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Interpretation of recent temperature and precipitation trends observed in Korea

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With 11 Figures

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Summary

The possibility of climate change in the Korean Peninsula has been examined in view of the general increase in greenhouse gases. Analyses include changes in annual temperature and precipitation. These analyses are supplemented with our observations regarding the apparent decrease of forest areas.

It was found that there was a 0.96 °C (0.42 °C per decade) increase in annual mean temperature between 1974 and 1997. The increase in large cities was 1.5 °C but only 0.58 °C at rural and marine stations. The difference in the mean temperature between large cities and rural stations was small from 1974 to 1981. However, the difference increased from 1982 to 1997. In particular, the warming appears most significant in winter. Prior to 1982, the lowest temperatures were often -18 °C in central Korea, and since then the lowest temperatures have been only $-12 \sim -14$ °C. Recently, the minimum January temperature has increased at a rate of 1.5 °C per decade. It is estimated that the increase of 1 °C in annual mean temperature corresponds to about a 250 km northward shift of the subtropical zone boundary.

The analysis of data from 1906 to 1997 indicates a trend of increasing annual precipitation, an increase of 182 mm during the 92-year peirod, with large year-to-year variations. More than half of the annual mean amount, 1,274 mm, occurred from June to September.

Meteorological data and satellite observations suggest that changes have occurred in the characteristics of the quasi-stationary fronts that produce summer rain. In recent years scattered local heavy showers usually occur with an inactive showery front, in comparison with the classical steady rain for more than three weeks. For instance, local heavy rainfall, on 6 August 1998 was in the range of 123–481 mm. The scattered convective storms resulted in flooding with a heavy toll of approx. 500 people. The northward shift of the inactive showery front over Korea, and of a convergence zone in central China, correlate with the increase in temperature. It has been suggested that the decrease in forest areas and the change in ground cover also contribute to the warming of the Korean Peninsula.

1. Introduction

Many environmental scientists are concerned with the increase in population, industrial activities, and consumption of fossil fuel. At the same time, atmospheric concentrations of CO_2 have been increasing at the rate of $0.3 \sim 2.5$ ppm per annum (Chung and Tans, 1997). This increase in “greenhouse gases”, combined with other factors, is thought to relate to climate change in the regional and global scales (Mitchell et al., 1995). Both numerical and observational studies in the literature have shown evidence of climate change particularly in the high latitudes of the Northern Hemisphere (Karl et al., 1993; Mitchell et al., 1995; Whetton et al., 1994).

In 1998, record rainfall and flooding were observed in central Korea. In this paper we describe our observations including satellite analysis. Bell et al. (1999) have found similar regional phenomena in central China. The change in precipitation regime is also discussed in earlier studies (Henderson-Sellers et al., 1998; Jones, 1988; Wetherald and Manabe, 1995).

2. Analysis and results

The Korean Peninsula is located between China and the Japanese Islands in East Asia and is surrounded by the Yellow Sea, Korea South and East Seas, on the west, south and east sides, respectively. Korea is in the sub-polar and subtropical climate zones from the north to Cheju Island in the south. The twenty meteorological stations in the present data analysis are shown in Fig. 1. The site locale of all stations has not changed, while observational practice has remained the same within the meteorological service.

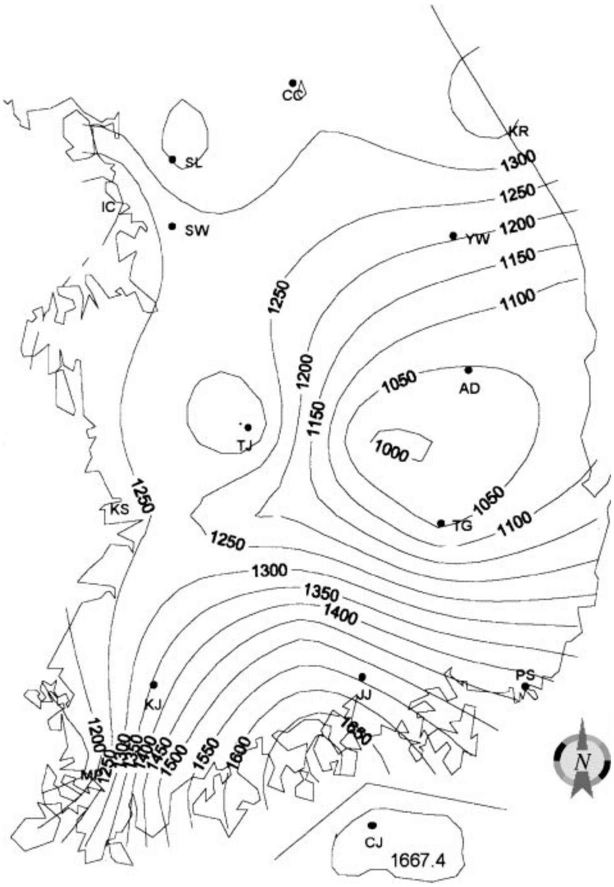

Fig. 1. Distribution of annual amounts of precipitation (mm) observed in south Korea during 1961∼1990

