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Spatio-Temporal Variability of Temperature and Precipitation in Seoul

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ABSTRACT

This study analyzes the spatial and temporal variability of temperature (℃) and precipitation (mm) in Seoul, Korea. The temperature and precipitation data were measured at 31 automatic weather stations (AWSs) in Seoul for 10 years from 1997 to 2006. In this study, inverse distance squared weighting (IDSW) was applied to interpolate the non-measured spaces. To estimate the temperature and precipitation variability, the mean values and frequencies of hot and cold days were examined. The maximum and minimum temperatures were 32.80℃ in 1999 and -19.94℃ in 2001, respectively. The year 2006 showed the highest frequency of hot temperatures with 79 hot days, closely followed by 2004 and 2005. The coldest year was in 2001 with 105 cold days. The annual mean temperature and precipitation increased by about 1℃ and 483mm during the 10-year period, respectively. The temperature variability differed between high-elevation forested areas and low-elevation residential areas. However, the precipitation variability showed little relation with the topography and land use patterns.

Keywords : Seoul, IDSW, temperature, precipitation, variability, land use

요 약

본 연구에서는 서울지역에서 기온(℃) 및 강수(mm)의 시·공간 구조 분석 및 변화경향과 변이성을 도출하였다. 1997년 1월부터 2006년 12월까지의 기상청에서 제공하는 31개 자동기상관측망의 기온 및 강수자료를 이용하였으며, 미 관측지점의 값을 추정하기 위하여 거리자승역산가중 (IDSW: Inverse Distance Squared Weighing)을 적용하여 보간 하였다. 기온과 강수량의 변이성을 평가하기 위하여 연평균 및 더운 날과 추운 날의 빈도를 알아보았다. 그 결과 최고기온 값은 1999년의 32.80℃, 최저기온은 2001년의 -19.94℃로 나타났다. 더운 날의 빈도가 가

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장 많았던 해는 79일을 기록한 2006년이며, 2004년과 2005년에도 비슷한 기록을 보였다. 추운 날의 빈도가 가장 많았던 해는 105일을 기록한 2001년이다. 또한 기온과 강수량 모두 지난 10년 동안 기온이 약 1.03℃, 강수량이 약 483.09mm 증가한 것으로 나타났다. 과거 10년 동안 기온변이의 경우 고도가 높은 산림지역과 고도가 낮은 주거지역에서 차이가 크게 나타난 반면, 강수량의 경우 지형 및 토지이용에 따른 변이성의 차이가 미미한 것으로 나타났다.

주요어 : 서울, IDSW, 기온, 강수, 변이성, 토지이용

1. Introduction

The most important anthropogenic influences on climate are greenhouse gas emissions and changes in land use, such as urbanization and agriculture (IPCC, 2001; Cai and Kalnay, 2003). The air temperature increase in urban regions is affected by both global warming and urbanization. With the expansion of commercial areas and public facilities, the total area of high-quality green spaces is falling, leading to a severe increase of urban surface air temperature known as urban warming, which is defined as the temperature difference between a city and the surrounding rural area (Bonan, 2002). Urban warming may be statistically measured from several connected properties such as land cover, land use change, construction activities, automobile registration and energy consumption.

The influence of urbanization on climate has been theorized by a number of studies examining human land use changes (Alig, 1986; Mauldin et al., 1999; Ahn et al., 2002; Alig et al., 2004). Urban effects tend to be complex, both spatially and temporally, with urban fluxes. Recent studies analyzed the influence of urban warming, especially the urban heat island (UHI) in Seoul, Incheon, Daejeon, Daegu, Gwangju and Busan, South Korea (Chung et al., 2004; Kim and Baik, 2004; 2005), Buenos Aires, Argentina (Bejarán and Camilloni, 2003), New York City, USA (Gedzelman et al., 2003), Lisbon, Portugal (Alcoforado and Andrade, 2006), Prague, Czech Republic (Beranova and Huth, 2005), and Debrecen, Hungary (Bottyán et al., 2005). Based on an analysis of temperature data for 1911-85, Cho et al. (1988) found a close relation between the warming trend and urban growth in Korea. Mayer et al. (2003) documented the spatial and temporal variability of humidity (vapor pressure) within the urban canopy layer across different land uses, although they did not examine significant relations according to the human perceptions of thermal comfort. Boo et al. (1999) analyzed the spatial and temporal distribution of temperature in Seoul and Koo et al. (2007) investigated the change of the spatial and temporal distribution of the UHI in Seoul.

