Temporal and Spatial Variability in Surface Air Temperature and Diurnal Temperature Range in Spain over the Period 1950–2011

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Abstract: Maximum (T_{max}), minimum (T_{min}), mean (T_{mean}) air temperature and diurnal temperature range (DTR) trends on a seasonal and annual time scale are evaluated from data recorded at nine Spanish weather stations during the period 1950–2011. Temporal and spatial variability in temperatures and in the diurnal temperature range (DTR) are presented. The non-parametric Theil-Sen approach and the Mann-Kendall test are used to evaluate anomaly temperature trends and their statistical significance, respectively. An air temperature reduction in Spain between 1950 and 1980 emerges and significant warming is observed between 1980 and 2011. On a seasonal scale, the weakest trends (mostly insignificant at the 5% confidence level) are noted during autumn, while the strongest warming rates were found during summer and spring. The rate of change between 1950 and 2011 in T_{max}, T_{min} and T_{mean} was 1.6 °C, 1.1 °C and 1.3 °C, respectively. DTR trends showed a decrease on the Mediterranean coast and a small change in northern, Atlantic and rural areas. The spatial distribution of annual and seasonal trends was plotted as isoline maps and strong trend gradients from the south to the north of the country are observed. DTR values were negatively correlated with relative humidity and precipitation and positively correlated with sunshine hours.

Keywords: surface air temperature series; DTR; anomalies; trend analysis; statistical significance; isoline trend maps; Spain; climate change

1. Introduction

Various studies have confirmed global warming on regional, continental and global scales, [1]. According to the Fifth Assessment Report (AR5) of the Intergovernmental Panel for Climate Change (IPCC), global mean surface temperature (GMST) has increased since the late 19th century, [1]. Each of the past three decades has been increasingly warmer at the Earth's surface than any previous decade, with the 2000s having been the warmest.

For instance, average combined overland and ocean temperature data were calculated by a linear trend and showed a warming of 0.85 (0.65 to 1.06) °C over the period 1880–2012 [1]. When multiple independently produced datasets exist, the warming trend was 0.89 (0.69 to 1.08) °C over the period 1901–2012 [1]. In addition, the trend and warming were 0.72 (0.49 to 0.89) °C over the period 1951–2012 when based on three independently produced datasets. Evaluating temperature trends on a global scale is essential although studying temperature variability on local and regional scales proves to be more inclusive, since changes on temperature are not uniform and vary over space and time.

Temperature and diurnal temperature range (DTR) are fundamental components of the climate system and changes in their pattern can affect human health, ecosystems, plants, animals and renewable energy systems [2]. As a result, research into temperature and DTR variability on regional and local scales is vital.

Although air temperature change occurs on a global scale, its impact varies from region to region and, as a consequence, studying air temperature trends is a key task in climate change research, as suggested by Giorgi and Lionello [3].

Despite the importance of air temperature trends, scant definitive spatial information has thus far been published at a local scale in the continental Mediterranean area. Due to its long observation records, Spain is well placed to monitor climate change in this area. In addition, such information is of interest vis-à-vis gaining a better understanding of climate system change and global warming in a country which is not densely populated country but which possesses agricultural, livestock, industrial, tourist and renewable energy resources that may be affected by temperature changes [4].

Numerous studies have researched temperature trends in recent years, although temperature trends have in fact been analysed in Spain by different authors [5–11] since the mid-19th century. For instance, annual T_{min} is seen to have changed between 0.13 and 0.25 °C decade^{-1} in the northern Spanish Plateau for the period 1869–1992, as reported by Esteban-Parra et al. [7]. In the Balearic Islands (Spain), T_{min} increased at a rate of 0.58 °C decade^{-1} and T_{max} also increased at a rate of 0.5 °C decade^{-1} for the period 1976–2006, as reported by Homar et al. [8]. Temperature has shown a significant growth trend of 0.09 ± 0.04 °C decade^{-1} since 1944 and night-time temperatures have risen by 0.17 ± 0.04 °C decade^{-1} while days have remained more stable, on the island of Tenerife Island, (Spain), Martin et al. [9]. More recently, Del Rio et al. [10] analysed T_{mean} in Spain from 1961 to 2006, obtaining positive significant trends in spring and summer. The annual trend was between 0.1 and 0.2 °C decade^{-1}. Del Rio et al. [11] studied and analysed the T_{mean}, T_{max} and T_{min} for the same period in Spain, with the results showing a rate of increase around 0.3 °C decade^{-1} in summer and spring seasons. T_{max} increased 0.37 °C decade^{-1} and 0.43 °C decade^{-1} in summer and spring, respectively; for T_{min}, warming was 0.34°C decade^{-1} in summer and 0.41°C decade^{-1} in spring.

Different authors point out that special attention should be paid to rural station temperature data since preliminary results suggest that the effect of rural heat on the increase in T_{min} and T_{max} is less than the temporal variations found in city stations [7]. Some authors have attributed the causes of trends and other variations to the Iberian Oscillation Index (IOI) and the Iberian sea surface temperature (ISST) has been suggested to account for the different seasonal temperature behaviour, as can be seen in Rodriguez-Puebla et al. [12].

Kadioglu [13] obtained $T_{mean,}$ T_{max} and T_{min} air temperature increases at a rate of 0.063, 0.003 and 0.124 °C decade^{-1}, respectively, over Turkey for the period 1939–1989. He also observed that the rate of change in the T_{mean} was 0.019 °C decade^{-1} between 1951 and 2010. Galdies [14] recently reported a warming trend of 0.22 and 0.18 °C decade^{-1} in the T_{max} and T_{min}, respectively for the Maltese Islands.

In addition, authors such as Del Rio et al. [11], Sayemuzzaman et al. [15], Ventura et al. [16], have analysed the difference between maximum and minimum temperatures (diurnal temperature range, DTR). Some authors have reported an increase in T_{min}, since 1950 when compared to T_{max}. This represents a downward trend in DTR. Nevertheless, most studies into Spanish temperature changes show that the maximum temperature has increased at a greater rate than the minimum temperature. As a result, this produces an upward trend in DTR, as explained by El Kenawy et al. [17], Del Rio [11]. Sayemuzzaman et al. [4,15] observed that maximum temperature decreased and minimum temperature increased in North Carolina during the period 1950–2009 and also reported that DTR decreases, concluding that the change can be associated with the positive North Atlantic Oscillation (NAO) index during 1970–2000.

In order to further current knowledge of DTR, the current work proposes studying the trends of the maximum, minimum and average temperatures as well as DTR behaviour at urban and rural measuring stations, distributed throughout Spain. The main objective is to evaluate local trends and to draw seasonal and annual trend maps, where isolines have been traced with intervals of 0.1 °C decade^{-1}.

