

Article

Weekday–Holiday Differences in Urban Wind Speed in Japan

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Abstract: Wind speed differences between weekdays and holidays at urban sites in Japan were investigated in search of the influence of urban anthropogenic heat on surface wind speed using data from the Automated Meteorological Data Acquisition System (AMeDAS) of the Japan Meteorological Agency (JMA) for 44 years. The wind speed was found to be lower on holidays than on weekdays, not only in large cities but also in areas with medium degrees of urbanization, which is interpreted to be due to the stronger stability of the surface boundary layer under lower temperatures with smaller amounts of anthropogenic heat. The rate of decrease is about -3% in central Tokyo, and about -0.5% for the average over stations with population densities between 1000 and 3000 km^{-2} . Additionally, an analysis using the spatially dense data on the Air Pollution Monitoring System of Tokyo Metropolis for 28 years showed that negative anomalies in wind speed on holidays were detected at many stations in the Tokyo Wards Area, although negative temperature anomalies were limited to a few stations in the central area or near big roads, suggesting different spatial scales in the response of temperature and wind speed to anthropogenic heat.

Keywords: urban climate; urban atmosphere; urban wind; weekly cycle; weekend effect; anthropogenic heat



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1. Introduction

It is believed that one of the causes of the urban heat island (UHI) is anthropogenic heat release, in addition to low moisture availability and thermal inertia over the complicated urban surfaces [1]. A detailed investigation in the 2000s revealed that the anthropogenic heat over the Tokyo Wards Area (see Section 2.1) in August amounted to approximately 2100 TJ day^{-1} , which is equivalent to 39 Wm^{-2} , and exceeded 200 Wm^{-2} in some grids of a $500 \text{ m} \times 500 \text{ m}$ size in the central business area [2]. A number of numerical studies incorporating urban canopy parameterization have indicated the contribution of anthropogenic heat to the UHI in large cities, although surface properties and geometry appears to have larger impacts on urban temperature [3–8].

An observational fact regarding the contribution of anthropogenic heat to the UHI is the temperature difference between weekdays and weekend days. The temperature in central Tokyo was found to be lower on holidays than on weekdays by about $0.2 \text{ }^{\circ}\text{C}$ [9,10], while negative holiday temperature anomalies less than $0.1 \text{ }^{\circ}\text{C}$ were detected even at weakly urbanized sites with population densities of 300 to 1000 km^{-2} in Japan [11,12]. During a period of self-restraint due to the COVID-19 pandemic in 2020, low temperature anomalies reaching $0.5 \text{ }^{\circ}\text{C}$ were observed in the Tokyo area [13]. Low temperatures on holidays, during vacation periods, and under COVID-19 lockdowns have also been found in cities in other countries [14–23].

The UHI also affects winds [1]. The high drag of urban surfaces can cause a decrease in wind speed, which may be called an “urban stilling island” [24], whereas the reduced stability of the surface boundary layer can enhance vertical turbulent mixing that accelerates surface wind, resulting in an “urban wind island”, in which wind speed is higher than in surrounding rural areas [25]. The latter feature has been detected in a number of statistical studies for large cities based on observed wind data, especially under a low ambient wind speed [26–29], although it is not found in some cities [30]. Additionally, the high

temperature over a city is accompanied by a local thermal circulation with converging surface winds [31,32]. However, there have been only a few studies examining urban wind changes from the viewpoint of weekday–holiday differences, which can isolate the effect of anthropogenic heat on winds. For central Tokyo, the wind speed on holidays was found to be lower than on weekdays by about 0.1 ms^{-1} [9], probably because of the stronger stability of the surface layer under a smaller amount of anthropogenic heat, whereas the surface wind field in the surrounding area was found to show a divergent anomaly [10], indicating a weaker thermal circulation under a weaker heat island. However, these two studies were conducted nearly 40 years ago, because of which our knowledge of weekday–holiday differences in urban winds is still limited in the absence of other studies on this topic.

The aim of the present study is to provide further statistical evidence on weekday–holiday differences in wind speed at urban sites in Japan using observational data over decades. Analysis on temperature was also made in order to compare the response of temperature and wind speed to weekday–holiday differences in anthropogenic heat. In addition to nationwide data from the Automated Meteorological Data Acquisition System (AMeDAS) operated by the Japan Meteorological Agency (JMA), spatially dense data from the Air Pollution Monitoring System (APMS) of the Tokyo Metropolis were used to explore detailed spatial features of the impact of anthropogenic heat on temperature and wind speed.

It is to be noted that a weekly meteorological cycle may also be created by anthropogenic aerosols [33–37], not only within a city but on a regional scale [33–39], with a possibility of higher temperature on holidays than on weekdays [34]. Indeed, there was a period in which the temperature in central Tokyo was higher on holidays than on weekdays in the early 20th century under heavy air pollution [40]. On the other hand, the periodicity inherent in nature can generate a spurious weekly cycle [41–43], while the effect of aerosols on temperature is likely to have decreased in Japan as air pollution has improved. The present study is focused on urban-specific temperature and wind speed anomalies, which are believed to arise from anthropogenic heat emission depending on the degree of urbanization at each site.

2. Data and Procedure of Analysis

2.1. Data and Station Grouping

The main part of this study was based on hourly AMeDAS data on air temperature and surface wind speed for the 44 years from April 1979 to March 2023. The reason for starting the analysis in April was to avoid missing data at the beginning of 1979 at some stations. Note that the period from April to March of the next year is a financial year (FY) in Japan. Data on temperature were obtained at a precision of $0.1 \text{ }^{\circ}\text{C}$. The precision of wind speed was 1 ms^{-1} until the late 2000s, after which it changed to 0.1 ms^{-1} . The thermometers were installed at a height of 1.5 m above the ground, except at stations in areas of deep snow in winter, while the height of the anemometers was different according to stations. The information on changes in site and anemometer height was obtained from a file provided by JMA [44]. The time is Japan Standard Time (JST), which is nine hours ahead of UTC.

The analysis was limited to the domain north of 30° N because of the difficulty of finding reference non-urban stations (see Section 2.2.3) in the small island area south of 30° N . Stations at which the percentage of missing data exceeded 10% in any one of the forty-four financial years or in any one of the twelve months through the period were not used. In order to avoid the influence of discontinuity due to site changes, stations that moved by a horizontal distance of 1 km or more or a height of 5 m or more were not used. As an exception, the Tokyo station was used, although it had experienced site changes because it provides valuable data in the central part of Tokyo. On the other hand, a station for which the area was long uninhabited after the 2011 Great East Japan Earthquake was excluded. The final number of stations used for analysis was 434. Figure 1b shows

the distribution of these stations. The climatic characteristics of Japan are outlined in the literature [45,46].

