Regional characteristics of hot days and tropical nights in the Honam area, South Korea

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Abstract
This study analyses the regional characteristics of heat extremes (hot days and tropical nights) in the Honam area of South Korea during the recent 23 years (1997–2019) by using weather station data. The results based on the binary classifications of stations, that is, inland versus coastal and urban versus rural, show hot days in inland regions are climatologically more frequent, and present higher interannual variability and more evident increasing trend than coastal regions. On the other hand, inland regions are exposed to less active tropical nights. The thermal characteristics associated with the oceanic (or continental) climate at which the station is located are responsible for the inland–coastal dependency of frequencies in hot days and tropical nights. The noticeable discrimination between urban and rural stations, categorized by population, appears only in tropical night occurrences, while hot days are independent of urban–rural contrast. In urban stations, tropical night occurrences are climatologically higher, interannually more active, and recently more frequent. Regarding the urban heat island, the additional nocturnal heat leads to the urban concentrated activity of tropical nights. Our analyses suggest that for accurate forecasts of hot days and tropical nights, different regional environments must be considered.

Keywords
heat extremes, heat wave, hot day, geography, tropical night, urbanization

1 | INTRODUCTION

Since the Industrial Revolution in the mid-18th century, Earth’s mean temperature has been steadily increasing (IPCC, 2013). Recently, the temperature increase is accelerated by the interaction with changes in the Earth’s climate system, including sea ice, vegetation, and atmospheric circulation, leading to many recent outbreaks of extreme weather events, such as heat wave, tropical night, cold surge, flood, and drought (IPCC, 2013). In particular, due to the vulnerability of living things to extremely hot environments, heat extremes are having a tremendous impact on human socioeconomic aspects, and causing worldwide deaths and heat-related illnesses. In the USA, heat extremes in 1980 and 1988 killed more than 25,000 people (Smoyer et al., 2000). In 2003, heat extremes swept across Western Europe, including the United Kingdom, France, Portugal, and Spain, resulting in approximately 35,000 deaths (Kosatsky, 2005; Stott et al., 2004). During the summer of 2010, heat extremes broke the 500 year-long temperature...
records over about half of the entire European continent, especially eastern Europe, and large parts of Russia experienced extremely hot summers (Barriopedro et al., 2011). In China, more than 5500 heat-related illnesses occurred during the 2013 heat extremes period (Gu et al., 2016).

A total of 442 deaths during the summers of 1991–2011 were reported due to the heat extremes in South Korea, and 92 people died from heat-related diseases, especially in 1994, when the heat extremes were the most frequent. In this regard, as the number of heat extreme occurrences increased, the number of related deaths also increased exponentially (Kim et al., 2014). Recently, South Korea has experienced two extremely hot summers, in 2016 and 2018, when 2125 (17) and 4526 (48) patients (deaths) occurred, respectively (Korean Meteorological Administration [KMA], 2017, 2019). In the summer of 2016 and 2018, many heat extremes occurred across the entire country of South Korea, but the characteristics of occurrences and the related fatal impact varied by region (Lee et al., 2020). In relatively less hot summers, these region-dependent characteristics stand out more (Kim et al., 2014; Park et al., 2017). The climatological environment around weather stations where heat extremes are reported can lead to region dependency. In terms of heat capacity, inland and coastal stations show evident differences in the temperature variability, resulting in inland-concentrated heat extremes (Park et al., 2020). The urban heat island effect, dependent on urban growth, land use, and land cover change, provides additional heat and local warming to urban areas, compared to rural areas (Oke, 1982). Thus, several behaviors of heat extremes, including climatological occurrence frequency, interannual variability, and long-term change, are more active in urban areas than in rural areas (Park et al., 2017). These regional characteristics corresponding to inland/coastal and urban/rural stations can be considered to contribute to the geographical distribution of the heat extremes.

For heat extremes in South Korea, most previous studies covered just the occurrence mechanisms in synoptic or large scale, rather than the mechanisms for regional characteristics (Hong et al., 2018; Lee et al., 2017; Lee & Lee, 2016; Lee et al., 2020). In addition, though Hong et al. (2018) analyzed differences in physical mechanisms for hot days and tropical nights separately, most studies did not deal separately with hot days and tropical nights to diagnose factors that affect them. Locally, hot days defined from daily maximum temperature are deeply connected with the thermal properties in response to solar radiation during the day (Kim et al., 2014). On the other hand, because tropical nights are derived from daily minimum temperature, additional heat release related to urban heat islands and the humidity at night contribute to the occurrence of tropical nights (Hong et al., 2018). Thus, the features of occurrence of hot days and tropical nights differ from each other, depending on the surrounding environmental factors, such as inland/coastal and urban/rural stations.

