Tropical nights in the Spanish Mediterranean coast: recent evolution (1950-2014)

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Abstract

The increase in the number of tropical night events constitutes some of the main evidence of the global warming process throughout the Mediterranean region. There has been a significant increase in the number of these events since the second half of the 20th century. From the meteorological observations in the period 1950–2014 in the regions of Valencia and Murcia, in the central sector of the Spanish Mediterranean coast, this work analyses the evolution of the number of tropical nights, the length of the episodes, and their frequency. We also discuss the relationship of the number of tropical nights with the increase of the Mediterranean Sea surface temperatures in the sectors of the Algerian and Balearic Seas, as

well as possible implications of the additions of this evidence with the urban heat island effect. Tropical nights have effects on thermal discomfort and raises the need to adapt buildings and urban planning to the new climatic reality that is registered in this region, as well as the possibility that events will likely increase in the future.

Key words

Tropical nights, heat waves, trends, sea surface temperature, Spanish Mediterranean coast

1. Introduction

In the last few decades, temperatures have shown a clear and permanent change leading to a warmer climate due to anthropogenic forcing (IPCC 2013). However, not only the mean temperatures show this effect but extreme episodes also evidence these changes in response to radiative forcing (Katz & Brown 1992). Extreme temperatures can influence several environmental aspects, like crop growth, agro-ecological regionalization, food supply and wildfires (Ye et al. 2013, Tian et al. 2017, Parente et al. 2018). In addition, temperatures over critical thresholds also cause a rise in morbimortality and human comfort (Keellings & Waylen 2012, Gasparrini et al. 2015, Royé 2017). Tropical Nights (TN) occur when minimum temperature is equal to or higher than 20°C (Vincent et al. 2005, Alexander et al. 2006, WMO 2009, EEA Report 2012, Donat et al. 2013, Royé 2015), affecting to human behaviour and rest. The Expert Team on Climate Change Detection and Indices makes use of TN as one of the climatic indicators for monitoring climate change or analyse trends in the second half of the 20th century (Klein Tank et al., 2002). However, there are references to the use of the concept of TN since the eighties of the last century.

In the western Mediterranean context, TN are linked with anticyclonic situations in Western Europe in the mid-troposphere level. They most often occur in littoral areas and low plains, being the Saharan air an important source of air masses heating that helps to create situations of extreme temperatures even during several days. From a climatic perspective, TN in the Spanish Mediterranean coast can be linked to: 1) heat waves episodes or 2) the high temperatures inherent to the summer months, both of them relatively frequent in the Mediterranean context.

In regard of the heat waves, these events represent a great adverse impact on human health that can become more frequent under increasing temperatures scenarios (Perkins-Kirkpatrick

1 & Gibson 2017, Vicedo-Cabrera et al. 2018). Such events are especially harmful in areas
 2 affected by water scarcity, as many of them in the Mediterranean basin, leading to negative
 3 effects on water resources and agriculture (Zittis et al. 2016). Several studies have shown that
 4 these kinds of events are increasing worldwide (Amengual et al. 2014, Piticar 2018, Wang et
 5 al. 2018) and will keep increasing (Barrera-Escoda et al. 2014). The occurrence of heat waves
 6 has been linked to sea surface temperature (SST) anomalies of both local and remote
 7 conditions (Purich et al. 2014) but studies have mainly focused on oceanic scales (Deng et
 8 al. 2018, Ham & Na 2017). For instance, in the contiguous United States, the amplification
 9 of the Pacific zonal SST gradient has been associated with an increase in summer extreme
 10 heat waves (Deng et al. 2018). In addition, the sea surface warming in the subtropical
 11 northwest Pacific has been proved as cause of heat waves in the Korean Peninsula with a
 12 delay of seven days on average (Ha & Yun 2011, Min et al. 2015). In both cases, SST
 13 anomalies lead to changes in atmospheric circulation, which induce warmer and dryer
 14 conditions in the studied regions.