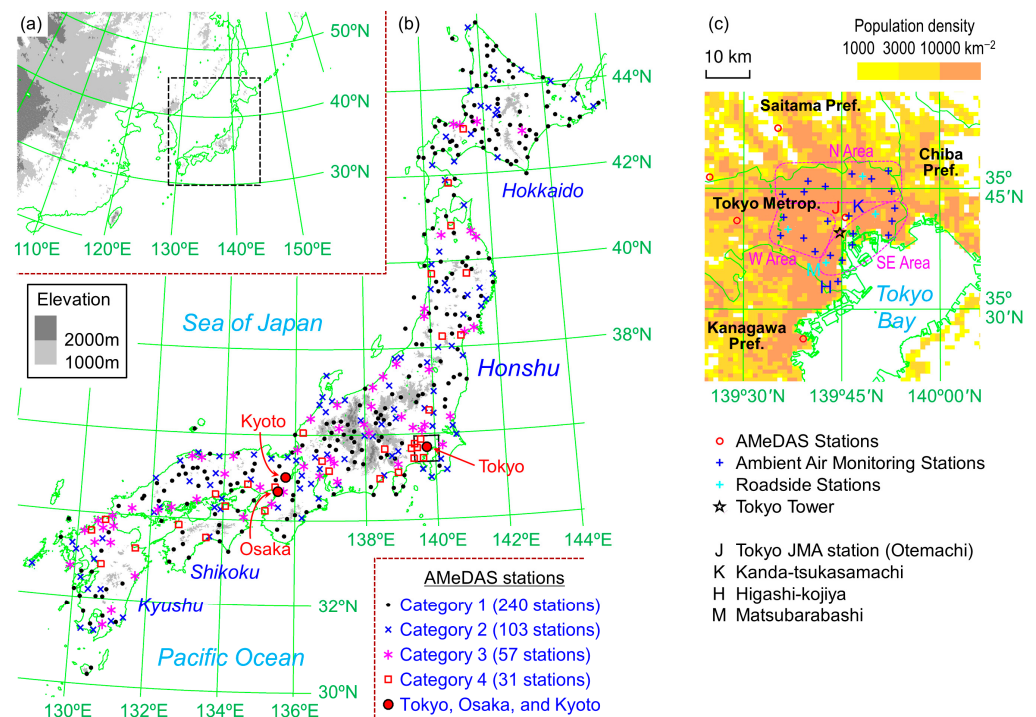


Figure 1. Map showing (a) the topography of East Asia, (b) locations of the AMeDAS stations used for analysis, and (c) the APMS and AMeDAS stations in the Tokyo Wards Area (TWA). The square in (a) indicates the region shown in (b), and the square in (b) indicates the region shown in (c). In (c), the boundaries of prefectures and the Tokyo Metropolis are shown in green solid lines, and the western border of the TWA is shown in a green dotted line.

As a measure of urbanness around each station, the population density in the surrounding area was calculated using the population data from the 2015 National Census. They were provided in the Portal Site of Official Statistics of Japan [47] on grids 30'' in latitude and 45'' in longitude (approximately 1 km × 1 km). A weighted spatial averaging was applied in the following form:

$$P(i) = \frac{\sum_g \exp\left\{-\left(\frac{r_{ig}}{R}\right)^2\right\} P^*(g)}{\pi R^2} \quad (1)$$

where r_{ig} is the distance from station i to grid g , $P^*(g)$ is the population in grid g , and $R = 3$ km. For a station that had undergone site changes, the P calculated for each site was averaged with a weight of the duration of operation there. There were three stations with $P \geq 10,000$ km⁻², namely, Tokyo, Osaka, and Kyoto (Figure 1b). These stations were analyzed separately. Other stations were grouped into four categories in P as category 1: $P < 300$ km⁻², 2: $300 \leq P < 1000$ km⁻², 3: $1000 \leq P < 3000$ km⁻², and 4: $3000 \leq P < 10,000$ km⁻².

The relocation of the Tokyo Station from Otemachi to Kitanomaru Park was on 1 November 2007 for the anemometer and on 2 December 2014 for the thermometer [48]. The two sites were approximately 900 m apart. The old site was in a business area beside a big street, while the new site is in a park that is part of a large, vegetated area neighboring the Imperial Palace. The striking difference in land use around the two sites enables us to assess the spatial extent of the effects of anthropogenic heat on temperature and wind speed. Parallel observations at the two sites for three years revealed that the daily mean

and minimum temperatures at the new site were lower than those of the old site by 0.9 °C and 1.4 °C, respectively [48].

A detailed analysis of the Tokyo area was made using hourly data of the APMS of Tokyo Metropolis for the 28 years from April 1995 to March 2023 [49]. The data precision was 0.1 °C for temperature and 0.1 ms^{−1} for wind. The heights of the thermometers and anemometers were different according to the stations. The Tokyo Metropolis consists of the Tokyo Wards Area (hereafter TWA) in its eastern part and the suburban Tama Area in its western part. The TWA is the former Tokyo City and has a population of nearly ten million in an area of 622 km². It is mostly flat, with the highest point at only 45 m above sea level. The present study was made using data at stations in the TWA (Figure 1c). On the condition that the percentage of missing data was less than 20% in each of the 28 financial years and each of the twelve months throughout the period, temperature data were available for 25 stations, and wind data were available for 23 stations. Among these, four stations were “Roadside Air Pollution Monitoring Stations” installed beside major roads to monitor the influence of automobile emissions. Others were “Ambient Air Monitoring Stations” installed in residential areas to measure the representative air quality in the surroundings. The Tokyo station operated by JMA will be referred to as “Tokyo JMA station” if it is needed to distinguish it from APMS stations.

Until July 2019, hourly observations were made at Tokyo Tower (333 m high) as part of APMS for temperature at six levels of 4, 64, 103, 169, 205, and 250 m and for wind at three levels of 25, 107, and 250 m above the ground. The data in 16 years (1998–2000, 2003–2011, and 2015–2018), for which missing data were less than 10% at all the levels in each year, were used to assess the vertical distribution of temperature and wind speed.

Table 1 shows the national holidays of Japan. The date of a holiday was changed, or a temporary holiday was set for some years. A list of holidays each year is available on the website of the Cabinet Office of the government [50]. Many government offices, companies, and schools are closed on Sundays, national holidays, and the first three days of the New Year. Since 1973, if a national holiday falls on a Sunday, the following Monday has been made a substitute holiday. Furthermore, many offices and schools were closed in the afternoon on Saturdays, and since the 1980s, most organizations have been closed all day on Saturdays. In the present study, holidays were defined as Sundays, national holidays, substitute holidays, and the first three days of the New Year. They were excluded from the statistics for weekdays and Saturdays.

Table 1. National holidays of Japan as of 2024.