2.1 Precipitation

Figure 1 shows the distribution of annual amounts of precipitation observed in south Korea during 1961∼1990. The amounts vary from slightly less than 1,000 mm in the Kyoungbook Province of SE Korea to above 1,650 mm in the south coastal area. Except in the dry region with about 1,000 mm, many parts of Korea receive 1,200∼1,400 mm, somewhat above average world wide. The annual mean amount of precipitation for Korea is 1,274 mm. Albeit, in some years Korea has experienced periods of regional drought and flood.

Table 1 shows the annual amounts of precipitation observed from 1906 to 1997. From 1906 to 1985 it includes data from all 20 stations. In the analysis, clearly interannual variability is large, and the variance was found to be large with $\sigma = 223.6$ mm. The minimum amount was 753 mm in 1907, while the maximum was recorded at 1,734 mm in 1990. In all, the number of years recording more than 1,500 mm is 15, (16.3%), and the number of drought years with less than 900 mm is 8 (8.7%). It should be noted that many lands in Asia and the Americas, for example, usually receive an annual amount of precipitation of less than 700 mm. The drought

Table 1. Annual precipitation (mm) observed in Korea from 1906 to 1997 (average of data from 20 stations)

Year	0	1	2	3	4	5	6	7	8	9
1900							1033	753	1047	879
1910	1200	1320	1019	831	1211	1279	1639	830	1186	1099
1920	1340	1148	1229	1236	931	1541	1355	1193	1095	887
1930	1476	1338	875	1531	1470	1088	1515	1048	1022	772
1940	1355	1321	1058	890	966	1421	1308	1197	1538	989
1950	1164	1022	1182	1228	1526	1074	1586	1308	1436	1338
1960	1201	1549	1173	1436	1259	1117	1344	1020	1053	1531
1970	1512	1136	1580	1025	1349	1315	1103	1016	1229	1404
1980	1459	1261	971	1201	1272	1667	1180	1513	906	1537
1990	1734	1423	1179	1359	918	1180	1175	1380		

years of 1932, 1939 and 1942–1944 were world wide in scope.

2.2 Temperature

Figure 2 shows profiles of annual mean temperature observed at 9 stations in Korea. The variations of annual temperature clearly indicate a general trend of temperature increase from 1974 to 1997. During this period significant industrialization and urbanization occurred. The increase in annual mean temperature recorded during the last 24 years was 0.96 °C (Table 2).

The influence of location and large cities on the variation of temperature was analysed. Figure 3 shows differences in temperatures recorded in large cities and at other stations. The temperature is higher in large cities than at any other sites. Interestingly, the temperature increase is larger for urban stations, with 1.8 °C in comparison with 0.58 °C for marine stations (Table 2). Also, it is striking that the difference in both the annual temperature and the temperature change from 1974 to 1981 is small, or nearly nonexistent. However, from 1982 to the present, the difference between large cities and rural-marine stations became large and distinct.

Figure 4 shows the changes in annual mean temperature observed at rural and marine sites, Chupoongryung and Seosan, respectively. Here the magnitudes and changes in temperature for the sites are similar. The annual mean temperature change is the smallest, only 0.39 °C in this case. Figure 5 also addresses the temperature changes in

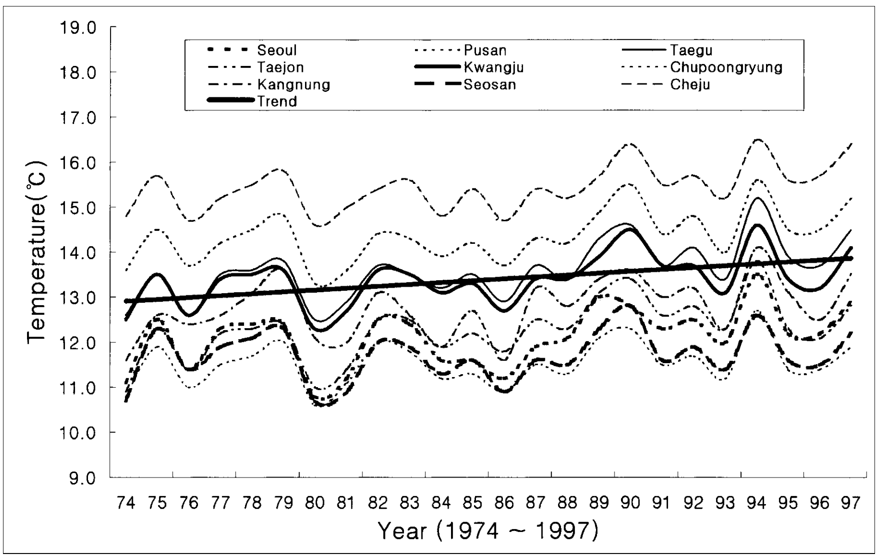

Fig. 2. Annual mean temperature (°C) and the observed trend at 9 stations in Korea