This study focuses on the Honam area, which is the southwestern administrative district in South Korea. The study investigates the occurrence variations of hot days and tropical nights in the sense of the climatological environment of each station. In comparison between inland and coastal, urban and rural stations, we analyze the climatological mean, interannual variability, and long-term change of the occurrences. The Honam area is vulnerable to heat extremes. Although the geographical distribution of heat extremes appears to be most frequent over the southeastern part of South Korea (i.e., the Youngnam area) (Hong et al., 2018; Kim et al., 2014; Park et al., 2020), a higher mortality rate responding to heat extremes associated with socioeconomic factors, such as economic development, population density, and aging population (Kalkstein, 1991; Kalkstein & Davis, 1989), is found in the Honam area, than in the Youngnam area (Kim et al., 2006). Although the Honam area has a relatively small number of deaths or patients due to less occurrences of hot days and tropical nights, the mortality rate relative to population might be the highest in South Korea. Thus, considering human adaptive capacity and vulnerability to the heat extremes, it is of importance to understand the regional characteristics of heat extremes in the Honam area.

This paper is organized as follows. Section 2 provides the data and methodology, including the definition of hot days and tropical night, and categorization into inland, coastal, urban, and rural stations. The section also includes the calculation of the Indices of oceanity and urban heat island showing the climatological characteristics of each station. Section 3 analyses the climatology and interannual to long-term variation of occurrences of hot days and tropical nights in the categorized group (inland/coastal and urban/rural stations), and then investigates the relationship between their occurrences and climatological characteristics related to oceanity and the urban heat island. Section 4 concludes the paper with a summary and discussion.

### 2 DATA AND METHODOLOGY

The characteristics of hot day and tropical night frequencies from 1997 to 2019 are analyzed over the Honam area. As shown in Figure 1, observed datasets from a total 15 stations (Buan, Gawanju, Goheung, Gunsan, Haenam, Heuksando, Imsil, Jangheung, Jangsu, Jeongeup, Jeonju, Mokpo, Namwon, Wando, and Yeosu) in the Automated Surface
Observing System in South Korea are analyzed. The geographical location (including longitude, latitude, and elevation) and population around each station are used. According to the distance between each station and the nearest coastline, we have classified nine coastal (≤10 km from the coastline; blue markers in Figure 1) and six inland stations (>10 km from the coastline; red markers in Figure 1). The distance threshold for classifying coastal and inland stations is chosen by considering the typical radius of meso-gamma scale (Orlanski, 1975), which resides in the middle of the stratified distribution of distance among the stations (Table 1). Meanwhile, based on the population of the administrative district to which each station belongs, 5 urban (≥200,000 residents; circles in Figure 1) and 10 rural (<200,000 residents; triangles in Figure 1) stations are classified. The population threshold is chosen by considering the stratification of population distribution among the stations (Table 1) as well as the conventional public recognition of district size.

To define the yearly occurrences of hot days and tropical nights at each station, daily maximum and minimum temperatures provided by the KMA (https://data.kma.go.kr/cmmn/main.do) are obtained throughout the year. In addition, to represent the climatological characteristic of each station, monthly mean temperature is calculated using the daily mean temperature obtained from the same source. The records of hot days and tropical nights are provided according to the definition used by the KMA. The hot day is defined when the daily maximum temperature in the nighttime, that is from 1801 to 0900 the next day in local time standard, is greater than or equal to 25°C.

By using the monthly mean temperature, Kerner’s Oceaneity Index (KOI) adopted in Stonievičius et al. (2018) is calculated to objectively estimate the degree of oceanic climate of each station as:

$$KOI = \frac{100(T_{\text{oct}} - T_{\text{apr}})}{T_{\text{max}} - T_{\text{min}}},$$

where, $T_{\text{max}}$ and $T_{\text{min}}$ denote the yearly highest and lowest values among the monthly climatological temperatures, respectively. Similarly, $T_{\text{oct}}$ and $T_{\text{apr}}$ denote the climatology in October and April, respectively. The basic concept of KOI considers the specific heat capacity difference between the land and ocean in seasonal time scale, which is in the denominator of the Equation (1). Larger value of KOI is obtained when the ocean has more dominant influence on the station and thus having smaller $T_{\text{max}} - T_{\text{min}}$.