15 Apart from heat waves, TN are highly associated with summer temperatures, especially
 16 during the last decades. Different studies have shown a significant rise in the number of TN
 17 in the eastern Mediterranean region (Abbasnia & Toros 2018, Zittis et al. 2015), the central
 18 (Boccolari & Malmusi 2013, Picarreta et al. 2014, Scorzini et al. 2018) and the western area
 19 (Sánchez-Lorenzo et al. 2011, Barrera-Escoda et al. 2014, Royé & Martí Ezpeleta 2016). The
 20 summer temperatures increase, which has been linked to the rise of the Mediterranean water
 21 temperature (Pastor et al. 2018), has been particularly evident in the Spanish Mediterranean
 22 coast, with a growth of TN over the last three decades (Basagaña et al., 2011; Royé, 2017).
 23 This growth has important implications for impacts on socioeconomic activities, especially
 24 in the tourism, being around 10% of the gross domestic product of the regions in eastern

1 peninsular Spain attributed to this industry (Saurí et al. 2011). Recent changes in the climatic
 2 conditions and those that may occur in the next few decades will jeopardize the development
 3 of touristic activity, thus adaptation measures in touristic destinations, both in urban planning
 4 and in building designs, will be needed (Olcina & Miró 2017). This demonstrates the
 5 importance of studying this climatic phenomenon, as it generates thermal discomfort and also
 6 leads to changes in other climate variables (e.g. precipitation) (Olcina 2017). Moreover, the
 7 rise of TN and its relationship with the rising frequency of heat waves have direct
 8 implications on human health (Royé et al. 2018).

9 All of these negative impacts of TN can be intensified by local effects and/or by future
 10 warming scenarios. Regarding the first ones, the urban heat island (UHI) effect plays a key
 11 role. The characteristics of the urban environment, such as the extent of the urbanized surface,
 12 the shape of urban grid, and the type of the buildings, describe higher temperatures than rural
 13 environments, and night-time cooling is slower, generating higher discomfort in cities than
 14 in their surroundings (Royé & Martí Ezpeleta 2015), leading to very warm nights.

15 On the other hand, future climate projections outline an uncertain scenario where hot events
 16 (both TN and heat waves) would become more frequent at the end of the century (Zittis et
 17 al., 2015) or even at a shorter temporal scale (Fallmann et al., 2017). In Spain, the patterns
 18 are very similar, with an already known upward trend of TN over the last decades (Sánchez-
 19 Lorenzo et al., 2011), drawing a future scenario with a more frequent occurrence of these
 20 episodes in 2050 (Barrera-Escoda et al., 2014).

21 The study of TN is based on a fixed threshold (20°C), which might not be adequate for a
 22 comparison between all regions due to the climatic differences between them. However, it
 23 has been proved as a good index for the Mediterranean region (Royé & Martí Ezpeleta 2015).
 24 Furthermore, the higher frequency of minimum temperatures exceeding 20°C in the last

decades has led to the use of higher thresholds, promoting expressions such as ‘equatorial nights’ or ‘torrid nights’ (Pechs 2018) to emphasize the importance of these very warm nights. For example, Chen and Lu (2014) used a threshold of 25°C in their study of extreme warm in Beijing, and they differentiate ‘TN’ ($T_{\min} > 25^{\circ}\text{C}$) from ‘pure TN’ considering also the daily maximum temperature (minimum temperature $> 25^{\circ}\text{C}$ and maximum temperature $< 35^{\circ}\text{C}$).

In this study, we present a comprehensive assessment of the spatial and temporal evolution of TN in the central sector of the Spanish Mediterranean coast. In particular, we analyse the spatial distribution of the annual trends of (1) tropical nights frequency, (2) the maximum consecutive days of tropical nights events, and (3) the number of episodes with events longer than 3 days (based on the usual definition of heat wave, we used three consecutive days to consider such TN heat waves (TNHW)).

The manuscript is organized as follows: section 2 presents the dataset and methods used to carry out the analyses and section 3 provides a full explanation of the results, which are discussed in section 4. A summary of the work and the main ideas extracted from the research are shown in the section 5.