This study was conducted to determine the spatial and temporal variability of temperature and precipitation in the large urban region of Seoul from 1997 to 2006, particularly in terms of the influence of urbanization.

2. Data and Methods

2.1 Study area

The study area covered Seoul, 126°62′E~127° 48′E and 37°25′N~37°99′N. Seoul is encircled by inner and outer mountains ranging from 111m to 836m above sea level, and is characterized by a high population density and densely built-up area covering approximately 605 square kilometers (Figure 1; Eum, 2008).

2.2 Data

We used the annual-mean temperature, annual precipitation, and frequency of hot and cold days each year from 31 automatic weather stations (AWSs) in Seoul. Hot and cold days were defined as those with a daily mean temperature above 30℃ and below -12℃, respectively (Parsons, 2003).

The precipitation data in non-measured space were interpolated with the inverse distance squared weighting (IDSW) approach (Eq. 1) from the data of 31 AWSs in Seoul.

$$W=\frac{\sum \frac{W_i}{d_i^2}}{\sum \frac{1}{d_i^2}} \qquad (1)$$

W : Estimated precipitation value in an unobserved point
W_i : Observed precipitation value in point i
d_i : Distance between a certain unobserved point and point i

To interpolate the temperature data in an unobserved point, we employed the modified IDSW approach that considers the temperature lapse rate by elevation (Eq. 2; Choi et al., 2003).

$$T=\frac{\sum \frac{T_i}{d_i^2}}{\sum \frac{1}{d_i^2}}+\left[z-\frac{\sum \frac{z_i}{d_i^2}}{\sum \frac{1}{d_i^2}}\right]\Gamma \qquad (2)$$

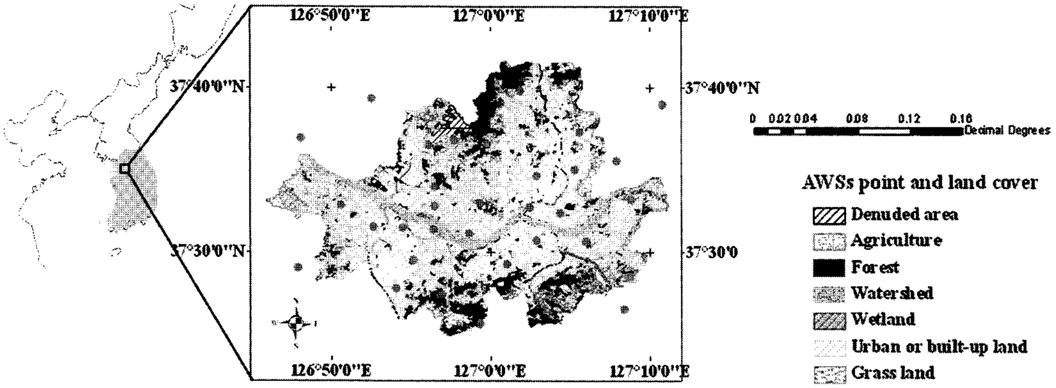

Figure 1. AWS points in Seoul depicted with land cover prepared by the Ministry of Environment (2001)

T : Estimated temperature value in an unobserved point
T_i : Observed temperature at point i
d_i : Distance from the site to point i
z : Elevation of the site
z_i : Elevation of point i
Γ : Temperature change per unit change in the elevation

2. 3 Estimation of variability and adaptability

The annual variability of the climate factor is estimated with the annual and average values during the previous 10 years (Eq. 3).

$$D = \frac{\sum_{i=1}^{n} |V_i - \overline{V}|}{\overline{V}} \qquad (3)$$

D : Variability of climate factor for n year
V_i : Value of climate factor in i year
$\overline{V}$: Value of climate factor for n years
i : Year of study period
n : Whole study period

2. 4 Spatial autocorrelation analysis of hot and cold days

Variogram analysis and kriging interpolation (Bailey and Gatrell, 1995; Mowrer and Congalton, 2000; Webster and Oliver, 2001; Lee et al, 2006) was employed to identify the spatial autocorrelation and variability of days using the S+SPATIAL STATS module of SPLUS (Kaluzny et al., 1998).