To achieve this, long-term measured daily temperature data over a period of 62 years, from 1950 to 2011 at different weather stations were analysed. A further goal was to quantify their anomalies, trends and diurnal temperature range at nine Spanish stations and in a temperature series that is representative of the average of the nine locations. This average series is representative of the country mean temperature and has been called the "Iberian Peninsula" (IP) series. Correlation analysis between DTR and meteorological variables (precipitation, relative humidity, sunshine hours) was carried out. A comparison of DTR trends at rural and urban stations has been performed. The present study helps to improve current knowledge of the temporal and spatial variability of surface air temperature trends and DTR on seasonal and annual time scales in Spain.

In relation to previous studies, the present work introduces the following novelties: first, this work highlights the difference between rural and urban stations from the point of view of DTR variability at each station and minimum temperatures in summer. Second, the selected measurement stations allow observations and comparisons to be made of the anomaly trends of global solar radiation, surface air temperatures and sunshine hours (not shown in this manuscript) [18]. Third, it has been observed that increases in T_{max} and T_{min} may be associated with surface solar radiation transition from dimming to brightening since the 1980s [18].

In the following sections, a description of the locations, different data control tests and the methodology are explained in Section 2. The results and discussion are in Section 3. Finally, a summary together with the most relevant conclusions are provided in Section 4.

2. Material and Methods

2.1. Place

The study area is the part of Spain, located on the Iberian Peninsula, in southwest Europe at 36°–44° N and between 10° W and 3° E. and covers an area of 505,990 km^2. Its mainland is bordered to the south and east by the Mediterranean and to the west and northwest by Portugal and the Atlantic Ocean. The major mountain systems from west to east and starting from the north are: the Cantabrian Mountains (across northern Spain), the Pyrenees (natural frontier with France) and the Central System. The Iberian System (which extends from the eastern foothills of the Cantabrian Mountains to the Betic System) and the previously mentioned Betic system (running along the southern and eastern parts of Spain) [10]. The climate is temperate with hot summers and cold winters inland and sunny summers and cloudy winters along the coast. The measurement stations are distributed between the Atlantic Ocean and the Mediterranean Basin, under the influence of the Azores High pressure and the Iceland Low. Table 1 shows the geographical characteristics of the measuring stations used in this study. The spatial distribution of the selected locations is also marked in Figure 1. Eleven meteorological stations are run by the Spanish Meteorological Agency (AEMet), [www.aemet.es] and one station, located in the rural village of "Villalba de los Alcores," is run by the Atmosphere and Energy Laboratory of the University of Valladolid (De Miguel et al. [19]; Román, [20]) and used AEMet Villanubla station data.
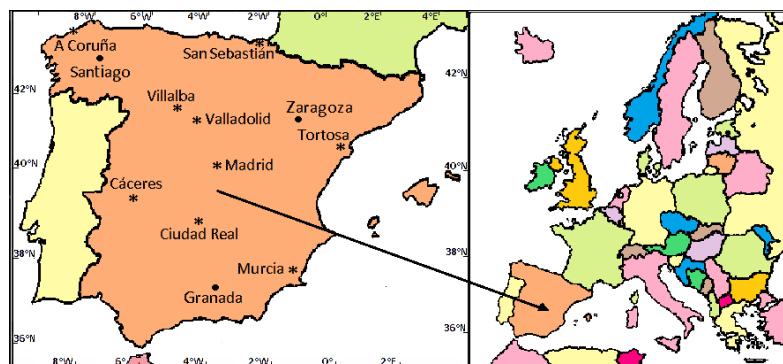

Figure 1. Spatial distribution of the selected measuring stations in Spain. (●) rural stations.

Table 1. Geographical characteristics of the stations for the present study. The first nine stations were used to calculate the Iberian Peninsula (IP) time series. (●) mean rural stations.

	Latitude (°N)	Longitude (°)	Altitude (m)	Type
Ciudad Real	38.99	3.92 W	628	Urban
San Sebastián (Igueldo)	43.31	2.04 W	251	Rural
A Coruña	43.37	8.42 W	58	Rural
Madrid (Ciudad Universitaria)	40.45	3.72 W	664	Urban
Cáceres	39.47	6.34 W	394	Urban
Murcia	38.00	1.17 W	61	Urban
Tortosa	40.82	0.49 E	44	Urban
Valladolid	41.65	4.77 W	735	Urban
Villalba de los Alcores	41.81	4.93 W	848	Rural
●Santiago de Compostela	42.89	8.41 W	346	Rural
●Zaragoza (airport)	41.66	1.01 W	370	Rural
●Granada (air base)	37.14	3.63 W	690	Rural

2.2. Instrumentation

All of these stations are equipped with instruments to take hourly global, G and ultraviolet solar measurements and with meteorological variable sensors. All instruments were well calibrated on a regular basis and instrument maintenance was performed following World Meteorological Organization (WMO) recommendations (WMO, 2008 [21]): cleaning domes, bubble levelling of the instruments and monitoring of desiccant state, as is explained in Román et al. [22].

2.3. Data

In the present study, series of daily T_{max}, T_{min} and T_{mean} from nine Spanish weather stations for the period 1950–2011, obtained from AEMet (Meteorology Spanish Agency), were initially analysed. Weather station selection was made according to their quality, length and period covered and ensuring they possess simultaneous records of meteorological variables, solar radiation and sunshine hours so as to be able to compare their trends. Daily values were averaged in order to obtain monthly temperatures and seasonal temperatures for each of the stations. Seasons were defined as follows: winter (December, January and February), spring (March, April and May), summer (June, July and August) and autumn (September, October and November). Mean annual temperatures were obtained by averaging the monthly values for each year. Further information regarding the measurement uncertainty is given in Román et al. [22].

Some necessary data quality control tests were performed before data were used. Al the variables were checked against empirical upper and lower limits, systematic errors, which resulted from different sources (e.g., archiving, transcription and digitalization). This can include non-existent dates, $T_{min} \geq T_{max}$, $T_{max} > 50\,^\circ C$, $T_{min} < -50\,^\circ C$. Further details about these tests can be seen in (El Kenawy et al. [17]; Bilbao et al. [23]; Miguel et al. [24]; Román et al. [25]). Checks were also applied in order to (1) detect, correct, and/or remove major errors, such as aberrant (more sunshine hours recorded than the possible maximum) or negative values; (2) confirm the consistency of calendar dates (days per month and year); and (3) remove false zeros; (4). Daily evolution of temperatures and global solar radiation is represented graphically. This has enabled us to detect, locate and correct data errors in relation to mistakes caused by, for example, systematic shadows on consecutive days, lags, repeated data and so forth. Finally, certain conditions about controlling missing data were taken into account following (Sánchez-Lorenzo et al. [26]). The available daily temperature data for carrying out the work show that four stations have over 30,000 daily data; for instance, Tortosa, Madrid and San Sebastián have the oldest data; data series start in 1920 in the case of the Madrid and Tortosa stations. The number of missing data is less than 1%. In addition, the absolutely highest maximum temperature was recorded at Murcia and the lowest minimum at Villalba de los Alcores.

Instrumentation and alteration of surrounding land cover might create non-homogeneity and/or inconsistencies in meteorological data recordings (Gocic and Trajkovic, [27]). In our study, homogeneity tests were carried out on monthly, seasonal and annual time scales. Further details about this method are shown in Section 2.4.