2. Materials and Methods

2.1 Study area and temperature dataset

We used 668 series of daily minimum temperature located within the territory of the Valencia and Murcia regions (34,568 km²) (Figure 1b) at elevations ranging from 1 to 1720 m a.s.l. (study area ranges from 0 to 2027 m a.s.l.). The data covered the period 1950–2014 and was sourced from the Spanish Meteorological Agency (AEMET) (572 series) and the Spanish Ministry of Agriculture, Fisheries and Food (96 series).

The study area comprises one of the highest densities of meteorological observatories in Spain (approximately 1 station per 50 km² considering all the observations). Unfortunately, not all the stations were recording during the whole period, which produces a high variability in the available information throughout the whole period. The number of observations within the studied period increased from 90 recording stations in 1950 to more than 300 in 2014 (Figure 1c).

With the aim of obtaining reliable and coherent spatial distributions and trends, we filled the gaps of all data series following an adaptation of the daily precipitation series filling algorithm, fully described in Serrano-Notivoli et al. (2017). The method is based on the computation of temperature estimates in three steps: 1) calculation of mean and standard deviation monthly estimates through multivariate linear regressions (MLR) based on all data and using latitude, longitude, altitude and distance to the coast as covariates, 2) refining of these estimates for each month by computing them again with MLR based only on the 15 nearest monthly observations plus the previously computed monthly value, with the same covariates, and 3) calculation of daily estimates through the same method but using the 15 nearest daily observations plus the refined monthly estimate. A final process of standardization applied to the daily estimates, using the refined mean and standard deviation, provided the values used to fill the gaps.

All missing values in the original series were reconstructed, thus providing a complete dataset from which to analyse tropical night evolution. To assess the reliability of the reconstruction, the above method was not only applied to the missing data but also to those days with observations. This allowed a comparison between the observations and their corresponding estimates by calculating the following set of statistics. We computed, by station, a goodness-of-fit (GOF) statistic: the mean absolute error (MAE), defined as the average of the absolute

differences between observations and estimates; two bias statistics: the mean error (ME), which is the mean difference between observations and estimates and the ratio of means (RM), computed as the ratio between the mean of the observations and the mean of the estimates, and a comparison (Pearson correlation) of annual linear trends both in observations and reconstructed data. The results were aggregated by their median values, and their kernel density estimations (KDE) were plotted. As the number of original observations was very different between stations, the statistics were calculated by dividing the dataset into four groups based on the number of original observations (all years, more than 20, 30 and 40 years, respectively) to avoid misinterpretations of the results.

2.2 Tropical night analysis

In order to assess the spatial and temporal evolution of TN in the study area, we first identified, in all stations, those days with minimum temperatures higher than 20 °C. Then, we grouped the resulting data series at three different (frequency, length and intensity) levels to obtain a set of six indices showing:

1. the annual frequency (total sum of daily cases) of TN (TNF),
2. the annual frequency of TN spells that encompass three or more days in length (TN3D), and
3. the annual mean first occurrence of TN (TNFirst),
4. the annual mean last occurrence of TN (TNLast),
5. the annual maximum length of TN hot spells (TNHS) (consecutive tropical nights),
6. the annual mean intensity of TN (the difference between minimum temperature and the TN threshold of 20°C) (TNI)

After this, a trend analysis was carried out to estimate the changes in these three indices through the application of nonparametric robust procedures for testing the existence of significant trends in all stations. These procedures were as follows:

- Mann–Kendall trend test (Salmi et al., 2002) applied for each of the available time-series to assess the significance at $\alpha = 0.01$, $\alpha = 0.05$ and $\alpha = 0.1$ (Figure 2). We consider different significance levels to evaluate if there is any influence in the spatial distribution of the station exhibiting the detected trends. Each station was classified according to whether it presented an upward (red point) or downward (blue point) significant trend. The achieved level of statistical confidence (or its absence) is displayed as a full coloured dot when confidence $>99\%$, a semi-filled dot when confidence $>95\%$, and a non-filled dot (only the circumference is coloured) when confidence $>90\%$. When the trend is non-significant for any of the previous levels, a grey non-filled dot (grey circumference) is shown.
- The magnitudes of change were estimated using Sen's slope (Salmi et al. 2002). The annual slope values are presented in a spatially interpolated manner in the results and must be analysed together with the Mann–Kendall test results to gauge the confidence of the slopes obtained over the analysed region.