Name	Date
New Year’s Day	1 January
Coming-of-Age Day	Second Monday of January
National Foundation Day	11 February
Emperor’s Birthday **	23 February
Vernal Equinox Day	Around 21 March
Showa Day *	29 April
Constitution Memorial Day	3 May
Greenery Day *	4 May
Children’s Day	5 May
Marine Day *	Third Monday of July
Mountain Day *	11 August
Respect-for-the-Aged Day	Third Monday of September
Autumnal Equinox Day	Around 23 September
Health and Sports Day	Second Monday of October
Culture Day	3 November
Labor Thanksgiving Day	23 November

* Established after 1979. ** 29 April until 1988; 23 December for 1989–2018.

2.2. Procedure of Analysis

2.2.1. Normalization of Wind Speed Data

Wind speed data were normalized by their long-term average in order to avoid the influence of different anemometer heights and surface roughness among stations. For stations that had experienced changes in location and/or anemometer height, the normalization was made using the average wind speed over each period bounded by the time of changes.

2.2.2. Deviation from the Climatic Norms

For both temperature and wind speed, deviations from the climatic norms were used. The climatic norm for the AMeDAS data was obtained by calculating the 44-year average for each time of the day and calendar day and then applying nine-day running averaging three times in order to filter out day-to-day irregularities. The same procedure was applied to the 28-year APMS data of Tokyo.

2.2.3. Detection of Weekday–Holiday Difference

The deviation of temperature and wind speed on holidays with respect to those on weekdays was evaluated by comparing the temperature/wind speed on a holiday with that which would have been observed if it was a weekday. The latter was estimated for each target station on the basis of the distribution of temperature/wind speed at nearby category 1 stations using a regression equation developed for weekdays. The procedure was in the following steps.

Step 1: A principal component analysis was applied to obtain representative patterns of temperature/wind speed around each target station. The analysis was made using category 1 stations within $r_0 = 300$ km of the target station in the following form:

$$Z_{ij} = \sum_{k=1}^K f_{jk} a_{ik} + \text{higher terms} \quad (2)$$

where z_{ij} is either temperature or wind speed (deviation from the norms) at a category 1 station i on date j , a_{ik} and f_{jk} are the spatial pattern and temporal change in the k -th principal component, respectively, and K is the number of principal components used for the analysis. The analysis was based on a covariance matrix $\mathbf{C} = \{c_{ih}\}$, where c_{ih} is the covariance between z_{ij} and z_{ih} ($j = \text{all weekdays}$) at reference stations i and h . Then, $\mathbf{C}$ was diagonalized as $\mathbf{C} = \mathbf{T}\mathbf{D}\mathbf{T}'$, where $\mathbf{T}$ is an orthogonal matrix and $\mathbf{D}$ is a diagonal matrix. The spatial pattern matrix $\mathbf{A} = \{a_{ik}\}$ was given by $\mathbf{A} = \mathbf{T}\mathbf{D}^{1/2}$, where $\mathbf{D}^{1/2}$ is a diagonal matrix having square-rooted elements of $\mathbf{D}$. The score f_{jk} was obtained by solving (1) as a multi-linear equation for $k = 1, \dots, K$, which was set to 20. The advantage of using principal components is to reduce the number of independent variables in the subsequent analysis (Equation (3) below) instead of using the data at individual reference stations. It also has the merit of reducing the influence of missing data among the reference stations.

Since temperature and wind patterns can vary according to the time of the day and season, principal components were defined separately for each time of the day and each month. For temperature at Tokyo, the contribution of the top 20 components was 96.2% on average over times of the day and months, with a minimum and maximum of 94.0% and 98.0%, respectively. For wind speed at Tokyo, it was 81.7% on average, with a minimum and maximum of 77.6% and 84.2%, respectively. Note that f_{jk} was calculated separately for each AMeDAS station, while the f_{jk} values for the Tokyo JMA station were used in the analysis of the Tokyo APMS data.

Step 2: A regression equation for temperature or wind speed at a target station on date j , hereafter denoted as Z_j , was created from the data on weekdays using a least-squares condition, as follows:

$$\sum \left[Z_j - \left(p_0 + \sum_{k=1}^K p_k f_{jk} \right) \right]^2 \rightarrow \text{minimum} \quad (3)$$

where p_k ($k = 0, \dots, K$) is a least-squares coefficient. The regression was made for each month and time of the day for the same reason as in Step 1.

Step 3: The regression equation obtained in Step 2 was applied to the data on holidays to estimate the temperature/wind speed that would have been observed if it had been a weekday. It is denoted as $\langle Z_j \rangle$ here. Then the departure of the observed value from $\langle Z_j \rangle$ was obtained as follows:

$$\Delta Z_j = Z_j - \langle Z_j \rangle, \quad (4)$$

and ΔZ_j was averaged over the analysis period. The same procedure was applied to Saturdays and other days of the week. Hereafter the statistical values of ΔZ_j for temperature and wind speed will be denoted as ΔT and Δv , respectively.

In order to improve the statistical confidence of the results, the analysis was made in three-hour units. For example, data from 0800 to 1000 JST were used as those of 0900 JST. The daily mean values of ΔT and Δv were defined by the average from 0800 JST to 0700 JST of the next day, considering the time of human activity in cities.

3. Results

3.1. Nationwide Features

Figure 2 shows the weekly variations of the daily mean values of ΔT and Δv for the three cities of Tokyo, Osaka, Kyoto, and category 2–4 stations. The period is from April 1979 to March 2023, although ΔT for Tokyo was obtained from the data at the old site until 1 December 2014, considering the possible effect of the relocation discussed later. Table 2 shows the ΔT and Δv values on holidays and Saturdays for each station and category. On holidays, ΔT has a negative value of -0.16 °C for Tokyo and is significantly negative at the 1% level down to category 2, while Δv is -0.028 for Tokyo and is significantly negative at the 1% level down to category 3. The differences between holidays and Sundays only are generally small. For Saturdays, ΔT has negative values that are about half of those of holidays, while Δv is much smaller than that of holidays, with only Tokyo and Osaka showing significant negative values at the 5% level.

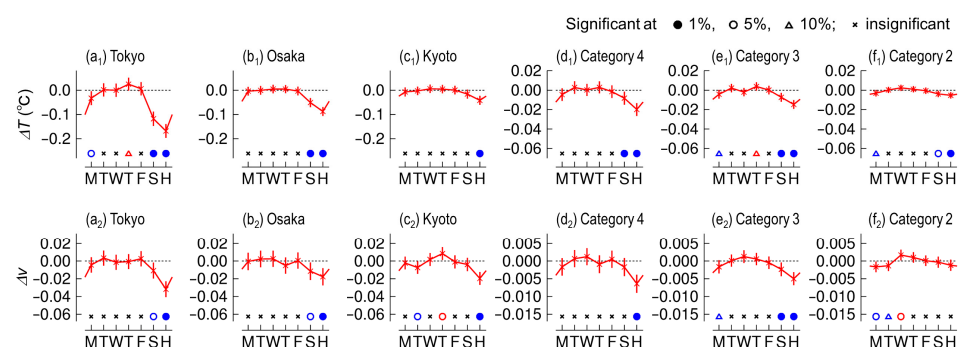


Figure 2. Weekly variations of daily mean values of ΔT and Δv for April 1979 to March 2023. Vertical bars indicate the 95% confidence ranges, and symbols at the bottom of each panel indicate the degree of statistical significance, in red and blue for positive and negative values, respectively (the same in the following figures).

