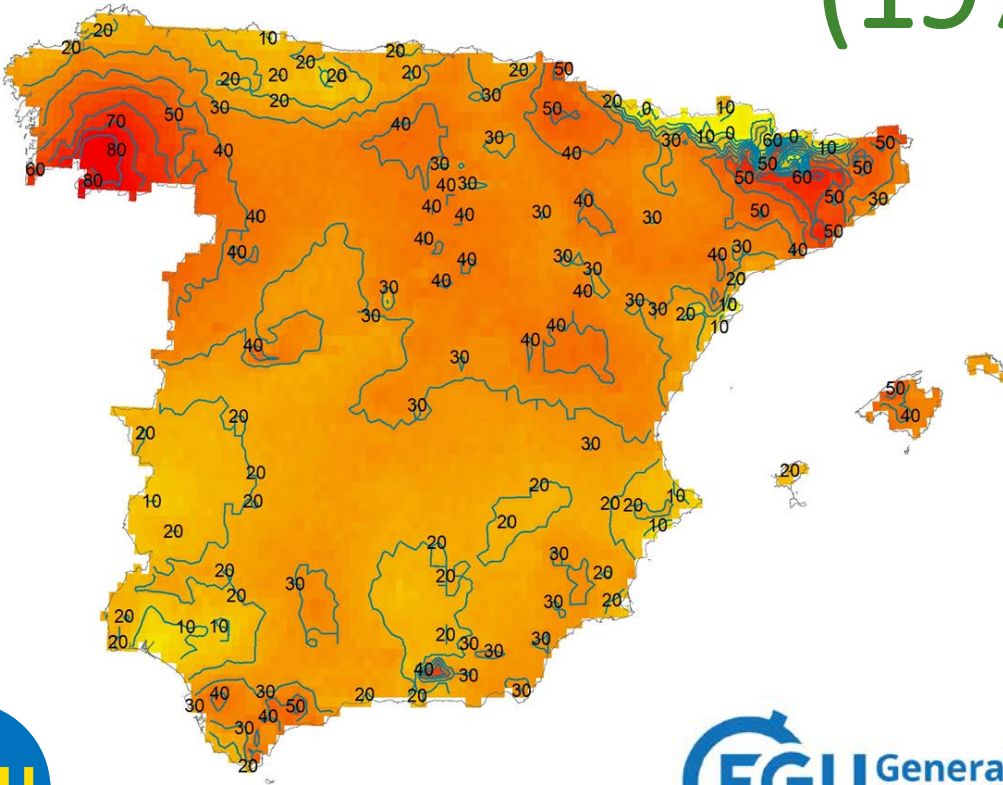




# Global Warming in Spanish Cities (1971-2022)



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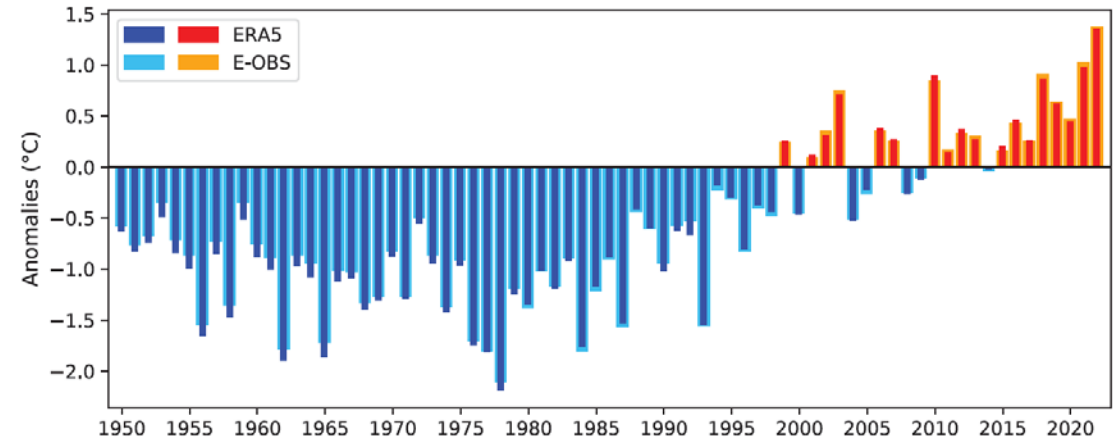
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Technical University of Catalonia  
<https://cpsv.upc.edu/en>



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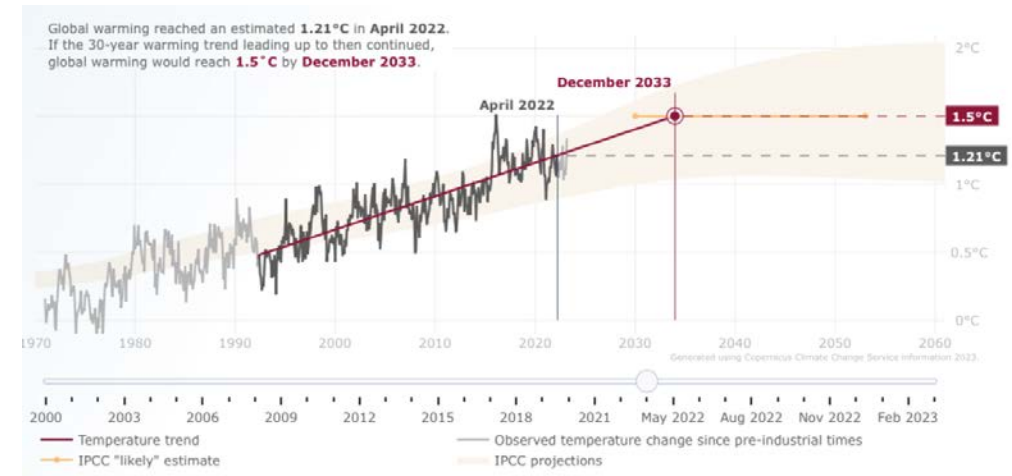
# Global Warming



European land surface air temperature anomalies for summer (JJA) 1950–2022, relative to the average for the 1991–2020 reference period. Data source: ERA5, E-OBS. Credit: C3S/ECMWF/KNMI.

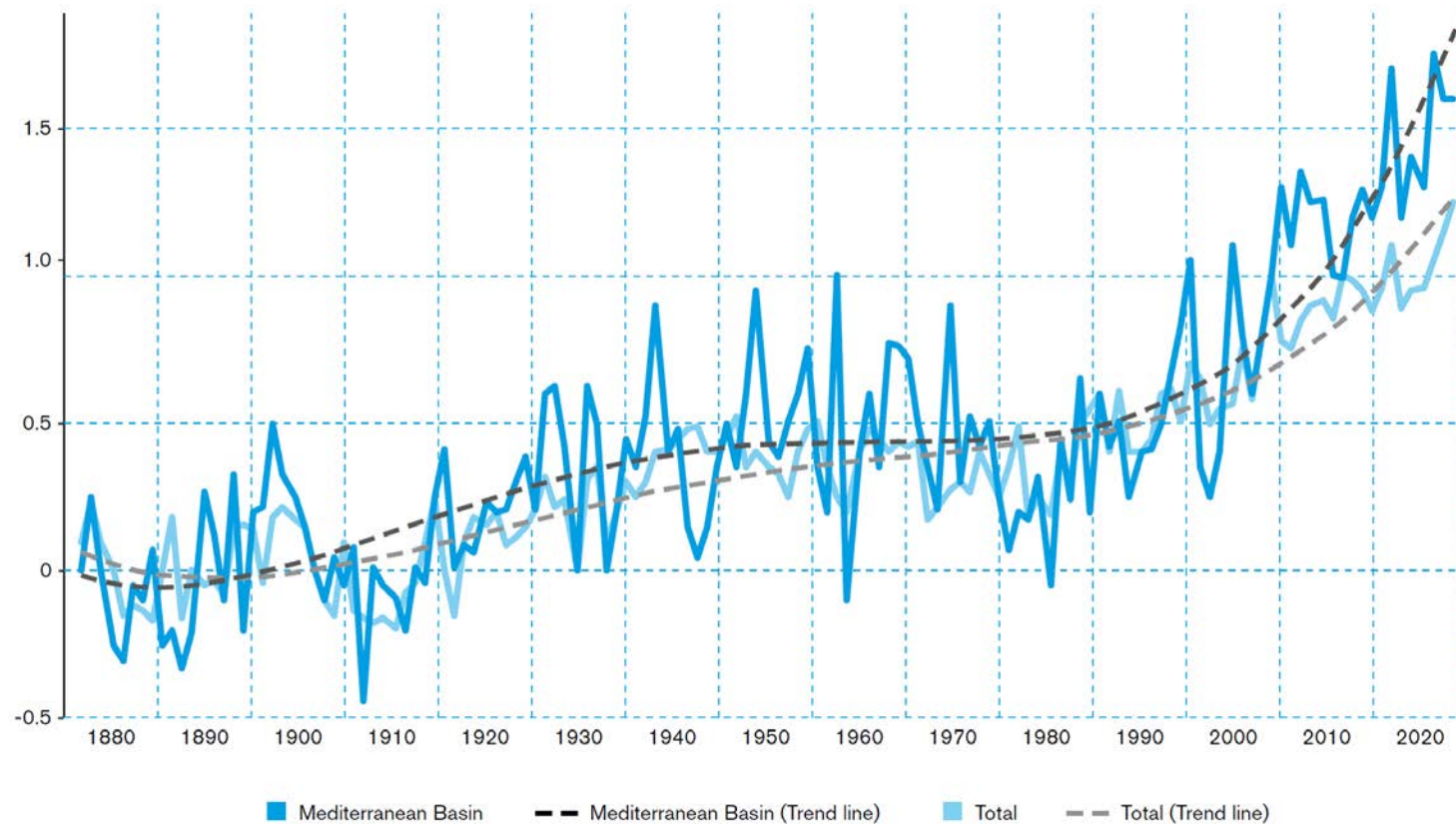
GW reached 1,21°C in April 2022. If the 30-year warming trend continued, GW would reach 1.5°C by 12/2033

**2022 was the second warmest year on record for Europe, at 0.9°C warmer than average. For many countries in southwestern Europe, the year was the warmest.** The highest anomalies in temperatures occurred in northeastern Scandinavia and those countries bordering the northwestern Mediterranean Sea (ESOTC2022)



# Global Warming in Mediterranean Area:

## Mean Temperature Anomalies



The **Mediterranean** is expected to be one of the **most vulnerable climate change 'hotspots'** of the 21st century

The mean temperature over the Mediterranean has higher increasing than the global average

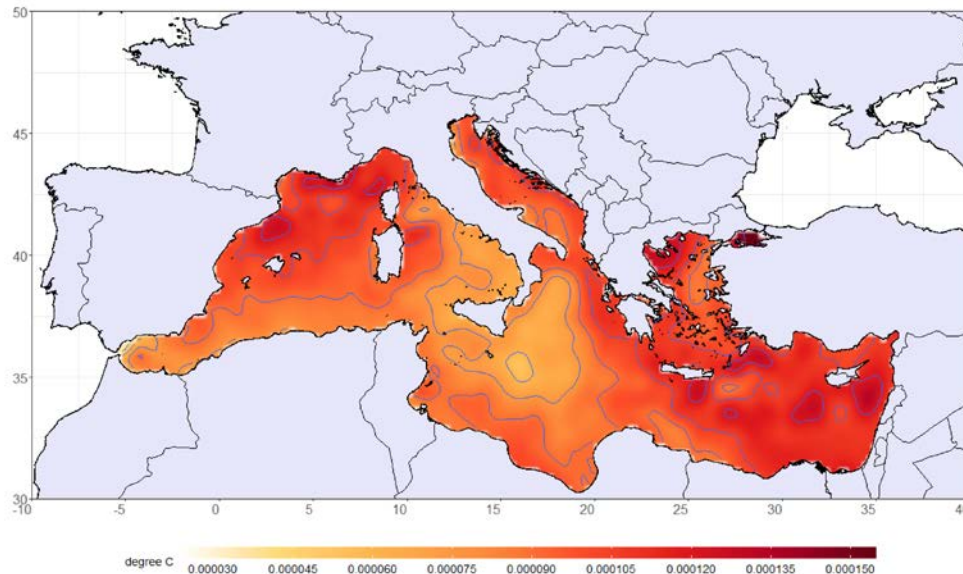
Lange, M. A. 2021. Climate Change in the Mediterranean: Environmental Impacts and Extreme Events. IEMed Mediterranean Yearbook 2021



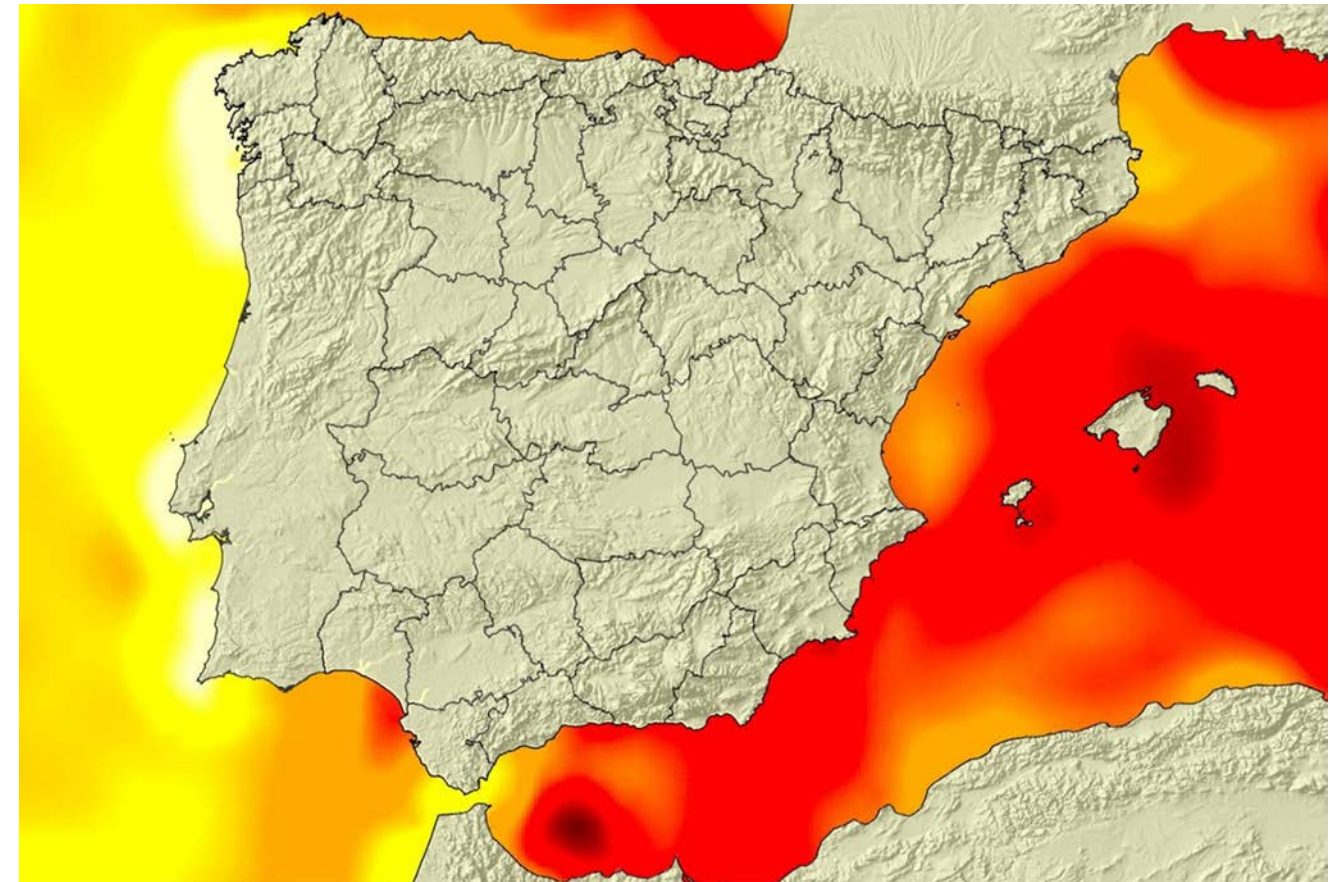
# Warming in Mediterranean Sea

Warming of the Mediterranean is an important factor in explaining the increase in temperatures in Spain. Coastal zones face heightened disaster risks, including flooding, erosion, and the salinization of river deltas and aquifers.