In order to perform the spatial interpolation of Sen's slope results, a local polynomial interpolation technique was applied (Wang et al. 2014) as used in Miró et al. (2018). The interpolations were obtained as a denoised result with a spatial resolution of 400 m.

Since it is important to have a picture of the spatial distribution of TNF, TNHS and TNHW for a correct interpretation of the change of magnitudes, a previous interpolation of their average annual values (1950–2014) was made (Figure 4) using the mentioned spatial interpolation technique.

3. Results

3.1. Dataset validation

There were slight differences in goodness-of-fit (MAE) and bias (ME and RM) between the different datasets (Table 1). The MAE was near to 1 °C in all cases, while the ME was within the range of ± 0.2 °C. The RM was also near to 1, indicating a very low bias between observations and estimates but showing a progressive underestimation while reducing the number of stations. The comparison of trends showed a Pearson correlation near to 0.9 when considering all the stations and from 0.62 to 0.67 when the dataset was constrained to select a higher number of observations. It is known that any estimation of the temporal series of an observed variable involves a reduction of the variance. These apparent large differences are likely due to 1) the low number of years in several series, causing very different trends with small changes in the estimates compared to the observations, and 2) the small values of annual trends that can be considered negligible (most of them are within the range of 1 standard deviation, which is approximately of ± 0.1 °C per year). Since this error statistic can be misleading for the purposes of the research, we replicated the results in order to correctly evaluate the potential effect of reconstruction in trends. This replication consisted in mapping the trends of the indices using three separate datasets containing different amounts of stations from reconstructed series depending on the length of the original observations (more than 20, 30 and 40 years, respectively). The comparison (Figure 2) showed that a reduction in the number of stations did not change the spatial patterns of the significant trends in any of the three indices.

The KDE showed slight differences between datasets in the three error statistics (ME, MAE and RM), with lower influence of RM. The comparison of annual linear trends showed a

good fit, being more dispersed when considering all stations due to the low number of years in some of the series, as mentioned before (Figure 3).

3.2. Tropical night analysis

The six indices showed a similar spatial distribution, being aligned with the coastline in all cases. This may indicate the spatial dependence with the SST of the Mediterranean Sea.

In regard of the frequency of the TN, the TNF (Figure 4a) showed that the entire coastal strip normally registers more than 25 TN per year, a threshold that also extends into the pre-littoral fringe in the southern half of the region, with maximums exceeding 50 days in the coast of Alicante and Murcia, in contrast with most of the inland and high-elevation areas that usually register less than 5 days. When considering spells of 3 or more days, the TNS3D index (Figure 4b) showed a clearer latitudinal pattern with more than five events per year in the coast of Murcia and Alicante (southern half), progressively decreasing to the north with three to four events in the northern half of the coastline. Again, a strong longitudinal gradient is revealed from higher values at the coast to a complete absence of them in inland, especially emphasized in the northern half of the study area.

The indices describing the length of the TN season showed a clear longitudinal gradient highly influenced by the coastline. The TNFirst (Figure 4c) obtained earlier dates of the starting TN season at the coast (about mid-June) to later one at inner land (about the end of July), coinciding with highest elevations. An inverse pattern was found in the TNLast (Figure 4d), with an average end of TN season at the coast in mid-September and in early August at high elevations. The annual maximum consecutive TN (TNSH) (Figure 4e) normally reaches more than 20 days in the southern third of the region and 30 days in the southern extreme of Murcia. The rest of the study area was within the range of 10 and 20 days.