By using daily maximum and minimum temperatures, the Urban Heat Island Index (UHII) from Taha (2017) is simplified to objectively estimate the degree of urbanization of each station, as:

$$UHII = \langle (T_{i,\text{max}} - \bar{T}_{\text{max}}) - (T_{i,\text{min}} - \bar{T}_{\text{min}}) \rangle,$$

where $T_{i,\text{max}}$ and $T_{i,\text{min}}$ indicate the daily maximum and minimum temperature of the $i$th station, respectively. The overbar denotes the station average, while the
bracket \langle > \rangle indicates the average during the entire analysis period in the \(i\)th station. The basic concept of UHII considers the heat productivity as well as longwave radiative cooling difference between the city and countryside in daily time scale. Larger value of UHII would indicate that the region is warmer than the domain average.

Student’s \(t\)-test is applied to compare the mean distribution of the dataset. In consideration of the data with small sample sizes (e.g., below ~20), the Wilcoxon rank-sum test is adopted, because the assumptions of Student’s \(t\)-test may not be met. Standard deviation is estimated when comparing the interannual variation with different mean value of the hot day and tropical night frequencies. Finally, linear regression is used to examine their long-term trends.

### 3 | RESULTS

The station climatology of hot day and tropical night frequencies are shown in Figure 2. The climatological frequency of each station is listed in decreasing order, while indicating the station’s geographical (inland/coastal) and city scale (urban/rural) features as well. The hot day climatology (Figure 2a) largely varies from station to station, presenting its maximum frequency in Jeonju (19.3 days), and its minimum frequency in Heuksando (0.5 days). Concerning the rank distribution of inland and coastal stations, it is notable that the inland stations (red bars) are mostly ranked higher, while the coastal stations (blue bars) are mostly ranked lower. The only exception for inland station is Jangsu, having the third lowest hot days frequency (2.8 days), possibly due to the high altitude of the station, of 406 m above sea level (Table 1). The contrasts between urban (hatched bars) and rural (solid bars) are not clear. The orders of urban and rural stations corresponding to the hot day frequencies are mixed, not classified according to frequent ranking. Thus, hot day frequency is hypothesized to be relevant to the geographical feature, depending on the land–sea contrast, rather than the city size. Since there could be more factors or physical processes that would affect the hot day frequency, the rank of hot day frequency cannot exactly correspond to the distance from the coastline. Overall tendency of hot day frequency among the stations is more of concern in this study.

The tropical night climatology (Figure 2b) also varies in large range from 16.5 days in Mokpo, to 0.1 days in Jangsu. In terms of inland/coastal stations (red and blue bars, respectively), the ranks are slightly mixed-distributed, without clear separation. However, tropical night frequency in urban (hatched bars) and rural (blanked bars) stations are clearly discriminated into higher and lower ranks, respectively. In other words, contrary to the hot day frequency, the tropical night frequency cannot exactly correspond to the distance from the coastline. Overall tendency of hot day frequency among the stations is more of concern in this study.

To closely examine the above two hypotheses, the distribution of yearly hot day and tropical night frequencies in the categorized station groups are box-plotted...
(Figure 3), and Wilcoxon rank-sum test is used to compare the distribution of station groups. In Figure 3a, the distribution of the hot day frequencies in inland stations is clearly shifted to the higher values, compared to that in coastal stations. They are significantly separated with 99% confidence level. The median of inland group is 16 days, which is more than twice that of the coastal group (i.e., 6.5 days). However, when considering those in urban and rural stations, the hot day frequency distribution is not clearly discriminated from each other (Figure 3b). The median value of rural group (8.1 days) is only 1.9 days higher than that of urban group (6.2 days), without significant difference. These statistics verify the hypothesis that hot day frequency is closely related to the geographical feature of land–sea contrast, while being irrelevant to the city size.

For the tropical night frequency, the distribution of the inland group tends to have somewhat lower value than that of the coastal group (Figure 3c). In Figure 2b, the ranks for the climatological values of tropical night frequencies are not clearly separated according to inland and coastal groups. However, the two distributions differ from each other with 99% confidence level, though the difference in median values is not very large (5.9 days in inland vs. 8.8 days in coastal). When comparing the distributions of urban and rural stations, urban stations tend to be evidently distributed into larger tropical night frequency than the rural stations, of which differences are significant with 99% confidence level (Figure 3d). The median value of the urban group (15.7 days) is nearly 2.5 times that of the rural group (6.1 days). Thus, the statistical comparison suggests a slight modification of the

**FIGURE 2** Climatological frequency of (a) hot day (days yr\(^{-1}\)), and (b) tropical nights (days yr\(^{-1}\)) in 15 stations, arranged in decreasing order from top to bottom. Red and blue bars represent inland and coastal stations, respectively, whereas hatched and blanked bars represent urban and rural stations, respectively.