2.4. Method: Temperature Anomalies and Data Homogeneity Testing

In order to deseasonalize the temporal temperature series and to obtain averaged series, monthly anomalies were evaluated. Anomalies provide an accurate description of climate variability and allow for data comparisons from different climatological areas, as suggested by Galdies [14]. Anomalies of various meteorological variables are known to be more representative than absolute values, which is why temperature anomaly evolution was plotted as a function of time.

Using the daily values of each daily temperature variable, the monthly average of daily series was calculated using at least 25 daily data per month, year and location (Román et al. [22]). Temporal monthly anomaly series are assessed considering the reference period climate norm of 1961–1990. The anomaly (A) in month "m" and year "y" is calculated as:

$$A_{m,y} = T_{m,y} - \frac{1}{N} \sum_{y'=1961}^{1990} T_{m,y'} \tag{1}$$

where N is the number of data used in the sum of Equation (1). Monthly T temperature anomalies were evaluated for all months and all locations. The monthly anomalies of each variable at nine locations were averaged and a new monthly series of anomalies, representative of the Iberian Peninsula, (IP), was created and called the "Iberian Peninsula" series. Annual anomalies were calculated by averaging the monthly anomalies when all twelve monthly data are available for each year (Román et al. [28]). Winter anomalies were calculated with the January and February anomalies for a specific year, together with the December anomaly of the previous year.

Homogeneity of the T_{mean}, T_{max} and T_{min} anomaly series was tested, as described by (Román et al. [22,28]). Four tests are mainly applied in order to ascertain whether the series are valid for trend studies or whether, by contrast, they are not valid due to changes on instrumentation or measurement problems. The null hypothesis assumes that a temporal series is homogenous. This hypothesis was verified using the following four tests: the Standard Normal Homogeneity Test (SNHT), the Pettit test, the Buishand test and the Von Neumann ratio, (Wijngaard et al. [29]).

Hakuba et al. [30] considered that if the null hypothesis is rejected with a confidence of 99% by at least three tests, then the series could be assumed inhomogeneous. The four tests were applied to the T_{mean}, T_{max} and T_{min} series and the annual series observed a non-homogeneity around 1970, which might be due to a change in temperature trend. Wild [31] reported a climate change in the mid-80s in the Northern Hemisphere due to the end of "global dimming" and the start of "global brightening." Global dimming was a period when aerosol presence in the atmosphere increased and global brightening corresponds to aerosol reduction in the atmosphere. No inhomogeneities were detected for any test in the annual T series for the periods 1950–1984 (dimming) and 1985–2011 (brightening), supporting the hypothesis of a mid-1980s climate change. Homogeneity analysis was thus performed for the same series for the periods 1950–1984 and 1985–2011. The first period evidenced inhomogeneities in wind speed and relative humidity.

The homogeneity of the T_{max}, T_{min} and T_{mean} monthly anomaly series was also tested using the four tests mentioned above but in a relative manner using synthetic reference series developed with the data from the other locations, as shown in Alexandersson and Moberg, [32]; Sánchez-Lorenzo et al. [33]. No temperature series evidences inhomogeneities for the 1950–1984 and 1985–2011 periods, thus indicating that all the temperature anomaly series can be considered homogeneous or at least not inhomogeneous enough to change the series values. Detailed information and test results concerning

this homogeneity analysis may be found in Román [20]. Finally, results indicate that all the temperature series can be considered homogeneous.

2.5. Theil-Sen Trend Estimator

Different statistical estimators have been used over the world to study the climatological temperature series. The climate variability study of data series and its analysis requires trends and their statistical significance to be evaluated. Trend evaluations in seasonal and annual temperatures (T_{max}, T_{min} and T_{mean}) and DTR anomalies series were performed using the Theil-Sen (T_{TS}) estimator and its 95% ($\alpha = 0.05$) confidence interval (95CI) for 1950–2011. This estimator has been calculated following the methods proposed by Sneyers, [34]; Gilbert, [35]. The results provide the most suitable trend values due to the sensitivity of the method to extreme data, [15]. Similar tests have also been used by Sayemuzzaman et al. [15]; Román et al. [22]; Espadafor et al. [36]; Gocic and Trajkovic, [27]. SURFER32 8 software was used for drawing the annual and seasonal trend spatial distributions of temperatures and DTR over the Spain map.

2.6. The Mann-Kendall Non-Parametric Trend Test of Significance

The Mann Kendall test is a statistical test widely used for trend analysis in climatological [11] and hydrological time series [8]. The Mann-Kendall statistical test is frequently used to quantify the significance of trends in meteorological time series. The advantage of the method is that normal distribution of data is not expected. The result is seldom influenced by the fewer abnormal values and calculation is simple. There are two advantages of using this test. First, it is a non-parametric test and does not require data to be normally distributed. Second, the test has low sensitivity to abrupt breaks due to inhomogeneous time series [4]. Any data reported as non-detects are included by assigning them a common value that is smaller than the smallest measured value in the data set. According to this test, the null hypothesis assumes there is no trend (data are independent and randomly ordered) and this is tested against the alternative hypothesis, which assumes there is a trend [20].

The statistical significance of each calculated trend was evaluated by the non-parametric Mann–Kendall test, (Mann [37]; Kendall [38]) considering three types of trends: with a confidence of 99% ($p < 0.01$), with a confidence of 95% but not 99% ($p < 0.05$) or non-significant at least at 95% confidence ($p \geq 0.05$), as explained in Román et al. [28]. If the Mann–Kendall test considered a trend to be statistically significant with at least 95% confidence, this trend was then assumed to be only significant.

2.7. Diurnal Temperature Range Analysis

DTR, defined as the difference between maximum and minimum temperature on a monthly basis, has been evaluated. The monthly DTR anomaly homogeneity was tested, following the method explained in Section 2.4 and the results indicate that DTR series can be considered homogeneous. DTR is a measure of climate change due to its sensitivity to variations in radiative energy balance, (Fernández-Montes et al. [39]; Wang et al. [40]). In addition, DTR decreased in most land areas since the 1950s due to diurnal changes in T_{max} and T_{min} (IPCC 2007, [41]). In some regions, T_{min} has increased, while T_{max} has decreased, (Wang et al. [40]). Different studies show that DTR reduction depends on meteorological variables such as cloud cover, soil moisture and precipitation. It is known that clouds reflect sunlight and that T_{max} therefore decreases. Moreover, longwave radiation increases at night and, as a result, T_{min} increases. Soil moisture reduces DTR by the surface evaporative cooling effect on T_{max} and precipitation affects DTR by increasing soil moisture, Wang et al. [40]. On a global scale, the (IPCC 2007, [41]) reports a decrease in DTR of around 0.1 °C per decade, for the period 1950–2004. In this study, the temporal and spatial variability of annual and seasonal DTR trends of urban stations were calculated. On a local scale, DTR trends of some new rural stations were evaluated and the results were compared with previous ones. The effects of sunshine hours, precipitation and relative humidity on DTR change are examined.