The intensity of the TN (TNI) (Figure 4f) showed mean temperatures (higher than 20 °C) from 0.2 to 2 °C. A gradient from the high values at the coastline to lower ones at inner areas were shown as in the rest of the indices, which means that the intensity of the TN is about one order of magnitude higher in areas near to the coast than the rest of the territory.

The trend analysis for frequency indices showed in the TNF (Figure 5a and b) the predominance of significant positive trends, especially in the littoral and pre-littoral southern and central areas of the study area. The zones in which no significant trends appeared coincided with inland and high areas where TN are rare and their year-on-year occurrence is very irregular. The exception to this appears in the littoral sectors on the border between Castellón and Valencia and on the border between Valencia and Alicante (non-significant weak changes). By contrast, the areas with the highest change and predominance of significant positive trends are the littoral and pre-littoral sectors close to the Gulf of Valencia and the South of Alicante together with the East and South of Murcia. These areas coincided with the main pre-littoral depressions, where annual slopes of change close to or above 0.5 days per year were reached. This represents an increase of 32 days of absolute change between 1950 and 2014 in the annual frequency of TN. Despite this, an average increase of 0.2 days per year was reached for the whole study area (11 days of absolute change for the entire period). However, a novelty is shown for the case of the trends of TN3D (Figure 5c and d). In this case, the main upward trends were not very common in the coastline areas in contrast to pre-littoral sectors, nearer to inland areas. These areas in Alicante and Murcia showed increases, in absolute numbers, between two and three events from 1950 to 2014 (0.03 to 0.05 occurrences per year), as well as the northern part, which also showed an increase of around two events. The rest of the study area presented non-significant trends.

The spatial distribution of TN length trends showed general positive trends in TNFirst (Figure 6a and b) and in TNLast (Figure 6c and d), which means that the occurrence of TN has been extended in both directions. Considering the studied period (1950-2014), TN occur earlier especially in the northern part while the high inland elevations experimented a negative trend. On the other hand, the last TN of the year marks belated occurrence, being this positive trend more intense in mountain area than in the coastline. In regards to the TNHS (Figure 6e and f), the increase was confined to a greater extent towards the coastal fringe. Particularly, there was a strong increase in the coast of Murcia and Alicante (except its north end) reaching ≥ 0.3 days per year. Thus, the length of the maximum annual spell increased by 19 days between 1950 and 2014 in the southern area, and by 13 days (0.2 days per year) on the central coast of the Gulf of Valencia. An increase of 0.1 days per year was reached on the coast of Castellón. Although statistically significant positive trends appear elsewhere further inland from the coast, the increase is much weaker.

The trends of the intensity of the TN (Figure 7), showed a very low rate of change (within the range of ± 0.2 °C per decade), with higher values in coastal areas of Alicante and Valencia and negative values (near to zero) in inner areas of the northern part of the study area.

4. Discussion

Based on a high-density stations network, we analysed the TN occurrence in the central sector of the Spanish Mediterranean coast through several temperature-based indices representing the frequency, length and intensity of the phenomenon. Since the first time that TN were mapped in Spain (Font Tullot, 1983), showing a higher occurrence in southern Iberian Peninsula, only a few more works addressed this topic (El Kenawy et al., 2011; Royé, 2017). The results of our analysis are in line with these previous researches and with others studying

1 this variable in Mediterranean environments trends (Abbasnia & Toros 2018, Scorzini et al.
 2 2018, Piccarreta et al. 2014, Boccolari & Malmusi 2013, Sánchez-Lorenzo et al. 2011),
 3 exhibiting a clear positive trend in the second half of the 20th century. This generalized
 4 warming is consistent with the trends of most of the indices related with temperature, not
 5 only in our study area but also in the rest of the Mediterranean basin (Miró et al., 2006;
 6 Xoplaki et al., 2006; Hertig et al., 2010; Efthymiadis et al., 2011). Furthermore, the projected
 7 changes indicate that this trend will continue with different magnitudes depending on the
 8 considered climate change scenario (Barrera-Escoda et al. 2014, Zittis et al. 2016).