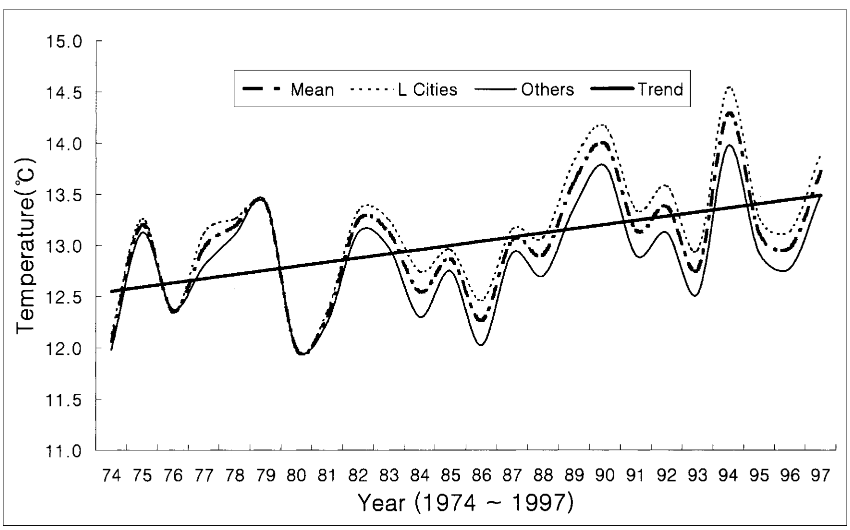

Fig. 3. Annual mean temperature (°C) and the observed trend in large cities and at marine-rural stations

Table 2. The changes in annual mean temperature (°C) observed in Korea

year / stations	1974	1982	1990	1997	change
9 stations	12.52	12.88	13.20	13.48	+0.96
Seosan and Chupoongryung	11.50	11.72	11.91	12.08	+0.58
Seoul	11.08	12.49	12.79	12.89	+1.81
Cheju	14.93	15.29	15.61	15.89	+0.96

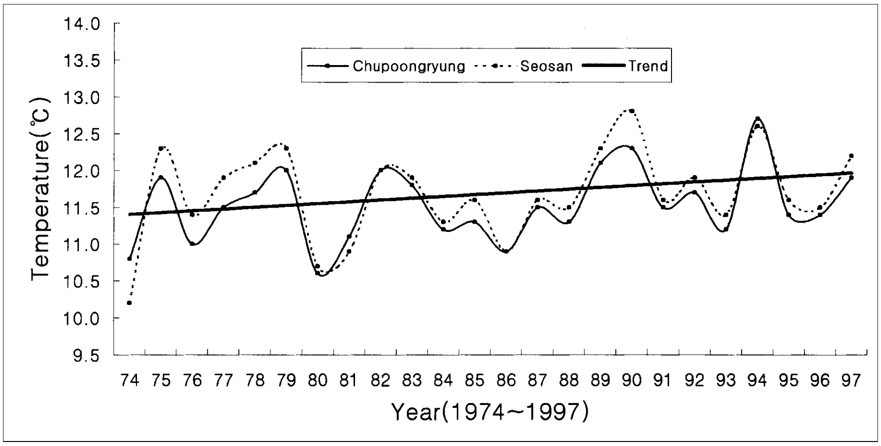

Fig. 4. Annual mean temperature (°C) and the observed trend at rural sites of Chupoongryung and Seosan