**FIGURE 3** Box plots of (a and b) hot days (days yr\(^{-1}\)) and (c and d) tropical nights (days yr\(^{-1}\)) among (a and c) inland and coastal stations, and (b and d) urban and rural stations, respectively.
previous hypothesis. Tropical night frequency is clearly discriminated by different city scales, as well as different geographical features, but the distribution difference is larger between the groups with different city scales, than the groups with land–sea contrast.

Such discrimination can also be found in their inter-annual variation and long-term change. Figure 4 presents the station composites for yearly time series of hot day and tropical night frequencies in each categorized group. The figure shows a high correlation between each group with similar year-to-year variabilities. All groups show large interannual variations of hot day and tropical night frequencies. The interannual variations have been increasing more recently, reflecting the extremely hot summers of 2016 and 2018 (Lee et al., 2020). In Figure 4a, we can see the hot days in the inland stations are more frequent for all analysis periods, except for 2003, when there was no hot day. The inland stations also have larger interannual variation, compared with the coastal stations. This is supported by the fact that the year-to-year standard deviations in the inland and coastal stations are (8.6 and 6.0), respectively, and their difference is statistically significant. On the other hand, Figure 4b shows that there is little difference in the interannual variation of hot day frequency between the urban and the rural stations, of which the standard deviations are 7.1 and 7.0, respectively.

In contrast to the hot day, the tropical night has more frequent occurrence and larger interannual variation in the coastal stations than the inland stations (Figure 4c). However, standard deviations of tropical nights in the inland and the coastal stations are 4.6 and 6.9, respectively, so that the difference of tropical nights is somewhat less than that of hot days. In addition, the standard deviations of tropical night are not statistically discriminated between the inland and the coastal stations. As shown in Figure 4d, the obvious discrimination of year-to-year variability of tropical night is found between the urban and rural stations. During the entire analysis period, there are many more tropical nights in the urban stations that those in the rural stations. The standard deviation values between the urban (8.2) and rural (4.9) stations are nearly twice as different. Thus, in the urban region, tropical nights always occur frequently, and their changes every year are also large.

For long-term change, both the hot days and tropical nights have been increasing during the analysis period, and their increases are significant with 99% confidence level, regardless of the categorized groups (Figure 4). Note that the statistical significance of increasing trend of hot day frequency is subject to the large values in the top-ranked warmest years, the years of 2016 and 2018, in Korea. However, our discussion below on relative slopes between the groups is still valid without the peak years (figure not shown). In Figure 4a, the hot day increase in inland stations is faster (0.61 days/yr) than that of the coastal group (0.44 days/yr). However, Figure 4b shows that the long-term changes in hot day frequencies in urban and rural groups are almost the same (0.52 and 0.50 days/yr, respectively). In combination with the above-mentioned results, it can be understood that the inland region tends to accompany higher frequency of hot days than the coastal region in climatology, and the frequency tends to increase faster, while the statistics of hot days are not distinguished between urban and rural stations. The lower frequency and slower long-term increase of hot days over coastal region could be related to the sea breeze from cool ocean, which might mitigate
the warming over coastal areas, but further investigation is required to confirm the inference.

For the long-term change in tropical night frequency, the tropical night tends to increase faster in the coastal group (0.49 days yr⁻¹) than in the inland group (0.33 days yr⁻¹). In addition, the tropical night increase in the urban group (0.64 days yr⁻¹) is faster than that in the rural group (0.32 days yr⁻¹). The increasing speed of the urban group is almost twice of that of the rural group. Compared to inland and coastal groups, which are 1.5 times different, the difference between urban and rural groups is more pronounced. Thus, for the tropical night frequency, this result suggests that the coastal region tends to accompany higher frequency in climatology than the inland region, and its long-term increase is faster in coastal region than in inland region. This makes sense, because more moist air over the coastal region than the inland region could keep more terrestrial radiation within the lower troposphere during the night. However, the contrast between urban and rural regions is more dramatic (Ha & Yun, 2012). The tropical night frequency in urban regions is much higher in climatology, and much faster in long-term increase than that in rural regions. Thus, the urbanization seems more responsible for the discrepancy in tropical nights. One may notice relatively low frequency of tropical nights in 2016 compared to that in 2018. Note that 2016 and 2018 are the two top-ranked warmest years in Korea. Simple investigation on the average cloudiness during July and August of each year presented extremely low level of cloudiness in 2016 (figure not shown). Efficient radiative cooling in the nighttime with clear sky in 2016 may possibly be one rationale behind, but further detailed investigation is required for comprehensive understanding.