3. Results

3.1. Temperature Long-term Trends (1950–2011)

Linear trends in T_{max}, T_{min}, T_{mean} temperatures and DTR were assessed in Spain for the period 1950–2011 using nine weather station records. Table 2 summarizes the linear trends of temperature variations in the data series on seasonal and annual timescales assessed at the 95% significance level. Results show that T_{max}, T_{min} and T_{mean} temperatures have a statistically significant uptrend that increased in the annual and seasonal scales

Table 2. Seasonal and annual maximum (Tmax), minimum (Tmin), mean (Tmean) air temperature and diurnal temperature range (DTR) anomaly trends (°C decade^{-1}) with the corresponding mean standard error, in Spain for the period 1950–2011. The results are significant at 99% confidence ($p < 0.01$), except T_{min} in autumn.

	Annual	Spring	Summer	Autumn	Winter
T_{max}	0.26 ± 0.04	0.26 ± 0.07	0.36 ± 0.06	0.20 ± 0.06	0.22 ± 0.06
T_{min}	0.17 ± 0.03	0.17 ± 0.05	0.24 ± 0.04	0.13 ± 0.05	0.14 ± 0.06
T_{mean}	0.22 ± 0.03	0.21 ± 0.06	0.30 ± 0.05	0.17 ± 0.06	0.18 ± 0.06
DTR	0.09 ± 0.02	0.09 ± 0.03	0.13 ± 0.02	0.06 ± 0.03	0.07 ± 0.03

Warming was seen not to be uniform with time. Specifically, T_{max}, showed stronger warming during summer and spring than in winter and autumn. Warming in T_{min} during winter and spring was slightly higher than in autumn. For instance, our findings indicate that the annual mean temperature has increased at a rate of 1.3 °C over the whole period, which is comparable to the 1.1°C trend observed for Mediterranean countries, Galdies, [14]; Del Rio et al. [11]; El Kenawy et al. [17]. Similarly, the study domain experienced an uptrend of 1.6 °C in T_{max} between 1950 and 2011, which is also analogous to the finding by Galdies, [14] in Malta. Annual T_{min} showed a stronger upward trend (1.1 °C) between 1950 and 2011, comparable to those of 1.1 °C between 1951 and 2010 reported in Galdies, [14] for Malta and the uptrend of 1.22 °C along 87 years reported by El Kenawy et al. [17] in north-eastern Spain.

Temporal evolution of temperatures and DTR anomalies for the period 1950–2011 is shown in Figure 2 as bars. The dark blue lines show a low Gaussian filter of 11 years and anomalies were calculated from the climatic norm of the 1961–1990 period. The 11-year moving line (dark line) average shows a strong increase in T_{max}, T_{min} and T_{mean} temperatures and DTR anomalies over the last three decades, particularly in spring, summer and annual periods. An air temperature reduction in Spain between 1950 and 1980 emerges and significant warming is observed between 1980 and 2011. The causes of this temperature variation would be the global and "dimming" and "brightening" phenomena as Román [20] explains with details.

The warmest years over the whole period (1950–2011) were restricted to the past two decades. Over this period, 1990, 1995, 1997, 2003, 2006, 2009, 2011 were identified as unusually warm years.

Moreover, the anomalies of summer maximum temperature during 1990, 1995, 1997, 2003, 2006, 2009 and 2011 were 1.92 °C, 2.19 °C, 1.90 °C, 1.75 °C, 2.06 °C, 2.14 °C and 2.33 °C, respectively and were four of the ten warmest years to occur in the past ten years (2003, 2006, 2009 and 2011). In contrast, the coldest on record were found during the earlier decades (e.g., 1950s, 1960s and 1970s).

These results probably imply that the uptrend observed in minimum temperature over the period (1950–2011) is largely attributed to the rapid warming in recent decades. In contrast to cold seasons, the annual behaviour of temperature anomalies is broadly consistent with the behaviour of temperature anomalies during warm seasons. Similarly, the temporal evolution of annual DTR anomalies is more consistent with temperature trends in hot seasons rather than in cold seasons.
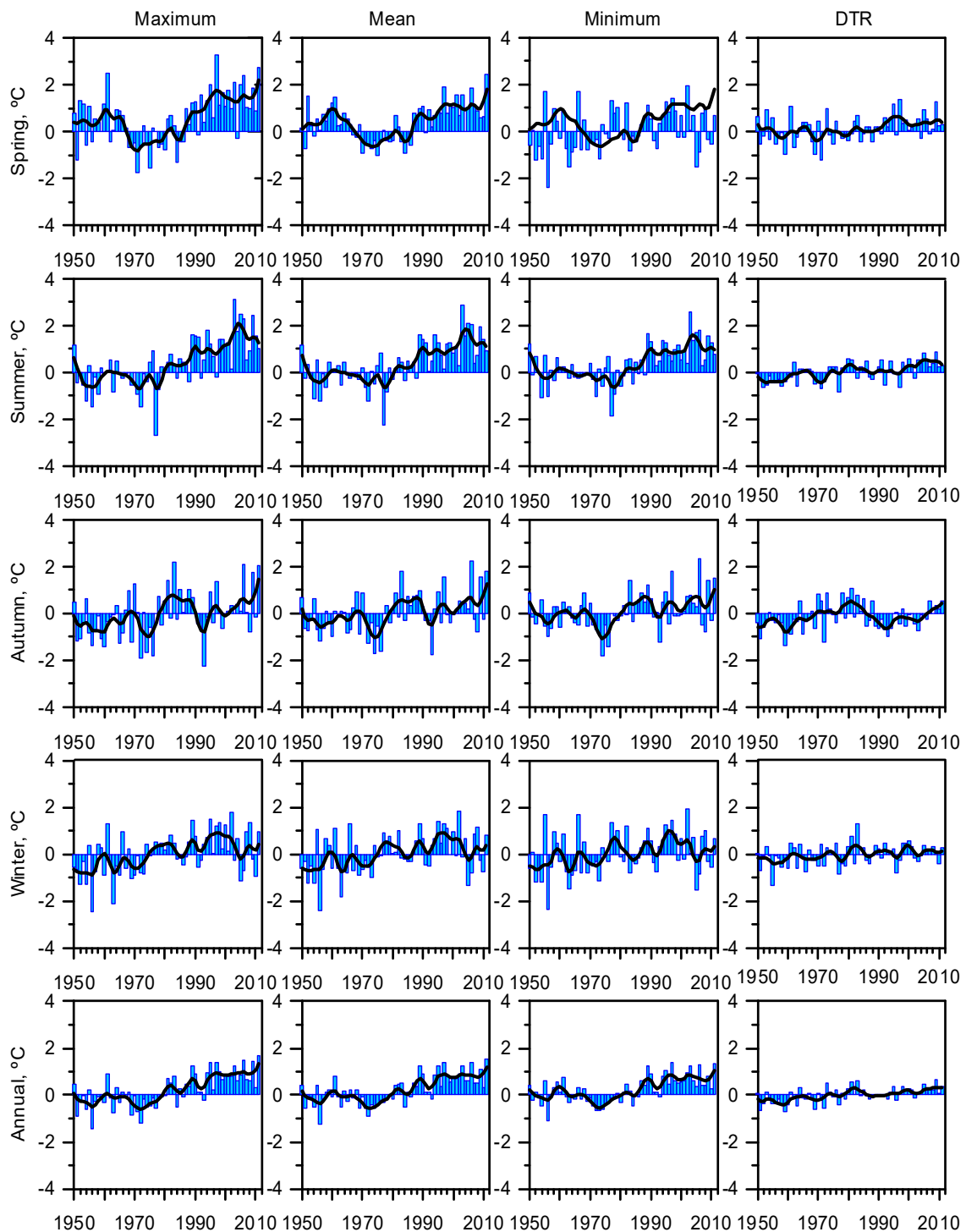
Figure 2. Seasonal and annual anomalies of maximum, mean and minimum temperatures (°C) and DTR time series for the period 1950–2011 shown as light blue bars. Dark blue lines show a low Gaussian filter of 11 years. The anomalies were calculated from the climatic norm of 1961–1990 period.

