Spain: Towards a Drier and Warmer Climate?

Analysis of Climate Change Effects on Precipitation and Temperature Trends in Spain

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Objectives

To analyze the climate change experienced in Spain between 1971 and 2022 and to estimate the future climate for 2050

Main objectives:

1. To analyze the temporal evolution of temperature, from 1971 to the present, in order to **quantify the warming process** experienced in Spain, as well as to evaluate the increase in **extreme heat events** (heat waves)

2. To study the **evolution of the precipitation regime** in order to determine whether there is a statistically representative **trend towards a drier climate** as well as an **increase in extreme precipitation**

3. To investigate the **correlation between annual precipitation and the continuous increase in temperature**

4. Forecast the **future climate scenario for the Iberian Peninsula and the Balearic Islands towards 2050**, analyzing the trends in land aridity and predicting a possible change from a Mediterranean climate to a warm steppe climate according to the Köppen classification

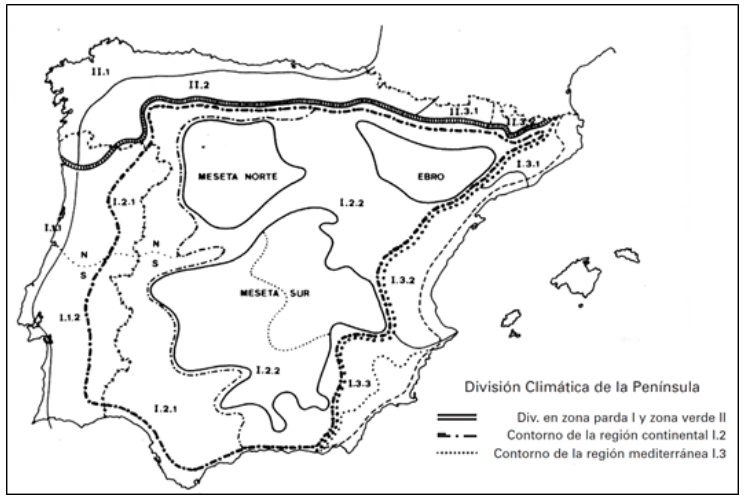
Hypothesis

The paper attempts to verify whether there is a statistically significant relationship between the trend towards warming and the trend towards drought in the mainland Spain and insular climate (Balearic Islands), generating **compound climatic events** that affect an increase not only in *meteorological drought*, but, above all, in environmental and *ecological drought*

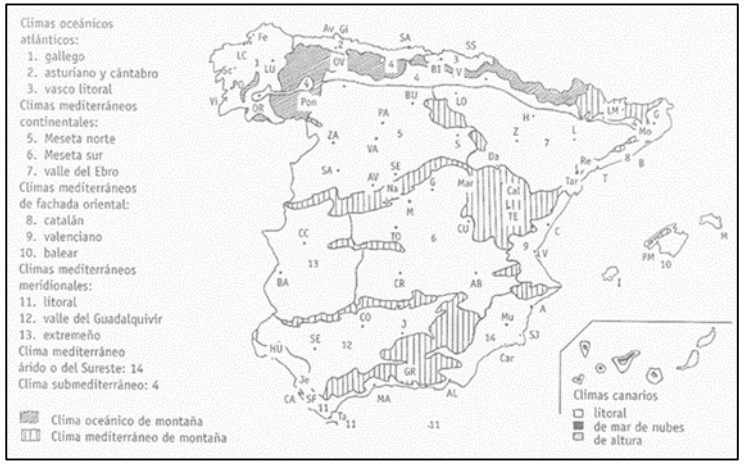
Specifically, to test the hypothesis that the increase in temperature resulting from the global warming process implies a tendency towards progressive drought:

↑ + Warming ➔ ↓ - Precipitation

This double trend, an increase in temperatures and a tendency towards a reduction in rainfall, is determining a change in climate. From the perspective of the Köppen climate classification, the priority climate in Spain is changing, from a *classic temperate Mediterranean climate (Csa) to a steppe-type climate and even a desert climate (BSk)*



Source: Font (1983)



Source: Martín Vide & Olcina Campos (2001)

Methodology

E-OBS dataset provided by European Climate Assessment and Dataset (ECA&D) project

