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MAXIMUM URBAN HEAT ISLAND INTENSITY IN LARGE CITIES OF KOREA

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Abstract

A documentation of heat island intensity in cities is an important step toward better understanding of urban-induced weather and climate changes. In this study, the characteristics of the maximum urban heat island (UHI) intensity in six largest cities of Korea are investigated. The annually averaged maximum UHI intensity in all cities tends to increase with time, but its increase rate differs. A spectral analysis shows a prominent diurnal cycle in the UHI intensity in all cities and its prominent annual cycle in costal cities. A multiple linear regression analysis is undertaken in order to relate the maximum UHI intensity to meteorological elements. Their relative importance is found to differ depending on city. A multidimensional scaling analysis and a cluster analysis distinguish three city groups. The analysis results indicate that the characteristics of the UHI intensity in a costal city are in several aspects different from those in an inland city.

Key words: urban heat island, maximum urban heat island intensity, large cities of Korea

1. INTRODUCTION

This study extends our previous work (Kim and Baik, 2002) to characterize the maximum urban heat island intensity in the six largest cities of Korea and find its characteristic similarities and differences among the cities. In particular, we focus on characteristic differences in the urban heat island intensity between coastal and inland cities. For this, spectral analysis, multiple linear regression analysis, multidimensional scaling analysis, and cluster analysis are performed using observational data.

2. DATA

The data used in this study are archived from the Korea Meteorological Administration (KMA). The data contain surface air temperature (z = 1.2~1.5 m), wind speed, cloudiness, and relative humidity measured at meteorological observatories in the six largest cities of Korea (Seoul, Incheon, Daejeon, Daegu, Gwangju, and Busan) and surface air temperature at nearby meteorological observatories (Yangpyong, Ganghwa, Geumsan, Yeongcheon, Suncheon, and Geoje, respectively). The data used span the years from 1973 to 2001 and are in 6-h intervals (03, 09, 15, and 21 local times). In this study, the daily maximum urban heat island intensity of a city is defined as the maximum temperature difference between the city and its nearby observatories during a day. Figure 1 shows the locations of the six paired observatories.

3. ANALYSIS RESULTS

3.1. Observed maximum urban heat island intensity

Figure 2 shows the time series of annual mean maximum urban heat island intensity in the six cities, together with linearly fitted regression lines. The average annual maximum urban heat island intensity over the 29-year period is also shown in parentheses. In all cities, an increasing temporal trend in the maximum urban heat island intensity is observed, although the rate of increase differs city by city. Also, interannual variability is observed in the time series. The increasing temporal trend is essentially due to increasing urbanization. As expected, the average annual maximum urban heat island intensity is strongest in Seoul (3.34°C). Although Busan is the second largest city, the average annual maximum urban heat island intensity is weakest (2.20°C) due to oceanic influences. The wind speed in Busan is highest among the six cities. It is well known that the urban heat island intensity decreases as the wind speed increases. So, this can be a reason for the weakest maximum urban heat island intensity in Busan. Based upon the linear regression line, the rate of increase in the maximum urban heat island intensity in Seoul, Incheon, Daejeon, Daegu, Gwangju, and Busan over the 29-year period is 0.15, 0.38, 1.68, 1.54, 1.38, and 0.38°C, respectively. Seoul experienced the smallest rate of increase in the maximum urban heat island intensity because Seoul had been rapidly urbanized before 1973. The maximum urban heat island intensity in Daejeon, Daegu, and Gwangju exhibits more rapid rate of increase than that in the other cities. This is consistent with the fact that those three cities have been rapidly urbanized during the past three decades. Incheon

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also has been rapidly urbanized, but the increase rate is small (0.38°C per 29 years, the same value as in Busan) due to oceanic influences.

3.2. Spectral analysis

Figure 3 shows the power spectrum of urban heat island intensity for each city. The data used for the spectral analysis is the urban heat island intensity data in 6-h intervals. In all cities, a period of one day (diurnal cycle) in the power spectrum is prominent. It is well known that that the urban heat island intensity is strong in the nighttime and weak in the daytime, thus exhibiting its prominent diurnal cycle. A period of one year (annual cycle) is prominent in Seoul and coastal cities (Incheon and Busan) and less prominent in Gwangju. Seasonally, the urban heat island intensity is strong in autumn and winter and weak in spring and summer, thus exhibiting its annual cycle. In Daejeon and Daegu (inland cities), a one-year period is observed, but its signal is very weak. A period of 6-month is observed in all cities except in Incheon where a period of 4-month is observed, although its signal is very weak.