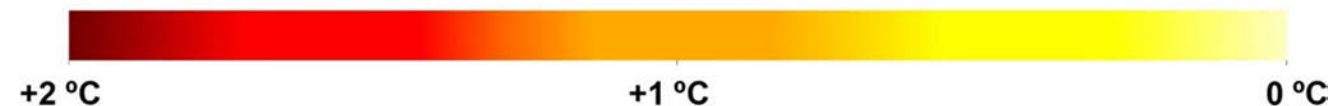
- 2°C global warming will reduce precipitation by ~10 to 15%.
- An increase of 2°C to 4°C would reduce precipitation by up to 30% in Southern Europe



Daily warming trend in the Mediterranean basin from 1982 to 2019. Pastor *et al* 2020

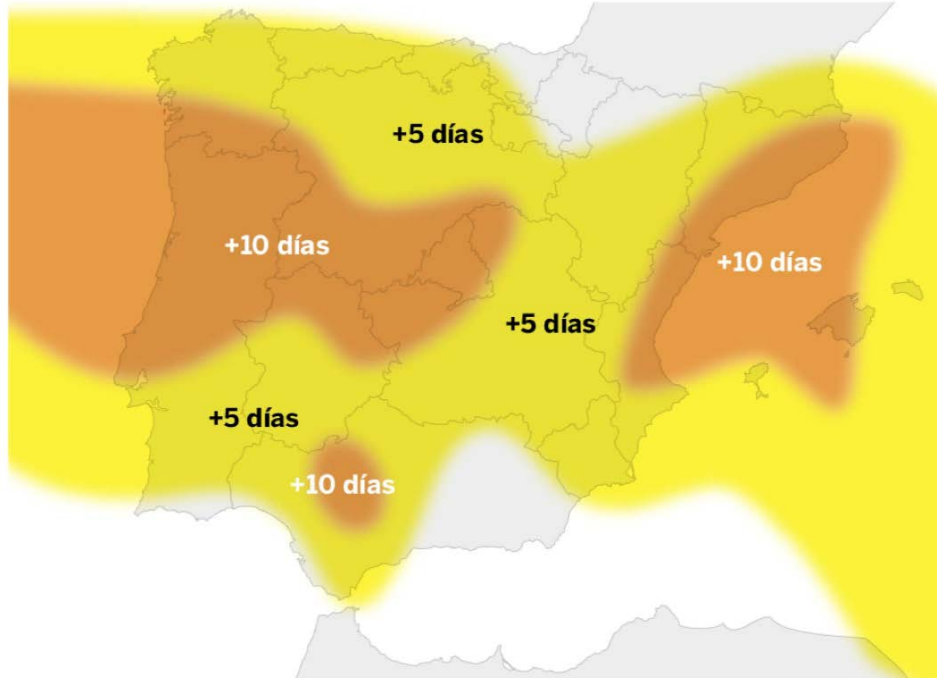


Sea surface temperatura increase in summer (1979-2018)



Changes in sea water temperature in the last 40 years (AEMET)

# Increase of Summer days per decade due to temperature increase

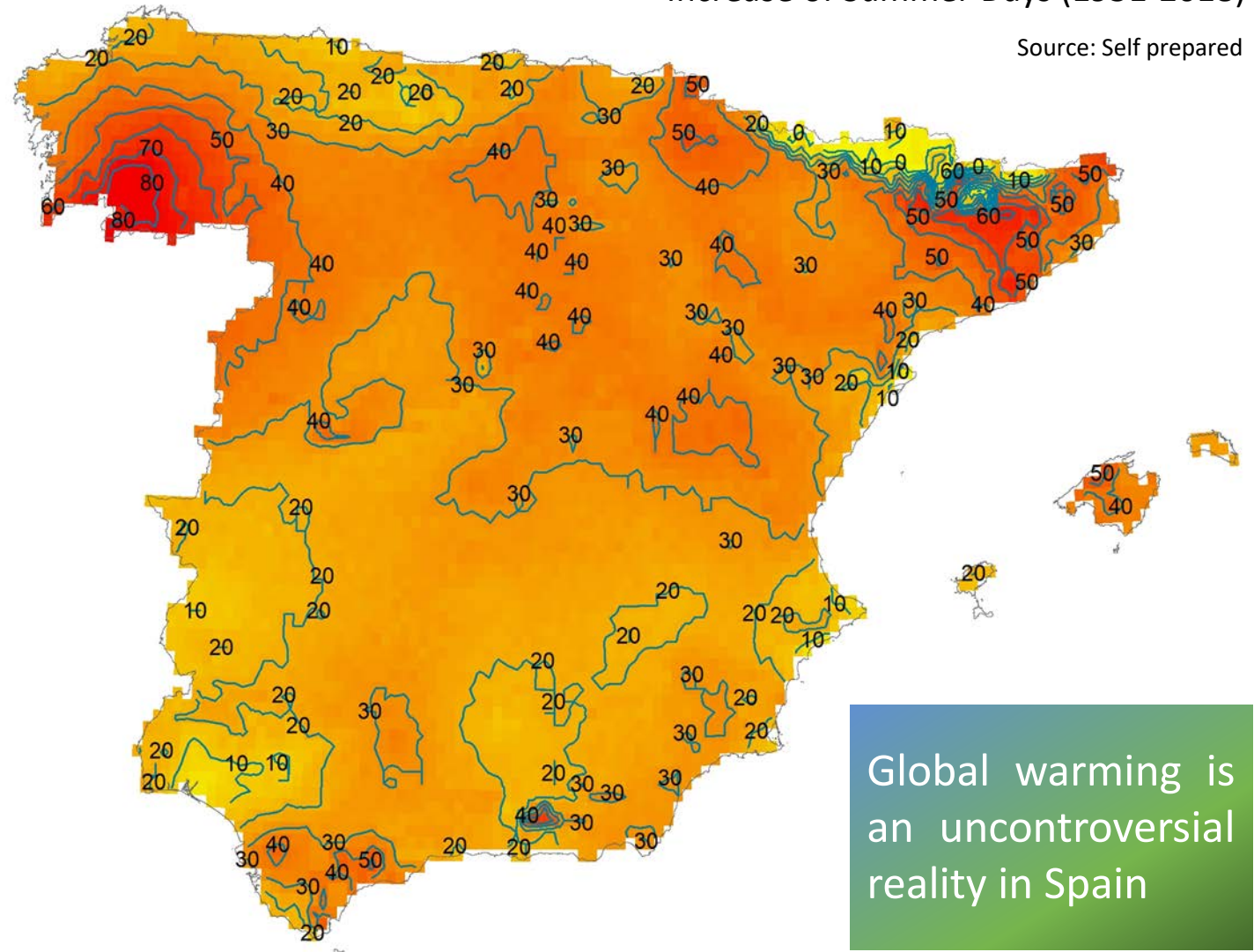


Source: AEMET, 2019

- Summer in Spain now lasts on average almost five weeks longer than in the early 80's.
- In addition, it is hotter.

## Increase of Summer Days (1951-2018)

Source: Self prepared



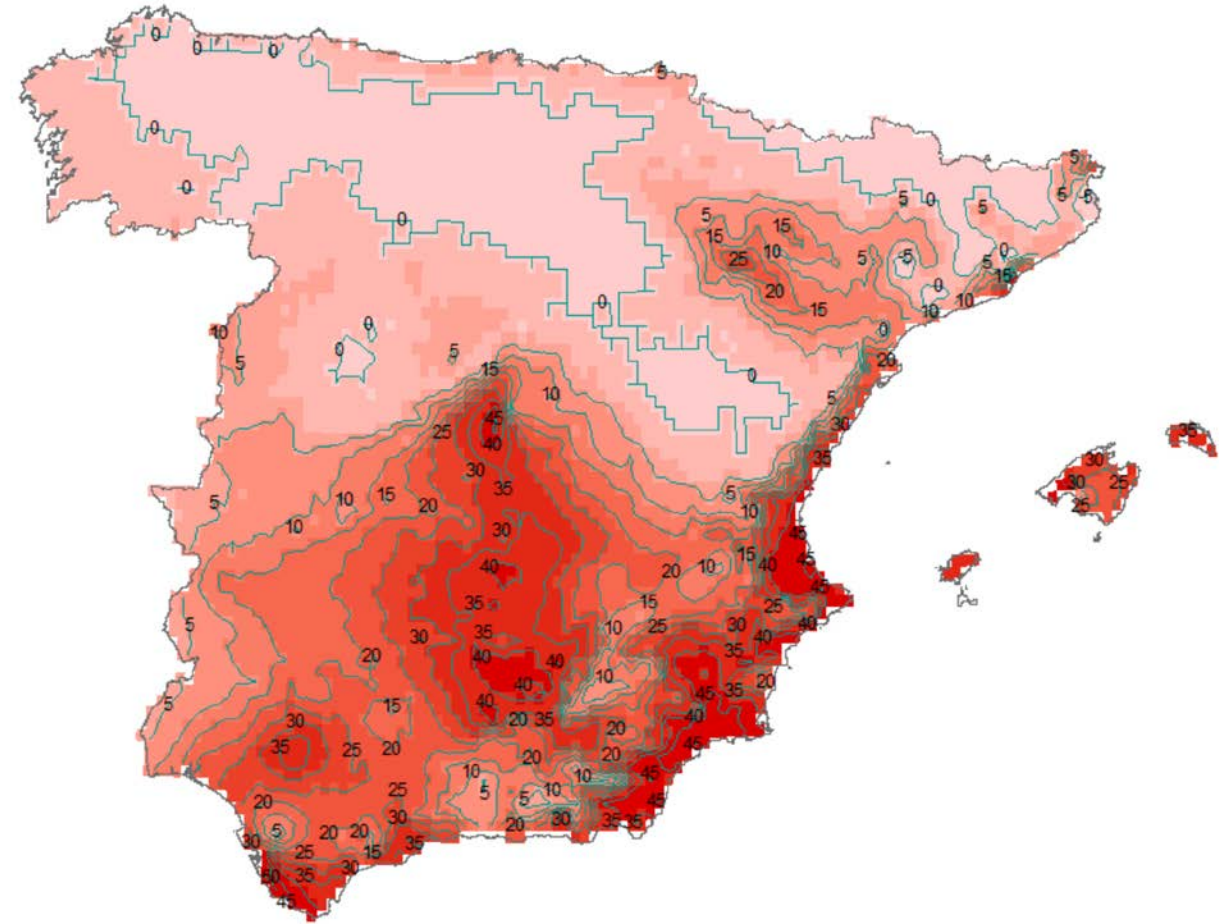
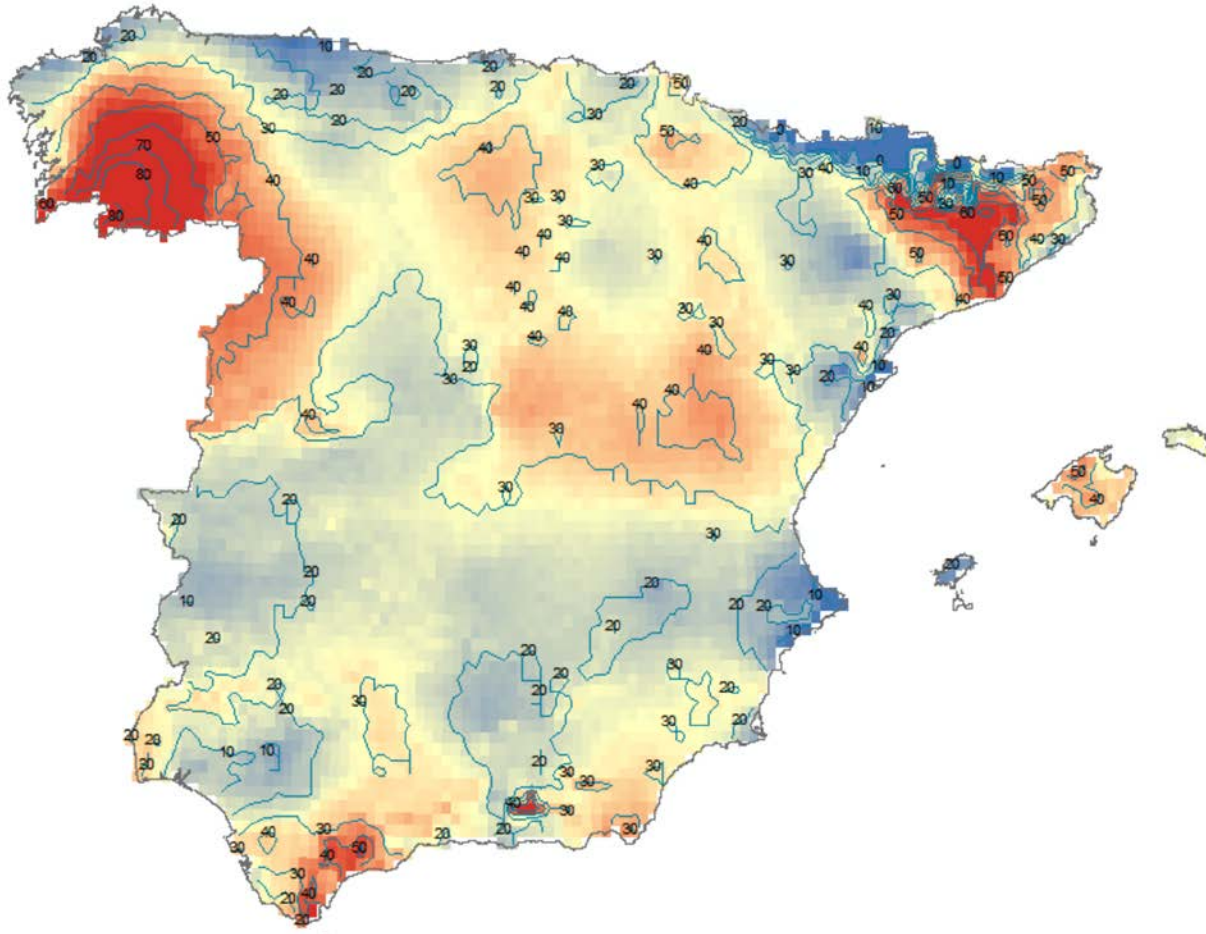
Global warming is an uncontroversial reality in Spain



# Global Warming in Spain

Increase in summer days (TX > 25) between 1951-54 and 2015-2018

Increase in tropical nights (TN > 20)



Source: Self prepared from [https://surfobs.climate.copernicus.eu/dataaccess/access\\_eobs\\_indices.php](https://surfobs.climate.copernicus.eu/dataaccess/access_eobs_indices.php)

# Health and Heat Waves in Spain

The extreme weather in summer affects people's health and comfort. The increase in mortality in the months of June, July and August were 22,249 additional deaths. It demonstrates the effects of the HW of 2022.