3.2. Seasonal and Annual Temperature and DTR Trends (1950–2011)

The values of seasonal and annual trends from 1950 to 2011 in T_{max} as isoline maps are presented in Figure 3. In general, spatial T_{max} trends decreased to the north and northeast and increased in the south of the country. Large positive trends can be seen in spring and summer that are significant ($p < 0.05$) in about 70% of all areas according to the Mann-Kendall test. For T_{max} trends values at

annual scale, in all stations show statistically significant trends at 99% ($p < 0.01$) except Murcia. All stations are statistically significant at least 95% confidence except Murcia and San Sebastian, in summer. Coruña, Madrid, Tortosa and IP stations show statistical significance at 99% in autumn. Caceres and Villalba are significant at 95%; San Sebastian and Murcia are not significant and the rest of stations are significant at 99% ($p < 0.01$) in spring; and finally San Sebastian, Coruña, Madrid, Tortosa, Villalba and IP are significant at 95% ($p < 0.05$) and the Ciudad Real, Caceres, Murcia and Valladolid T_{max} trends are not statistically significant in winter. The magnitude of the trends varies according to the seasons. The lowest recorded trends were detected in winter and significant uptrends in T_{max} are obtained to the south of the country. T_{max} shows the greatest warming in spring and summer, with trend values ranging from 0.2 to 0.8 °C decade $^{-1}$ in spring and 0.2 to 0.7 °C decade $^{-1}$ in summer. Annual T_{max} trends range from 0.2 to 0.5 °C decade^{-1} and are more related to the increase in summer.

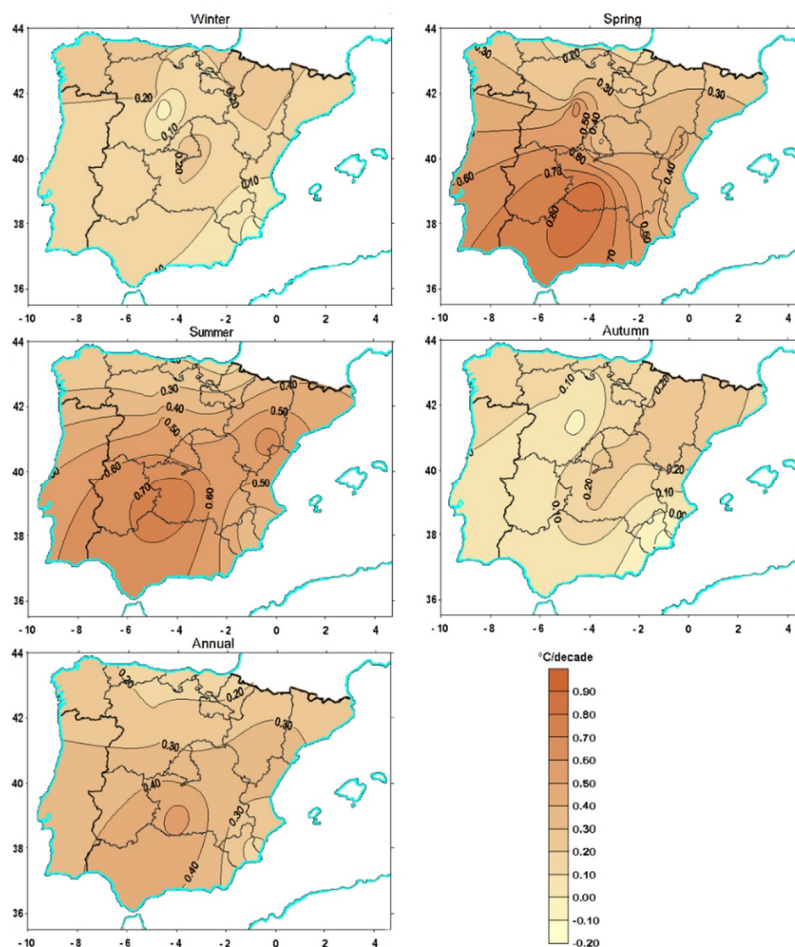**Figure 3.** Isolines of seasonal and annual trends in maximum temperature anomalies in Spain over the period 1950–2011, expressed in °C decade^{-1}.

The isolines of seasonal and annual trends in T_{min} anomalies over the period 1950–2011, expressed in °C decade^{-1}, in Spain area are shown in Figure 4. Annual trends are significant in about 70% of the area. For T_{min} trends values at annual scale, all stations present statistically significant trends at 99% ($p < 0.01$) significant except Caceres and Villalba. All stations are statistically significant with at least 95% confidence except Caceres and Villalba, in summer. In addition, all stations are significant at 99% except, Caceres, Villalba and Tortosa, in autumn. Ciudad Real, Coruña, Madrid, Murcia, Valladolid and IP are significant at 99% confidence; San Sebastian and Caceres are significant at 95% ($p < 0.05$) in spring; and finally all stations are significant at 95% confidence except Caceres, Tortosa, Valladolid

