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URBAN EFFECTS ON REGIONAL SURFACE TEMPERATURE SERIES OF SOUTH KOREA

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1. INTRODUCTION

Unusual upward trends of surface temperature over recent decades have received much attention with an increasing interest in climatic changes due to natural causes and man-induced CO_2 effects. The IPCC WG1 Third Assessment Report concluded (IPCC, 2001), "In the light of new evidence and taking into account the remaining uncertainties, most of the observed warming over the last 50 years is likely to have been due to the increase in greenhouse gas concentration." However, there have been suggestions that a proportion of the long-term warming trend may be related to some non-climatic factors. The urban effect is considered as the most serious source of errors identified in the land surface climatological measurements and is believed to exist in all of the most widely used global and regional land surface. Therefore, to quantify the magnitude of urban bias is considered vital for the detection and monitoring of possible long-term trends associated with increasing concentrations of atmospheric greenhouse gases even though a precise correction of error cannot be achieved.

However, a few studies (Kim et al. 1999) have conducted to examine the effect of urban bias in surface temperature series of South Korea. Their results suggested the warming rate of 0.3-0.4°C in annual mean surface temperature due to urban effects for the recent 20-30 years in South Korea. The purpose of this paper is to produce the urban bias-adjusted surface temperature series in South Korea estimating quantitatively the magnitude of urban bias in the regional surface temperature series.

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2. DATA AND METHODOLOGY

Monthly mean temperatures of 19 stations were obtained for the period of 32 years (1968-1999). All selected stations are located below 250 m mean sea level elevation and 8 out of 19 stations set inland while 11 stations near the coast.

This study is basically performed in two steps. The first step is to identify inhomogeneity in surface temperature series and the second is to construct adjusted surface temperature series after removing urban bias. Inhomegeneity can be easily examined with consulting the station history. Korea Meteorological Administration (KMA) has published "*Meteorological Stations Circumstance*" in 1995, which provides operation histories of a station such as change of observation instruments and station relocations. An alternative method used for examining discontinuities in surface temperature series is to compare the series of differences calculated between a station and a neighboring station. Station-to-station temperature differences are expressed in terms of median rank-score procedure here, which was developed by Portman (1993).

To identify urban bias, stations are divided into an urban station or a rural station using population statistics. Urban (rural) stations are defined as those that had population densities greater (less) than 1000 persons per km_2 in 1995: ten urban stations and six rural stations. Again, urban stations are subdivided into two groups according to their population totals to examine whether there are magnitude changes of urban bias with the size of urban areas: a group of four large urban stations (more than one million populations) and a group of six smaller urban stations (less than one million populations).

The most straightforward method identifying the effects of urbanization is to compare each urban station with a neighboring station that is considered free of urban influence and industrial growth. Unlike most of recent urban bias studies, this study estimates the yearly urban bias magnitude averaging the difference between each urban station and six rural stations. Estimates of 32-year mean urban bias magnitude ($\overline{T}$ *u-r*) are calculated by averaging the yearly urban bias estimates over the period of 1968-1999. Estimates of the 32-year urban trend (ΔT *u-r*) are obtained using period means (doubling the differences obtained between yearly estimates averaged over two 16-year periods, 1968-1983 and 1984-1999). Finally, an attempt is made to remove the magnitudes and trends of urban bias from the regionally averaged urban station temperatures. For annual or seasonal mean temperature (T_i), the adjusted temperature (T'_i) is determined from Eq. (1).

$$T_i' = T_i - \{\overline{T}\ u\text{-}r + \{(\Delta T\ u\text{-}r/32) \times (i-1968)\} \quad \text{Eq. (1)}$$

where *i* is any year between 1968 and 1999. Trends in the 32-year time series of original and adjusted temperatures are estimated by differencing period means.

3. RESULTS

3.1. Test of homogeniety

Application of the median rank-score procedures to 16 stations indicated that annual mean temperature series might be considered as homogeneous. Using that procedure to screen all data and identify the most blatant discontinuities prevented the introduction of many large errors in urban bias calculations.

3.2 Annual and seasonal mean temperature series of South Korea

The annual and seasonal mean temperature series of South Korea were constructed averaging data out of 16 stations, which had no distinct discontinuities in annual mean temperature series. In general, an increasing trend was present for all the series with different magnitudes. The increasing trend in the annual mean temperature resulted from persistent positive anomalies from the late 1980s. In seasonal basis, the positive anomalies have become more distinct and these features especially were true in winter from the late 1980. These trends were all statistically significant except for in summer. The mean difference between the first 16-year period and the second 16-year period was showed that the second period was 0.55°C warmer than the first period for annual mean temperature. In season, the second period was 0.38-0.60°C warmer than the first period and the difference was the largest in winter while the smallest in summer.

