Analysis of mean and minimum temperature trends for the urbanized and rural meteorological observatories in Japan, USA and China

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1. Introduction

It has been hypothesized that air temperatures worldwide have increased because of increased concentrations of atmospheric CO2. In China and Japan, the tendency of observed air-temperature data is for warmer temperatures. However, many of the meteorological stations where temperature data have been recorded have become more urbanized during the past 50 years. In addition, the representative area of the observed temperature data has decreased because of increases in population, anthropogenic heat energy, road pavement, decreases in vegetation area, etc. In other words, in urbanized areas air temperatures may increase for reasons other than those associated with global warming. Such influences are large in countries that have experienced rapid economic development and have high population densities (e.g., Japan, China, and other countries in Asia). The influence is smaller in countries with a history of city planning as seen in parts of Europe and America (see Fig 1-3).

The Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report (hereafter TAR) and Fourth Assessment Report pointed out that the smaller diurnal air temperature range and lower rate of warming observed in the lower troposphere compared to the surface over the past 20 years might have been caused by the effects of urbanization on climate change (IPCC, 2001). TAR estimated that urban heat island effects do not exceed 0.05°C in global temperature records through 1990. The report therefore assumed an uncertainty in global land-surface air temperatures due to urbanization of zero in 1900 that increased linearly to 0.06°C (2 SD = 0.12°C) in 2000 based on Easterling et al. (1997).

The effect of urbanization has been estimated in the present study.

2. Analysis method

Urbanization

1) As the numbers of buildings and geographical features increase, the sky factor decreases.

2) Anthropogenic heat flux increases.

3) Thermal parameters near the ground surface (the product of thermal capacity and thermal conductivity) change.

4) Other factors include a decrease in vegetation area and a change in turbulence near the ground surface.

Windless sunshine effect

Geographical features suppress wind speeds by up to several meters per second above the ground surface. The windless sunshine effect differs from the effects of urbanization because it can occur even if the sky factor shows no change. In addition, anthropogenic heat, as in (a), can be ignored. Furthermore, the windless sunshine effect can occur in suburbs and other areas with low population densities.

Characterizing urbanized and rural meteorological observations by comparing long-term changes in annual mean temperatures

Urban and rural meteorological observations can be partitioned by comparing the differences in long-term temperature changes. The term rural meteorological observatory here denotes an ideal location far from any urban area with no nearby obstacles. This classification differs from past classifications that used population index, nighttime luminosity, vegetation index, etc. The classification depends on long-term temperature changes and an investigation of environmental changes near the observation station. Time series of temperature data are easily obtained; the need for investigation of the observation stations limited this analysis to domestic Japan.

Temperature data and information about urbanization and environmental changes in the vicinity of observation stations are needed to investigate urbanization and the effects of environmental changes included in temperature changes. These data were collected as follows for the United States, Japan, and China.

China

Data from China between 1960 and 2000 were collected from "the monthly report of surface meteorological data." This study used daily mean temperatures, daily minimum temperatures, and daily mean wind speeds at 62 locations in the Yellow River basin. The daily mean wind speed data were used to characterize the environment around the observation stations.

Information about changes in the environment around observation stations in China is scarce. Urbanization and the windless sunshine effect can be determined from the following indexes.

1) The long-term change in the extrema of annual minimum air temperatures is constant.

2) The rate of the long-term change in the extrema of annual minimum air temperatures is less than the rate of the long-term change in annual mean air temperatures.

3) Almost no changes occur in the time series of wind speeds.

If the environment surrounding an observation point is changed, such as by the addition of buildings or removal of trees, then the observed wind speeds should reflect that change. This will alter the intensity of the windless sunshine effect, which in turn affects air temperatures. The three indices were used for the 62 observation stations in the Yellow River basin.

Japan

This study used temperature data from the Meteorological Bureau of the Japan Meteorological Agency for 32 locations, In addition to the data from the library of the Japan Meteorological Agency, the present study used rural station data from local meteorological bureaus and data from the "Annual Report of the Japan Meteorological Agency, 2003," as well as meteorological observations and meteorological statistical information available from the Website of the Japan Meteorological Agency. The environment surrounding the observation points was investigated using maps and field surveys.

United States

Minimum temperature data are included in the National Climatic Data Center (NCDC) Cooperative Station Data (Peterson and Vose, 1997), and the long-term annual mean temperature from the GISS Surface Temperature Analysis (Hansen et al., 1999) of NASA/GISS TEMP was used. This dataset combines air-temperature data from the Global Historical Climatology Network

(GHCN) ver. 2, and NCDC's U.S. Historical Climatology Network (USHCN) data. Datasets from 32 locations that included extrema of both minimum and mean temperatures for more than 40 years were selected. Temperature trends for these locations were analyzed statistically. Information regarding the meteorological observation stations' surroundings were determine from the Tiger Map Server Browser of the U.S. Census Bureau, and satellite imagery from Google Earth.