and Villalba in winter. Trend values of T_{min} show a south north gradient in all seasons from very high values on coastal sites.
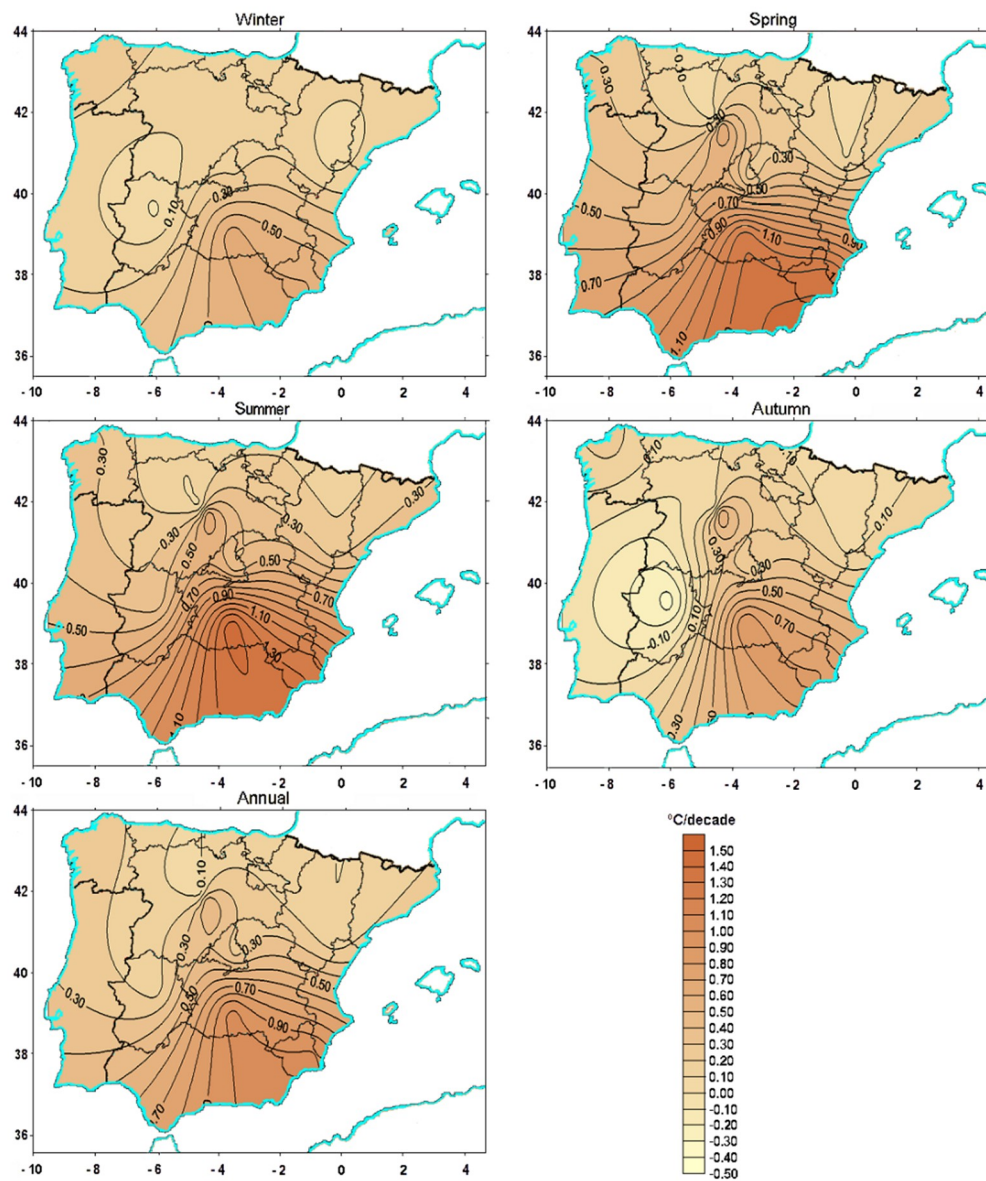

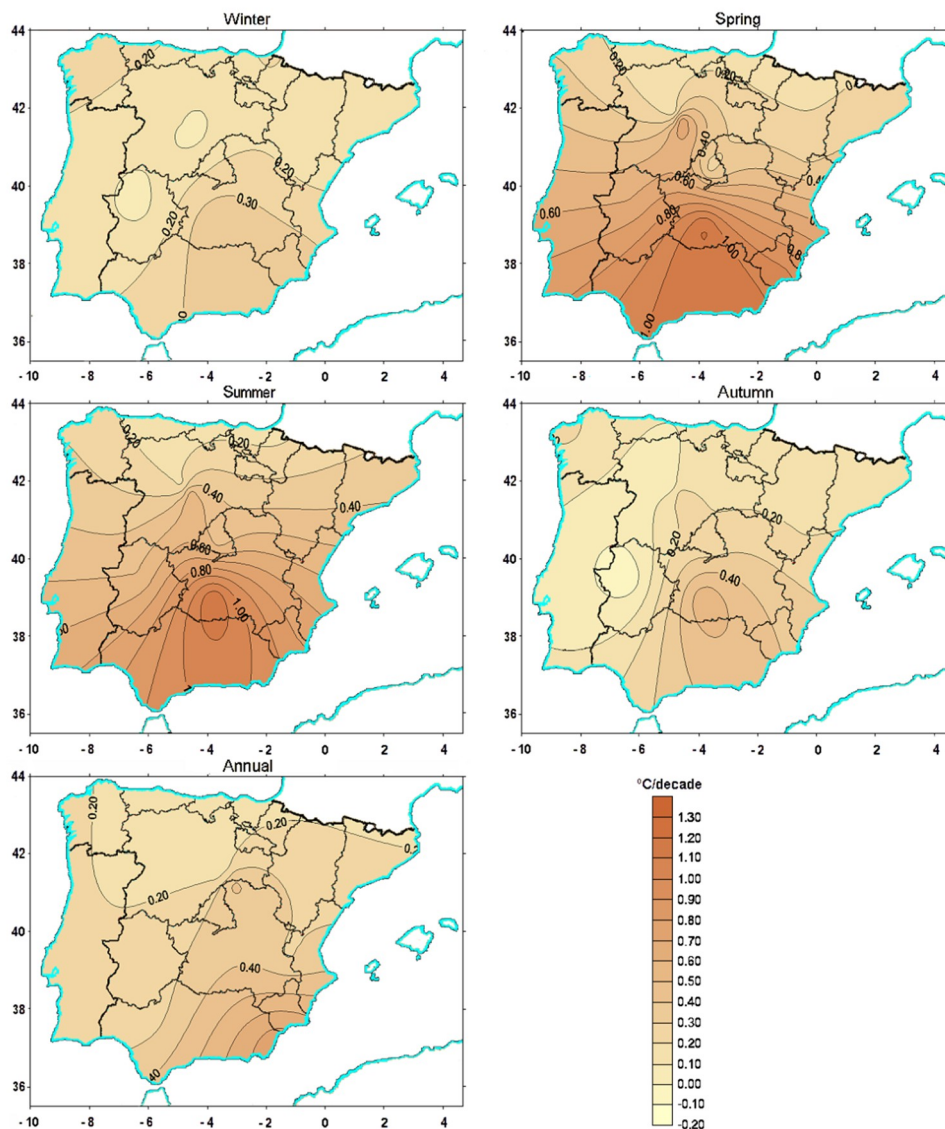**Figure 4.** Isolines of seasonal and annual trends in minimum temperature anomalies in Spain over the period 1950–2011, expressed in °C decade^{-1}.

Rates of change in trend range from 0.1 to 1.4 °C decade^{-1}, in spring and summer. The seasonal T_{min} trends change in a range from 0.1 to 1.40 °C decade^{-1} in summer and from 0.1 to 0.8 °C decade^{-1} in autumn, as can be seen in Figure 4. Annual T_{min} trends range from 0.1 to 1.0 °C decade^{-1} and are more related to the increase in summer and spring.