The preceding comparisons are based on the binary classification of stations in two ways: inland/coastal stations based on the distance from the coast, and urban/ rural stations based on the population of the administrative districts that the station belongs to. Next, to reduce the logical gap regarding the relationship between the geography/city size and hot days/tropical nights, we adopt indices that reflect the climatological characteristic of each station. The indices that are calculated from meteorological variables (i.e., monthly or daily temperatures) enable the coefficient of determination to be quantified using continuous measure.

First, the KOI is adopted to quantify the climatological thermal properties related to land–sea contrast in each station. In the region of larger KOI, diurnal and seasonal variations of temperature, that is the difference between $T_{\text{max}}$ and $T_{\text{min}}$, is small. This tendency is well presented in Figure 5, as the coastal stations (blue markers) tend to have larger KOI than the inland stations (red markers). All coastal stations have KOI values above 10, while inland stations show smaller values below 10. The scatter plot of Figure 5a suggests that when the KOI increases ($R^2 = 0.33$), the hot day frequency of an arbitrary station tends to decrease. When particularly focusing on the inland stations, however, the hot day frequency of two stations, Imsil and Jangsu, may delude as if the hot day frequency among inland stations has direct proportion to KOI. The altitudes of Imsil and Jangsu stations are 247.04 and 406.49 m, respectively (Table 1). Thus, when excluding two stations, the relationship among inland stations becomes unclear ($R^2 = 0.09$). The contrasts between the inland and coastal stations are clearly presenting the inverse relationship between the KOI and the hot day frequency. The averages of KOI and hot day frequency in inland stations are 7.5 KOI and 13.8 days (red cross). On the other hand, in the coastal stations, the averages of KOI and hot day frequency are 15.5 KOI and 6.3 days, respectively (blue cross). However, the urban and rural stations are not divided, which can be easily noted by the close distance between urban and rural averages (empty circle vs. empty triangle). The average KOI and hot day frequency are respectively 13.5 KOI and 9.7 days for the urban stations, and 11.7 KOI and 9.0 days for the rural stations. Figure 5b presents the relationship between tropical night and KOI. The values of stations in the scatter plot are spread, and the relationship is unclear ($R^2 = 0.099$). A notable outlier (KOI larger than 25), however, seems to heavily skew the regression, of which station is Heuksando, located over the island far apart from the continent (the western most station in Figure 1) with extremely low population (Table 1). When excluding it, the coefficient of determination becomes larger ($R^2 = 0.517$) indicating that the tropical night frequency is directly proportion to KOI.

Second, the UHII is used to estimate the magnitude of the urban heat island related to the city scale, that is, the urban and rural stations. In Figure 6, the urban stations tend to have positive UHII, except for one station (Gunsan), while rural stations are widely distributed from the negative values to near zero, except for one station (Wando). In Figure 6a, the scatter plot suggests a lack of relationship between the UHII and the hot day frequency. When focusing on the coastal stations, the hot day frequency seems to inversely proportion to UHII due to two lowest values of hot day frequency obtained from Heuksando (UHII ~ 0 and hot day frequency ~ 0) and Yeosu (UHII ~ 2.5 and hot day frequency ~ 2) stations. Close proximity of two stations to the coast (distance <1 km, Table 1) may attribute to the low frequency of hot days. When excluding two stations, the relationship between hot day frequency and
UHII is yet unclear \( (R^2 = 0.19) \). However, Figure 6b shows that when the UHII increases, the tropical night frequency of an arbitrary station tends to increase \( (R^2 = 0.697) \). While the urban average of the UHII and tropical night frequency are 1.7 and 14.3 days (empty circle), the values averaged for rural stations are -0.7 and 1.43 days (empty triangle), respectively. However, the inland and coastal stations are not divided, which can also be easily noted by the close distance between the averages (red cross vs. blue cross).