0.1 and 0.25 degree regular grid daily mean temperature (TG), daily minimum temperature (TN), daily maximum temperature (TX), daily precipitation sum (RR)

Due to the lower density of meteorological stations in periods prior to 2008, and therefore the greater uncertainty of the indicators when going back in time, it was decided to use the spatial resolution of 0.25°

In this study, we obtained daily temperature data, including the average, maximum and minimum temperature, and precipitation from 1971 to 2022, using the 27.0e dataset. Data from the last 52 years allow us to reflect the current climate situation in Spain and to trace the main trends in climate change in recent decades

Given the high variability of climate, in addition to the conventional OLS, the Mann-Kendall (MK) test and the non-parametric Kendall-Theil-Senn (KTS) regression are used to analyze the climatic trends in temperature and precipitation

Methodology: Climatic Indicators

For Temperature

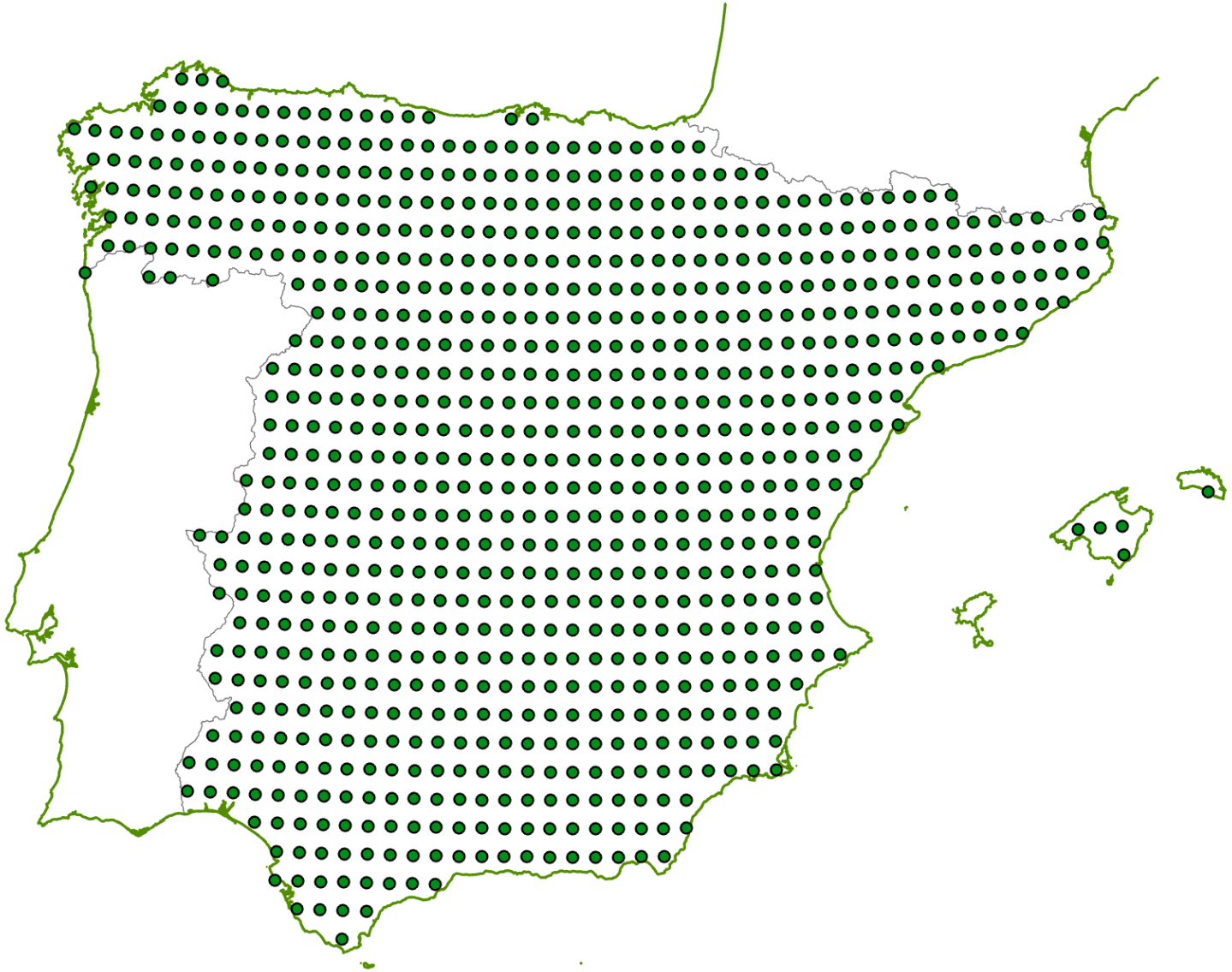
- Daily mean temperature (TG),
- Daily minimum temperature (TN),
- Daily maximum temperature (TX),
- Summer days (SU),
- Tropical nights (TR)
- Daytime and nighttime extreme heat thresholds (DHT & NHT) for the identification of daytime and nighttime heat waves (DHW & NHW).