466.601

Observadas

431.828

Estimadas base

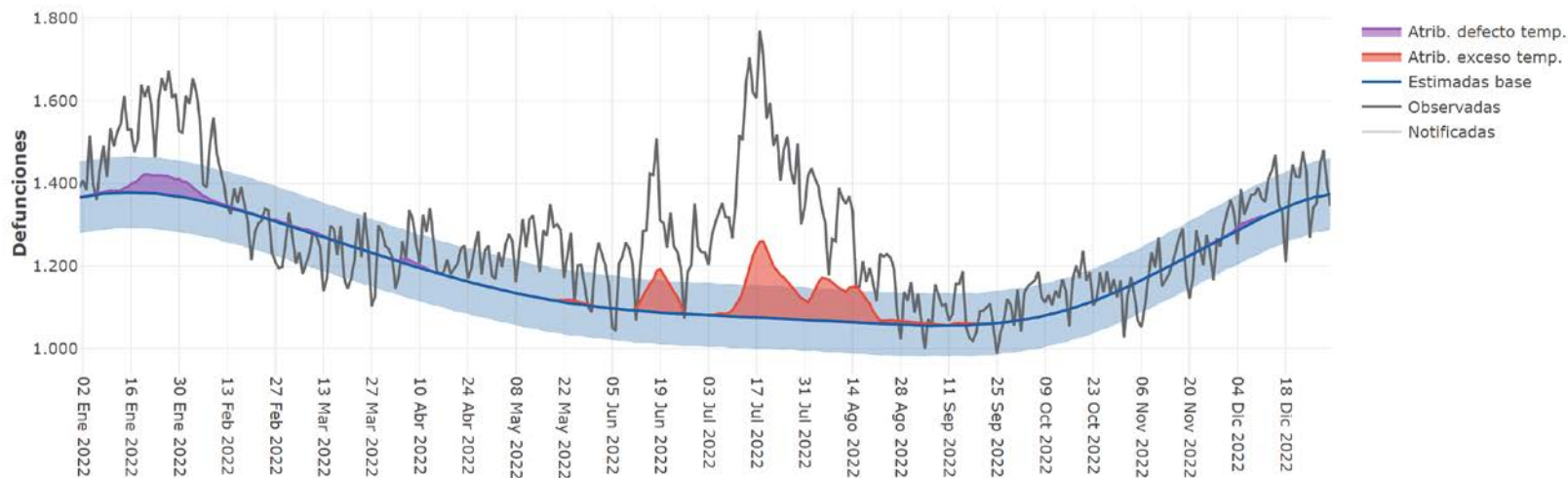
34.773

Exceso por todas las causas

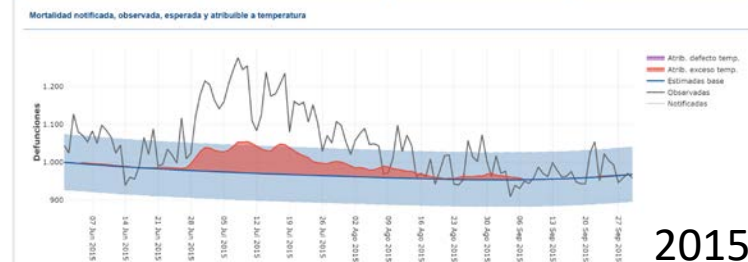
5.876

Atribuibles a temperatura

Mortalidad notificada, observada, esperada y atribuible a temperatura

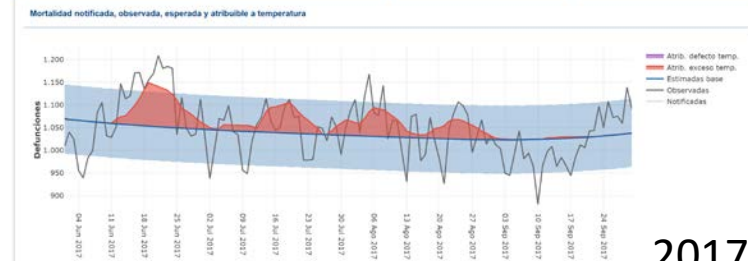


|            |                |                             |                           |
|------------|----------------|-----------------------------|---------------------------|
| 127.645    | 118.057        | 9.588                       | 2.486                     |
| Observadas | Estimadas base | Exceso por todas las causas | Atribuibles a temperatura |



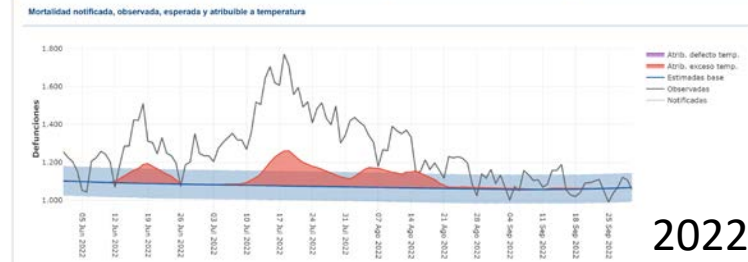
2015

|            |                |                             |                           |
|------------|----------------|-----------------------------|---------------------------|
| 127.706    | 126.557        | 1.150                       | 2.808                     |
| Observadas | Estimadas base | Exceso por todas las causas | Atribuibles a temperatura |



2017

|            |                |                             |                           |
|------------|----------------|-----------------------------|---------------------------|
| 153.064    | 130.815        | 22.249                      | 4.732                     |
| Observadas | Estimadas base | Exceso por todas las causas | Atribuibles a temperatura |



2022

Especially hot years

# General Objective

## Study of Extreme Heat Events in the Spanish Cities between 1971 and 2022

The objective is to analyze the warming process in the main Spanish urban areas since unified records in the early 1970s.

Analyzing 21 meteorological stations representative of all the Spanish Autonomous Communities

## Hypothesis

It is important to differentiate Daytime Heat Wave (DHW) from those at night (NHW), since the latter are becoming more numerous and longer, affecting people's health more widely

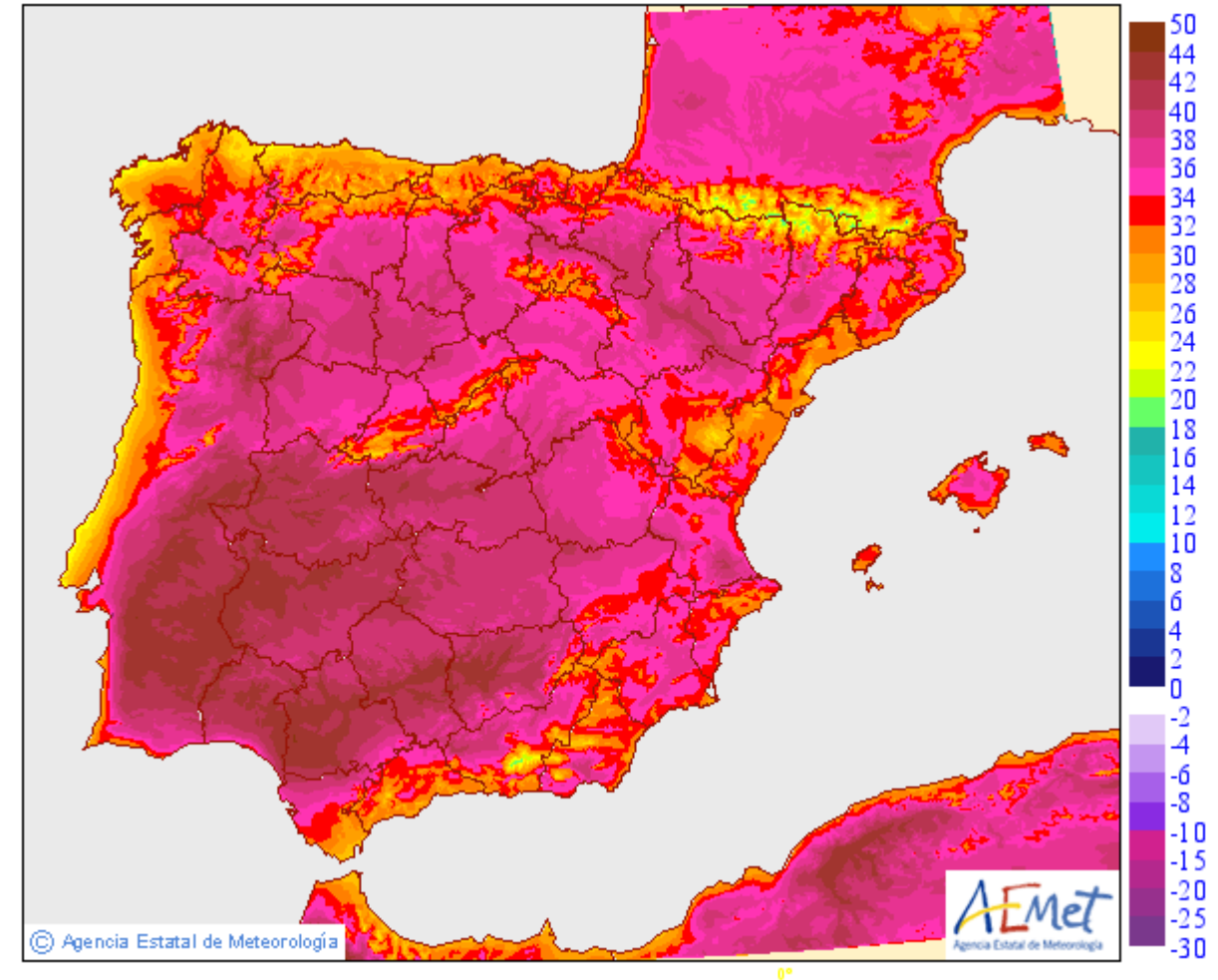
|                                 |                                    |                                         |                                                                                 |
|---------------------------------|------------------------------------|-----------------------------------------|---------------------------------------------------------------------------------|
| Barcelona<br>(Catalonia)        | Madrid<br>(Community of<br>Madrid) | Valencia (Valencian<br>Community)       | Zaragoza (Aragon)                                                               |
| Seville & Malaga<br>(Andalusia) | Bilbao (Basque<br>Country)         | Valladolid (Castilla<br>and León)       | Ciudad Real<br>(Castilla–La<br>Mancha)                                          |
| Badajoz<br>(Extremadura)        | Asturias (Asturias)                | Santander<br>(Cantabria)                | Corunya & Ourense<br>(Galicia)                                                  |
| Murcia (Region of<br>Murcia)    | Logroño (Rioja)                    | Palma de Mallorca<br>(Balearic Islands) | Las Palmas de Gran<br>Canaria and Santa<br>Cruz de Tenerife<br>(Canary Islands) |



# Heat Wave

There is no universal definition of a heat wave, but such extreme events, associated with particularly hot sustained temperatures, have been known to produce notable impacts on human mortality, regional economies, and ecosystems.

The main element to define a heat wave is the presence of periods (three or more days) with extremely hot weather, in which there is no significant relief from the minimum temperatures and could have significant impacts on people's health.



Maximum temperature in the Heat Wave in July 2022

# Heat Wave (Method 1)

Concept of heat wave used in the Spanish Meteorological Agency (AEMET):

A 'heat wave' is considered an episode of at least three consecutive days, in which at least 10% of the stations considered register maximums above the 95% percentile of their series of maximum daily temperatures for the months of July and August from the period 1971-2000

This definition has an important limitation: **it refers only to maximum temperatures, not minimum ones**. As indicated, it is the high minimum temperatures that mainly make the difference in health

Maximum temperatures can have serious consequences, especially "heat strokes", but health effects are more pronounced in the case of night heat, where the inability to rest (especially in homes without air conditioning as occurs mainly in Spain) can cause a significant worsening of respiratory and cardio-vascular diseases that produce premature deaths

For this reason, in this work we will differentiate Daytime Heat Waves (DHW) and Nighttime Heat Waves (NHW), **emphasizing the NHW** (Arellano & Roca, 2022)

# Heat Wave (Method 2)

We assume that HW is detected when **three or more consecutive days reach temperatures above the 95 percentile on each calendar day**. These percentiles are obtained with a 15 day moving window of the maximum (TX) and minimum (TN) temperatures for each day of the year, and are calculated for the reference period 1971-2000 (Serra *et al*, 2022)

Daytime heat waves (DHW) are obtained if  $TX \geq 95\% TX_{1971-2000}$  for 3 or more consecutive days, and at nighttime heat waves (NHW) if  $TN \geq 95\% TN_{1971-2000}$  for 3 or more consecutive nights

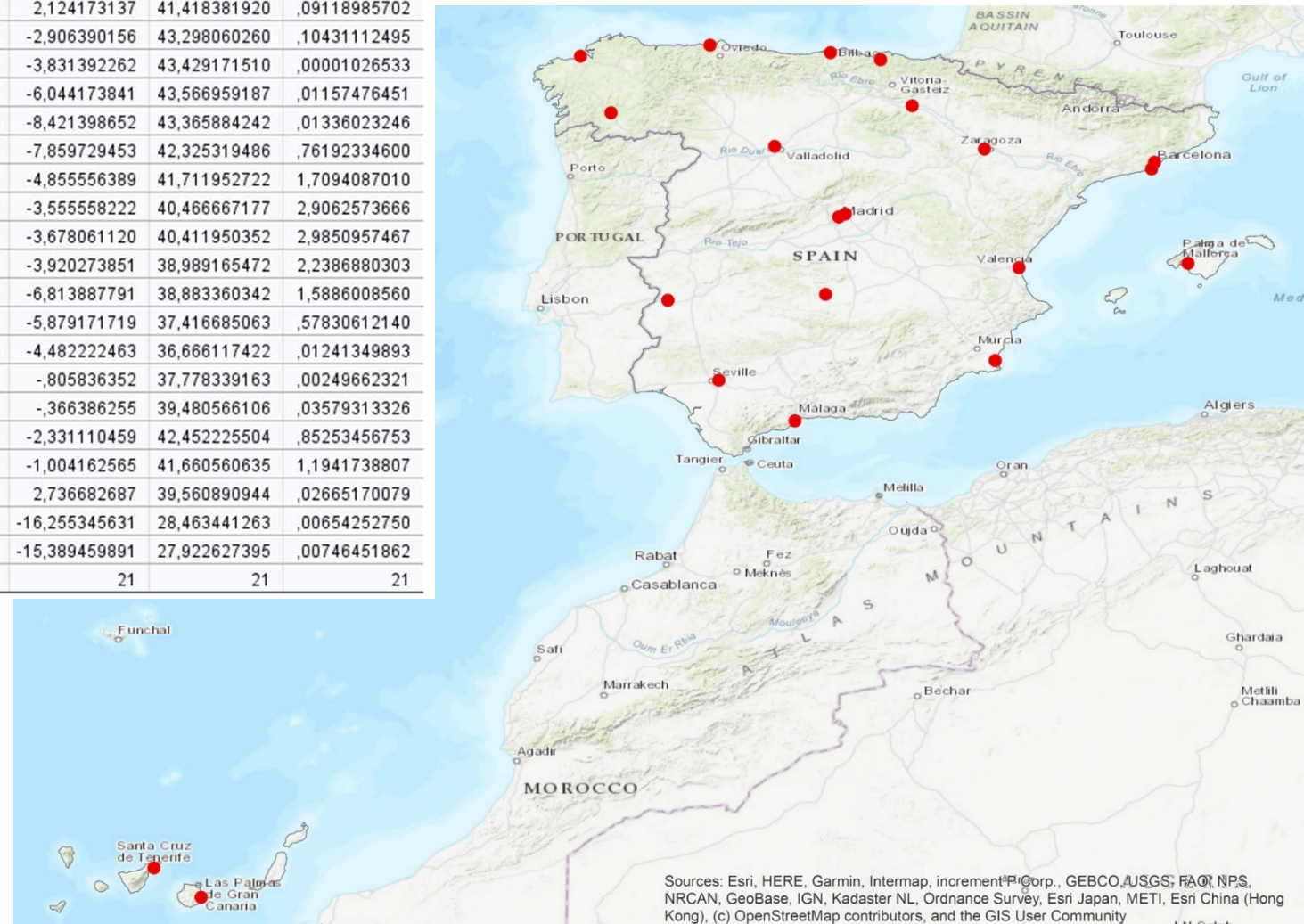
This methodology obtains a reference threshold for all calendar days, and therefore **obtaining daytime and nighttime heat waves throughout the year, not only in the months of July and August**

Also, the methodology allows to identify daytime (DCW) and nighttime (NCW) Cold Waves if temperatures are below the 5 percentile of each calendar day on three or more consecutive days