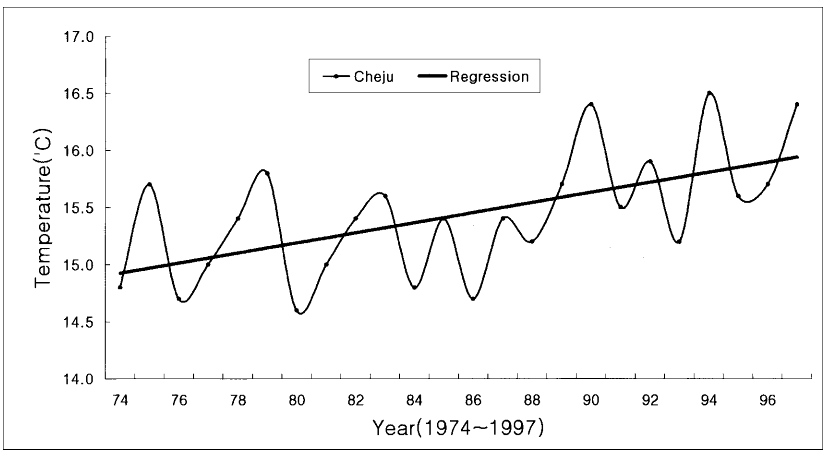

Fig. 5. Annual mean temperature (°C) and the observed trend at Cheju

Cheju in the southernmost island. During the past 24 years, the temperature increase in Cheju was 0.96 °C, while the city has doubled in size during that time.

3. Discussion

3.1 Characteristics in precipitation regime

Of the annual mean amount of precipitation, 1,274 mm, a little more than half occurs from June to September. The summer monsoon, with a stationary "Changma" front, and typhoons produce major rainfalls in Korea. Figure 6 shows the general trend of rainfall in the warm months. Rainfall amounts start to increase steadily from the first third (1–10 June) of June, with a sudden further increase in the last part of June. The increasing trend levels off in the first third of August. In fact, the summer rainfall, Changma, usually starts from the last third of June beginning at Cheju, when a quasi-stationary polar (Changma) front is over southern Korea.

After the Changma front shifts northward to north Korea and to northeast China, the maritime tropical air from the Pacific dominates the weather in Korea, and rainfall decreases from the first third to the middle third of August. From the last third of August the amount of rainfall increases again and produces the second maximum in annual precipitation. This usually occurs with a typhoon and/or with the southward movement of the quasi-

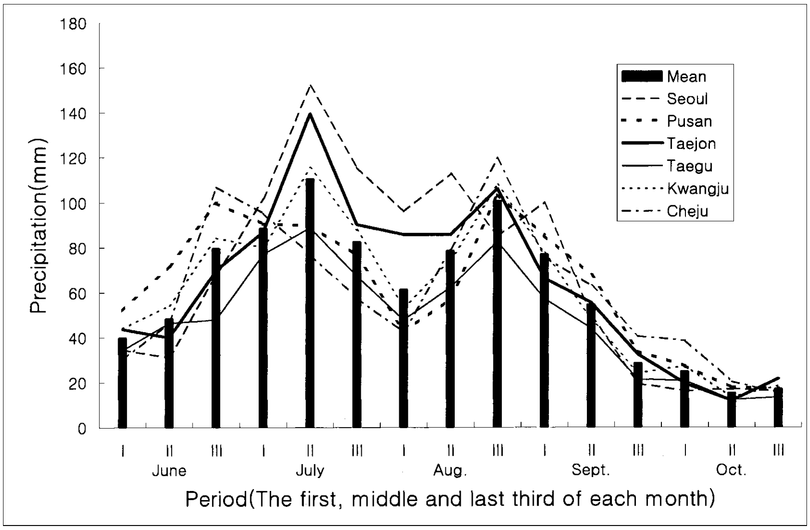

Fig. 6. Rainfall amounts (mm) during 3 summer periods of in 1961–1990

stationary polar front from northeast China to the Korean Peninsula. The bi-modal frequencies in rainall maxima are the characteristics that produce significant replenishment of water resources in summer months. Precipitation in autumn and winter is almost evenly distributed in each month, and drought may occur during these seasons in some of the dry areas over inland parts of Korea.

3.2 Characteristics of the temperature regime

We have observed clear indications of a temperature increase in various parts of Korea. For example, in Seoul and other major stations of central Korea, an extreme low temperature of to $-18 \sim -20\,°C$ was observed each winter until the 1960's. Moreover, the Han River in central Korea used to freeze with ice thick enough to support the national winter games of skating, ice hockey, etc. In recent years, we have observed an extreme low temperature of only $-12 \sim -14\,°C$. The Han River no longer freezes solidly enough to permit crossing by people. Thus it would appear that the warming trend is more pronounced in winter. In addition, the number of days with snow-cover lasted for a month until two decades ago; now there is usually less than one week of snow cover in the central plain. The anthropogenic impact of the warming is minimal during the summer.