3.3. Multiple linear regression analysis

Figure 4 shows normalized regression coefficients for the four meteorological variables (PER: maximum urban heat island intensity at previous day, WS: wind speed, CL; cloudiness, RH: relative humidity) for each city. The value in parentheses is the percent of total variance explained by the multiple linear regression equation. The sample size of each variable is 10592 over the 29-year period.

In all cities, PER variable is positively correlated with the maximum urban heat island intensity, meaning that the maximum urban heat island intensity tends to be strong (weak) if the maximum urban heat island intensity at previous day was strong (weak). WS, CL, and RH variables are negatively correlated with the maximum urban heat island intensity. These negative correlations are physically consistent, as explained in Kim and Baik (2002). The most important variable in all cities is PER. PER variable is a persistent one and is dependent upon the duration of certain types of weather. The relative importance of the other three variables differs according to city. In Seoul, Incheon, and Daegu, the second most important variable is WS and the least important variable is RH. In Seoul, the normalized regression coefficient of WS (-0.24) is slightly larger in magnitude than that of CL (-0.21). In Deajeon, the contribution of CL to the maximum urban heat island intensity is much larger than WS or RH. This is a peculiar feature compared with the other cities. In Gwangju, each of WS, CL, and RH similarly contributes to the maximum urban heat island intensity. In Busan, the magnitude of normalized regression coefficient of CL is slightly larger than that of WS. Note that all normalized regression coefficients in Fig. 4 are statistically significant at the 95% confidence level.

The total variance explained by the multiple linear regression equation is 44.7% in Seoul, 36.6% in Incheon, 29.9% in Daejeon, 40.7% in Daegu, 35.0% in Gwangju, and 43.2% in Busan. The difference in the total variance between Seoul and Daejeon is 14.8%. This relatively large difference implies that the controlling effects of the four meteorological variables (PER, WS, CL, and RH) on the maximum urban heat island intensity are relatively much stronger in Seoul than in Daejeon. The total variance of less than 50% in all cities implies that other relevant variables such as synoptic variables should be taken into account in order to increase the variance explained.

3.4. Multidimensional scaling analysis

A multidimensional scaling analysis is performed with the correlation matrix produced using the maximum urban heat island intensity data in the six cities. The scaling technique used in this study is based upon Kruskal's work. The analysis result is plotted in Fig. 5. The badness-of-fit criterion representing stress (a numerical measure of closeness) in a two-dimensional configuration is 0.49%. This indicates that a representation of the cities in two dimensions is reasonable. Three city groups appear. Seoul and Incheon form one group, Daejeon and Gwangju form another, and Daegu and Busan form the last. These three groups are essentially connected according to distances between cities (Fig. 1). If two cities are close to each other, meteorological conditions (including mesoscale and synoptic conditions) that affect urban heat island intensity are also similar. Thus, the temporal trend of the maximum urban heat island intensity of a city is more similar to that of its nearby city than to that of a distant city. This is reflected in Fig. 5.

From the multiple linear regression analysis, a linear combination of the four variables (PER, WS, CL, and RH) for the maximum urban heat island intensity of each city is obtained. For the linear system $Z = CX$ ($\mathrm{UHI}_i = c_{i1}\mathrm{PER} + c_{i2}\mathrm{WS} + c_{i3}\mathrm{CL} + c_{i4}\mathrm{RH}$, where c_{ij} are normalized regression coefficients and subscripts i and j denote the city and variable, respectively), a variance-covariance matrix of X is obtained. With this variance-covariance matrix, a multidimensional scaling analysis is undertaken in order to find city groups based upon the normalized regression coefficients obtained from the multiple linear regression analysis. The analysis result is plotted in Fig. 6. The badness-of-fit criterion in a two-dimensional configuration is 3.4%. Therefore, a representation of the cities in two dimensions is reasonable. Incheon and Busan form one group, whose points in two-dimensional space are very close. Incheon and Busan have the common feature of being coastal cities, where the combined effects of WS and CL on the maximum urban heat island intensity appear to be relatively large and the effect of PER is relatively small. Seoul and Daegu may form another group or Daejeon and Daegu may form another group.

Gwangju is most dissimilar to the other cities. Among the six cities, Gwangju exhibits in magnitude the smallest normalized regression coefficient of WS except for Daejeon, the smallest normalized regression coefficient of CL, and the largest normalized regression coefficient of RH.