9 Our study shows that, since TN frequency and persistence have increased over time with a
 10 major influence of SST (discussed in section 4.1), it is weak when considering the temporal
 11 evolution of events of long duration. TN frequency showed clear dependence on the
 12 coastline, as did TN trends, which also exhibited an especially strong coastal pattern at the
 13 southern part of the study area. Besides, while the TN hot spells and heat waves followed the
 14 same spatial distribution as the frequency, their corresponding increasing trends became
 15 diluted, where the first trends were confined to a narrow line at southern coast and the second
 16 ones were marginal and reduced to inland areas of the south.

17 The atmospheric mechanisms behind the increasing frequency of this phenomenon are both
 18 large and synoptic in scale (Sánchez-Lorenzo et al. 2011). In the Southwest Pacific, the Asian
 19 Zonal Circulation and the Western Pacific Subtropical High drive these changes
 20 simultaneously (Wang et al., 2018). In the Western Mediterranean region, some circulation
 21 types transport towards Europe air masses from the north Atlantic, mostly in summer, when
 22 the Iberian thermal low, linked to a positive temperature anomaly, appears (Michaelides et
 23 al. 2018, Santos et al. 2015).

4.1. SST influence

TN spatial and temporal behaviour in the studied area is directly linked with the Western Mediterranean SST, as noted in Purich et al. (2014). The littoral and pre-littoral location of TNF, TNHS and TNHW confirmed this relationship, with null or almost null events in inland locations, which can be also influenced by altitude in most part of the inland. The mean temperature trends could be stronger in the mainland rather than in the coastal areas. However, minimum temperature in higher-elevation inland regions is still usually below the 20°C threshold, as pointed before.

Pastor et al. (2018) identified warming trends up to 2 °C between 1982 and 2016 for summer months (mainly June and July), when TN are more frequent. SSTs anomalies in summer present very different values and distributions from those recorded in winter. The relationship of such particular distribution to and meteorological configurations leading to extreme events are identified in Pastor et al. (2018). Pastor et al. (2018) also purported that the global warming have directly influenced this SST warming rates during the present century. This could be related to more frequent TN in the future.

Pastor et al. (2018) also identified different spatial patterns in the SST warming trends for the Western Mediterranean, being higher in the south of the studied area, close to the Alborán Sea. This could be related to the higher warming trends found in this study in the Murcia and Southern Valencia regions.

4.2. UHI influence

It should be noted that the sectors that show a greater increase of TN matches relatively well with areas that have suffered major urbanization processes and growing peri-urbanization of main urban centres (Valencia, Alicante and Murcia cities) throughout the period studied. This

is a widely discussed problem in the scientific literature (e.g., Quereda-Sala et al. 2000, Royé & Martí Ezpeleta 2015) because it can distort the minimum temperatures and linked trends. Miró et al. (2015) performed a statistical downscaling in the study region that reconstructed the temperature series observed from the low tropospheric reanalysis data. This concluded that, while a greater and generalized upward trend in maximum temperatures matched well with the downscaling, strong trends in the minimum temperatures in certain urban or peri-urban areas were not consistent with the downscaling. However, the results are consistent in rural areas and inland. This suggests that a predominance of surface observed series affected by strong urbanization processes in the same area could confuse the correct signal in the homogenization process. Of course, the SST increase also weighs here, thus, it is very difficult to isolate the climate change signal from the urban effect with the purchased analysis (Barros Pozo & Martín-Vide 2018, Wiesner et al. 2018). However, even assuming there is some urban effect in certain areas, there is a clear underlying trend that TN have increased throughout the region by 11 days on average for the whole region and the entire period 1950–2014. In addition, there was a generalized and greater (≥ 17 days) increase in the littoral fringe, which cannot be explained by the urban effect. In any case, the relationship between minimum temperatures and climate change is complex in mountainous regions, so in the studied region it has been estimated that the effects of climate change are clearer in the high parts of the mountains due to the upward trend in the frequency of nocturnal air temperature inversions (Miró et al., 2015, 2016).

