0.009 × (Year-1935) + 12.31 | 0.032 × (Year-1965) + 12.13 |
| 40 | Sochongdo | 0.012 × (Year-1935) + 10.87 | 0.017 × (Year-1965) + 11.16 |
| | Average | 0.007℃/Year | 0.024℃/Year |

anomalies have been increased at 17 stations among 18 stations with average increase rate of 0.019℃/Year. Linear regressions of both the annual averages of SST and pentad SST anomalies show that the SST at coastal areas of Korea have been increased. The rate of increase during the recent 30 years (1966~1995) were more than 2 times larger than those during the last 60 years (1935~1995).

### Annual range of SST

Linear trends of the annual amplitudes of SST during the last 60 and 30 years are shown in Table 6. During the last 60 years (1936~1995) the annual amplitudes of SST have been decreased at all of 12 stations with average decrease rate of 0.014℃/Year. During the recent 30 years (1966~1995) the annual amplitudes of SST have been decreased at 15 stations among 18 stations with average decrease rate of 0.021 ℃/Year. The average decrease rates of annual range of SST during the last 60 years and more recent 30 years are 0.028℃/Year and 0.042℃/Year, respectively.

### Winter SST and summer SST

Linear trends of winter SST during the last 60

Table 5. Linear trends of the SST anomalies during the last 60 and 30 years (in ℃)

| No | Station | 60 Years (1936~1995) | 30 Years (1966~1995) |
|---|---|---|---|
| 01 | Kojin | | 0.033 × (Year-1965) − 0.70 |
| 03 | Jumunjin | | 0.039 × (Year-1965) − 0.74 |
| 05 | Ullungdo | | 0.016 × (Year-1965) − 0.28 |
| 06 | Jukbyun | | 0.040 × (Year-1965) − 0.70 |
| 10 | Jangigab | 0.024 × (Year-1935) − 1.02 | 0.025 × (Year-1965) − 0.34 |
| 12 | Ulgi | 0.007 × (Year-1935) − 0.19 | 0.013 × (Year-1965) − 0.08 |
| 14 | Kadokdo | 0.014 × (Year-1935) − 0.56 | 0.015 × (Year-1965) − 0.19 |
| 18 | Sorido | 0.015 × (Year-1935) − 0.64 | 0.032 × (Year-1965) − 0.53 |
| 19 | Komundo | 0.005 × (Year-1935) − 0.12 | −0.003 × (Year-1965) + 0.14 |
| 20 | Wudo | | 0.007 × (Year-1965) − 0.06 |
| 25 | Marado | 0.004 × (Year-1935) − 0.13 | 0.009 × (Year-1965) − 0.11 |
| 26 | Jukdo | 0.004 × (Year-1935) − 0.03 | 0.013 × (Year-1965) − 0.17 |
| 27 | Sohuksando | −0.001 × (Year-1935) + 0.18 | 0.005 × (Year-1965) + 0.00 |
| 28 | Hongdo | | 0.025 × (Year-1965) − 0.54 |
| 33 | Ochongdo | −0.005 × (Year-1935) + 0.35 | 0.010 × (Year-1965) − 0.13 |
| 34 | Kyogrolbido | −0.004 × (Year-1935) + 0.20 | 0.028 × (Year-1965) − 0.55 |
| 36 | Budo | 0.006 × (Year-1935) − 0.32 | 0.024 × (Year-1965) − 0.47 |
| 40 | Sochongdo | 0.012 × (Year-1935) − 0.54 | 0.009 × (Year-1965) − 0.13 |
| | Average | 0.008℃/Year | 0.019℃/Year |