3.3 Estimation of urban bias in annual and seasonal mean temperature series

The annual and seasonal mean temperature series for each group (a group of urban stations, a group of large urban stations, a group of smaller urban stations, and a group of rural stations) were constructed to examine whether there were any different features among those groups as the size of cities varies. All the temperature series including the group of rural stations showed the increasing trend and all three groups of urban station had warmer temperature than the group of rural station. However, the feature was different when the trends on seasonal basis were considered. The increasing trend was more distinct in the group of large urban station series than in the group of the smaller one except for fall. The 32-year annual mean temperature for the group of urban station was 0.41°C higher than the rural group and the difference was statistically significant. Also, the 32-year annual temperature mean of the large urban group was 0.50°C higher than the rural group and that of the smaller urban group was 0.35°C higher than the rural group. In the seasonal basis, the group of urban stations was warmer than the group of rural stations ranging from 0.37°C in summer to 0.47 °C in fall. The magnitude of 32-year seasonal temperature mean in the group of large urban stations was greater than the rural group except for summer and the smaller urban group. Differences of 32-year annual and seasonal mean were used as $\overline{T}$ *u-r,* estimates of 32-year mean urban bias magnitude.

As all estimates of $\overline{T}$ *u-r* were greater than zero, it suggested that temperatures in urban stations were warmer than those in rural stations. These magnitudes are relatively smaller than those from other regions such as China and the United States (Portman, 1993). It might result from that rural stations sampled for this study have experienced more urbanization than rural stations used for those regions.

All estimates of ΔT *u-r* were positive, indicating an increasing trend in urban bias time series. Seasonal variations were found in $\overline{T}$ *u-r* and ΔT *u-r*. For urban stations, maximum $\overline{T}$ *u-r* occurred in fall while minimum $\overline{T}$ *u-r* in summer. For all of three groups of urban stations, ΔT *u-r* was largest during winter. However, due to a larger variation, in some instances temperatures of individual urban stations may be cooler than those of the rural stations. Therefore, it is recommended that the urban bias estimates obtained from regionally averaged quantities should not be used to adjust temperatures of the individual urban station.

Estimates of urban bias calculated for each year, 1968-1999, are plotted as annual and seasonal time series. All of these yearly estimates are greater than zero and have been increased since 1980s. Differences of bias between the group of large urban stations and the group of smaller urban stations were greater during spring and fall than during summer and winter. Also, the interannual variations of urban bias seemed to be highly correlated due to all estimates were calculated to temperature of the rural stations. Based on the results presented so far, it appeared that the magnitude of urban bias in surface temperature was greater for the group of large urban stations than for the group of smaller urban stations. It might imply that the bigger cities are, the greater urban biases are.

3.4 Correction of urban bias

The larger trends were found in original temperature of the urban stations while trends in the rural station temperatures and in the adjusted temperatures of the urban stations were smaller. In both original and adjusted temperature series, maximum positive trends were found during winter. Before adjusting the urban bias, there were relatively large differences between urban stations and rural stations and even they have become larger since 1990s. However, differences between them are partly eliminated after estimates of urban bias are removed. Therefore, it might be said that the urban effects played an important role for the warming trends in surface temperature series of South Korea. It should be mentioned that temperature differences might also occur because of difference in station location or as a result of biases associated with local, environmental factors such as closeness to coast, or nearby mountains. However, these factors were not considered here, yet.

It also noted that warming trends still remained even though the urban bias has been removed. Annual mean temperature has been increased an order of 1.17°C without adjusting the urban bias, but it has reduced into 0.76°C after the adjustment. This rate is slightly higher than previous studies. The difference of rate might result from the different study period, the addition of data from the period of 1993-1999.

4. SUMMARY

A detailed analysis of urban bias in the regional surface temperature series of South Korea was performed using some statistical procedures. The application of median rank-score procedure showed that annual surface temperature series at16 station stations found to exhibit no large potential inhomogeneity. Results of this study showed that temperatures of large urban stations exhibited higher urban bias than smaller urban stations and the magnitude of urban bias has been increased since 1990s. The estimated magnitudes of urban bias were found to be greater during fall than other seasons, but trends were more distinct during winter. For this study, temperatures of each group of urban stations were compared with those of the rural stations so that urban and rural stations have somewhat different geographical distributions. However, it has been eliminated the need to make as hoc decision to mach each urban station with a single rural station. None of rural stations used for this study can represent a true non-urbanized environment. Therefore, estimates of urban bias magnitude and trend from this study might be considered as measures of relative bias between heavily urbanized, industrialized centers and less urbanized, agricultural centers as other studies did. Results showed that the urban growth biases are very serious in South Korea and must be taken into account when assessing the reliability of temperature trends.

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