For Precipitation and Drought

- Daily precipitation sum (RR)
- Number of days without rain (RR = 0, or dry days, DD)
- Number of consecutive days with a precipitation less than 1 mm/day (CDRR1mm).
- The highest 5-day precipitation amount (RRX5day)
- Precipitation above the 99th percentile of wet days (total precipitation due to extremely wet days, RR30mm)
- Torrential precipitation (95th percentile of extremely wet days, RR60mm)

Methodology: Spain Grid

The OLS and KTS models developed for the whole mainland Spain and Balearic Islands and for each of the 839 cells that make up the E-OBS database, at a scale of 0.25°



Results: Warming in Spain (1971-2022)

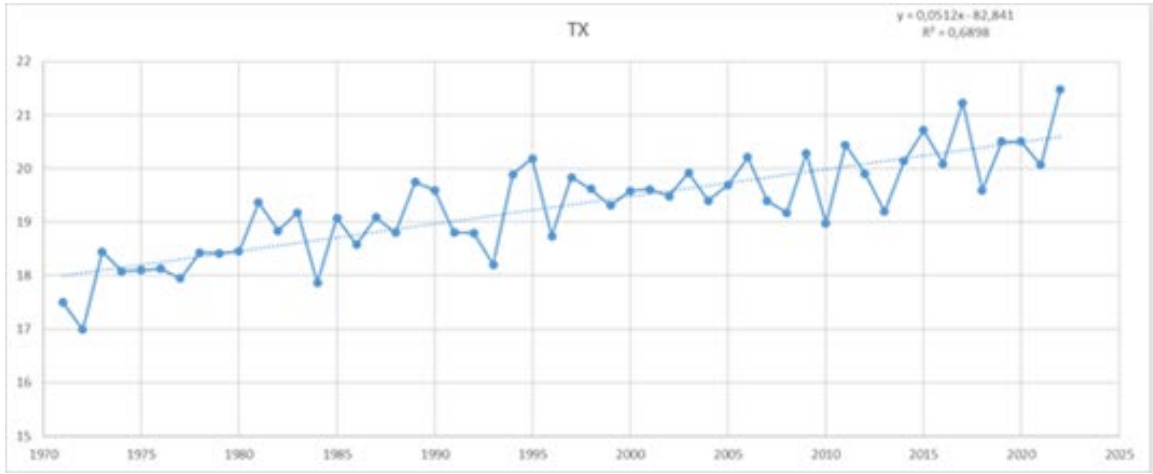
Between 1971 and 2022:

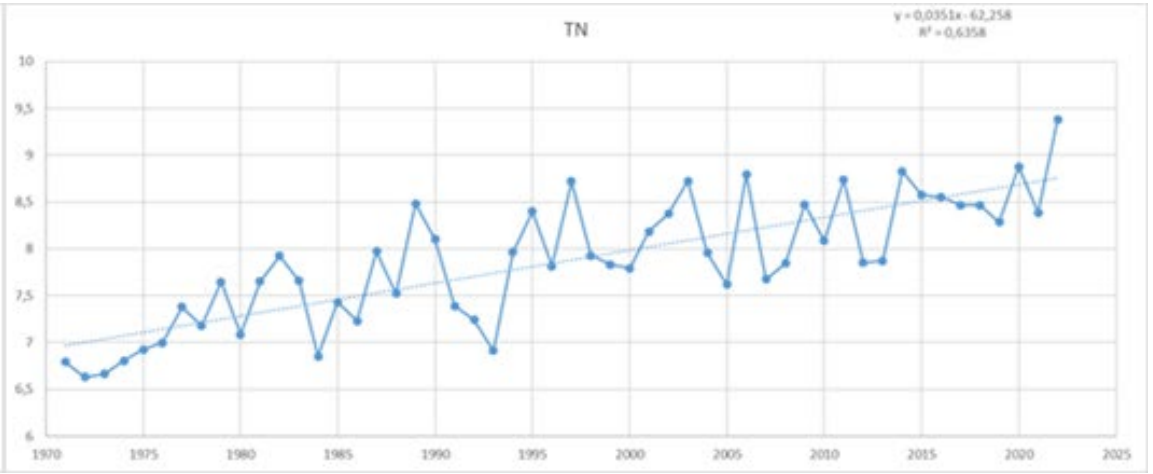
- Maximum temperatures (TX) have increased on average 0.051°C per year,
- Minimum temperatures (TN) 0.035°C per year, and
- Mean temperatures (TG) have increased 0.042°C per year