Table 6. Linear trends in annual amplitudes of SST during the last 60 and 30 years (in ℃)

| No | Station | 60 Years (1936~1995) | 30 Years (1966~1995) |
|---|---|---|---|
| 01 | Kojin | | −0.043 × (Year-1965) + 9.15 |
| 03 | Jumunjin | | −0.019 × (Year-1965) + 8.14 |
| 05 | Ullungdo | | 0.010 × (Year-1965) + 6.67 |
| 06 | Jukbyun | | 0.012 × (Year-1965) + 6.04 |
| 10 | Jangigab | −0.016 × (Year-1935) + 7.81 | −0.043 × (Year-1965) + 7.78 |
| 12 | Ulgi | −0.014 × (Year-1935) + 5.57 | −0.021 × (Year-1965) + 5.20 |
| 14 | Kadokdo | −0.010 × (Year-1935) + 6.80 | 0.051 × (Year-1965) + 5.54 |
| 18 | Sorido | −0.016 × (Year-1935) + 7.69 | −0.024 × (Year-1965) + 7.38 |
| 19 | Komundo | −0.011 × (Year-1935) + 6.18 | −0.030 × (Year-1965) + 6.18 |
| 20 | Wudo | | −0.011 × (Year-1965) + 5.08 |
| 25 | Marado | −0.014 × (Year-1935) + 6.32 | −0.021 × (Year-1965) + 6.01 |
| 26 | Jukdo | −0.013 × (Year-1935) + 6.02 | −0.021 × (Year-1965) + 5.72 |
| 27 | Sohuksando | −0.012 × (Year-1935) + 7.33 | −0.031 × (Year-1965) + 7.41 |
| 28 | Hongdo | | −0.043 × (Year-1965) + 8.54 |
| 33 | Ochongdo | −0.010 × (Year-1935) + 9.50 | −0.052 × (Year-1965) + 9.96 |
| 34 | Kyogrolbido | −0.016 × (Year-1935) + 10.39 | −0.026 × (Year-1965) + 10.12 |
| 36 | Budo | −0.017 × (Year-1935) + 10.74 | −0.033 × (Year-1965) + 10.50 |
| 40 | Sochongdo | −0.018 × (Year-1935) + 8.81 | −0.030 × (Year-1965) + 8.45 |
| | Average | −0.014℃/Year | −0.021℃/Year |

and 30 years are shown in Table 7. The winter SST have been increased during the last 60 years at all of 12 stations with an average increase rate of 0.020℃/Year. In recent 30 years, the winter SST have been increased at 15 stations among 18 stations with an average increase rate of 0.035℃/Year. Increasing rate of winter SST during recent 30 years (1966~1995) is almost two times larger than that during the last 60 years (1936~1995).

Linear trends of summer SST are shown in Table 8. Contrary to an increase of winter SST, the summer SST have been slightly decreased. The summer SST during the last 60 years have been decreased at 10 stations among 12 stations with an average decrease rate of 0.014℃/Year. During recent 30 years the summer SST have been decreased at 11 stations among 18 stations with an average decrease rate of 0.010℃/Year.

Table 7. Linear trends of the winter SST during the last 60 and 30 years (in ℃)

| No | Station | 60 Years (1936~1995) | 30 Years (1966~1995) |
|---|---|---|---|
| 01 | Kojin | | 0.131 × (Year-1965) + 2.85 |
| 03 | Jumunjin | | 0.086 × (Year-1965) + 5.11 |
| 05 | Ullungdo | | 0.032 × (Year-1965) + 9.14 |
| 06 | Jukbyun | | 0.031 × (Year-1965) + 8.59 |
| 10 | Jangigab | 0.029 × (Year-1935) + 7.83 | 0.051 × (Year-1965) + 8.29 |
| 12 | Ulgi | 0.020 × (Year-1935) + 10.79 | 0.017 × (Year-1965) + 11.48 |
| 14 | Kadokdo | 0.022 × (Year-1935) + 9.04 | −0.037 × (Year-1965) + 10.60 |
| 18 | Sorido | 0.025 × (Year-1935) + 8.77 | 0.043 × (Year-1965) + 9.22 |
| 19 | Komundo | 0.030 × (Year-1935) + 10.87 | 0.022 × (Year-1965) + 11.88 |
| 20 | Wudo | | 0.017 × (Year-1965) + 14.05 |
| 25 | Marado | 0.031 × (Year-1935) + 13.02 | 0.047 × (Year-1965) + 13.64 |
| 26 | Jukdo | 0.016 × (Year-1935) + 8.32 | −0.005 × (Year-1965) + 9.12 |
| 27 | Sohuksando | 0.008 × (Year-1935) + 9.49 | 0.004 × (Year-1965) + 9.52 |
| 28 | Hongdo | | 0.066 × (Year-1965) + 6.22 |
| 33 | Ochongdo | 0.002 × (Year-1935) + 4.88 | 0.051 × (Year-1965) + 4.04 |
| 34 | Kyogrolbido | 0.011 × (Year-1935) + 3.71 | 0.020 × (Year-1965) + 3.77 |
| 36 | Budo | 0.020 × (Year-1935) + 2.05 | 0.064 × (Year-1965) + 1.87 |
| 40 | Sochongdo | 0.025 × (Year-1935) + 2.86 | −0.012 × (Year-1965) + 4.25 |
| | Average | 0.008℃/Year | 0.019℃/Year |