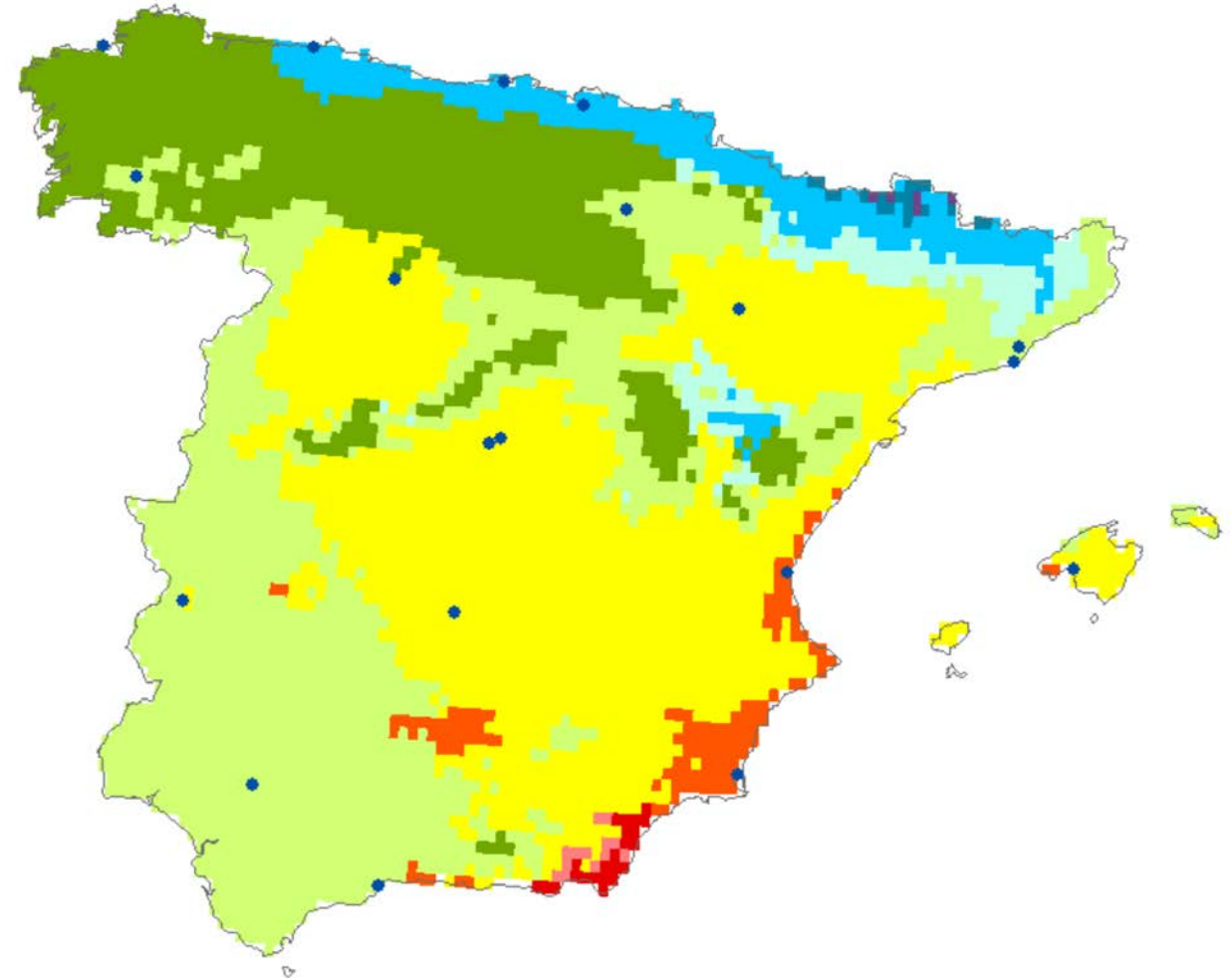
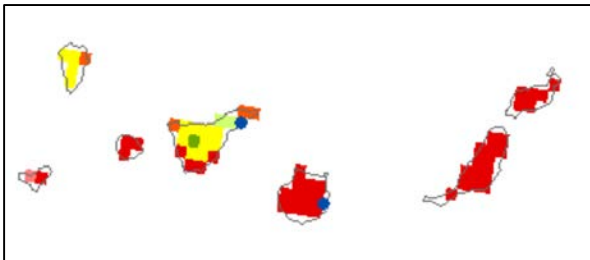
# Weather Stations

|       | INDICATIVO | NOME                           | PROVINCIA     | ALTITUDE | LONGITUDE     | LATITUDE     | Continentality |
|-------|------------|--------------------------------|---------------|----------|---------------|--------------|----------------|
| 1     | 0076       | BARCELONA/Airport              | BARCELONA     | 4        | 2,070010009   | 41,292825367 | ,01313132919   |
| 2     | 0200E      | BARCELONA (FABRA)              | BARCELONA     | 408      | 2,124173137   | 41,418381920 | ,09118985702   |
| 3     | 1082       | BILBAO/Airport                 | BIZKAIA       | 42       | -2,906390156  | 43,298060260 | ,10431112495   |
| 4     | 1109       | SANTANDER/PARAYAS              | CANTABRIA     | 5        | -3,831392262  | 43,429171510 | ,00001026533   |
| 5     | 1212E      | ASTURIAS/AVILÉS                | ASTURIAS      | 127      | -6,044173841  | 43,566959187 | ,01157476451   |
| 6     | 1387       | A CORUÑA                       | A CORUÑA      | 58       | -8,421398652  | 43,365884242 | ,01336023246   |
| 7     | 1690A      | OURENSE                        | OURENSE       | 143      | -7,859729453  | 42,325319486 | ,76192334600   |
| 8     | 2539       | VALLADOLID/MILLANUBLA          | VALLADOLID    | 846      | -4,855556389  | 41,711952722 | 1,7094087010   |
| 9     | 3129       | MADRID/BARAJAS                 | MADRID        | 609      | -3,555558222  | 40,466667177 | 2,9062573666   |
| 10    | 3195       | MADRID,RETIRO                  | MADRID        | 667      | -3,678061120  | 40,411950352 | 2,9850957467   |
| 11    | 4121       | CIUDAD REAL                    | CIUDAD REAL   | 628      | -3,920273851  | 38,989165472 | 2,2386880303   |
| 12    | 4452       | BADAJOS/TALAVERA LA REAL       | BADAJOS       | 185      | -6,813887791  | 38,883360342 | 1,5886008560   |
| 13    | 5783       | SEVILLA/SAN PABLO              | SEVILLA       | 34       | -5,879171719  | 37,416685063 | ,57830612140   |
| 14    | 6155A      | MÁLAGA/Airport                 | MÁLAGA        | 5        | -4,482222463  | 36,666117422 | ,01241349893   |
| 15    | 7031X      | MURCIA/SAN JAVIER II           | MURCIA        | 4        | -,805836352   | 37,778339163 | ,00249662321   |
| 16    | 8416       | VALENCIA                       | VALENCIA      | 11       | -,366386255   | 39,480566106 | ,03579313326   |
| 17    | 9170       | LOGROÑO/AGONCILLO              | LA RIOJA      | 353      | -2,331110459  | 42,452225504 | ,85253456753   |
| 18    | 9434       | ZARAGOZA/Airport               | ZARAGOZA      | 263      | -1,004162565  | 41,660560635 | 1,1941738807   |
| 19    | B278       | PALMA DE MALLORCA/SON SAN JUAN | BALEARES      | 8        | 2,736682687   | 39,560890944 | ,02665170079   |
| 20    | C449C      | STA.CRUIZ DE TENERIFE          | SANTA CRUIZ D | 35       | -16,255345631 | 28,463441263 | ,00654252750   |
| 21    | C649I      | GRAN CANARIA/Airport           | LAS PALMAS    | 24       | -15,389459891 | 27,922627395 | ,00746451862   |
| Total | N          | 21                             | 21            | 21       | 21            | 21           | 21             |



# Köppen Climate Classification & Weather Stations

- BWh** - Warm aggregate
- BWk** - Temperate-cold aggregate
- BSh** - Warm semi-arid
- BSk** - Semi-arid temperate-cold or steppe
- Csa** - Typical Mediterranean (warm summer)
- Csb** - Oceanic Mediterranean (mild summer)
- Cfa** - Humid subtropical or no dry season (warm summer)
- Cfb** - Temperate oceanic (mild summer)
- Cfc** - Oceanic subpolar
- Dfc** - Subpolar without dry season (short summer)



# Spanish Cities Warming estimate 1971-2022

To estimate the warming process experienced by Spanish cities, different methodologies are used.

1. Comparison of the annual mean maximum (TX) and minimum (TN) temperatures of each of the weather stations between 1971 and 2022
2. OLS model with the annual mean temperatures TX and TN of all meteorological stations as dependent variables and the year, longitude, latitude, altitude and distance to the sea (continentally) as independent variables
3. OLS model for each meteorological station with the maximum and minimum daily temperatures as dependent variables, and the year, the month and the calendar day (cd\*), as independent variables

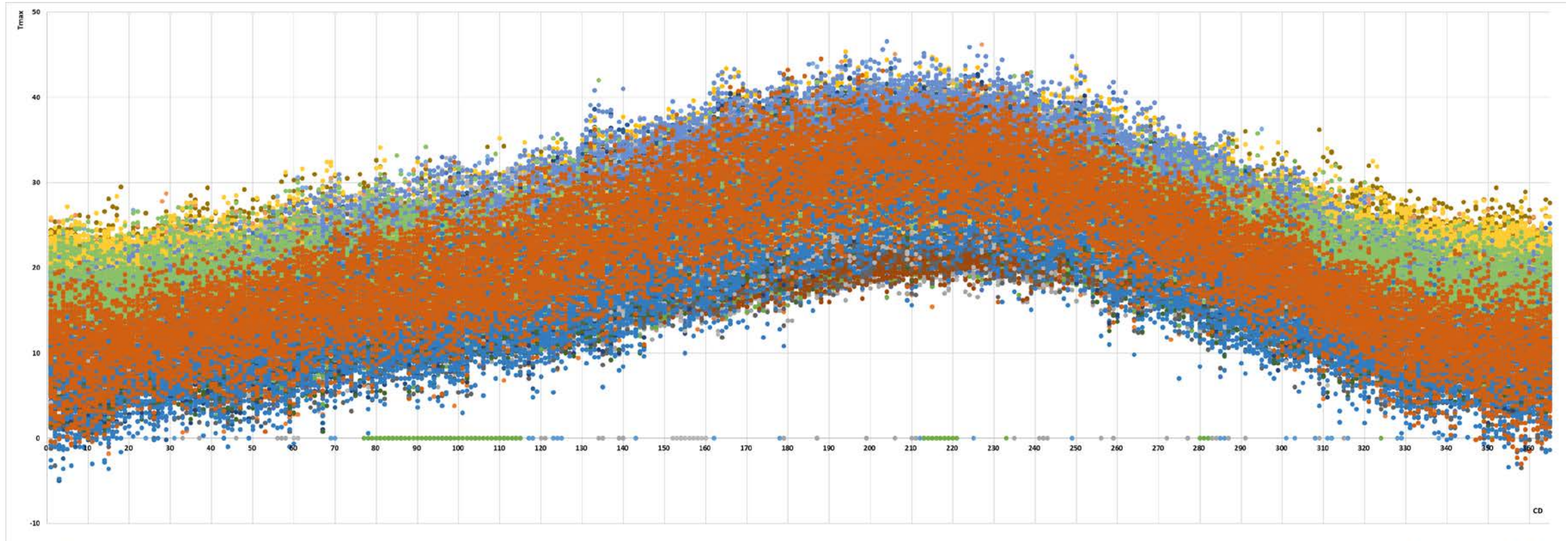
The calendar day (cd) is linearized by the following equation:

$$cd^* = \cos \frac{2\pi(cd - cd_{\max})}{365}$$



# Calendar Day Temperatures (1971-2022)

The hottest Calendar Day (Tmax) was Day 210 (August 8)



Calculation of  $cd^*$ , first summarize the raw data of all weather stations and draw a scatter diagram

# Global Warming in Spanish Cities (1971-2022)

The increase in temperatures between 1971 and 2022, both during the day and at night, is clearly higher than the Mediterranean average

Highlights Palma de Mallorca (day and night), Murcia and Barcelona (day), as well as Ciudad Real, Zaragoza, Barcelona and Madrid (night)

The maximum temperature (TX) increased  $3.54^{\circ}\text{C}$  between 1971 and 2022.

The minimum (Tm) increased  $2.73^{\circ}\text{C}$

| Name                   | Autonomous region | GW_Tmax_Average | GW_Tmin_Average |
|------------------------|-------------------|-----------------|-----------------|
| Barcelona Airport      | Cataluña          | 3,12            | 3,23            |
| Fabra                  | Cataluña          | 4,81            | 3,15            |
| Madrid Airport         | Madrid            | 3,71            | 3,11            |
| Retiro                 | Madrid            | 4,30            | 3,00            |
| Valencia               | Valencia          | 2,67            | 2,65            |
| Zaragoza Airport       | Aragón            | 4,05            | 3,51            |
| Sevilla Airport        | Andalucía         | 3,07            | 2,45            |
| Málaga Airport         | Andalucía         | 3,00            | 2,60            |
| Bilbao Airport         | País Vasco        | 3,03            | 2,48            |
| Valladolid Airport     | Castilla-León     | 4,08            | 2,08            |
| Ciudad Real            | Castila La Mancha | 4,02            | 5,32            |
| Badajoz Airport        | Extremadura       | 3,47            | 3,02            |
| Asturias Airport       | Asturias          | 2,67            | 1,55            |
| A Coruña               | Galicia           | 2,25            | 2,18            |
| Ourense                | Galicia           | 4,03            | 2,48            |
| San Javier Airport     | Murcia            | 4,93            | 2,56            |
| Santander Airport      | Cantabria         | 3,35            | 2,33            |
| Logroño Airport        | La Rioja          | 4,10            | 1,27            |
| Gran Canaria Airport   | Canarias          | 2,00            | 1,72            |
| STA. Cruz De Tenerife  | Canarias          | 2,19            | 1,90            |
| Palma Mallorca Airport | Islas Baleares    | 5,42            | 4,71            |
| <b>Total</b>           |                   | <b>3,54</b>     | <b>2,73</b>     |

# 2022 An Exceptionally Warm Year

13 of the 21 Weather Stations, the year 2022 was the warmest year of the entire historical series, in both, maximum (TX) and minimum temperature (TN). Thus, the simple comparison between 1971 and 2022 can be misleading

|       | Indicativo | NAME                      | Year_TX |
|-------|------------|---------------------------|---------|
| 1     | 0076       | BARCELONA/Airport         | 2022    |
| 2     | 0200E      | BARCELONA (FABRA)         | 2022    |
| 3     | 1082       | BILBAO/Airport            | 2022    |
| 4     | 1109       | SANTANDER/PARAYAS         | 2022    |
| 5     | 1387       | A CORUÑA                  | 2022    |
| 6     | 1690A      | OURENSE                   | 2022    |
| 7     | 2539       | VALLADOLID/MILLANUBLA     | 2022    |
| 8     | 3129       | MADRID/BARAJAS            | 2022    |
| 9     | 6155A      | MÁLAGA/Airport            | 2022    |
| 10    | 7031X      | MURCIA/SAN JAVIER II      | 2022    |
| 11    | 9170       | LOGROÑO/AGONCILLO         | 2022    |
| 12    | 9434       | ZARAGOZA/Airport          | 2022    |
| 13    | B278       | PALMA DE MALLORCA/Airport | 2022    |
| 14    | 3195       | MADRID, RETIRO            | 2017    |
| 15    | 4121       | CIUDAD REAL               | 2017    |
| 16    | 4452       | BADAJOS/TALAVERA LA REAL  | 2017    |
| 17    | 5783       | SEVILLA/SAN PABLO         | 2017    |
| 18    | 1212E      | ASTURIAS/AVILÉS           | 2015    |
| 19    | 8416       | VALENCIA                  | 2001    |
| 20    | C449C      | STA. CRUZ DE TENERIFE     | 1998    |
| 21    | C649I      | GRAN CANARIA/Airport      | 1998    |
| Total | N          | 21                        | 21      |