3. Results and Discussions

3.1 Non-spatial variation

The mean temperature and precipitation exhibited a slightly increasing tendency during the 10-year study period (Figures 2 and 3). The annual mean temperature increased by about 1℃ from 1997 to 2006 and the annual mean precipitation increased by 483mm from 1997 to 2006.

Table 1 shows the maximum and minimum temperatures in Seoul from 31 AWSs during the

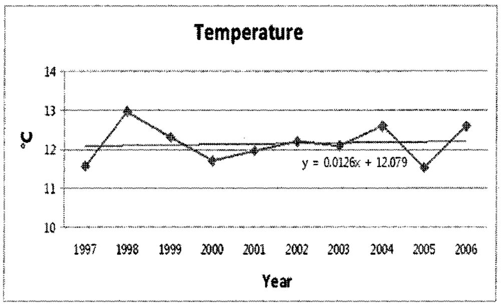

Figure 2 Annual average temperature (1997-2006)

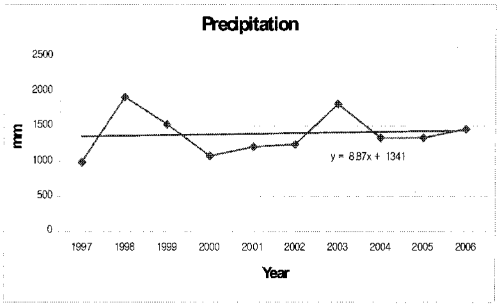

Figure 3 Annual average precipitation (1997-2006)

10-year period from 1997 to 2006. The maximum temperature ranged from 30 ℃ to 33℃, with an average of 31.64℃, and the minimum temperature ranged from -12℃ to -20℃, with an average of -15.16℃. The coefficient of variation showed that the variation of minimum temperature was much higher than that of maximum temperature.

The number of hot days tend to increase and recorded 79 days in 2006, but no hot days were recorded in any AWSs in 1998 and 2003. We could not determine the reason for this phenomenon and the two years were excluded from the 10-year average of hot days. The average number of hot days was 60 days in the 8-year period, but ranged from 75 to 79 days during the last 3 years of 2004-2006 (Table 3).

It is notable that cold days in 2001 and 2004 were recorded in almost AWSs. Usually 2-8 cold days were recorded from some AWSs. The temperature record of Seoul in the website of the Korean Meteorological Administration (http://www.kma.go.kr) supports the aforementioned pattern of hot and cold days from AWS (Table 2).

3.2 Spatial autocorrelation of hot and cold days

Spatial autocorrelation existed in hot days but not in cold days (Figures 4 and 5). Spatial autocorrelation in hot days existed within a range of about 600m, suggesting that hot temperature can be spatially similar within 600m.

Figure 6 depicts the total hot and cold days of each point of the 31 AWSs. In tables 2 and 3, most of the hot days were recorded in the central part of Seoul where built-up residential areas are largely covered. However, the cold days showed no district spatial pattern. The resulting kriging prediction is presented in

Table 1. Annual maximum and minimum temperature (℃) by 31 AWSs (1997-2006)

	Year										
	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	Mean (CV)
Tmax	32.73	29.58	32.8	31.82	32.1	32.42	29.91	31.88	31.7	31.46	31.64 (0.03)
Tmin	-13.92	-14.08	-11.67	-13.65	-19.94	-14.43	-17.21	-18.04	-14.05	-14.59	-15.16 (-0.15)

CV: Coefficient of Variation

Table 2. Frequency of hot and cold days in Seoul (Korean Meteorological Administration)