The seasonal and annual trend values in T_{mean} over the period 1950–2011 in Spain are shown as isoline maps in Figure 5. The magnitude of trends varies among the seasons.

T_{mean} shows the greatest and most widespread warming in spring and summer. The trend change ranges from 0.1 to 1.1 °C decade^{-1} in summer and from 0.2 to 1.1 °C decade^{-1} in spring. Annual T_{mean} trends range from 0.2 to 0.7 °C decade^{-1} and are more related to the increase in autumn and winter.

Figure 5. Isolines of seasonal and annual trends in mean temperature anomalies in Spain over the period 1950–2011, expressed in °C decade^{-1}.

Figure 6 shows the isolines of seasonal and annual trends in DTR over the period 1950–2011 in the Iberian Peninsula. For DTR trends at annual scale, all stations present statistically significant trends at 99% confidence, except Caceres that is not significant. In addition, all stations trends are statistically significant at 99% except Caceres and San Sebastian that are significant at 95% ($p < 0.05$), in summer. Murcia trends are statistically significant at 95% ($p < 0.05$); San Sebastian, Caceres, Valladolid and Villalba DTR trends are not significant and the rest of stations are significant at 99% in autumn. Villalba trends are not statistically significant; San Sebastian and Caceres are statistically significant at 95% ($p < 0.05$); the rest of stations are statistically significant at 99% ($p < 0.01$) in spring. Caceres, Murcia, Tortosa and Valladolid are not statistically significant in winter. San Sebastian and Villalba are statistically significant at 95% ($p < 0.05$); and Ciudad Real, Coruña, Madrid and IP are statistically significant at 99% ($p < 0.01$) in winter.
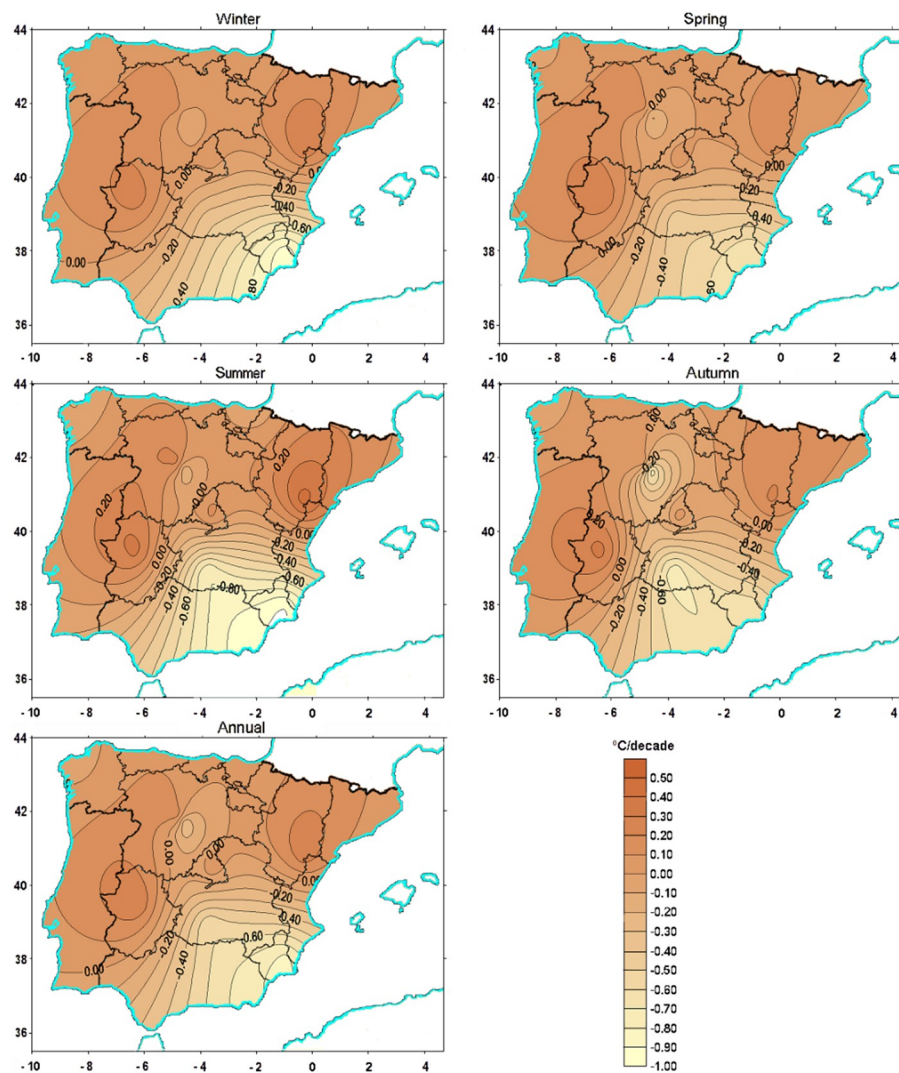
Figure 6. Isolines of seasonal and annual trends in diurnal temperature range (DTR) in Spain over the period 1950–2011, expressed in °C decade^{-1}.

The significant negative trends in 75% of the area, namely the south and part of the south east up to the region of Valencia, are shown in Figure 6. The results obtained concur with other authors' results; Del Rio et al. [10]; Galdies [13]; El Kenawy et al. [17]; Fernández-Montes et al. [39]; Makouski et al. [42]; Vose et al. [43]. Spatial DTR trends decrease over annual and seasonal periods at the stations located in the south and southeast of the country. The magnitude of temporal DTR trends changes with the season. The smallest DTR trends are obtained in winter and autumn, where trends range from 0.20 to −0.90 °C decade^{-1} and 0.40 to −0.70 °C decade^{-1}, respectively. The highest negative trends in DTR are shown in spring and summer and range from 0.20 to −0.60 °C decade^{-1} and 0.4 to −1.0 °C decade^{-1}, respectively. Annual DTR trends range from 0.2 to −0.8 °C decade^{-1} and they are more related to the increase in T$_{min}$. These negative DTR trends are due to the fact that stations like Ciudad Real, Murcia, San Sebastian and Valladolid reach high negative values in seasonal and annual DTR trends, which fall within the following intervals: Ciudad Real (−0.40 to −0.80 °C decade^{-1}), Murcia (−0.7 to −1.0 °C decade^{-1}) and Valladolid (−0.20 to −0.70 °C decade^{-1}). It should also be clarified that in Table 2, DTR trends are positive because they are averaged values for IP station, which was defined at the end of Introduction section.