Figure 7 shows for the changes in minimum temperature observed at three stations from 1980 to 1997. An upward trend is apparent. We have also examined monthly temperature observed at

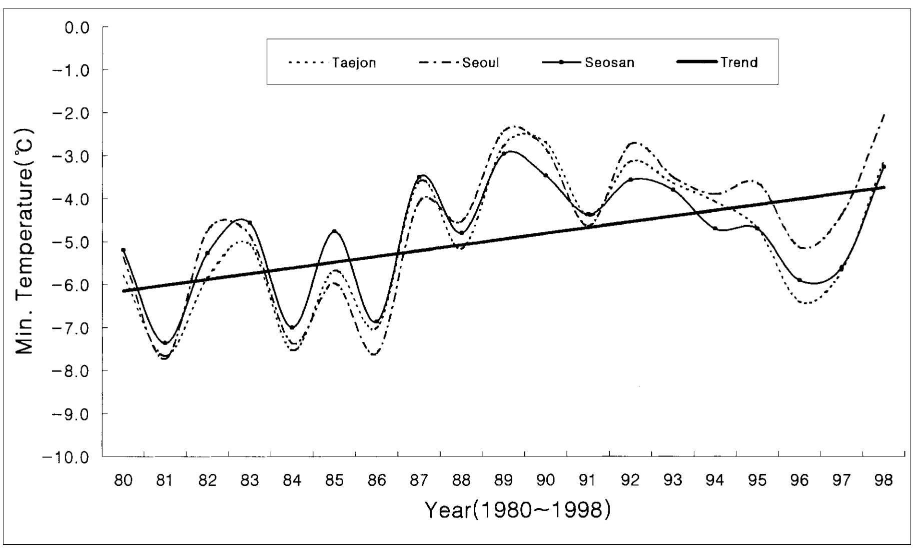

Fig. 7. Variations of minimum temperature (°C) in winter from 1980 to 1997 at three stations

Table 3. Monthly mean and minimum temperatures (°C) observed in winter at 11 stations during the periods 1981–1990 and 1991∼1998

	December		January		February	
		Change		Change		Change
Mean Temp.						
1981–1990	1.5	–	−1.5	–	0.8	–
1991–1998	2.7	+1.2	0.0	+1.5	1.8	+1.0
Minimum Temp.						
1981–1990	−2.5	–	−5.5	–	−3.3	–
1991–1998	−1.4	+1.1	−4.0	+1.5	−2.7	+0.6

11 stations in winter. According to Table 3, monthly mean temperature in January has increased 1.5 °C from the 1980s to the 1990s. This can be compared with the increase of 1.2 °C in December and 1.0 °C in February.

The warming trend in the early summer tends to produce a northward shift of the convergence zone in the lee of major mountains. The convergence zone over northern China associated with an upper airflow then produces a weak Changma front, with less moisture over middle China (more moisture over southern China). We have observed in recent years a lesser distinct Changma front producing scattered sporadic convective clouds over the Yellow Sea. Up until the 1970s, in contrast, a persistent Changma front produced somewhat continuous rainfall in Korea. Characteristically, the Changma rain now occurs over a relatively short period, and rainy days occur more or less intermittently. Meanwhile, more drought occurs in dry seasons, particularly in winter and spring.

As mentioned earlier, the increase in annual mean temperature is more pronounced in large urban areas. Also, climate change is greater over the inland areas at high latitudes. The change of 1 ∼ 2 °C in annual mean and winter mean temperatures over the region is significant enough to cause an impact in the environment, particularly in the growth rate of plants, bacteria and virus, etc.

It has been pointed out that the increase of 1 °C in annual mean temperature corresponds to the 200∼300 km northward shift in the boundary of a climate zone (IPCC, 1995). In turn, the warming trend of Korea results in the northward shift of a subtropical boundary of about 250 km, i.e., to central Korea. In fact, we have also observed a northward migration of subtropical plants.

In considering the IPCC (1995) concept, we have examined the change in January average air-temperature. According to the classification of Köppen, the northern boundary of a subtropical climate can be defined by the isotherm of −3 °C in January mean temperature. Figure 8 (the isotherms of January mean temperatures) shows the northward shift of the subtropical climate boundary to the north of Seoul since the 1961–90 period. We estimate that the northward shift was approximately 70∼120 km during the last 10-year period.

3.3 Reduction of forest areas

Ground cover and albedo play an important role in the absorption and retention of solar radiation. Also, forests act as a major CO_2 sink. In the past half century, forest areas have been drastically reduced worldwide, cleared for agricultural land and burned for domestic and industrial use. We have observed a pronounced decrease in forest areas and density in Asia, the Americas, and Africa. The decrease is pronounced over the Korean Peninsula and China.

The decrease in forest areas and the creation of ‘‘semi-desert’ looking landscapes clearly visible from an aircraft, particularly after snowfall in winter. The barren landscape can also be observed with satellite imagery.

A change in ground cover disturbs the radiation and moisture regimes. Many studies have indicated that the decrease in forests contributes to the increase in the concentration of greenhouse gases and also leads to an increase in air temperature and evaporation.