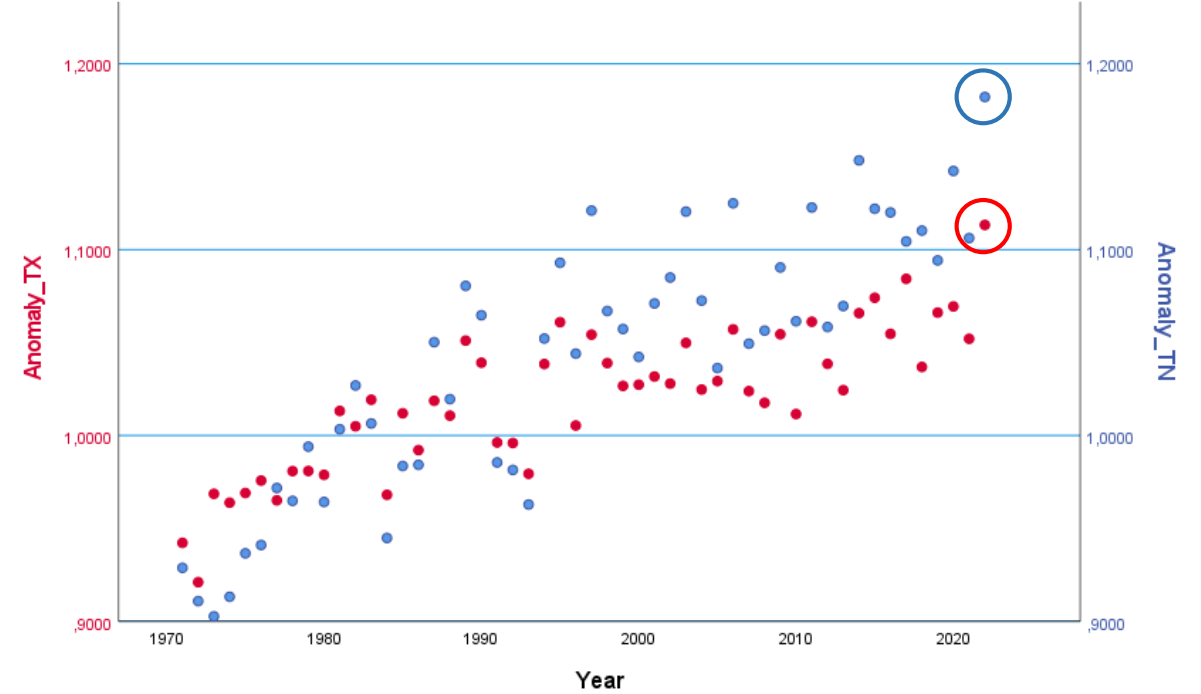
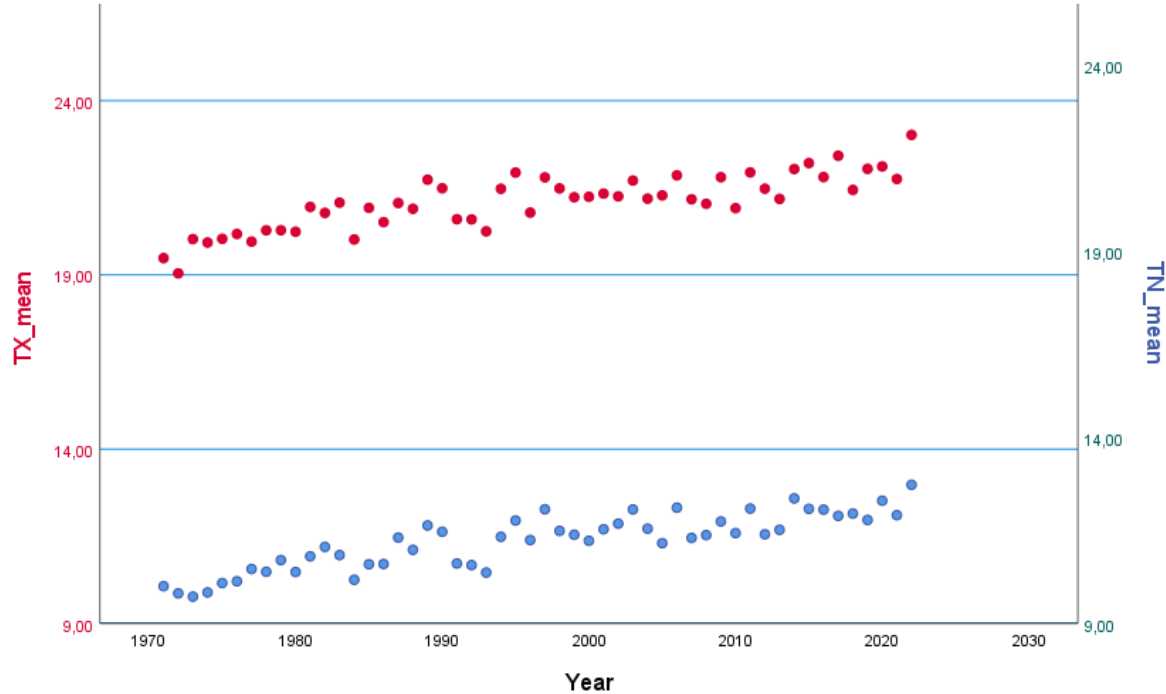
|       | Indicativo | NAME                      | Year_TN |
|-------|------------|---------------------------|---------|
| 1     | 0076       | BARCELONA/Airport         | 2022    |
| 2     | 0200E      | BARCELONA (FABRA)         | 2022    |
| 3     | 1109       | SANTANDER/PARAYAS         | 2022    |
| 4     | 1212E      | ASTURIAS/AVILÉS           | 2022    |
| 5     | 1387       | A CORUÑA                  | 2022    |
| 6     | 1690A      | OURENSE                   | 2022    |
| 7     | 3129       | MADRID/BARAJAS            | 2022    |
| 8     | 3195       | MADRID, RETIRO            | 2022    |
| 9     | 4121       | CIUDAD REAL               | 2022    |
| 10    | 6155A      | MÁLAGA/Airport            | 2022    |
| 11    | 8416       | VALENCIA                  | 2022    |
| 12    | 9434       | ZARAGOZA/Airport          | 2022    |
| 13    | B278       | PALMA DE MALLORCA/Airport | 2022    |
| 14    | C449C      | STA. CRUZ DE TENERIFE     | 2017    |
| 15    | 7031X      | MURCIA/SAN JAVIER II      | 2016    |
| 16    | 4452       | BADAJOS/TALAVERA LA REAL  | 2014    |
| 17    | 1082       | BILBAO/Airport            | 2011    |
| 18    | 2539       | VALLADOLID/MILLANUBLA     | 2011    |
| 19    | 5783       | SEVILLA/SAN PABLO         | 2010    |
| 20    | 9170       | LOGROÑO/AGONCILLO         | 2003    |
| 21    | C649I      | GRAN CANARIA/Airport      | 1998    |
| Total | N          | 21                        | 21      |



# 2022, an exceptionally warm year

The exceptionality of the year 2022 is evidenced by presenting an anomaly in maximum temperatures (TX) of 1.13 times higher than the average for the period 1971-2000

In relation to the minimums, the anomaly of 2022 was even more pronounced: a 1.18



# Global Warming (OLS Model, Annual Means)

The exceptionality of 2022 means that the simple comparison 1971/2022 is not appropriate to estimate the GW, so an OLS model is tested, with all the weather stations, and with the year, longitude, latitude, altitude and continentality (distance to the sea) as explanatory variables, and with TX and TN (**annual means**) as dependent variables. The  $R^2$  reaches 0.796 in the TX and 0.849 in the TN

This means that the maximums would have increased 2.21 °C, and the minimums 2.16 °C, between 1971 and 2022

Resumen del modelo

| Modelo | R                 | R cuadrado | R cuadrado ajustado | Error estándar de la estimación |
|--------|-------------------|------------|---------------------|---------------------------------|
| 1      | ,893 <sup>a</sup> | ,797       | ,796                | 1,12753                         |

a. Predictores: (Constante), Continentability, Year, Longitude, Latitude, Altitude

Coefficientes<sup>a</sup>

| Modelo |                  | Coefficients no estandarizados |             | Coefficients estandarizados<br>Beta | t       | Sig.  |
|--------|------------------|--------------------------------|-------------|-------------------------------------|---------|-------|
|        |                  | B                              | Desv. Error |                                     |         |       |
| 1      | (Constante)      | -46,294                        | 4,561       |                                     | -10,149 | <,001 |
|        | Year             | ,044                           | ,002        | ,266                                | 19,473  | <,001 |
|        | Altitude         | -,007                          | ,000        | -,764                               | -29,563 | <,001 |
|        | Longitude        | ,169                           | ,009        | ,326                                | 18,233  | <,001 |
|        | Latitude         | -,506                          | ,011        | -,847                               | -46,552 | <,001 |
|        | Continentability | 1,805                          | ,065        | ,705                                | 27,695  | <,001 |

a. Variable dependiente: TX

Resumen del modelo

| Modelo | R                 | R cuadrado | R cuadrado ajustado | Error estándar de la estimación |
|--------|-------------------|------------|---------------------|---------------------------------|
| 1      | ,922 <sup>a</sup> | ,849       | ,849                | 1,22285                         |

a. Predictores: (Constante), Continentability, Year, Longitude, Latitude, Altitude

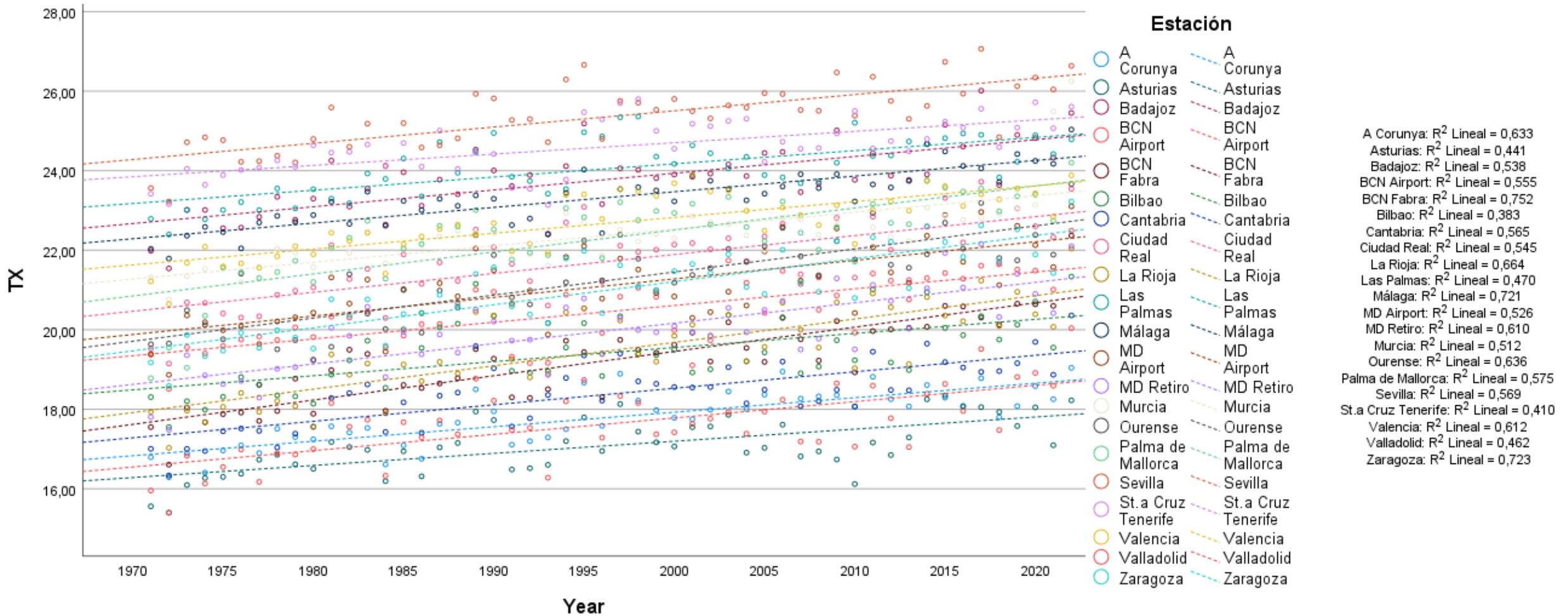
Coefficientes<sup>a</sup>

| Modelo |                  | Coefficients no estandarizados |             | Coefficients estandarizados<br>Beta | t       | Sig.  |
|--------|------------------|--------------------------------|-------------|-------------------------------------|---------|-------|
|        |                  | B                              | Desv. Error |                                     |         |       |
| 1      | (Constante)      | -53,017                        | 4,947       |                                     | -10,717 | <,001 |
|        | Year             | ,043                           | ,002        | ,206                                | 17,519  | <,001 |
|        | Altitude         | -,004                          | ,000        | -,327                               | -14,673 | <,001 |
|        | Longitude        | ,023                           | ,010        | ,035                                | 2,274   | ,023  |
|        | Latitude         | -,524                          | ,012        | -,698                               | -44,479 | <,001 |
|        | Continentability | -,489                          | ,071        | -,152                               | -6,917  | <,001 |

a. Variable dependiente: TN

# Global Warming in Spanish Cities (1971-2022)

The increase has been widespread in all the cities studied





# Global Warming in Spanish Cities (1971-2022)

## OLS Model, Daily Temperatures

The realization of an OLS model, with the maximum and minimum **daily temperatures** of the last 50 years, of the different studied weather stations, with year, month and calendar day (cd\*) as independent variables allows modeling the increase in temperatures between 1971 and 2022

This approximation, more precise than the one previously carried out in the OLS model of the annual means, allows us to estimate that between 1971 and 2022, **the increase in the maximum temperature has been 2.30°C and in the minimum, 2.26°C.**

| Name                      | Autonomous region | GW_Tmax_Regression | GW_Tmin_Regression |
|---------------------------|-------------------|--------------------|--------------------|
| Barcelona Airport         | Cataluña          | 2,187520548        | 3,935475943        |
| Fabra                     | Cataluña          | 3,178041755        | 2,554076566        |
| Madrid Airport            | Madrid            | 2,42447823         | 1,95236333         |
| Retiro                    | Madrid            | 2,669320424        | 2,126795615        |
| Valencia                  | Valencia          | 2,068729557        | 2,158112385        |
| Zaragoza Airport          | Aragón            | 3,015532883        | 2,31571854         |
| Sevilla Airport           | Andalucía         | 2,123469709        | 2,685954168        |
| Málaga Airport            | Andalucía         | 2,047390542        | 2,853774           |
| Bilbao Airport            | País Vasco        | 1,844870218        | 1,976284105        |
| Valladolid Airport        | Castilla-León     | 2,136460516        | 1,249645296        |
| Ciudad Real               | Castila La Mancha | 2,473439523        | 4,342824982        |
| Badajoz Airport           | Extremadura       | 2,191947887        | 1,900631015        |
| Asturias Airport          | Asturias          | 1,582940916        | 1,574580185        |
| A Coruña                  | Galicia           | 1,896217182        | 1,66776096         |
| Ourense                   | Galicia           | 3,014989341        | 1,522320797        |
| San Javier Airport        | Murcia            | 2,181488428        | 2,780202174        |
| Santander Airport         | Cantabria         | 2,157636403        | 2,180503064        |
| Logroño Airport           | La Rioja          | 3,056707368        | 0,591155193        |
| Gran Canaria Airport      | Canarias          | 1,727218145        | 1,665493595        |
| STA. Cruz De Tenerife     | Canarias          | 1,48418646         | 1,60845035         |
| Palma De Mallorca Airport | Islas Baleares    | 2,874500725        | 3,521863736        |
| Total                     |                   | 2,301766036        | 2,245904095        |

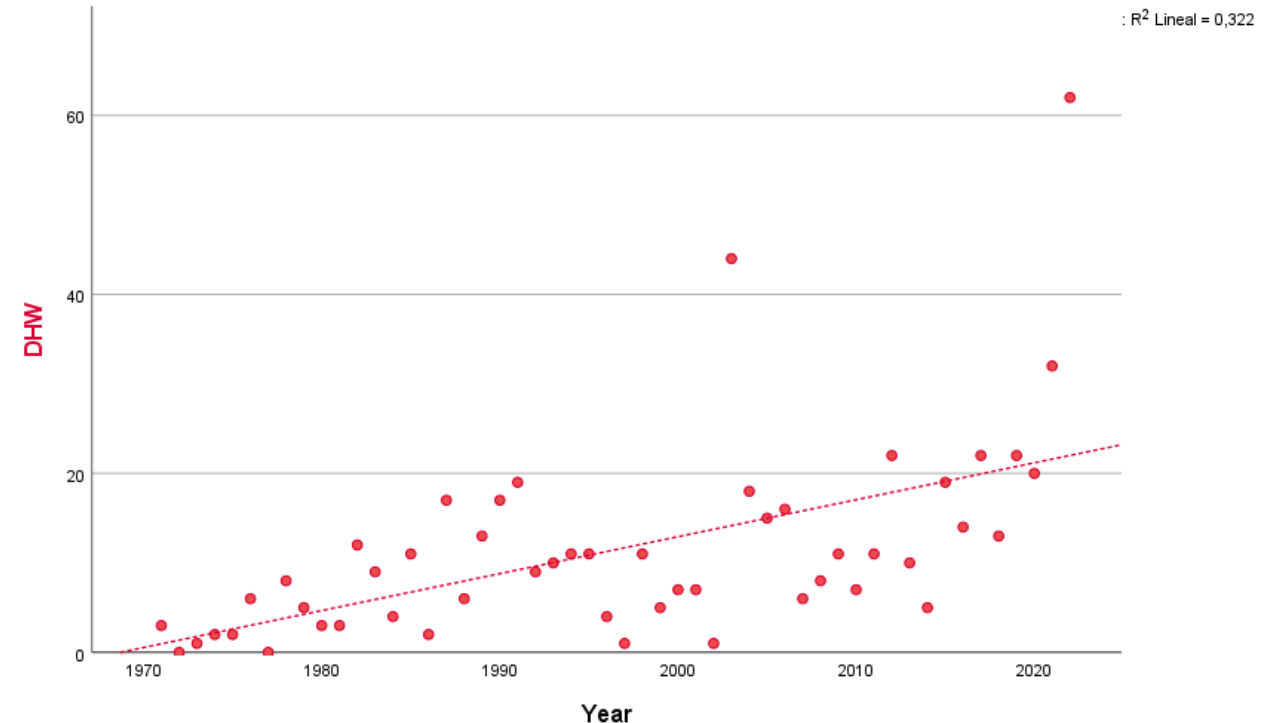
# Daytime Heat Waves (Approach 1)