4. Discussion

4.1. DTR Trends in Rural Stations

DTR trend is an important climate variable and it is widely known that changes in clouds, aerosol, sunshine hours and urbanization may affect it. In this section, the pairwise comparison between rural and urban stations is shown in order to observed DTR differences. Table 3 shows the seasonal DTR trends in three different areas and at four rural stations, Santiago de Compostela, Zaragoza, Granada and Villalba, Acero et al. [44] and it observed that seasonal DTR trend values were relatively small, almost all positive and they ranged between 0.23 and -0.08 °C decade^{-1}. The comparison in DTR trend values in urban and rural areas reveals that the effect of urbanization on DTR trends entails lower DTR trend in rural areas. In addition and for clarifying the idea, the influence of urbanization on DTR was evaluated by comparison between DTR at rural and nearby urban station. From Figure 1, three pairs of stations selected and their DTR monthly differences calculated for each pair. The pairs of selected stations were Santiago de Compostela and Coruña, Villalba and Valladolid and Zaragoza and Tortosa. Finally, the statistical significance of each time series was tested by Kolmogorov-Smirnov and t-Student tests and the results showed that the difference series were significant at 95% confidence level, $p < 0.05$, where Santiago de Compostela and Coruña obtained $p = 0.001$; Villalba and Valladolid $p = 0.04$ and Zaragoza and Tortosa $p = 0.02$. The results indicated that the series analysed were statistically significant with a confidence of 95% ($p < 0.05$) and therefore there was a difference between rural and urban DTRs. It recommends that the estimations should be repeated using a greater number of rural stations in order to reach definitive conclusions.

Table 3. Seasonal DTR trends (°C decade^{-1}) at three different areas and four rural stations (*) with the corresponding mean standard error in Spain for the period 1950–2011 The results are significant at the 0.05 level.

Area	Spring	Summer	Autumn	Winter
Centre	0.16 ± 0.06	0.25 ± 0.05	0.15 ± 0.08	0.17 ± 0.06
Atlantic	0.00 ± 0.00	-0.01 ± 0.01	-0.01 ± 0.00	0.01 ± 0.01
Mediterranean	-0.29 ± 0.04	-0.20 ± 0.07	-0.11 ± 0.06	-0.22 ± 0.06
*Villalba	0.13 ± 0.04	0.23 ± 0.06	0.06 ± 0.03	0.13 ± 0.06
*Granada (air base)	0.07 ± 0.05	-0.06 ± 0.05	0.03 ± 0.04	0.22 ± 0.09
*Santiago de Compostela	0.10 ± 0.04	-0.07 ± 0.04	0.01 ± 0.01	0.01 ± 0.01
*Zaragoza (Airport)	0.00 ± 0.01	0.07 ± 0.03	-0.08 ± 0.04	0.02 ± 0.02

4.2. Causes of DTR Decreases

In an initial study, the decrease in DTR attributed to the high rate of increase in T_{min} with regard to T_{max}. The possible causes of DTR variation studied by analysing the trends and correlation between DTR and the meteorological variable values, as suggested by Wang et al. [40]. Annual DTR trends in the Iberian Peninsula series correlated with relative humidity, precipitation and sunshine hour annual values. Results showed that relative humidity and precipitation were negatively correlated with DTR, with the obtained correlation coefficients being -0.88 and -0.79, respectively. The correlation coefficient between sunshine hours and DTR was 0.57. This study found that the magnitude of DTR decreases when precipitation and relative humidity increase. These results were compared with Zhou et al. [45], who obtained a similar correlation coefficient for precipitation and DTR in a semi-arid region of China, with values between -0.82 and -0.54. In addition, Zhou et al. [45] observed that DTR and precipitation correlation may reflect the large-scale effects of increased global greenhouse gases and aerosols (and associated changes in cloud, soil moisture and water vapour) in DTR. Although in our case, a negative correlation between DTR and precipitation would be expected just because both are regulated by clouds and water vapour.

DTR is considered a suitable measure of climate change because of its sensitivity to variations in the radiative energy balance. In our results, DTR has decreased because T_{min} increases more than

T_{max} and DTR is negative. In physical terms, DTR reduction is generally a consequence of increases in cloud cover, relative humidity, precipitation, atmospheric gases and the optical properties of aerosol. Clouds affect DTR because during the day they reflect sunlight, as a result of which T_{max} decreases, while at night they increase downward longwave radiation, such that T_{min} increases. Soil moisture may reduce DTR at surface by the evaporation cooling effect on T_{max}. Precipitation may affect DTR indirectly by increasing soil moisture content. Other atmospheric components, such as aerosol and greenhouse gases may also contribute to reducing DTR, (IPCC 2007, [41]). Aerosol may affect DTR by reflecting solar radiation and by modifying cloud properties and greenhouse gases may play a role in altering DTR by controlling the surface energy and hydrological balance. The highest reduction of DTR trends in summer season may be associated with the combination of the higher increasing trends in relative humidity in some stations and high temperatures in the southeast Mediterranean area, for example, Murcia that shows maximum in relative humidity and temperature in August.

5. Conclusions

It has been observed that T_{max}, T_{min} and T_{mean} trends increased and DTR trends decrease at certain stations in Spain. The results also show that the difference between the DTR trends in urban and rural stations may be due to phenomena such as the increase in the number of urbanized areas in certain parts of the country. DTR variation is controlled by meteorological variables and anthropogenic factors such as greenhouse gases and planned urban development. More studies investigating the causes of DTR variations are required to complete the study.

The main aim of this study was to evaluate T_{max}, T_{min}, T_{mean} trends and DTR variability and to obtain some estimates of the potential causes of said variability for the period of 1950–2011 over certain stations in Spain. The main conclusions to emerge from this work are:

1. T_{max}, T_{min} and T_{mean} seasonal and annual trends were positive and T_{min} obtained the highest trend values. Seasonal and annual DTR trends decreased for the period 1950–2011, in Spain.

2. The largest increase in T_{min} was observed in the NE and SE. Intense urbanization and increasing irrigation might be causing night-time warming. This result concurs with trends found by different authors.

3. The causes of DTR decreases were studied, correlating meteorological surface variables and DTR trends. Decreases observed in DTR trends might be related to the influence of certain meteorological variables and particularly to relative humidity, precipitation and sunshine hours. Data from the three meteorological variables used for correlation analysis. Results show that sunshine hours have a positive correlation with DTR and precipitation and relative humidity have negative correlation with DTR. The highest reduction of DTR trends in summer season may be associated with the combination of the higher increasing trends in relative humidity and high temperatures in the southeast Mediterranean area.

4. Small towns and airports chosen as rural stations and their DTR trends were evaluated. Results show that rural DTR trends were small and positive in all seasons and annual series. These results reveal that aerosols (such as desert dust and smoke) in urban stations may have an important influence on solar irradiation reduction, so, T_{max} and DTR should decrease and DTR trend should be more negative.

The causes of DTR decreases were studied by analysing the correlation between DTR and meteorological surface variables. Results indicate that sunshine hours have a positive correlation with DTR while DTR and precipitation and relative humidity evidence a negative correlation. In general, a number of factors control DTR variations. In addition to the meteorological surface variables and anthropogenic factors analysed in this study, other factors (e.g., boundary layer, greenhouse gases) may also affect DTR changes. In view of the results, further analysis of the causes underlying DTR variation is necessary. Given the importance of climate change, further research is also encouraged to assess the impact of climate variation on the energy resources in this country.

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