3.4 Heavy rainfall in 1998

As discussed earlier, there is clear evidence of large variance in the amounts of precipitation

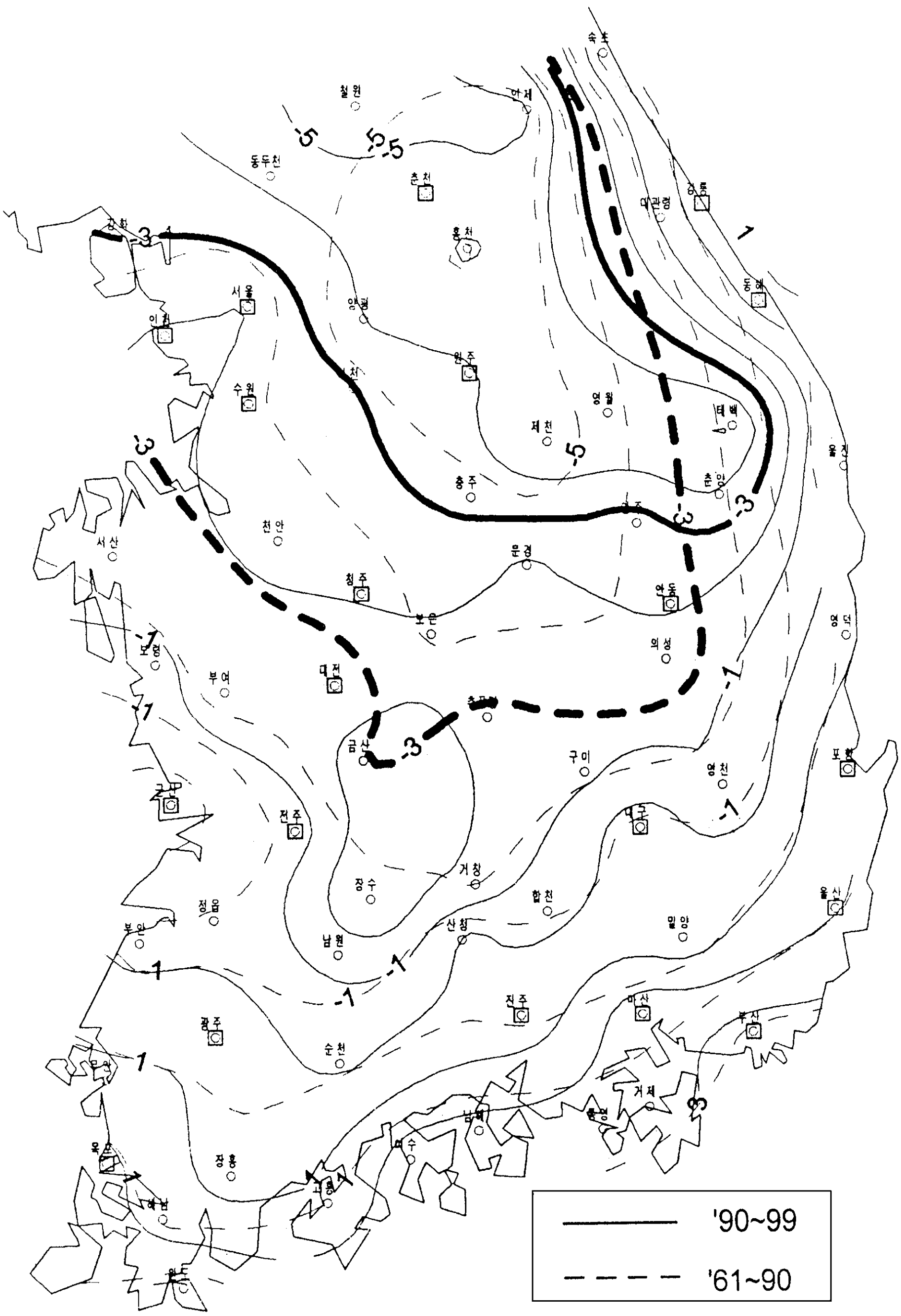

Fig. 8. The observed warming trend of January mean temperature (isotherms in °C) between a 30-year and the recent 10-year periods, and a northward shift of a subtropical climate boundary

according to area and year even in the small peninsula of south Korea (Table 1). We have examined data for 1998 and found it to be a very wet year, except for November and December. In Seoul, the August rainfall was 1,238 mm, which equals the annual rainfall for a normal year. Surprisingly, rainfalls of 1,164 mm occurred in the first half of August, with 211.4 mm on the 4 and 332.8 mm on the 8. The unusual episode of heavy rain over central Korea in August 1998 could be related to the El Niño outbreak.