	Year									
	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Hot days	1				1	1		2	1	1
cold days					3		1	2		

Table 3. Frequency of hot days (temperature >= 30℃)

Branch	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	Total
Gangnam			3		2	1		5	4	4	19
Seocho	4		7	3	6	2		6	8	9	45
Gangdong	1				2	4		1	4	1	13
Songpa	4		2		4	1		5	5	5	26
Gangseo	1					1		1	1	2	6
Yangcheon			12	6	5	1		6	5	7	42
Dobong						1			1		2
Nowon						1			1		2
Dongdaemun	8		4		4	1		7	6	6	36
Jungnang	6		4		3	1		5	5	5	29
Dongjak	2			1		1		2	3	1	10
Mapo	3		9		5	2		4	2	1	26
Seodaemun					1						1
Gwangjin			2		2	1		5	5	7	22
Seongbuk						1			1		2
Yongsan	5		3	1	4	2		7	5	8	35
Eunpyeong	2					1		1	1		5
Geumcheon					3	1				2	6
Hangang	1				4	1		1	1		8
Junggu	2										2
Bukhansan			1								1
Seongdong					4	1		5	5	7	22
Gwanak			1			1					2
Yeongdeungpo	8		11	2	5	2		7	6	9	50
Goyang					1	1		1	1		4
Sanung											0
Bucheon	18		13	6	4	2				1	44
Guri	1				2	1		1	1		6
Seongnam	1		2		2	1		5	4	4	19
Nunggok											0
Gwacheon						1			1		2
Total	67	0	74	19	63	34	0	75	76	79	487

Figures 8 and 9.

Ordinary Kriging of hot and cold days was performed with the above empirical variogram models (Figures 7 and 8). The hot days tended

Table 4. Frequency of cold days (temperature =< −12℃)

	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	Total
Gangnam					3		1	2			6
Seocho					3		1	2			6
Gangdong					4			2			6
Songpa					3		1	2			6
Gangseo					4		1	2			7
Yangcheon											0
Dobong					4		2	2			8
Nowon					4		2	2			8
Dongdaemun					3		1	2			6
Jungnang					3		1	2			6
Dongjak				1				2			3
Mapo					3		1	2			6
Seodaemun		1			4		2	2		1	10
Gwangjin	1				3		1	2			7
Seongbuk		1			4		2	2		1	10
Yongsan					3		1	2			6
Eunpyeong		1			3		2	2			8
Geumcheon					2						2
Hangang					3		1	2			6
Junggu		2			4	2	2	2	1	1	14
Bukhansan	2			1	7	2	4	3	3	2	24
Seongdong					3		1	2			6
Gwanak					4		2	2		1	9
Yeongdeungpo					3		1	2			6
Goyang		1			5		2	2			10
Sanung		1			4	2	3	3	1		14
Bucheon					4		2	2			8
Guri		1			4		2	2			9
Seongnam					3		1	2			6
Nunggok					4		2	2			8
Gwacheon					4		2	2			8
Total	3	8	0	2	105	6	44	60	5	6	239

to be more numerous in the central part of Seoul and less in the outer part of Seoul, similar to the total hot days from AWSs in figure 7.