Table 2. Daily mean values of ΔT and Δv for holidays, Sundays, and Saturdays for April 1979 to March 2023.

		Tokyo **	Osaka	Kyoto	Cat. 4	Cat. 3	Cat. 2
ΔT (°C) *	Holiday	<u>−0.165</u>	<u>−0.086</u>	<u>−0.043</u>	<u>−0.021</u>	<u>−0.014</u>	<u>−0.005</u>
	Sunday	<u>−0.168</u>	<u>−0.088</u>	<u>−0.042</u>	<u>−0.020</u>	<u>−0.015</u>	<u>−0.005</u>
	Saturday	<u>−0.118</u>	<u>−0.051</u>	(−0.016)	<u>−0.008</u>	<u>−0.007</u>	<u>−0.004</u>
Δv *	Holiday	<u>−0.0285</u>	<u>−0.0165</u>	<u>−0.0156</u>	<u>−0.0059</u>	<u>−0.0048</u>	(−0.0007)
	Sunday	<u>−0.0318</u>	<u>−0.0176</u>	<u>−0.0196</u>	<u>−0.0064</u>	<u>−0.0050</u>	(−0.0012)
	Saturday	<u>−0.0108</u>	<u>−0.0115</u>	(−0.0038)	(−0.0017)	<u>−0.0023</u>	(−0.0003)

* Values in bold letters with a double underline are significant at the 1% level, and those with a single underline are significant at the 5% level. Parentheses indicate insignificant values. ** Until 1 December 2014 for ΔT . The values for April 1979 to March 2023 are -0.137 , -0.142 , and -0.100 °C for holidays, Sundays, and Saturdays, respectively, all significant at the 1% level.

Figure 3 shows the diurnal variations of ΔT and Δv on holidays. For Tokyo, ΔT keeps below -0.1 °C, and Δv keeps below -0.02 from morning to midnight on holidays. The other two cities and stations in categories 4 and 3 also show negative values of ΔT and Δv for most of the day. In category 4 to 2 stations, ΔT has a negative peak at 0900 JST, which can be explained by a relatively low mixing height, below which the anthropogenic heat is confined, while no such feature is found for Δv . There is little difference in ΔT and Δv values between holidays and Sundays. Figure 4 shows the results for Saturdays. Significant negative ΔT values are found for most of the day for Tokyo and Osaka, and for some time periods for Kyoto and category 4 to 2 stations. In contrast, Δv is mostly insignificant, except for some time periods in Tokyo and Osaka.

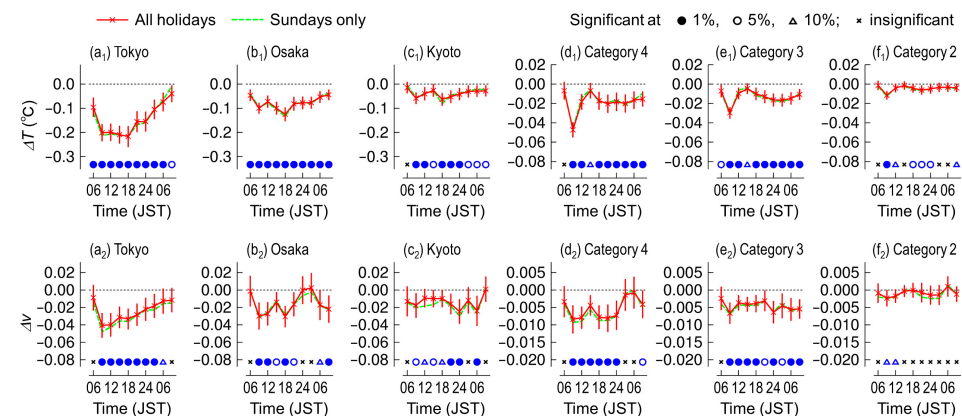
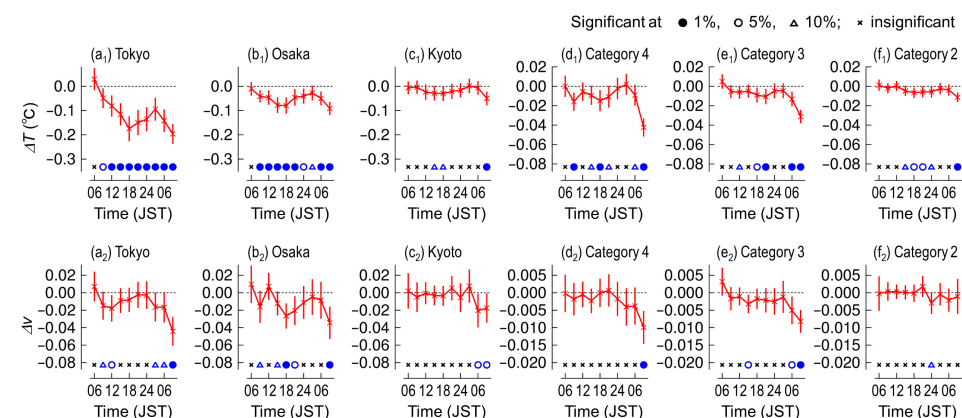
**Figure 3.** Diurnal variations of ΔT and Δv for holidays. The values on Sundays only are shown in dashed green lines without confidence ranges.**Figure 4.** Same as Figure 3, but for Saturdays.

Figure 5 shows the seasonal variations of ΔT and Δv on holidays. Negative ΔT values are the largest in winter in all three cities and categories. Seasonal variations of Δv are generally small, although the negative Δv value is largest in the summer in Tokyo.

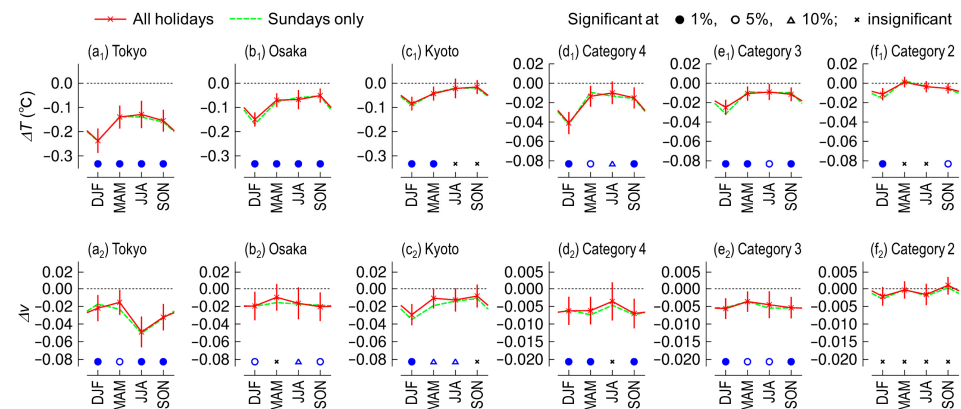


Figure 5. Seasonal variation of daily mean values of ΔT and Δv on holidays.