5. Conclusions

The temporal evolution of frequency, length and intensity of TN have been analysed for the central sector of the Mediterranean coast of mainland Spain. The results showed a general

1 increase in trends for the three facets over the 1951–2014 period. The spatial distribution
 2 showed a strong influence of coastline, indicating a potential effect of the Mediterranean Sea
 3 surface temperatures. This influence was also noted in the trends of the TN frequency and
 4 TNHS but was less important in the trends of event duration.

5 Over the last few years, scientific literature has highlighted the study of TN in many areas of
 6 the world, including Spain. The increase of these overnight warmth episodes has especially
 7 been proven over the Mediterranean coast, where the increase has been greater than other
 8 areas.

9 This study has shown how the regions of Valencia and Murcia, in the central area of the
 10 Spanish Mediterranean coast, have experienced a significant increase in TN within the last
 11 three decades. The causes are related to the global increase in temperatures due to the climatic
 12 change process, but TN have also acquired their own unique characteristics in this area due
 13 to the warming of sea surface temperatures of the central area of the Western Mediterranean
 14 basin (maritime sectors of Algiers and Gulf of Valencia).

15 The number of TN has tripled in cities like Valencia or Alicante since 1980 to the present
 16 day, which shows that we are in an underlying trend process where general and regional
 17 factors converge. The increase of TN in this Mediterranean sector spawns a loss of nocturnal
 18 climatic comfort, acting as a regional factor to a potential reduction of touristic
 19 competitiveness, which is added to the long-term climatic projections already made (Ciscar
 20 et al. 2018, Greiving 2011).

21 Together, these reasons have forced policymakers to look for short-term adaptation solutions
 22 with a high cost of energy (i.e. air conditioning in housing and hotels), which, in the future,
 23 will be related with the building and urban layout design to include “coolness islands” (i.e.
 24 green areas and green infrastructure) in the planning processes.

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Table 1. Evaluation statistics (median values) comparing observations and their corresponding estimates for minimum temperature: mean absolute error (MAE) (°C), mean error (ME) (°C), ratio of means (RM) and Pearson correlation (all correlations are significant at 99%) of monthly linear trends (TC) considering all stations (All), and those with more than 20, 30 and 40 years of original daily observations. Best result for each statistic is highlighted in italics.

Num. of years	MAE	ME	RM	TC
All	<i>0.951</i>	0.121	1.011	<i>0.921</i>
> 20	0.970	<i>0.002</i>	<i>1.000</i>	0.621
> 30	1.022	-0.128	0.988	0.629
> 40	1.037	-0.178	0.985	0.671

Figure 1: (a, b) Study area (Regions of Valencia and Murcia – Spain), elevation, regional division and location of all the stations used in the study (black dots). (c) Number of available recording stations over time.

Figure 2: Significance and sign of the trends, by station, using series with more than 20, 30 and 40 years of original data for TNF (a, b, c), TN3D (d, e, f), TNFirst (g, h, i), TNLast (j, k, l), TNHS (m, n, o) and TNI (p, q, r).

Figure 3: Kernel density estimates (KDE) of mean error (top-left), mean absolute error (top-right) and ratio of means (bottom-left) considering different sets of data series based on the original number of recording years (coloured lines), and annual linear trends comparison (bottom-right). Vertical dashed lines represent median values of the statistic.

Figure 4: Mean annual values (1950–2014) of TN frequency: (a) TNF, (b) TN3D; length: (c) TNFirst, (d) TNLast, (e) TNHS; and intensity: (f) TNI.

Figure 5: Spatial distribution of TN frequency trends (1950–2014) showing the significance by station (a, c) and the interpolated rate of change (b, d) of TNF and TN3D, respectively.

Figure 6: Spatial distribution of TN length trends (1950–2014) showing the significance by station (a, c, e) and the interpolated rate of change (b, d, f) of TNFirst, TNLast and TNHS, respectively.

Figure 7: Spatial distribution of TN intensity trends (1950–2014) showing the significance by station (left) and the interpolated rate of change (right) of TNI.