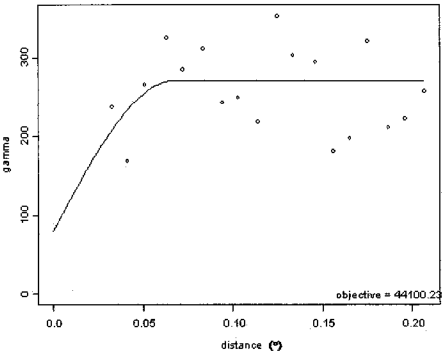

Figure 4. Variogram of hot days

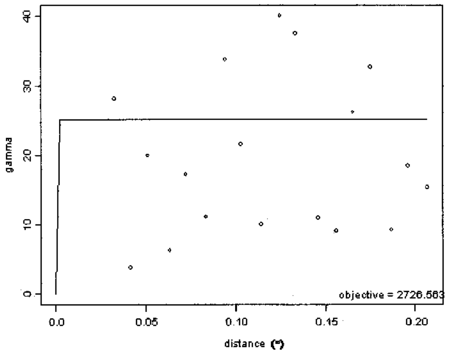

Figure 5. Variogram of cold days

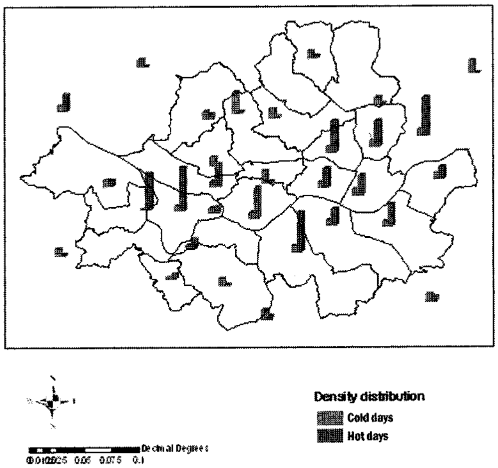

Figure 6. Spatial distribution of hot and cold days

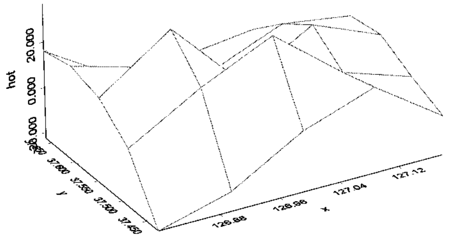

Figure 7. Kriged 3D contour map of hot days

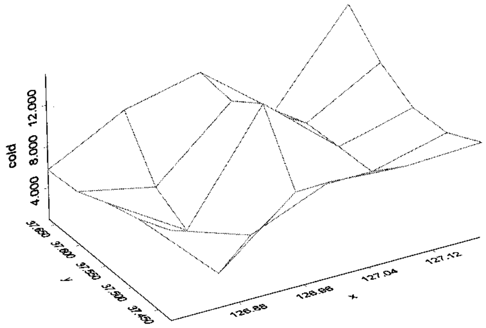

Figure 8. Kriged 3D contour map of cold days

3. 3 Spatial variability and adaptability

While the variability of temperature was higher in the high-elevation forest area (Figure 9), the temperature variability of the high-elevation forest area was more adaptive than that of low-elevation residential area (Figure 10). These two figures indicated that the temperature variability in the high-elevation forested was relatively higher than that of the low-elevation residential area, but the temperature variability in the former tended to decrease, and thus be more adaptive, while the temperature variability in the latter showed an increasing tendency, and thus be less adaptive.