Figure 6 shows the long-term changes in ΔT and Δv by dividing the analysis period into six subperiods of seven to eight years each. For Tokyo, the times of the relocation of the anemometer and the thermometer were used for division. The relocation of the anemometer in 2007 did not affect Δv , whereas that of the thermometer in 2014 was accompanied by a dramatic reduction in ΔT . However, ΔT has smaller values in the final period (FY2015 to 2022) than before, even for Osaka and Kyoto, which did not undergo relocation, and for the three categories. Therefore, the relationship between the reduction of ΔT and the relocation of the Tokyo station needs to be carefully assessed. Indeed, there appears to be an overall diminishing trend in ΔT in Figure 6. Table 3 shows the result of an analysis in which a linear trend term was added in the final stage of Section 2.2.3. A positive ΔT trend, which means a decrease in negative ΔT , is found at the 10% significance level for Tokyo and Osaka and at the 5% level for the category 3 stations. For Δv , no trend is found for any cities and categories. As an alternative method, the Mann–Kendall test was applied to the year-to-year values of ΔT and Δv . The results were basically the same as those presented in Table 3 in terms of the significance of trends, except that the positive trend of ΔT for the category 3 stations was significant at the 1% level, and that of Δv for Osaka was significant at the 10% level.

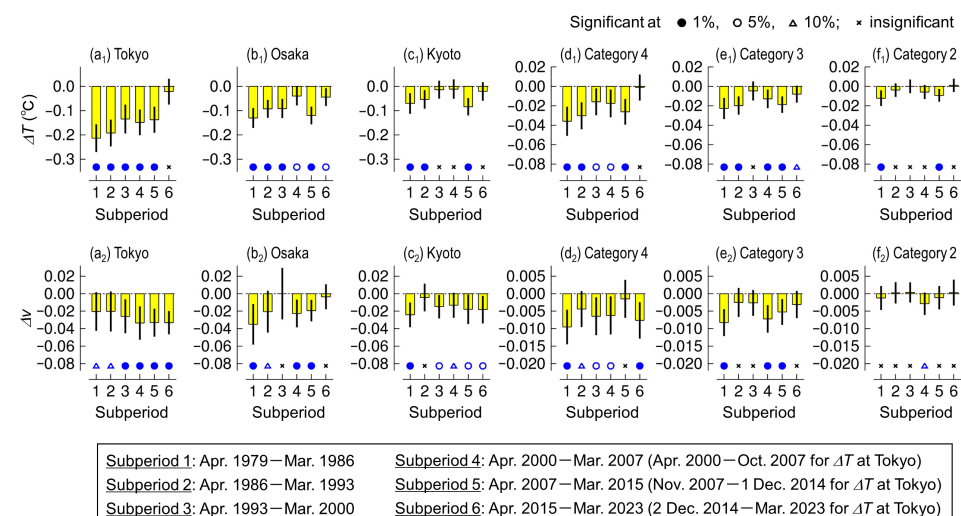


Figure 6. Daily mean values of ΔT and Δv on holidays for each subperiod.

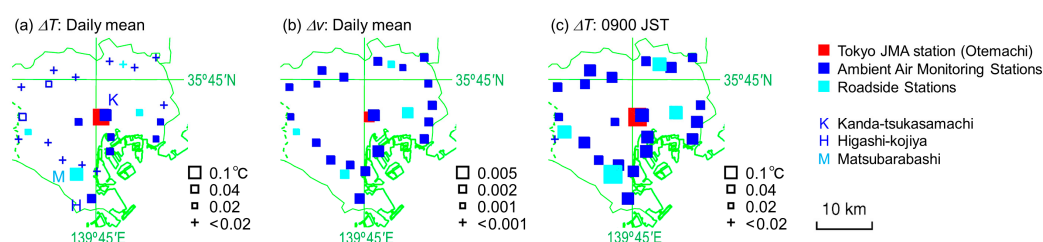
Table 3. Linear trends of ΔT and Δv for holidays obtained using an analysis in which a term of linear trend was added.

	Tokyo **	Osaka	Kyoto	Cat. 4	Cat. 3	Cat. 2
ΔT ($^{\circ}\text{C decade}^{-1}$) *	<u>0.026</u>	<u>0.014</u>	(0.004)	<u>0.007</u>	(0.003)	(0.002)
Δv (decade^{-1}) *	(−0.0037)	(0.0048)	(−0.0006)	(0.0008)	(0.0007)	(0.0001)

* Values with a single underline are significant at the 5% level, and those with italic letters with dotted underlines are significant at the 10% level. Parentheses indicate insignificant values. ** Until 1 December 2014 for ΔT . The value for April 1979 to March 2023 is $0.044\text{ }^{\circ}\text{C decade}^{-1}$, which is significant at the 1% level.

3.2. Local Features in Tokyo Wards Area (TWA)

Figure 7 shows the distribution of daily mean values of ΔT and Δv obtained from the APMS data in Tokyo for the period from April 1995 to March 2023. For reference, ΔT and Δv values at the Tokyo JMA station and other AMeDAS stations are also shown. An overall feature is that larger negative values of ΔT and Δv are found in the central area compared with the periphery, and among the periphery, larger negative values are found in the southeastern area compared with the western and the northern areas. More specifically, negative ΔT values that are statistically significant at the 1% level are found at only three stations, in addition to the Tokyo JMA station, namely, Kanda-tsukasamachi ($\Delta T = -0.074\text{ }^{\circ}\text{C}$), Higashi-kojiya ($\Delta T = -0.037\text{ }^{\circ}\text{C}$), and Matsubarabashi ($\Delta T = -0.090\text{ }^{\circ}\text{C}$). The Kanda-tsukasamachi station is located in Kanda Park, which is a small park 700 m northeast of the Tokyo JMA station at Otemachi, and the Higashi-kojiya station is within 100 m of a six-lane national highway, while Matsubarabashi is a roadside station. For other stations, ΔT is between $-0.03\text{ }^{\circ}\text{C}$ and $0.04\text{ }^{\circ}\text{C}$ and is statistically significant at the 10% level at only two stations. In contrast, Δv has widespread negative values and is significant at the 1% level at 14 stations. The largest negative value of Δv is -0.039 at Kanda-tsukasamachi.

**Figure 7.** Distribution of ΔT and Δv on holidays in TWA for April 1995 to March 2023. Open and closed squares indicate positive and negative values, respectively.