Climatological thermal characteristics around stations associated with land–sea contrast lead to larger diurnal range in inland regions than in coastal regions (Chen & Lu, 2014). In inland regions, higher daily maximum and lower minimum temperatures at day and night, respectively, contribute to climatologically more frequent, interannually more active, and long-term increase in hot day occurrences. On the other hand, due to the higher daily minimum temperature related to smaller diurnal range, tropical night occurrences in coastal regions are considerable. In particular, the inland and coastal contrasts are more pronounced in hot days, than in tropical nights.

With regard to the urban heat island, climatological urbanized characteristics related to city size are deeply connected to daily minimum temperature, affected by additional heat at night (Park et al., 2017). Thus, occurrences of tropical nights are clearly distinguished by urban and rural regions, while in the occurrences of hot days, the distinction between urban and rural regions does not appear. The urban stations have been experiencing interannually fluctuating, more frequent, and more recent tropical nights.
SUMMARY AND DISCUSSION

Focusing on the Honam area in South Korea, we investigated the regional occurrences of hot days and tropical nights through the station-based comparisons: inland vs. coastal, and urban vs. rural. Climatological mean, inter-annual variation, and long-term change in the occurrences were examined. Climatologically, hot days occur more frequent in inland stations, while tropical nights frequently occur in coastal stations. As is well-known, hot day occurrences have been increasing with large interannual variability (IPCC, 2013), and their characteristics are more pronounced in inland stations. On the other hand, coastal stations have been exposed to tropical nights that are more rapidly changing year-by-year, and that are recently increasing. The discrimination between inland and coastal stations clearly appears in the occurrences of hot days relative to those of tropical nights. City size has a dominant impact on tropical night occurrences, but has little to do with hot days. While hot days occur without distinction between urban and rural stations, the tropical nights in urban stations are climatologically more frequent, more volatile each year, and have been occurring more and more recently, compared to those in rural stations.

Beyond the binary classification of stations, the analysis based on the KOI supports that the climatological thermal characteristics of land–sea contrast to which the stations belong can modulate more frequent hot days under lower oceanity. On the contrary, while tropical nights occur more under the higher oceanity, their relationship tends to be smaller than that of hot days. The higher the UHII, the more tropical nights that occur, while the hot day frequencies are irrelevant to the UHII variations. The proportional relationship between the UHII and the tropical night frequencies is clearly robust. The nocturnal heat formed from the urban heat island, which is concentrated in the urban regions, can lead to frequent occurrences of tropical nights.

The binary classification and the indices-based analysis indicate clear regional occurrences of heat extremes, depending on the continental/oceanic climate, and the city size. However, in this study, we utilized only 15 stations, focusing on the Honam area, for 23 years, which is rather short for climate research. Although statistically reliable results have been presented, it seems that in the future, long-term analysis covering more than 30 years will be necessary for a lot of stations across South Korea.

This study covered only the local characteristics of the stations, and the synoptic or large-scale physical mechanisms that lead to hot days and tropical nights were not diagnosed. However, the heat waves are connected with large-scale circulation, such as the El Niño–Southern Oscillation, and the Arctic Oscillation (Lee & Lee, 2016). Some previous studies have shown the principal impact of planetary waves on heat waves (Lee et al., 2017; Mann et al., 2017; Teng et al., 2013). Tropical nights occur well in favorable atmospheric conditions where high humidity is generated by monsoonal westerly flow to South Korea (Ha & Yun, 2012). Hong et al. (2018) revealed that pure heat waves and pure tropical nights are apparently modulated by different atmospheric circulations. Thus, in order to determine the cause of hot days and tropical nights, various factors related to the local characteristics around each station and atmospheric circulation should be considered together. Furthermore, it is necessary to quantitatively distinguish the contribution of local and other influences to hot days and tropical nights. This may lead to the improvement of heat extreme forecasts on a regional scale.

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AUTHOR CONTRIBUTIONS

Tae-Won Park: Conceptualization; data curation; investigation; methodology; resources; supervision; validation; writing – original draft; writing – review and editing. Chan-Gi Lee: Formal analysis; investigation; methodology; software; validation; visualization; writing – review and editing. Doo-Sun R. Park: Conceptualization; data curation; investigation; methodology; project administration; supervision; validation; writing – review and editing.

DATA AVAILABILITY STATEMENT

The station datasets of daily and monthly temperature in the Automated Surface Observing System in South Korea are freely available at https://data.kma.go.kr/cmmn/main.do provided by the Korean Meteorological Administration (KMA).

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