Table 8. Linear trends of the summer SST during the last 60 and 30 years (in ℃)

| No | Station | 60 Years (1936~1995) | 30 Years (1966~1995) |
|---|---|---|---|
| 01 | Kojin | | 0.010 × (Year-1965) + 21.54 |
| 03 | Jumunjin | | 0.013 × (Year-1965) + 22.31 |
| 05 | Ullungdo | | 0.011 × (Year-1965) + 23.35 |
| 06 | Jukbyun | | 0.049 × (Year-1965) + 20.63 |
| 10 | Jangigab | −0.008 × (Year-1935) + 23.49 | −0.037 × (Year-1965) + 23.73 |
| 12 | Ulgi | −0.022 × (Year-1935) + 22.29 | −0.017 × (Year-1965) + 21.51 |
| 14 | Kadokdo | −0.004 × (Year-1935) + 23.02 | −0.088 × (Year-1965) + 21.83 |
| 18 | Sorido | −0.002 × (Year-1935) + 24.17 | −0.030 × (Year-1965) + 23.82 |
| 19 | Komundo | −0.008 × (Year-1935) + 24.31 | −0.027 × (Year-1965) + 24.43 |
| 20 | Wudo | | −0.027 × (Year-1965) + 24.80 |
| 25 | Marado | −0.012 × (Year-1935) + 26.61 | −0.031 × (Year-1965) + 26.49 |
| 26 | Jukdo | −0.017 × (Year-1935) + 20.55 | −0.026 × (Year-1965) + 19.20 |
| 27 | Sohuksando | −0.016 × (Year-1935) + 24.54 | −0.026 × (Year-1965) + 24.27 |
| 28 | Hongdo | | −0.041 × (Year-1965) + 24.25 |
| 33 | Ochongdo | −0.032 × (Year-1935) + 24.74 | −0.067 × (Year-1965) + 24.42 |
| 34 | Kyogrolbido | −0.035 × (Year-1935) + 25.20 | −0.048 × (Year-1965) + 24.31 |
| 36 | Budo | −0.013 × (Year-1935) + 23.37 | −0.003 × (Year-1965) + 22.75 |
| 40 | Sochongdo | −0.010 × (Year-1935) + 21.22 | −0.075 × (Year-1965) + 22.05 |
| | Average | −0.014℃/Year | −0.010℃/Year |

## Conclusions

Analysis of the daily observations of SST at coastal station of Korea shows that the SST climate in Korea are rapidly changing in the recent decades. The rate of change during the recent 30 years (1966~1995) is more pronounced than that during the last 60 years (1936~1995). General trends of coast SST changes in Korea are as follows. (1) The annual averages of SST are increasing. (2) The annual ranges of SST variation are decreasing. (3) The winter SST are increasing. (4) The summer SST have a decreasing tendency. (5) Climatic changes in more recent 30 years are more pronounced than those in the last 60 years.

The climate of the subtropical zone is characte-

rized by higher values in annual means and smaller values in annual range of temperature variation compared to those of the temperate zone. The observed trend of coastal SST, shown in this paper, implies that the climate of coastal SST in Korea has a tendency to shift toward the climate of subtropical zone. This tendency of subtropicalization during the recent 30 years (1966~1995) were more pronounced than that during the last 60 years (1936~1995).

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