While there were differences in temperature

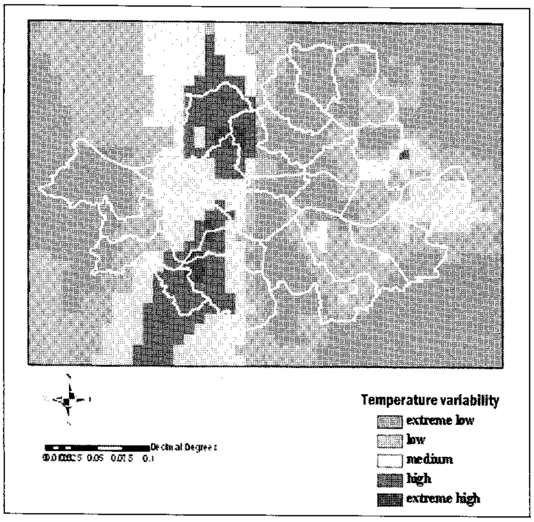

Figure 9. Variability of temperature

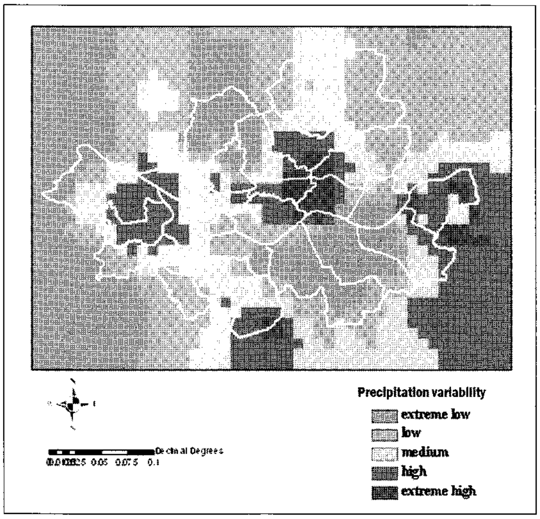

Figure 11. Variability of precipitation

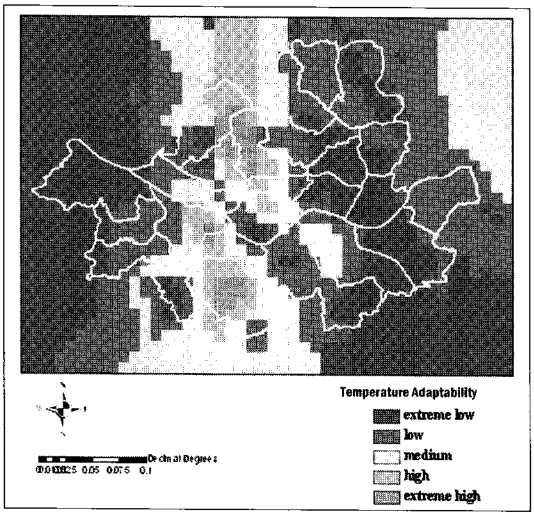

Figure 10. Variability trend of temperature

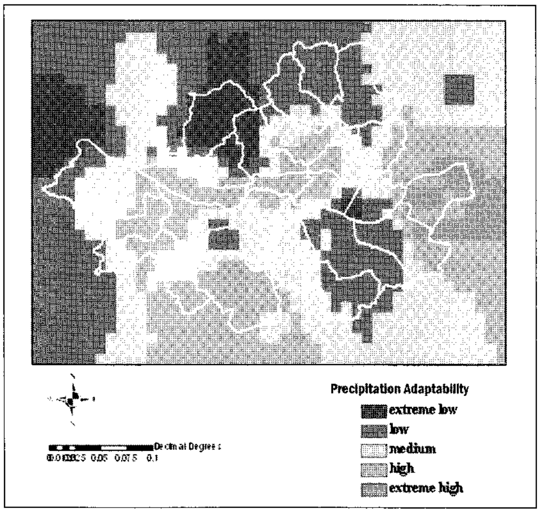

Figure 12. Variability trend of precipitation

variability and adaptability between the high-elevation forest area and the low-elevation residential area, the spatial differences in precipitation variability and adaptability showed a low relation with the topographic and land use patterns (Figures 11 and 12).

Boo et al. (1999) and Koo et al. (2007) analyzed the spatial and temporal distribution of temperature from the observed AWS data over short period from 1 month to 1 year. Whereas, we analyzed the variability and adaptability using geostatistical analysis of variogram and ordinary kriging. However, some errors in interpolated data for non-measured area can appear due to low density and spatially unhomonized distribution of AWSs. This interpolation error can be overcome by using sufficient data from a denser and spatially homonized AWS network in future study.

4. Conclusions

In this study, the spatial and temporal variability of temperature and precipitation in Seoul were analyzed. The temperature and precipitation data were measured at 31 AWS stations in Seoul for 10 years from 1997 to 2006.

The mean temperature and precipitation showed a slightly increasing tendency during the 10-year period. The variation of minimum temperature was much higher than that of maximum temperature. Most of the hot days were recorded in the central part of Seoul where built-up residential areas are largely covered. However, the cold days showed no district spatial pattern.

The temperature variability in the highly elevated areas was relatively higher than that of the lowly elevated residential area, but the temperature variability in the former tended to decrease, and thus be more adaptive, while the temperature variability in the latter showed an increasing tendency, and thus be less adaptive. While there were differences in temperature variability and adaptability between the high-elevation forest area and the low-elevation residential area, the spatial differences in precipitation variability and adaptability showed a low relation with topographic and land use patterns.

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