Figure 9 shows the total amount of rainfall that occurred in Korea during August 1998 (Korea Met. Admin., 1998). Strikingly, large amounts of rainfall occurred in the central area, while the monthly amounts of rainfall in the northern and southernmost areas were less than 100~200 mm. Figure 9 clearly indicates the regional bias in the occurrence of rainfall in the tiny Korean Peninsula.

Figure 10 compares the difference in summer rainfall amounts between 1997 and 1998. The bi-modal curve represents the 30-year rainfall amount (1961–1990), which shows that 1997 was almost an average summer. However, in 1998, more than twice the amount of rainfall fell, primarily in the last third of June, the first and second thirds of August, and in the last third of September. Figure 9 and Table 1 also show a bias in the occurrence of rainfall in season and year.

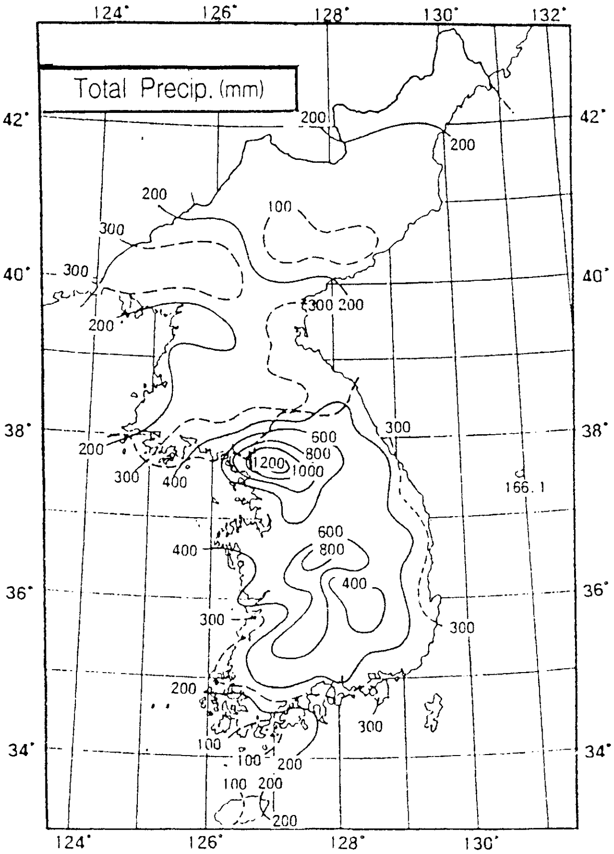

Fig. 9. Distribution of rainfall (mm) in August 1998 in Korea (Korea Meteor. Admin., 1998)

Figure 11 shows satellite imagery of convective storms that caused heavy rainfall in central Korea. On 6 August 1998, when the Changma (polar) front was active, a wide cloud band was situated over the Yellow Sea and SE Korea, and sporadic convective storms occurred along the polar front. Convective storms were generated over the Yellow Sea, then moved inland where they grew and produced intensive rainfall due to the nocturnal cooling of the cloud top. Heavy rainfalls recorded on August 6 at 5 stations were 123 mm Seoul, 127 Kimpo, 148 Inje, 209 Tongduchon, and 481 mm Kanghwa! Such convective storms produced heavy rainfall and resulted in flooding with a heavy toll of lives (approx. 500 people in 1998) and property. It may also be noted that in 1999, surprisingly, heavy rainfalls and flooding occurred again in central Korea from Seoul to Kaesong. The amounts recorded in 3 days of early August were in the range of 200~850 mm!

Using daily analysis of meteorological and satellite data, we found that there was a change in the characteristics of the Changma front in producing summer rain in Korea. Until the 1970's, the formation and movement of a quasi-stationary front was distinctive with appreciable width, and it propagated gradually northward. It produced steady rain for about 20~30 days from the end of June, rain typical of generally predictable Changma rainfall. However, the Changma rainfalls in recent years have been more showery

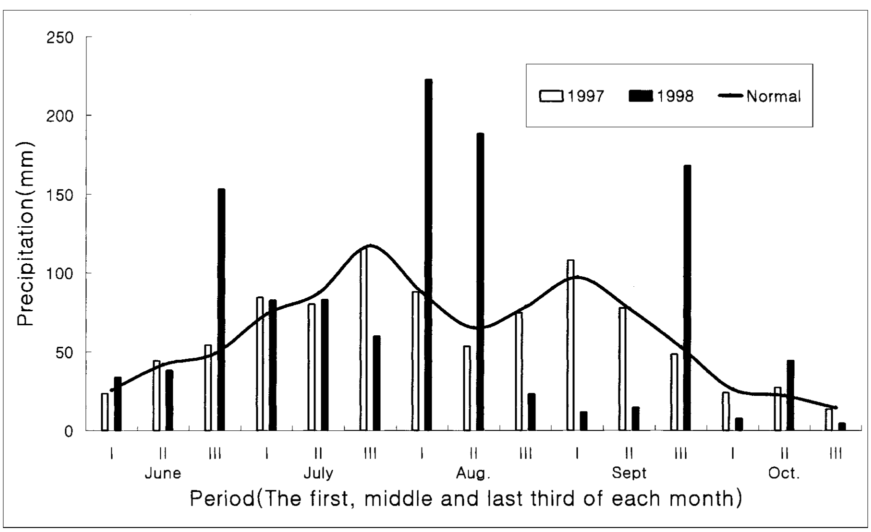

Fig. 10. Average rainfall amounts (mm) at 10 stations in Korea in 1997, 1998 and for a 30-year period