The increase in daytime Heat Waves has been constant throughout the period studied.  
The years 2003 (great HW in Europe) and the exceptional year of 2022 stand out as outliers

Highlighted, with more than 35 DHW between 1971 and 2022,

- Barcelona Airport (49 DHW, 260 days),
- Zaragoza Airport (42, 170),
- Madrid-Retiro (39, 199),
- BCN-Fabra Obs. (38, 177)
- Gran Canaria Airport (38, 137)

| Time period | DHW  | Number of days |
|-------------|------|----------------|
| 1971-1980   | 3    | 10,6           |
| 1981-1990   | 9,4  | 36,5           |
| 1991-2000   | 8,8  | 34,2           |
| 2001-2010   | 13,7 | 59,8           |
| 2011-2020   | 15,8 | 62,1           |
| 2013-2022   | 21,9 | 105,7          |



In total, 597 DHW at 21 weather stations,  
with a total of 2,570 days

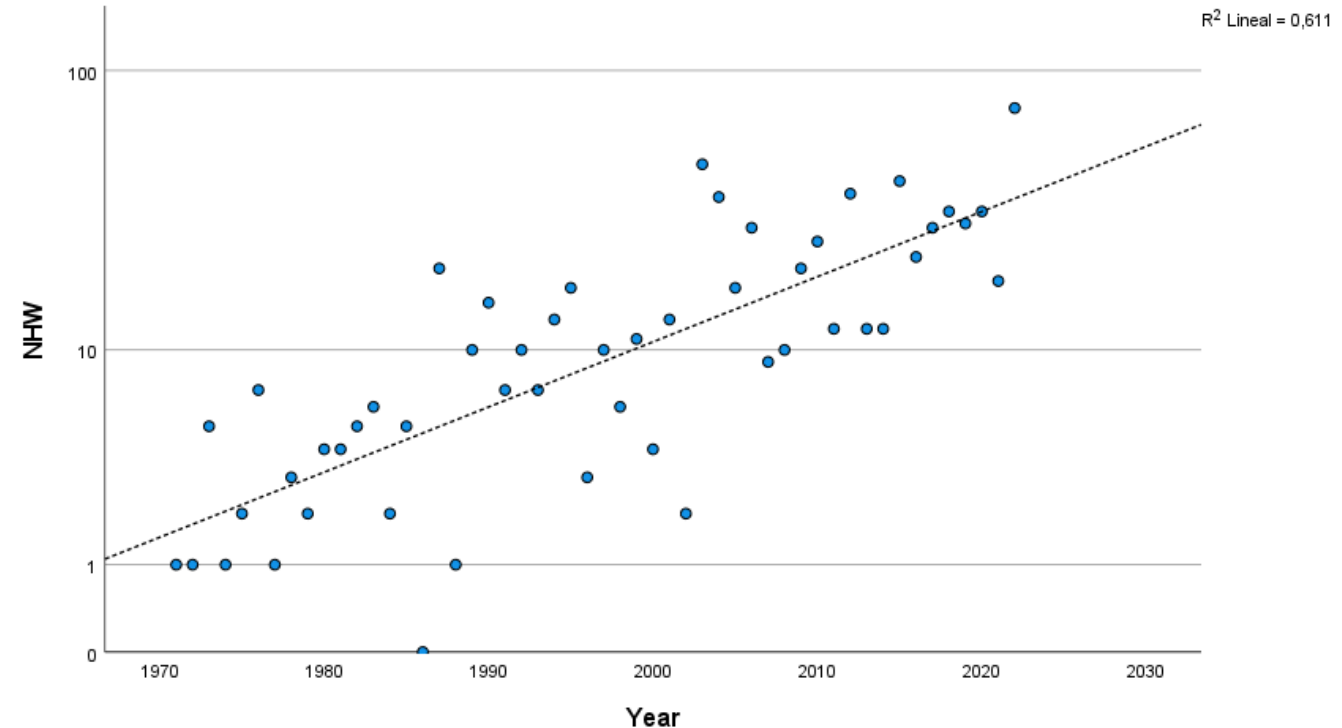
# Nighttime Heat Waves (Approach 1)

The evolution of Nighttime Heat Waves (NHW) shows an **exponential increase**

Stand out, with more than 40 NHW between 1971 and 2022

- Barcelona Airport (82 NHW, 459 days)
- BCN Fabra Obs. (47, 211)
- Sevilla Airport (46, 255)
- Tenerife (44, 178)
- Bilbao Airport (43, 173)
- A Coruña (41, 158)
- Gran Canaria Airport (40 NHW, 151 days)

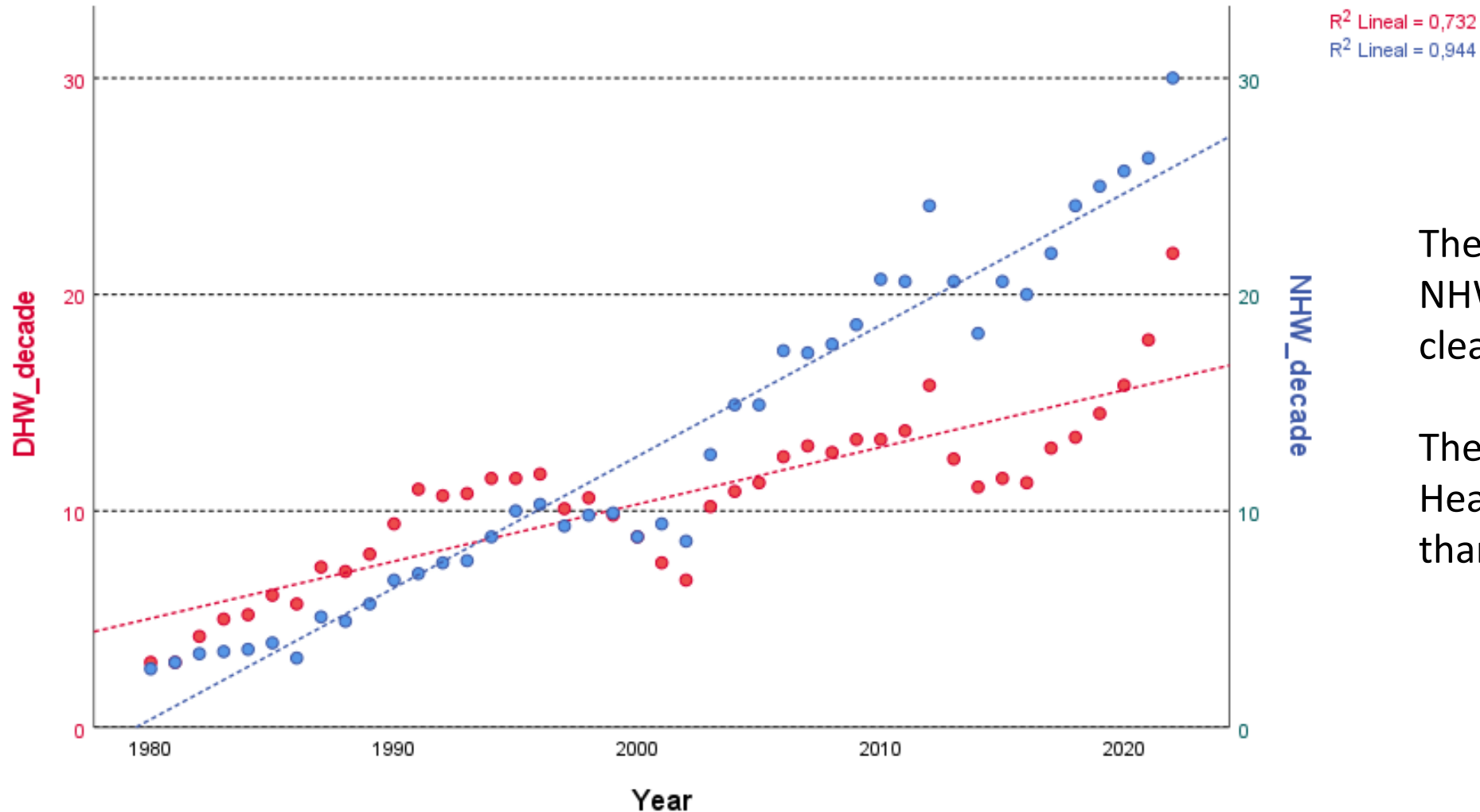
| Time period | NHW  | Number of days |
|-------------|------|----------------|
| 1971-1980   | 2,7  | 9              |
| 1981-1990   | 6,8  | 25,1           |
| 1991-2000   | 8,8  | 33,6           |
| 2001-2010   | 20,7 | 94,4           |
| 2011-2020   | 25,7 | 113,6          |
| 2013-2022   | 30   | 140,6          |



In total, 739 NHW at 21 weather stations, with a total of 3,204 nights



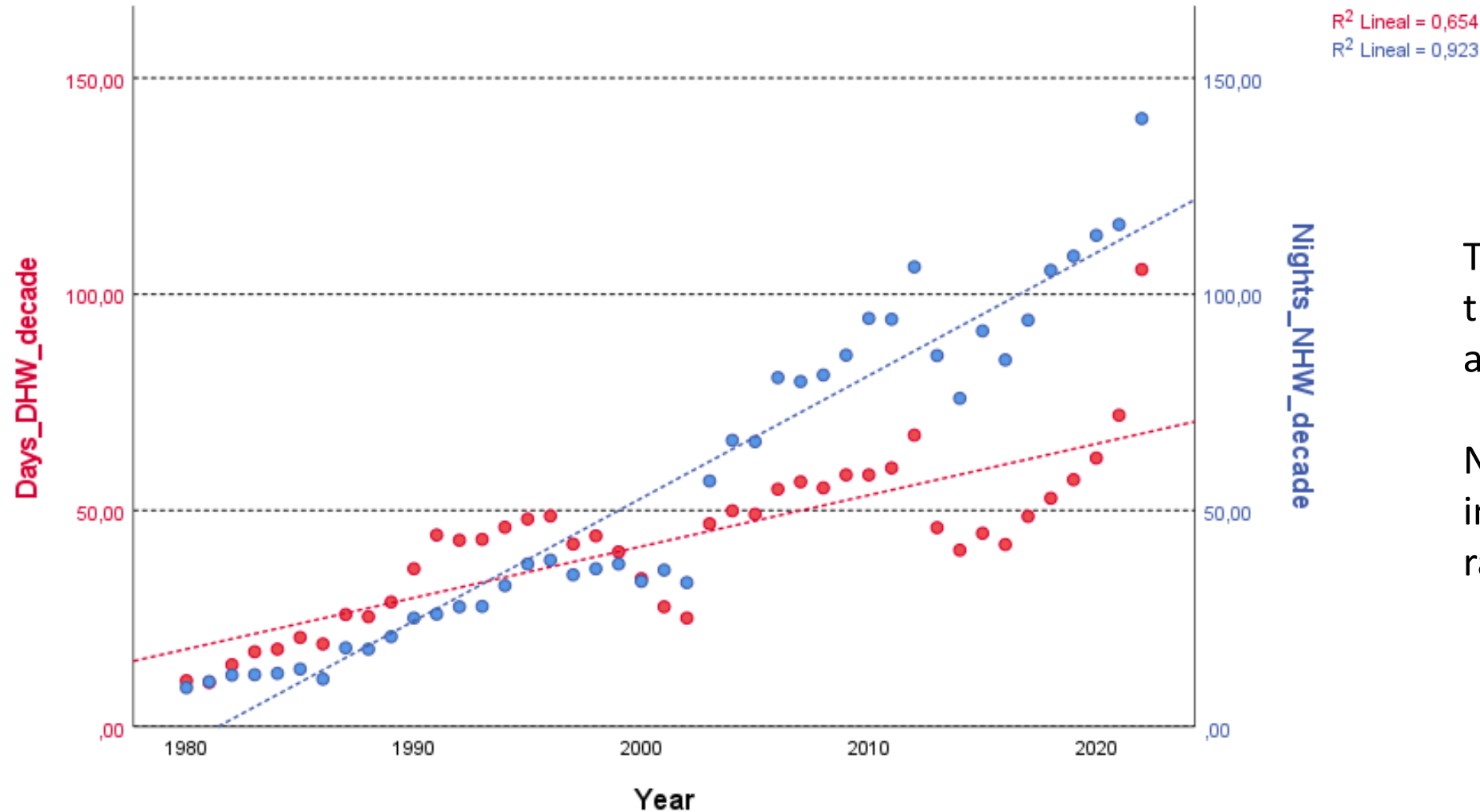
# Daytime & Nighttime Heat Waves per Decade (Approach 1)



The evolution of DHW and NHW for decades shows a clear increase

The increase in Nighttime Heat Waves is clearly higher than Daytime HW.

