

A Comparative Study on Extreme Heat between Guadalquivir Valley and Segura River Valleys: Trend and High Resolution Cartography

David Espín-Sánchez

Universidad de Murcia

david.espin1@um.es

Carmelo Conesa-García

Universidad de Murcia

cconesa@um.es

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The Guadalquivir and Segura Valleys are geographical areas in the south of the Iberian Peninsula where extremely high summer temperatures have become increasingly frequent, especially during recent summers. A comparison of the characteristics of extreme heat of the two zones is presented, analyzing the statistical trend (1900-2017) of the cities of Seville and Murcia, and a detailed cartography of the warm poles of maximum and minimum temperatures is provided using high resolution modeling tools (AROME 1.3 km) and remote sensing (MYD11A1). The results are conclusive, since there is a statistically significant increase in the number of days with extreme heat indices (TX35, TX40, and TN20), while periods of warm spells (WSDI) increase in frequency and duration. The regime of the maximum and minimum daily temperatures is explained in relation to the factors that determine it (among them, the influence of the great mountain ranges of the Sierras de Segura and Cazorla -2100 m- in the genesis of catabatic winds that descend towards both valleys).

Material and methods. In order to study summer temperatures, data of the meteorological observatories of the first order of the State Meteorological Agency (AEMET) of Murcia and Seville were analyzed, using the recently constituted Open Data Service of AEMET. For both stations, the temperature series of the period 1900 - 2016 were used, already homogenized and treated by the Agency itself (in total 116 years of records). Based on this information, certain extreme climate indices proposed in the CLIMDEX Project were calculated, such as the TX25, TX35, TX40, TN20, TN25, and Warm Spell Duration Index (WSDI). The TXx is the maximum temperature above the threshold x (expressed in °C), while TNx alludes to the minimum temperature that exceeds x°C. The WSDI is defined as the number of days per year that include streaks of at least six consecutive days whose maximum daily temperature exceeds the 90th percentile (P90) of the annual maximum. For each of these indices, their statistical trend is analyzed in both cities through the Mann Kendall non-parametric test provided in the free package of R Studio (Climdex). The study of extreme heat variables was completed with the information provided by various meteorological observatories belonging to the Agroclimatic Information System for Irrigation (SIAR) of the Ministry of Agriculture and Fisheries, Food, and Environment. The spatial distribution of the maximum and minimum temperatures of both zones was represented by a high resolution map made with the mesoscale model AROME 1.3 km (downloaded through the Open Data service of www.meteofrance.com), and with data of the *Land Surface Temperature Data and Emissivity Daily* channel (MYD11A1) provided



by the Moderate Resolution Imaging Spectroradiometer satellite (MODIS / AQUA) (Land Processes Distributed Active Archive Center -LPDAAC-, NASA)

The thermal differences estimated or observed using AROME and MODIS, respectively, were validated with the maximum and minimum temperature data from the observatories of Cantillana (Sevilla), Córdoba, Andújar (Jaén), Calasparra-Rotas (Murcia), and Murcia. For the calculation of the trend of the summer extreme heat variables, mobile means of band 10 were estimated, as representative of the changes produced per decade. The warm pole mapping was generated by implementing the available climate data and the *Humidex* index in a GIS. This index, widely used in Canada and the United States, is based on the increase in the sensation of heat felt by the human body in conditions of high temperature (above 20°C) and high relative humidity.

Results. There are municipalities in the Guadalquivir Valley, such as Andújar (Jaén), or cities, such as Córdoba, where in recent years it has been usual for more than 20 days per year to have been recorded with absolute maximum temperatures above 40°C, while in the Vega Media del Segura (La Vereda - Murcia) several districts have had more than 60 tropical dawns (> 20°C) per year. The most paradigmatic case is that of Córdoba, which - during the last few summers - has had more than 25 summer days with minimum temperatures above 25°C (TN25) and maximum values above 40°C (TX40) too often. Indeed, during the recent summer of 2017, a total of 37 days of TX40 were registered, representing a new record. The meteorological events registered during the past summer provided very significant data. Specifically, the average summer temperature, from June 1 to August 31, was 28.9°C, setting a new record, 0.4°C above the summer of 2016. Also, the average maximum temperature (38.4°C) set another new record; in addition, it was the first occasion when a summer in Córdoba exceeded the barrier of 38°C on average (previous record: 37.7°C in 2016), and the first time that all three months registered maximums of 44°C or more in the same year (June: 44.5°C, July: 46.9°C, and August: 44.7°C). It should also be noted that the trend towards more extreme heat is significantly positive in both study areas, especially in the case of the TX30 and TN20 indices, which show increases of 1.6 and 3.3 days per decade, respectively, and the WSDI (index of recurrence and duration of warm spells), whose increase is more noticeable in the month of July. All these indices indicate a lengthening of the periods of heat, in line with the increase in the average temperature, as has already been proven in many other regions. The greatest increase in WSDI episodes has occurred in the tropical regions of the planet, mainly in the summer and autumn months. Outside these zones, the southern Iberian Peninsula has one of the highest WSDI values of any area, worldwide, possibly related to changes in the length of its heat waves.

The best fit, and therefore the most satisfactory results, for AROME 1.3 were obtained in the case of maximum temperatures, with a margin of error between 0.2 and 0.3°C for the July-August period. On the other hand, for the minimum values in areas of thermal inversion the model had more limitations, since it generated temperature deviations of 1.6 to 2.5°C.

The mapping of warm poles shows that the Guadalquivir Valley has the greatest thermal extremes, for both maximum and minimum values; hence, Level 1 appears in the maps corresponding to that area. In particular, the warm poles of maximum temperatures follow a well defined axis on the course of the Guadalquivir river, from the city of Córdoba to the easternmost sectors of the province

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of Jaén (Vilches and Peal del Becerro), which is the warmest area of the Iberian Peninsula. The minimum temperatures, unlike the linear distribution of the maximum values, are concentrated in isolated warm poles that have a circular perimeter or little elongation. Among them stand out the ones located in the northeastern regions of the province of Jaén (Vilches - Linares), the metropolitan area of Córdoba, several enclaves of the municipalities of Marmolejo and Adamuz (Córdoba), and the city of Seville, together with some isolated northern sectors of this province. This spatial distribution is supported by the averages recorded by the AEMET observatories in the Guadalquivir Valley, according to which higher average summer temperatures, from 28.5 to 28.8°C, are concentrated in the Bailén-Vilches-Linares area, mainly due to the influence of the high minimum temperatures during the months of July and August.

By comparison, the results obtained in Las Vegas del Segura show more modest values than in the Guadalquivir Valley, although the sector located in the vicinity of Calasparra - Cieza (Rotas, Macaneo and Almadenes) is an important thermal pole, with maximum temperatures that are highly significant. The highest minimum temperatures during the summer season are concentrated, however, in the metropolitan area of Murcia, but they are far below those registered in the interior of Jaén and in the large cities of the Guadalquivir Valley, increasingly influenced by the heat-island effect (De la Morena, 2010, attributed to this effect differences of up to 5°C between the center of Seville and the nearby Puebla del Río during the months of July and August). Regarding the average summer temperatures estimated according to AEMET data, the highest corresponds to the city of Murcia (27.5°C), followed by Abarán-Blanca-Cieza (27°C), undoubtedly also due to the high minimum temperatures at this station.