As shown in Figure 1c, the ambient monitoring stations, other than Kanda-tsukasamachi and Higashi-kojiya, were divided into three groups in the southeastern (SE), western (W), and northern (N) areas. Figure 8 shows the diurnal variations of ΔT and Δv for Kanda-tsukasamachi, Higashi-kojiya, and Matsubarabashi stations and the average of the stations in each area. The diurnal variations of ΔT at Kanda-tsukasamachi and Higashi-kojiya are similar to that at the Tokyo JMA station with respect to large negative values from the late morning to the evening. On the other hand, ΔT for the three areas is generally small and statistically insignificant, with values mostly between $-0.05\text{ }^{\circ}\text{C}$ and $0.05\text{ }^{\circ}\text{C}$ for most of the day. However, it has a negative peak at 0900 JST, just like the category 4–2 stations in Figure 3. The values of ΔT at 0900 JST are $-0.062\text{ }^{\circ}\text{C}$ in the SE area and $-0.040\text{ }^{\circ}\text{C}$ in the N area and are significant at the 1% and 10% levels, respectively. By station, ΔT at 0900 JST has significant negative values at the 1% level at 12 sites, including Kanda-tsukasamachi, Higashi-kojiya, and four roadside stations, and significant negative values at the 5% or 10% levels are found at seven more sites. In contrast, Δv has negative values between -0.01 and -0.02 from morning to night in each area. About half of these values are significant at the 1%–10% levels. The daily mean values of Δv are -0.019 in the southeast and -0.013 in the west and north areas, all of which are significant at the 1% level.

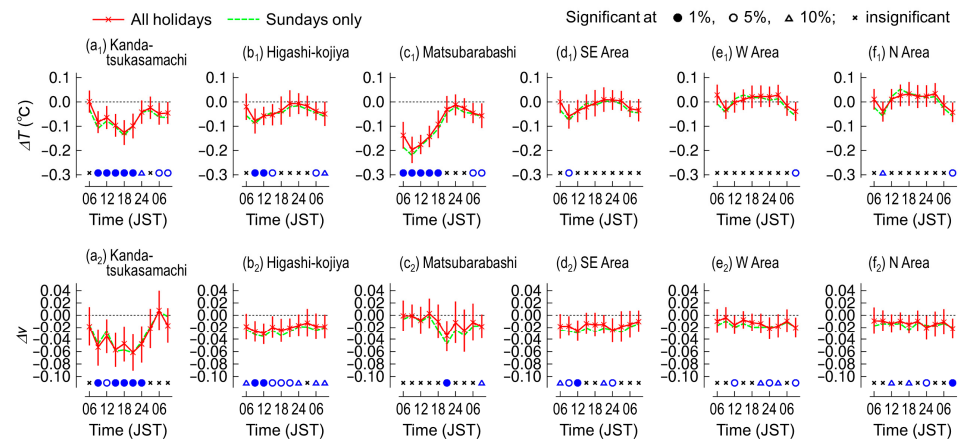


Figure 8. Diurnal variations of ΔT and Δv for holidays at APMS stations in TWA.

3.3. Vertical Distribution of ΔT and Δv

Figure 9a shows the daily mean values of (a₁) ΔT and (a₂) Δv at Tokyo Tower. Both ΔT and Δv are negative at all the levels. They tend to diminish with height but are significant at the 5% level, except for ΔT at 250 m. Figure 9b–d show the diurnal variations of ΔT and Δv at three levels of the tower. The diurnal variation pattern is common to each level in that negative ΔT values are limited to the daytime from 0900 to 1800 JST, while Δv remains negative through the night.

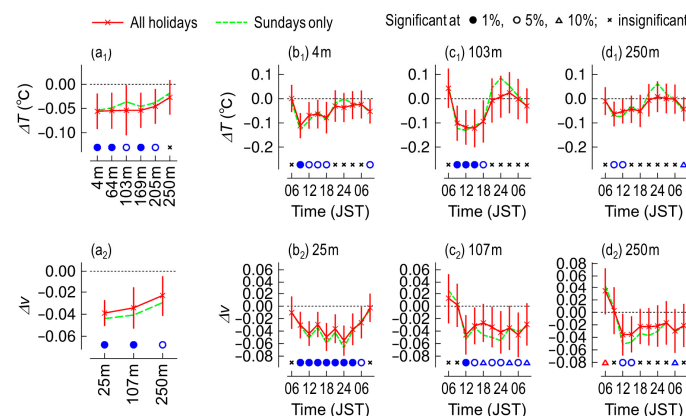


Figure 9. Daily mean values of ΔT and Δv on holidays at each level on Tokyo Tower, and their diurnal variations at three levels on the tower.

4. Discussion

This study has revealed lower wind speeds in Japanese cities on holidays than on weekdays. The negative anomaly on holidays was about -3% in central Tokyo. It corresponds to a real wind speed of the order of -0.1 ms^{-1} because the mean wind speed at Tokyo is approximately 3 ms^{-1} . The reduction in wind speed on holidays was found even for sites with population densities between 1000 and 3000 km^{-2} , namely, with a medium degree of urbanization. Previous studies have shown that the UHI can be accompanied by the acceleration of surface winds [25–29], presumably due to a decrease in the surface layer stability, while the present study has indicated that anthropogenic heat release can contribute to this effect.

On the other hand, the present study has raised some points that would require further research concerning the spatial scales and temporal changes in the impact of anthropogenic heat on the urban atmosphere. It has been found that the anthropogenic heat emission in Tokyo is concentrated in the central area [2], whereas the daily average ΔT values are small at most of the APMS stations in the TWA. This fact implies a small spatial scale of the influence of anthropogenic heat on temperature. In contrast, negative Δv values

are more widely distributed over the TWA, suggesting that the change in wind speed, or the change in the stability of the surface boundary layer due to anthropogenic heat, may have a larger horizontal range than the change in temperature. However, a regional-scale temperature decrease was detected for the 2020 COVID-19 self-refraining period [13], which is inconsistent with the present result. There may be a diversity of spatial scales of the impact of anthropogenic heat on urban climate.

The present study has indicated a long-term reduction in ΔT for part of the stations where a positive ΔT trend (namely, diminishing negative anomaly) was observed. Urban warming has decelerated in Japanese cities since around 2000 [51], suggesting the possibility of decreasing anthropogenic heat emissions in the last few decades. However, ΔT trends are not seen at all the stations, while the effect of relocation cannot be ruled out for the Tokyo JMA station. At present, the reduction of ΔT is only a possibility.

The analysis for Tokyo Tower has shown that both ΔT and Δv mostly have the same diurnal variation patterns from the lowest level to the 250 m height. The vertical coherence of ΔT , for which negative values appear mainly in the daytime, is in agreement with the concept of strong vertical heat diffusion in the mixing layer. On the other hand, the constant sign of Δv up to a height of 250 m is inconsistent with the general understanding that the stability-induced wind speed change is reversed at a height of 100 m or less, e.g., [52]. This situation implies some peculiar nature of the urban boundary layer or a possibility of some extraneous factors, such as local thermal circulations [10]. Tower data are insufficient to cover the entire urban boundary layer, and the vertical structure of wind speed changes due to anthropogenic heat needs further investigation, including a numerical approach.