# Daytime & Nighttime Heat Waves Duration per decade (Approach 1)



The same happens with the number of nights and days in a heat wave

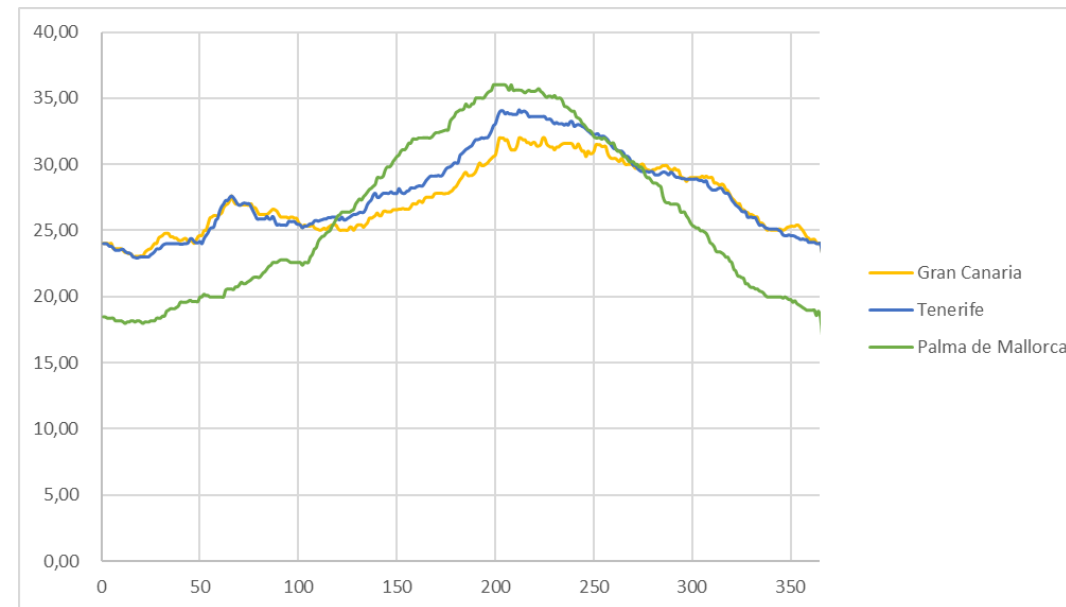
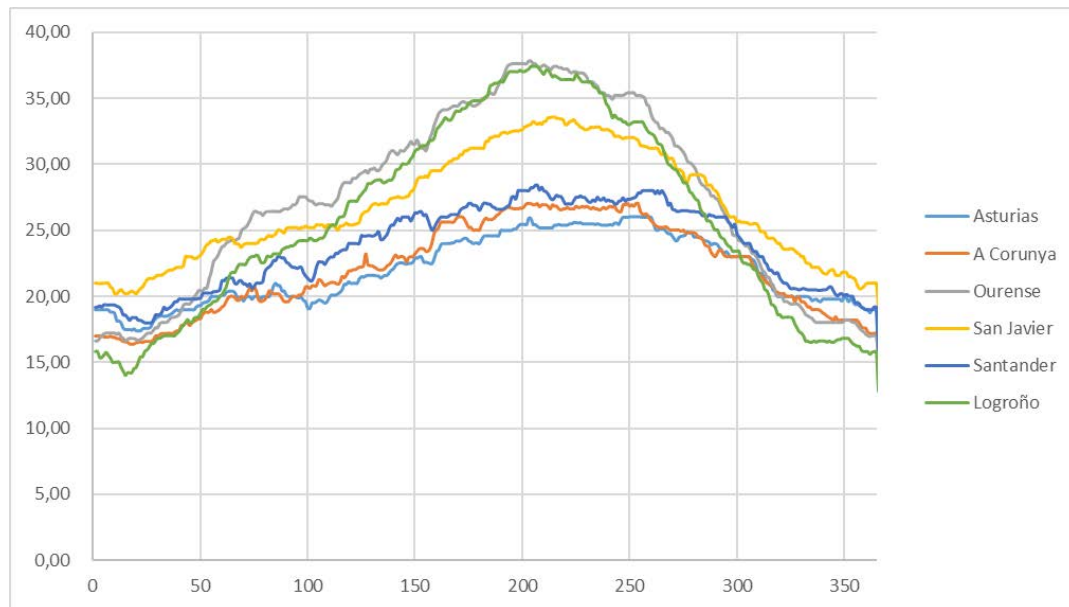
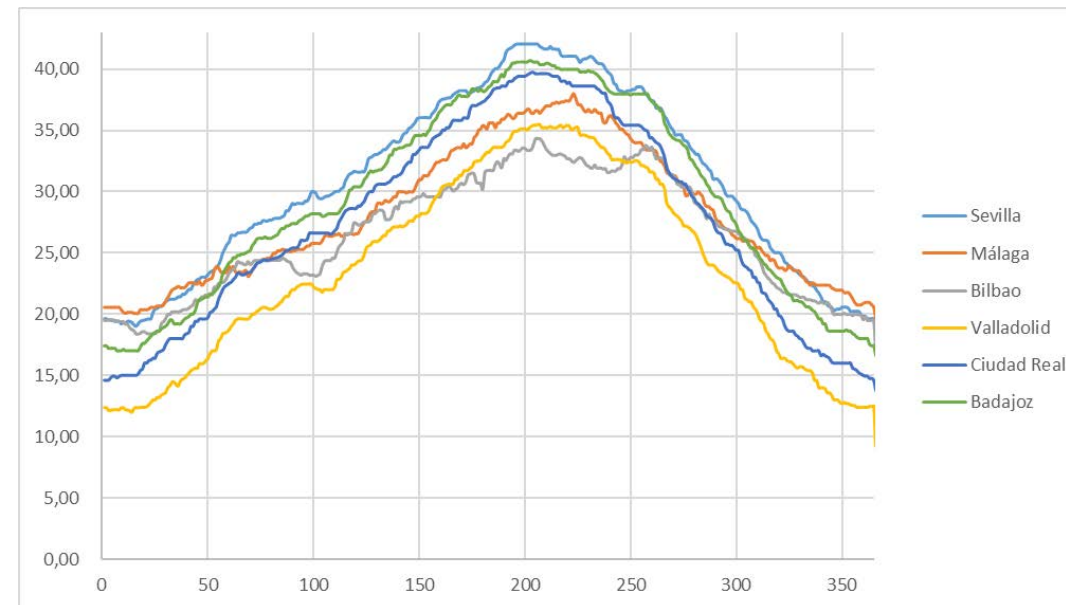
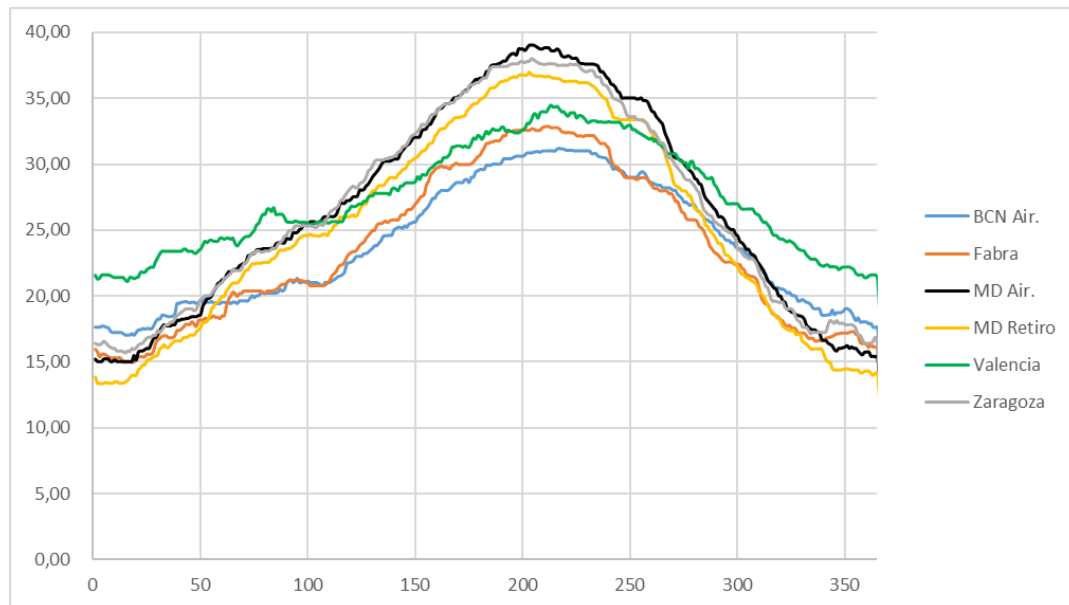
Nights in NHW are increasing at a faster rate than days in DHW

# 95th percentile reference temperatures (Approach 2)

Moving windows of 15 days for each calendar day in the period 1971-2000 for establish the thresholds for the DHW & NHW of each of the 21 meteorological stations

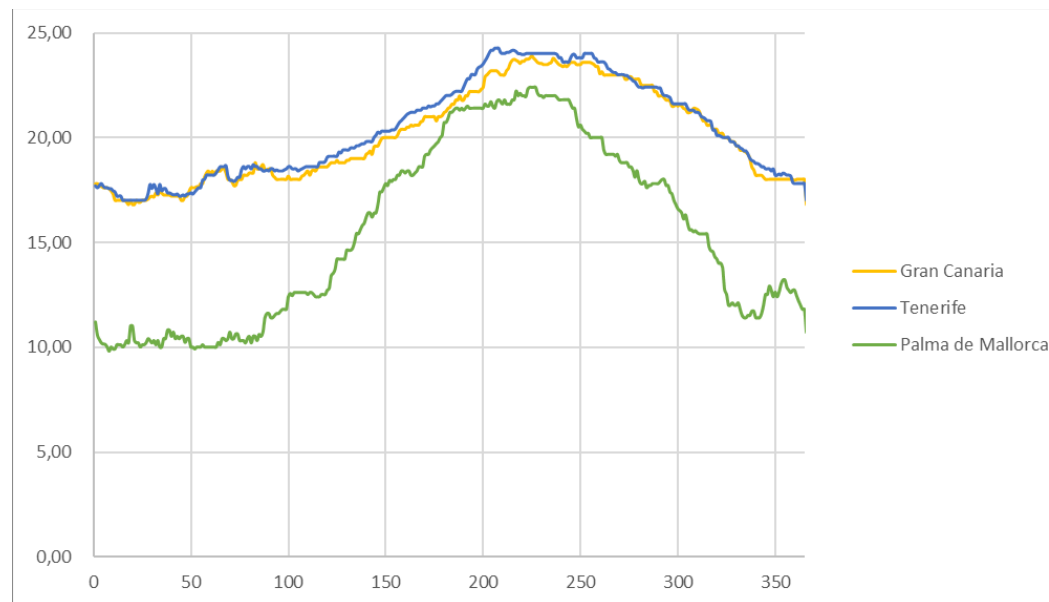
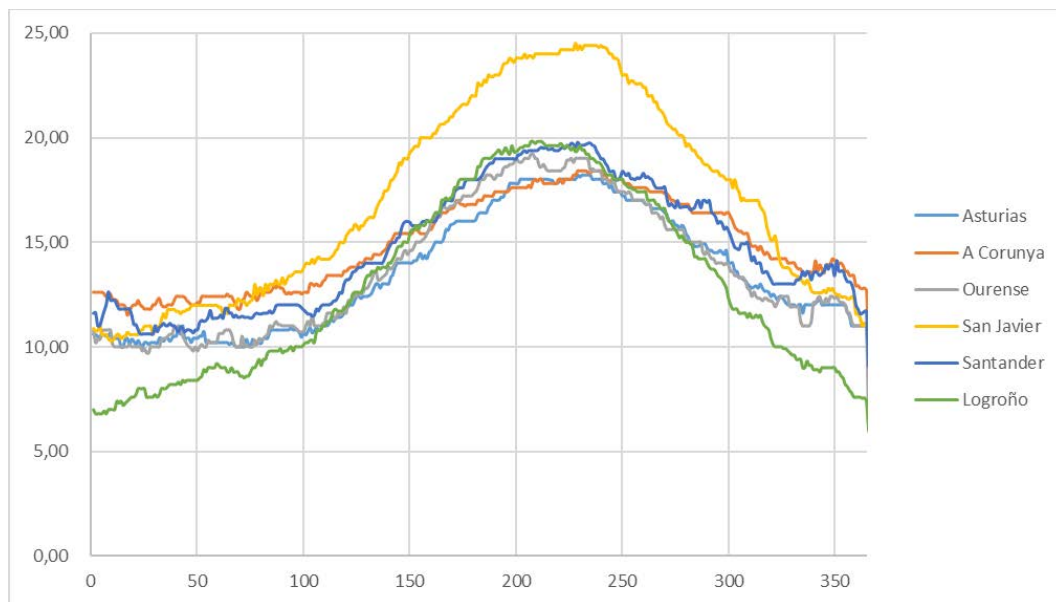
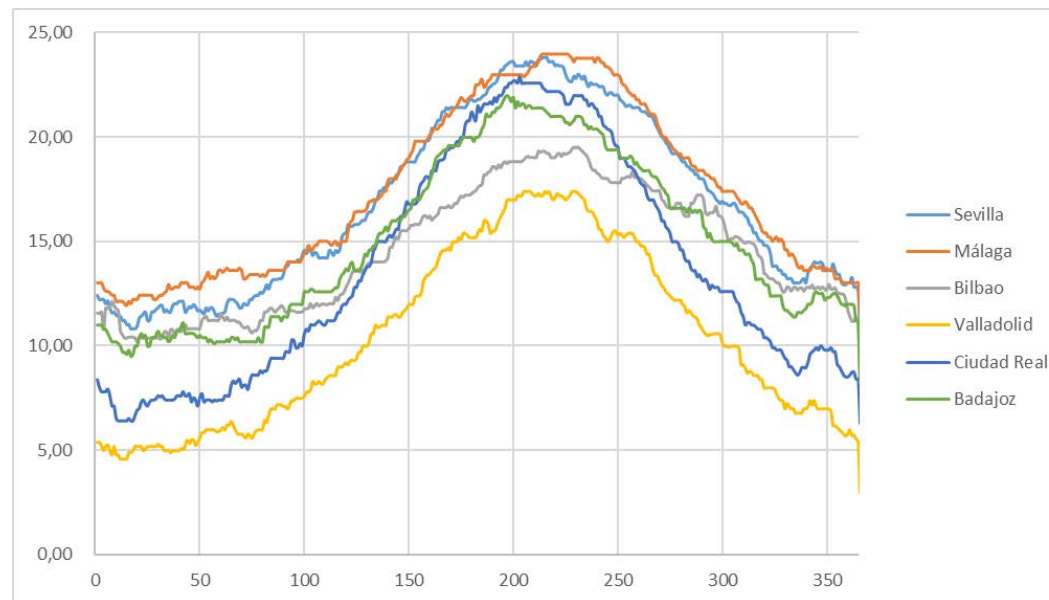
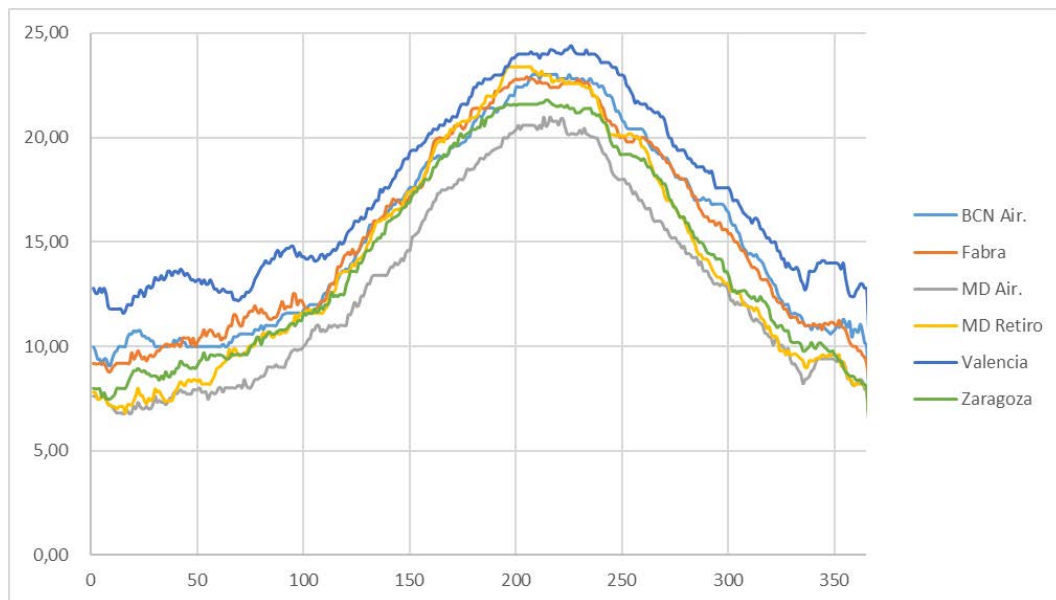


# Daytime HW thresholds (Approach 2)





# Nighttime HW thresholds (Approach 2)



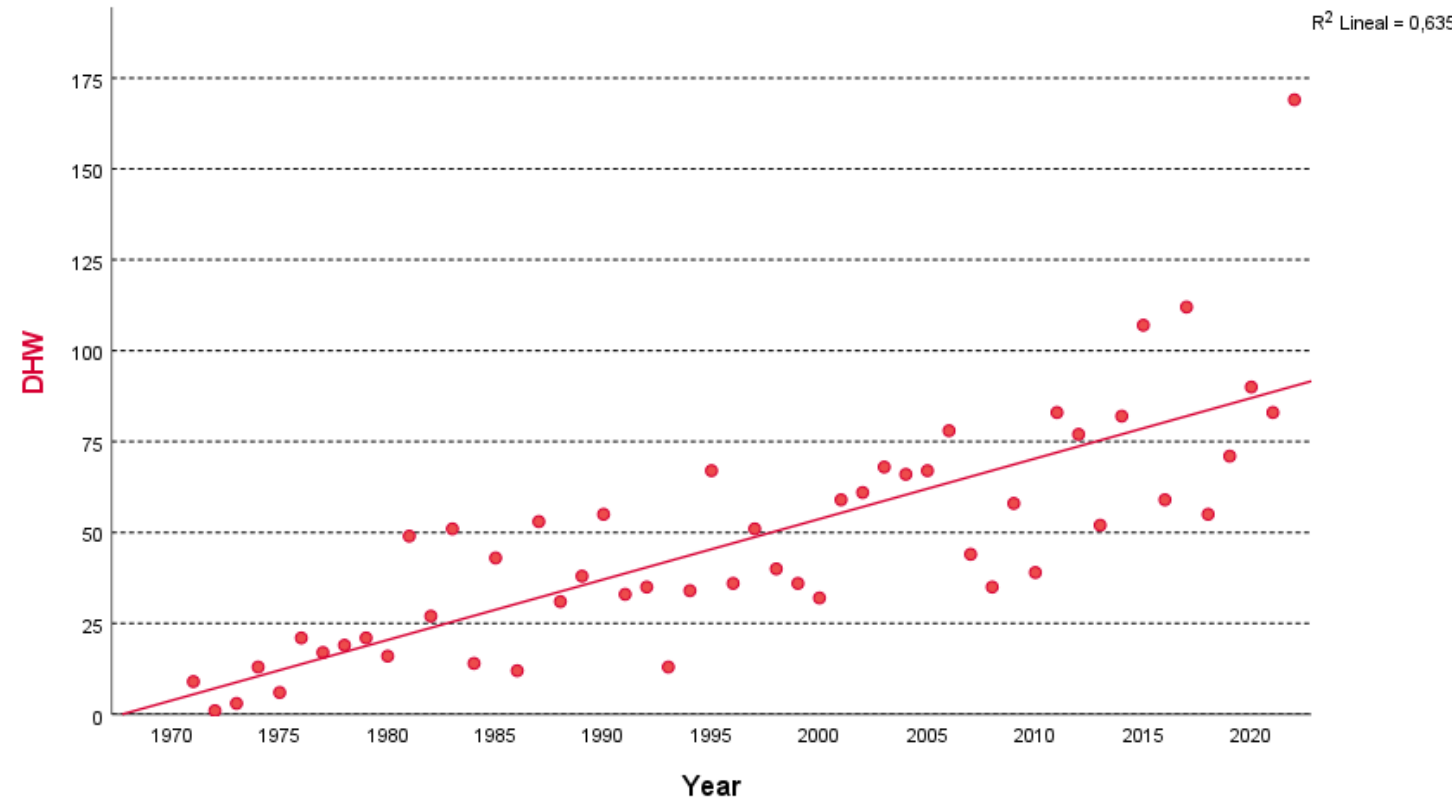
# Daytime Heat Waves (Approach 2)