3.5. Cluster analysis

In order to classify cities by climatological propensity affecting the maximum urban heat island intensity, a cluster analysis is performed using the multivariate data of the previous-day maximum urban heat island intensity, wind speed, cloudiness, and relative humidity. The analysis result is shown in a dendrogram (Fig. 7). As expected from Fig. 6, Incheon and Busan form a cluster (cluster 3), where the maximum urban heat island intensity is weak and the wind speed is strong. These two cities are most similar to each other among the six cities. Seoul and Daegu form a cluster (cluster 5), where the maximum urban heat island intensity is strong. Daejeon and Gwangju form a cluster (cluster 4), where the wind speed is weak and the relative humidity is high. Next, clusters 3 and 5 are combined into a cluster (cluster 2) that includes Seoul, Daegu, Incheon, and Busan. These four cities have strong wind speed and low relative humidity. These cluster analysis results are similar to those of the multidimensional scaling analysis (Fig. 6).

4. ACKNOWLEDGMENTS

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References

Kim, Y.-H., and J.-J. Baik, 2002, Maximum urban heat island intensity in Seoul, *J. Appl. Meteor.*, **41**, 651-659.

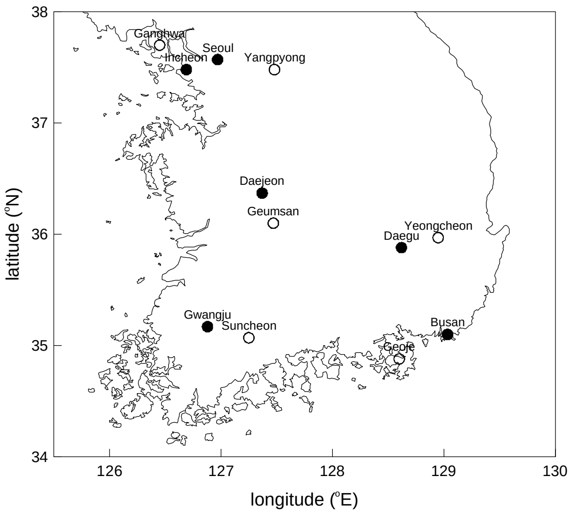

Figure 1. The locations of meteorological observatories selected for this study. The distance between Seoul and Yangpyong observatories is 60 km, Incheon and Gwanghwa 33 km, Daejeon and Guemsan 32 km, Daegu and Yeongcheon 38 km, Gwangju and Suncheon 41 km, and Busan and Geoje 54 km.

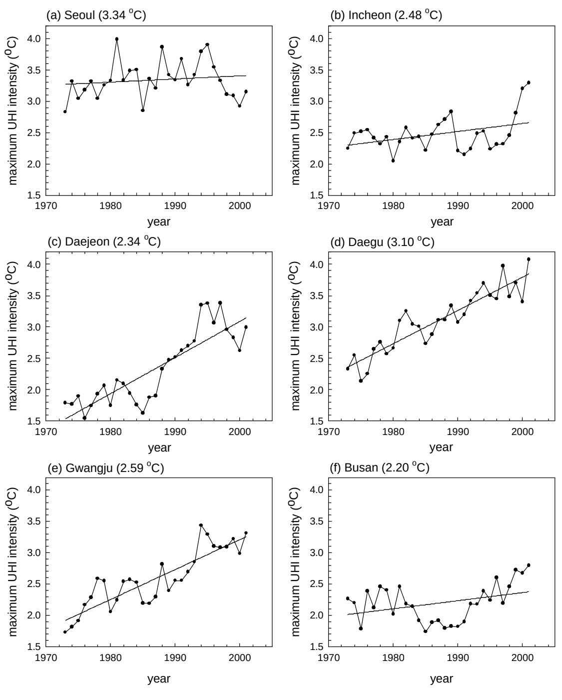

Figure 2. The time series of annual mean maximum urban heat island intensity in (a) Seoul, (b) Incheon, (c) Daejeon, (d) Daegu, (e) Gwangju, and (f) Busan. In each figure, the linear regression line is drawn and the average annual maximum urban heat island intensity over the 29-year period is shown in parentheses.