5. Summary

- Wind speeds on holidays were found to be lower than those on weekdays in urbanized locations in Japan. The reduction was about 3% in central Tokyo and about 0.5% in locations with population densities of 1000–3000 km^{−2}. The lower wind speed on holidays than on weekdays is likely to reflect the stronger stability of the surface boundary layer due to reduced anthropogenic heat release;
- Weekday–holiday differences in temperature and wind speed have some different features in spatial and temporal variations. In the Tokyo Wards Area, the weekday–holiday difference in wind speed is less concentrated in the central area in comparison to that of temperature, implying different spatial scales in the effects of anthropogenic heat on temperature and wind speed, or temperature and surface layer stability.

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References

1. Oke, T.R.; Mills, G.; Christen, A.; Voogt, J.A. *Urban Climates*; Cambridge University Press: Cambridge, UK, 2017; 546p. [CrossRef]
2. Ministry of Land, Infrastructure, Transport and Tourism; Ministry of the Environment. Report on Heat Island Countermeasures by Controlling Anthropogenic Heat in Cities. 2004; 165p. Available online: https://www.mlit.go.jp/sogoseisaku/heat_island/index.html (accessed on 11 August 2024). (In Japanese)
3. Kusaka, H.; Kimura, F. Coupling a single-layer urban canopy model with a simple atmospheric model: Impact on urban heat island simulation for an idealized case. *J. Meteorol. Soc. Jpn.* **2004**, *82*, 67–80. [CrossRef]
4. Kusaka, H.; Kimura, F. Thermal effects of urban canyon structure on the nocturnal heat island: Numerical experiment using a mesoscale model coupled with an urban canopy model. *J. Appl. Meteorol.* **2004**, *43*, 1899–1910. [CrossRef]
5. Aoyagi, T.; Kayaba, N.; Seino, N. Numerical simulation of the surface air temperature change caused by increases of urban area, anthropogenic heat, and building aspect ratio in the Kanto-Koshin area. *J. Meteorol. Soc. Jpn.* **2012**, *90B*, 11–31. [CrossRef]

6. Ryu, Y.-H.; Baik, J.-J. Quantitative analysis of factors contributing to urban heat island intensity. *J. Appl. Meteorol. Climatol.* **2012**, *51*, 842–854. [\[CrossRef\]](#)
7. Nakajima, K.; Takane, Y.; Kikegawa, Y.; Furuta, Y.; Takamatsu, H. Human behaviour change and its impact on urban climate: Restrictions with the G20 Osaka Summit and COVID-19 outbreak. *Urban Clim.* **2021**, *35*, 100728. [\[CrossRef\]](#)
8. Takane, Y.; Nakajima, K.; Kikegawa, Y. Urban climate changes during the COVID-19 pandemic: Integration of urban-building-energy model with social big data. *npj Clim. Atmos. Sci.* **2022**, *5*, 44. [\[CrossRef\]](#)
9. Fujibe, F. Weekday-weekend differences of urban climates. Part 1. Temporal variation of air temperature and other meteorological parameters in the central part of Tokyo. *J. Meteorol. Soc. Jpn.* **1987**, *65*, 923–929. [\[CrossRef\]](#)
10. Fujibe, F. Weekday-weekend differences of urban climates. Part 3. Temperature and wind fields around Tokyo and Osaka. *J. Meteorol. Soc. Jpn.* **1988**, *66*, 377–385. [\[CrossRef\]](#)
11. Fujibe, F. Weekday-weekend differences of urban climates. Part 2: Detection of temperature differences for medium- and small-sized cities. *J. Meteorol. Soc. Jpn.* **1988**, *66*, 373–376. [\[CrossRef\]](#)
12. Fujibe, F. Day-of-the-week variations of urban temperature and their long-term trends in Japan. *Theor. Appl. Climatol.* **2010**, *102*, 393–401. [\[CrossRef\]](#)
13. Fujibe, F. Temperature anomaly in the Tokyo Metropolitan area during the COVID-19 (coronavirus) self-restraint period. *SOLA* **2020**, *16*, 175–179. [\[CrossRef\]](#)
14. Simmonds, I.; Keay, K. Weekly cycle of meteorological variations in Melbourne and the role of pollution and anthropogenic heat release. *Atmos. Environ.* **1997**, *31*, 1589–1603. [\[CrossRef\]](#)
15. Earl, N.; Simmonds, I.; Tapper, N. Weekly cycles in peak time temperatures and urban heat island intensity. *Environ. Res. Lett.* **2016**, *11*, 074003. [\[CrossRef\]](#)
16. Wang, C.; Zhan, W.; Liu, X.; Liu, Z.; Miao, S.; Du, H.; Li, J.; Wang, C.; Li, L.; Yue, W. Strong modulation of human-activity-induced weekend effect in urban heat island by surface morphology and weather conditions. *J. Geophys. Res. Atmos.* **2022**, *127*, e2022JD036905. [\[CrossRef\]](#)
17. Du, H.; Zhan, W.; Liu, Z.; Wang, C.; Wang, S.; Li, L.; Li, J.; Bechtel, B.; Sismanidis, P. Weekly rhythms of urban heat islands: A multicity perspective. *Sustain. Cities Soc.* **2024**, *106*, 105385. [\[CrossRef\]](#)
18. Zhang, J.; Wu, L.; Yuan, F.; Dou, J.; Miao, S. Mass human migration and Beijing's urban heat island during the Chinese New Year holiday. *Sci. Bull.* **2015**, *60*, 1038–1041. [\[CrossRef\]](#)
19. Dou, J.; Miao, S. Impact of mass human migration during Chinese New Year on Beijing urban heat island. *Int. J. Climatol.* **2017**, *37*, 4199–4210. [\[CrossRef\]](#)
20. Zhang, J.; Wu, L. Influence of human population movements on urban climate of Beijing during the Chinese New Year holiday. *Sci. Rep.* **2017**, *7*, 45813. [\[CrossRef\]](#)
21. Zhan, W.; Liu, Z.; Bechtel, B.; Li, J.; Lai, J.; Fu, H.; Li, L.; Huang, F.; Wang, C.; Chen, Y. Urban-rural gradient in urban heat island variations responsive to large-scale human activity changes during Chinese New Year holiday. *Geophys. Res. Lett.* **2022**, *49*, e2022GL100689. [\[CrossRef\]](#)
22. Liu, Z.; Lai, J.; Zhan, W.; Bechtel, B.; Voogt, J.; Quan, J.; Hu, L.; Fu, P.; Huang, F.; Li, L.; et al. Urban heat islands significantly reduced by COVID-19 lockdown. *Geophys. Res. Lett.* **2022**, *49*, e2021GL096842. [\[CrossRef\]](#)
23. Sun, S.; Zhou, D.; Chen, H.; Li, J.; Ren, Y.; Liao, H.; Liu, Y. Decreases in the urban heat island effect during the Coronavirus Disease 2019 (COVID-19) lockdown in Wuhan, China: Observational evidence. *Int. J. Climatol.* **2022**, *42*, 8792–8803. [\[CrossRef\]](#)
24. Yang, P.; Ren, G.; Yan, P.; Deng, J. Temporal pattern of surface wind speed and the “urban stilling island” in Beijing City. *J. Meteorol. Res.* **2020**, *34*, 986–996. [\[CrossRef\]](#)
25. Droste, A.M.; Steeneveld, G.J.; Holtslag, A.A.M. Introducing the urban wind island effect. *Environ. Res. Lett.* **2018**, *13*, 094007. [\[CrossRef\]](#)
26. Bornstein, R.D.; Johnson, D.S. Urban-rural wind velocity differences. *Atmos. Environ.* **1977**, *11*, 597–604. [\[CrossRef\]](#)
27. Lee, D.O. The influence of atmospheric stability and the urban heat island on urban-rural wind speed differences. *Atmos. Environ.* **1979**, *13*, 1175–1180. [\[CrossRef\]](#)
28. Fortuniak, K.; Klysik, K.; Wibig, J. Urban–rural contrasts of meteorological parameters in Łódź. *Theor. Appl. Climatol.* **2006**, *84*, 91–101. [\[CrossRef\]](#)
29. Baidar, S.; Bonin, T.; Choukulkar, A.; Brewer, A.; Hardesty, M. Observation of the urban wind island effect. *EPJ Web Conf.* **2020**, *237*, 06009. [\[CrossRef\]](#)
30. Shreffler, J.H. Urban-rural differences in tower-measured winds, St. Louis. *J. Appl. Meteorol.* **1979**, *18*, 829–835. [\[CrossRef\]](#)
31. Shreffler, J.H. Detection of centripetal heat island circulations from tower data in St. Louis. *Bound. Layer Meteorol.* **1978**, *15*, 229–242. [\[CrossRef\]](#)
32. Fujibe, F.; Asai, T. Some features of a surface wind system associated with the Tokyo heat island. *J. Meteorol. Soc. Jpn.* **1980**, *58*, 149–152. [\[CrossRef\]](#)
33. Forster, P.M.D.F.; Solomon, S. Observations of a “weekend effect” in diurnal temperature range. *Proc. Natl. Acad. Sci. USA* **2003**, *100*, 11225–11230. [\[CrossRef\]](#) [\[PubMed\]](#)
34. Gong, D.-Y.; Guo, D.; Ho, C.-H. Weekend effect in diurnal temperature range in China: Opposite signals between winter and summer. *J. Geophys. Res.* **2006**, *27*, D18113. [\[CrossRef\]](#)