The increase in DHW has been constant throughout the period studied. The year 2022 stands out very sharply, truly exceptional in what corresponds to the maximum temperatures

Stand out, with more than 150 DHW between 1971 and 2022:

- Fabra Observatory (177 DHW, 781 hot days)
- Ourense (165, 709)
- MD-Retiro (162, 720)

| Time period | DHW | Number of days |
|-------------|-----|----------------|
| 1971-1980   | 126 | 421            |
| 1981-1990   | 373 | 1453           |
| 1991-2000   | 377 | 1415           |
| 2001-2010   | 575 | 2393           |
| 2011-2020   | 788 | 3305           |
| 2013-2022   | 880 | 3990           |



In total, 2,491 DHW at 21 weather stations, with a total of 10,348 hot days

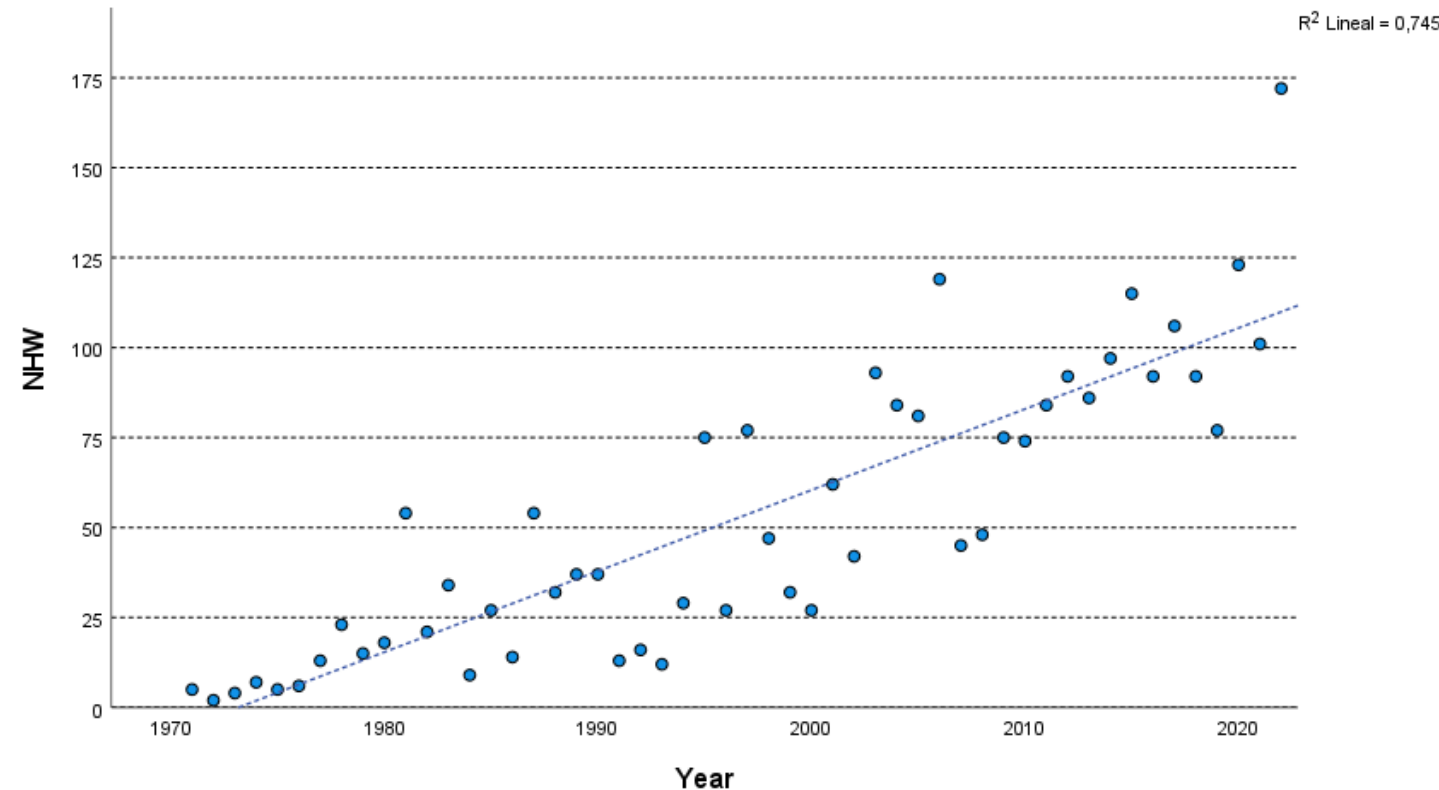
# Nighttime Heat Waves (Approach 2)

The evolution of the NHW is constant throughout the period 1971-2022. 2022 appears as an outlier, although less pronounced than the DHW. The R2 of the linear model is higher than in Approach 1

Stand out, with more than 150 NHW between 1971 and 2022:

- Barcelona Airport (238 NHW, 1336 hot nights)
- Fabra Observatory (180, 817)
- Sevilla Airport (159, 713)
- MD Retiro (153, 667)

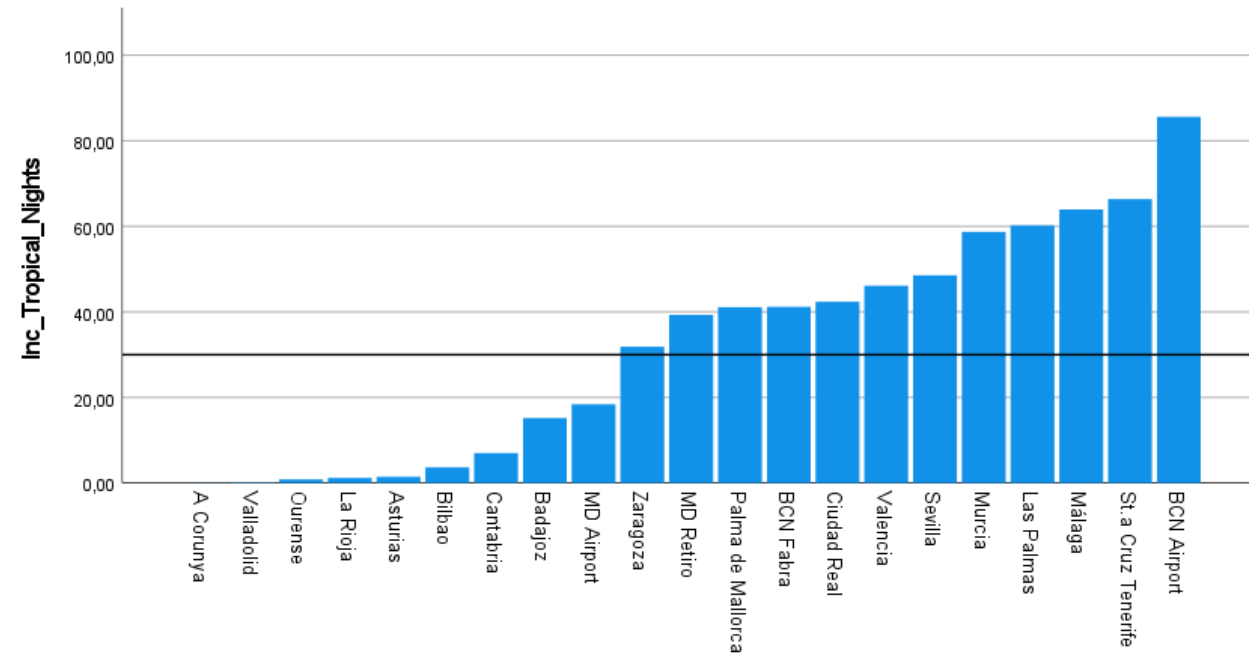
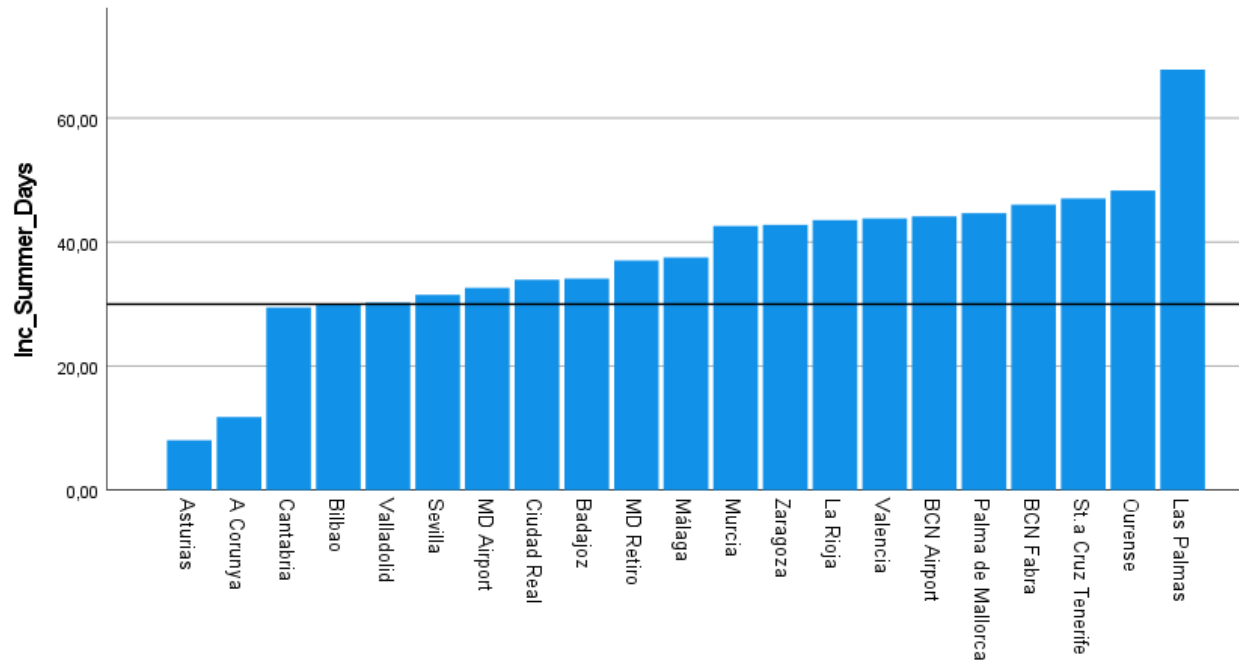
| Time period | DHW  | Number of days |
|-------------|------|----------------|
| 1971-1980   | 98   | 371            |
| 1981-1990   | 319  | 1133           |
| 1991-2000   | 355  | 1269           |
| 2001-2010   | 723  | 3170           |
| 2011-2020   | 964  | 4187           |
| 2013-2022   | 1061 | 4801           |



In total, 2,732 NHW at 21 weather stations, with a total of 11,469 nights

# Increase of Summer Days and Tropical Nights (1971-2022)

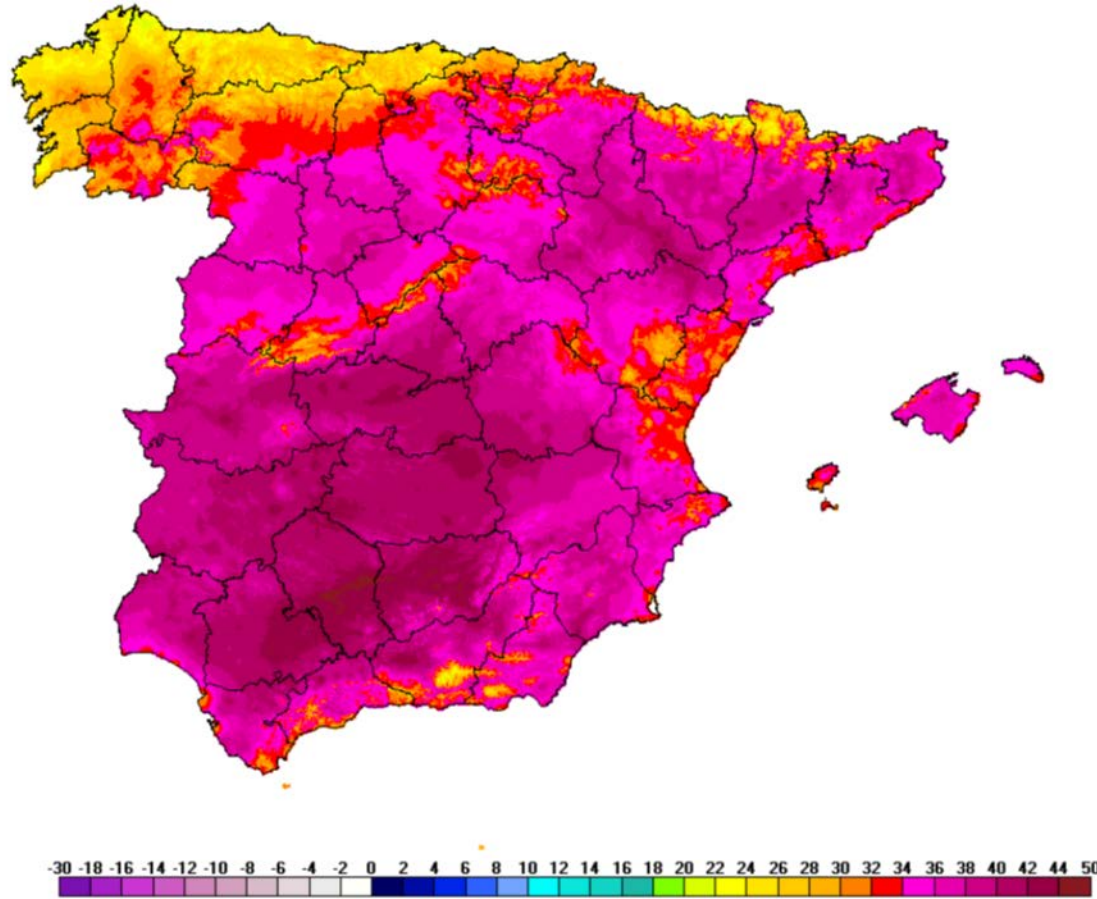
- Most of the meteorological stations have more than 1 month of increase in summer days
- The same happens with tropical nights; the weather stations near to the sea stand out for its larger increases





# Conclusions

- The study of 21 representative meteorological stations in all Spanish regions between 1971 and 2022, confirms that the increase in temperatures is greater in Spain than in the Mediterranean basin, and of course, than Global Warming
- With the development of the Calendar Day methodology (Approach 2), we have been able to prove not only the greater importance of the nighttime heat waves, but we were also able to specify in greater detail the heat related extreme events in quantity and extent.
- This methodology propose a model for all seasons, not only summer, to explain the annual variation in temperatures for each weather station
- The trend in the evolution of daytime and nighttime heat waves between 1971 and 2022 seems to indicate a strong increase in extreme weather events in the coming decades



# Thanks for your attention and take care!



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