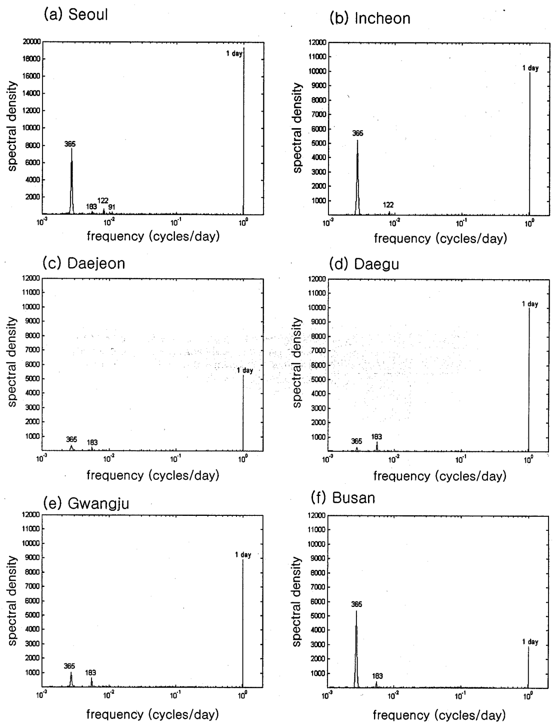

Figure 3. The power spectrum of urban heat island intensity in (a) Seoul, (b) Incheon, (c) Daejeon, (d) Daegu, (e) Gwangju, and (f) Busan. The horizontal axis is on a logarithmic scale and the vertical axis is on a linear scale. The dominant periods are shown.

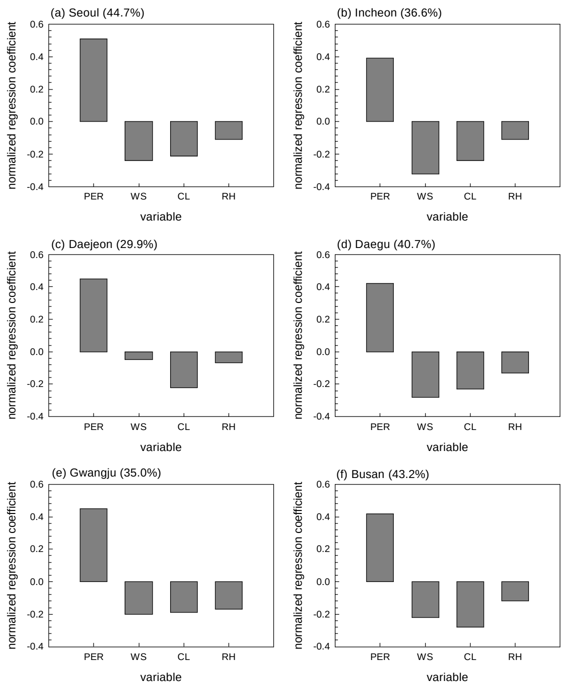

Figure 4. Normalized regression coefficients of the four meteorological variables (PER: maximum UHI intensity at previous day, WS: wind speed, CL: cloudiness, RH: relative humidity) for each city. The percent of total variance explained by the multiple linear regression equation (r^2) is shown in parentheses.

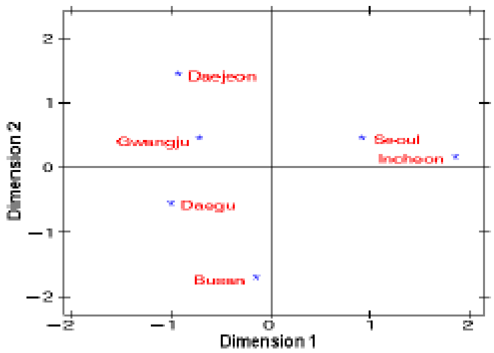

Figure 5. A representation of the six cities in two dimensions through a multidimensional scaling analysis. The multidimensional scaling analysis is performed with the correlation matrix produced using the maximum urban heat island intensity data in the six cities.

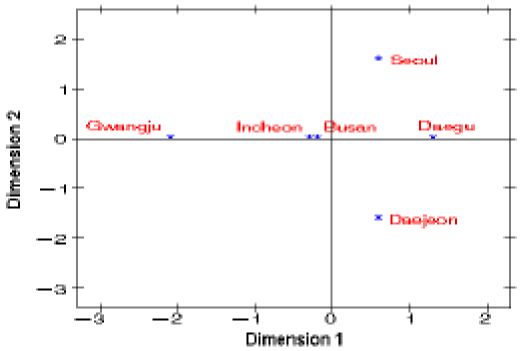

Figure 6. A representation of the six cities in two dimensions through a multidimensional scaling analysis. The multidimensional scaling analysis is performed with the variance-covariance matrix produced using the normalized regression coefficients in the six cities obtained from the multiple linear regression analysis.

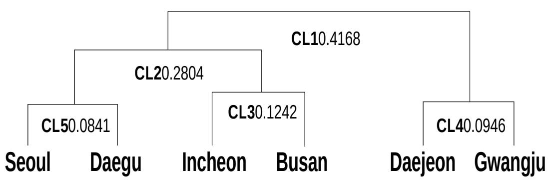

Figure 7. A dendrogram constructed through a cluster analysis. The cluster analysis is performed using the multivariate data of the previous-day maximum urban heat island intensity, wind speed, cloudiness, and relative humidity. CL means the cluster and the number in each cluster is the value of semi-partial R^2.