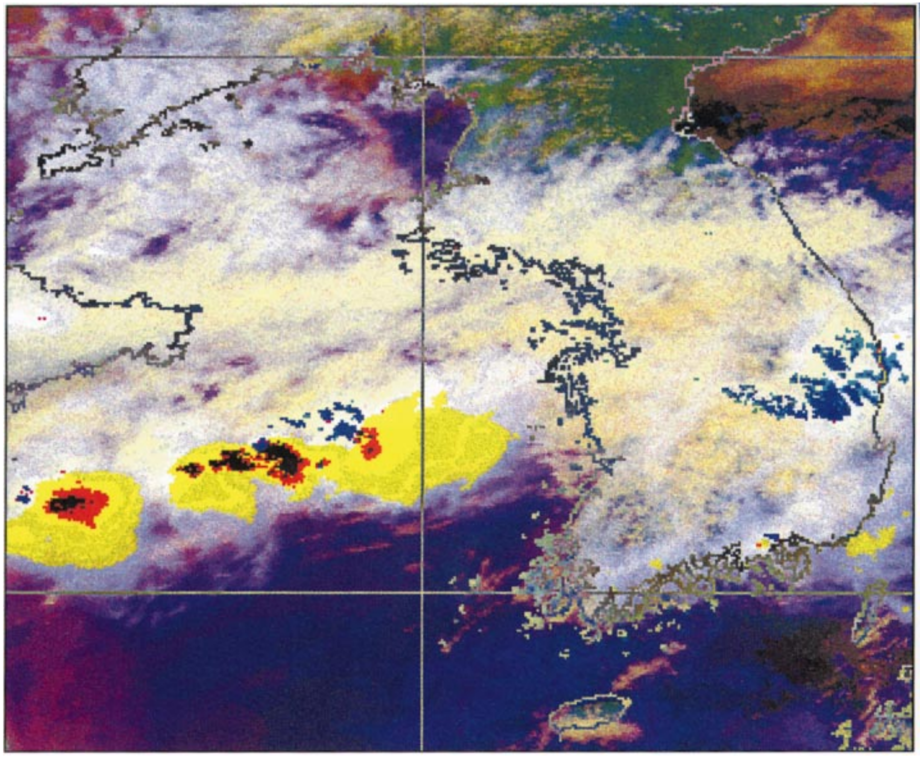

Fig. 11. Satellite imagery showing scattered convective clouds over the Yellow Sea and Korea on 6 August 1998

and sporadic under the scattered convective storms with a somewhat indistinctive polar front. Also, the Changma front forms in association with a convergence zone of the airflow in the lee of the East Asian mountain complex, e.g., the Tibetan Plateau and the Altai Mts. We have observed that with the recent warming trend there is a change and northward shift of the convergence zone from central China.

4. Summary and conclusions

The precipitation data from 1906 to 1997 indicate a general increase in annual amounts of precipitation. The analysis shows, however, that there is a large year to year variability in the amounts. More than half of the annual mean amount, 1,274 mm, occured in summer and most of the rainfall ran out to sea due to a lack of reservoirs. Because of increasing consumption, better management of precipitation resources is urgently required.

From satellite analyses and meteorological data, we have observed that in recent years, sporadic convective clouds over the Changma front usually produce local heavy showers rather than steady rain over the Korean Peninsula. Until the 1970s, steady rain for about two weeks or longer associated with the distinctive polar front, was a common summer phenomenon. In recent years, however, scattered convective storms along the otherwise inactive Changma front have produced local heavy showers. In August 1998, these convective clouds produced about 300∼600 mm rainfall per day and flooding in many locations in central Korea. In Seoul, rainfall recorded during August alone was 1,238 mm.

In the case of annual mean temperature, we have observed an 0.96 °C increase in Korea from 1974 to 1997. The increase in large cities was 1.5 °C, while the increase in rural and coastal areas was smaller, 0.58 °C. Due to the present warming trend, southern Korea appears to be within a subtropical climate zone, except the east Tae-Baek Mts.

Acknowledgements

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