3. Analysis result

Figures 4 shows the trends in the minimum and mean surface air temperatures at all observation points. If there is no influence from urbanization or from other changes in the environment surrounding an observation point, then the mean surface air temperature and the maximum and minimum temperatures should show the same magnitude of increase as if the temperature had increased several degrees naturally during the past 100 years. The patterns of diurnal and annual changes in mean surface air temperatures and maximum and minimum temperatures should also be the same. In this case, the patterns of temperature change are fixed and the rates of increase of mean and minimum temperatures should be the same. This means that the marks in Fig.4 should fall on the dotted line ($y = x$). Thus, locations on the dotted line were little influenced by urbanization. In Figs.1, the change in the annual extrema of minimum temperatures is larger than that of the change in annual mean temperatures at most locations. In other words, changes in geographical features and other urbanization factors weakened radiative cooling under clear skies in winter. The slopes of the linear regression lines for Japan (open circles) and China (diagonal crosses) are 0.12 and 0.2, respectively. The rates of increase of the annual extrema of minimum temperatures are five to eight times larger than the rates of increase of mean temperatures. The extremum of minimum temperature is more sensitive to urbanization than the mean temperature. The points where the linear regression lines intersect the vertical axis correspond to the rates of the increase in temperature when urbanization is not present. This value is 0.2°C (50 yr^{-1}) for Japan and 0.4°C (50 yr^{-1}) for the Yellow River basin in China. These rates are smaller than the temperature changes found in other studies. In the United States, the rate is 0.5°C (50 yr^{-1}); if the cool island phenomenon (dotted line) is not included in the calculations, the rate is 0.1°C (50 yr^{-1}). The effect of urbanization on surface air temperatures between 1950 and 2000 is an increase of 0.2 to 0.3°C. The warming trend is small if the influence of urbanization is considered. Figs.4 shows that urbanization cannot be neglected. In addition, it is unclear whether air temperatures in North America are representative of global change. Past studies have used only monthly climatological data for analyzing time series of air temperature because of continuity and the weight of the statistical significance. The analysis of annual minimum temperatures in this study makes it clear that long-term air-temperature data are greatly affected by local changes, such as those due to urbanization. It will be necessary to reevaluate the increase in air temperatures resulting from global warming by considering environmental changes in the vicinity of air-temperature sites and using data that are representative of air temperatures over broader areas.

Fig.1 A representative meteorological observatory in USA.

Fig.2 A representative meteorological observatory in China.

Fig. 3 Worse case in China.

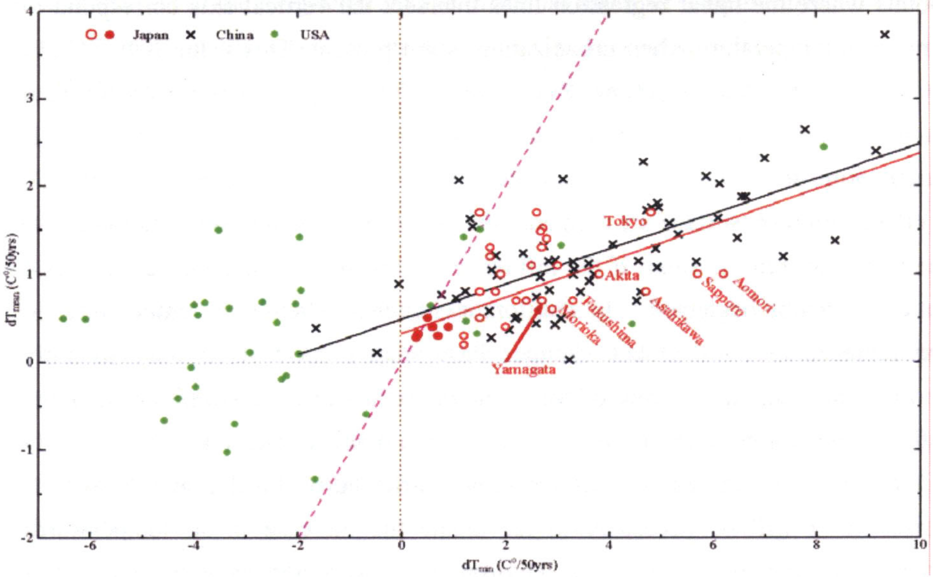

Fig.4 Increment of annual minimum and mean air temperature at selected sites in the USA, Japan, and China.