35. Bäumer, D.; Vogel, B. An unexpected pattern of distinct weekly periodicities in climatological variables in Germany. *Geophys. Res. Lett.* **2007**, *34*, L03819. [CrossRef]
36. Kim, B.-G.; Choi, M.-H.; Ho, C.-H. Weekly periodicities of meteorological variables and their possible association with aerosols in Korea. *Atmos. Environ.* **2009**, *43*, 6058–6065. [CrossRef]
37. Song, Z.; Zhang, J. Weekend effect in summertime temperature and precipitation over the Yangtze River Delta region. *Theor. Appl. Climatol.* **2022**, *150*, 379–388. [CrossRef]
38. Laux, P.; Kunstmann, H. Detection of regional weekly weather cycles across Europe. *Environ. Res. Lett.* **2008**, *3*, 044005. [CrossRef]
39. Jiang, S.; Wang, K. Exploring the holiday effect on air temperatures. *Sci. Rep.* **2018**, *8*, 17943. [CrossRef]
40. Fujibe, F. Long-term changes in weekday-holiday temperature difference in central Tokyo: Analysis since the early 20th century. *Geogr. Rep. Tokyo Metropol. Univ.* **2023**, *58*, 25–32. Available online: <https://tokyo-metro-u.repo.nii.ac.jp/record/10027/files/20005-058-004.pdf> (accessed on 11 August 2024).
41. Kim, K.-Y.; Park, R.J.; Kim, K.-R.; Na, H. Weekend effect: Anthropogenic or natural? *Geophys. Res. Lett.* **2010**, *37*, L09808. [CrossRef]
42. Daniel, J.S.; Portmann, R.W.; Solomon, S.; Murphy, D.M. Identifying weekly cycles in meteorological variables: The importance of an appropriate statistical analysis. *J. Geophys. Res. Atmos.* **2012**, *117*, D13203. [CrossRef]
43. Sanchez-Lorenzo, A.; Laux, P.; Hendricks Franssen, H.-J.; Calbó, J.; Vogl, S.; Georgoulas, A.K.; Quaas, J. Assessing large-scale weekly cycles in meteorological variables: A review. *Atmos. Chem. Phys.* **2012**, *12*, 5755–5771. [CrossRef]
44. Japan Meteorological Agency. History of AMeDAS Stations. Available online: <https://www.data.jma.go.jp/obd/stats/data/mdrr/chiten/meta/amdmaster.index4> (accessed on 11 August 2024).
45. Arakawa, H.; Taga, S. Climate of Japan. In *World Survey of Climatology Volume 8: Climates of Northern and Eastern Asia*; Arakawa, H., Ed.; Elsevier: Amsterdam, The Netherlands, 1969; pp. 119–158. ISBN 978-0444407047.
46. Japan Meteorological Agency. General Information on Climate of Japan. Available online: <https://www.data.jma.go.jp/gmd/cpd/longfcst/en/tourist.html> (accessed on 29 August 2024).
47. Statistics Bureau of Japan. Population Census. Available online: <https://www.e-stat.go.jp/en/stat-search/files?toukei=00200521> (accessed on 11 August 2024).
48. Japan Meteorological Agency; Tokyo Regional Headquarters. On the Site Change of the Tokyo Surface Observation Station. *Weather Serv. Bull. JMA* **2016**, *83*, 1–32. Available online: <https://www.jma.go.jp/jma/kishou/books/sokkou/83/vol83p001.pdf> (accessed on 11 August 2024). (In Japanese)
49. Tokyo Metropolitan Government. Air Quality of Tokyo. Available online: https://www.kankyo.metro.tokyo.lg.jp/air/air_quality_monitor (accessed on 11 August 2024). (In Japanese)
50. Cabinet Office. National Holidays. Available online: <https://www8.cao.go.jp/chosei/shukujitsu/syukujitsu.csv> (accessed on 11 August 2024). (In Japanese)
51. Fujibe, F. Recent decelerating trends of urban warming in Japan. *SOLA* **2024**, *20*, 94–98. [CrossRef]
52. Crawford, K.C.; Hudson, H.R. The diurnal wind variation in the lowest 1500 ft in central Oklahoma: June 1966–May 1967. *J. Appl. Meteorol.* **1973**, *12*, 127–132. [CrossRef]

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