The warming process resulting from climate change has been very pronounced in mainland Spain and the Balearic Islands, representing a true hotspot.

- Spain has widely exceeded not only the 2°C threshold, compared to the pre-industrial era

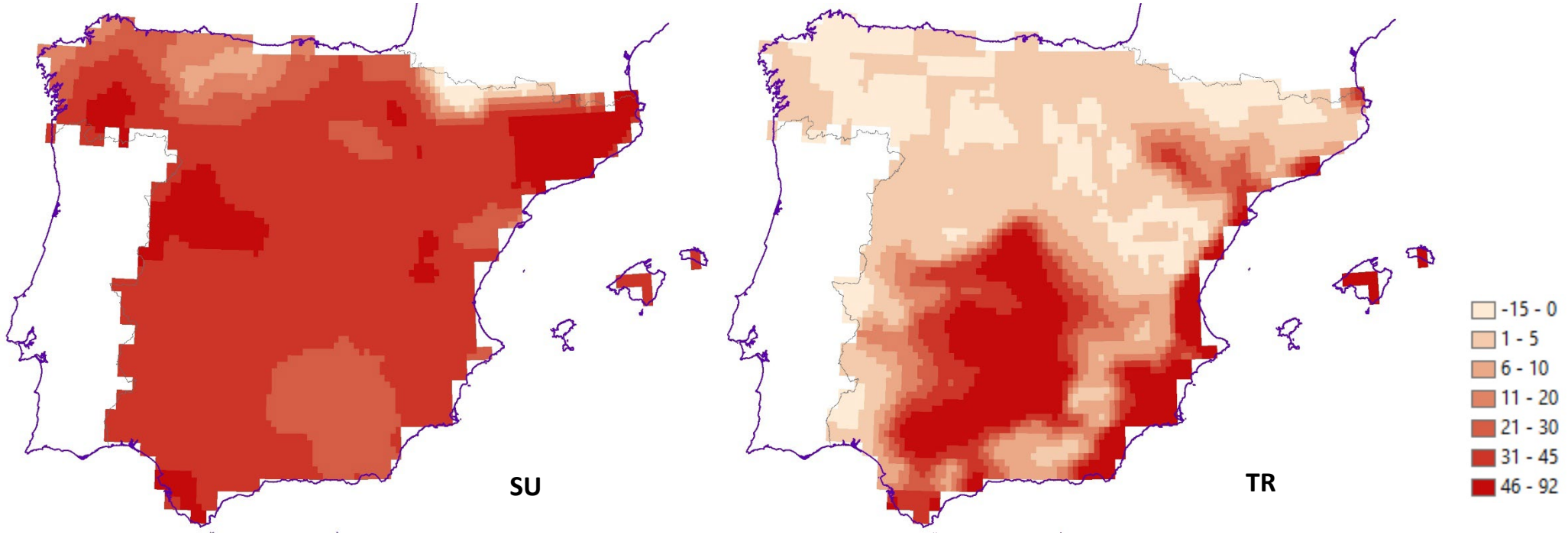
- Difference between 2022 and 1971, in mainland Spain and the Balearic Islands is 3.27°C, above the world average of 1.19°C and average for Mediterranean area of 1.58°C (Historical estimates of the CMIP6 as a reference (https://atlas.climate.copernicus.eu/atlas)





Summer Days (SU) & Tropical Nights (TR)

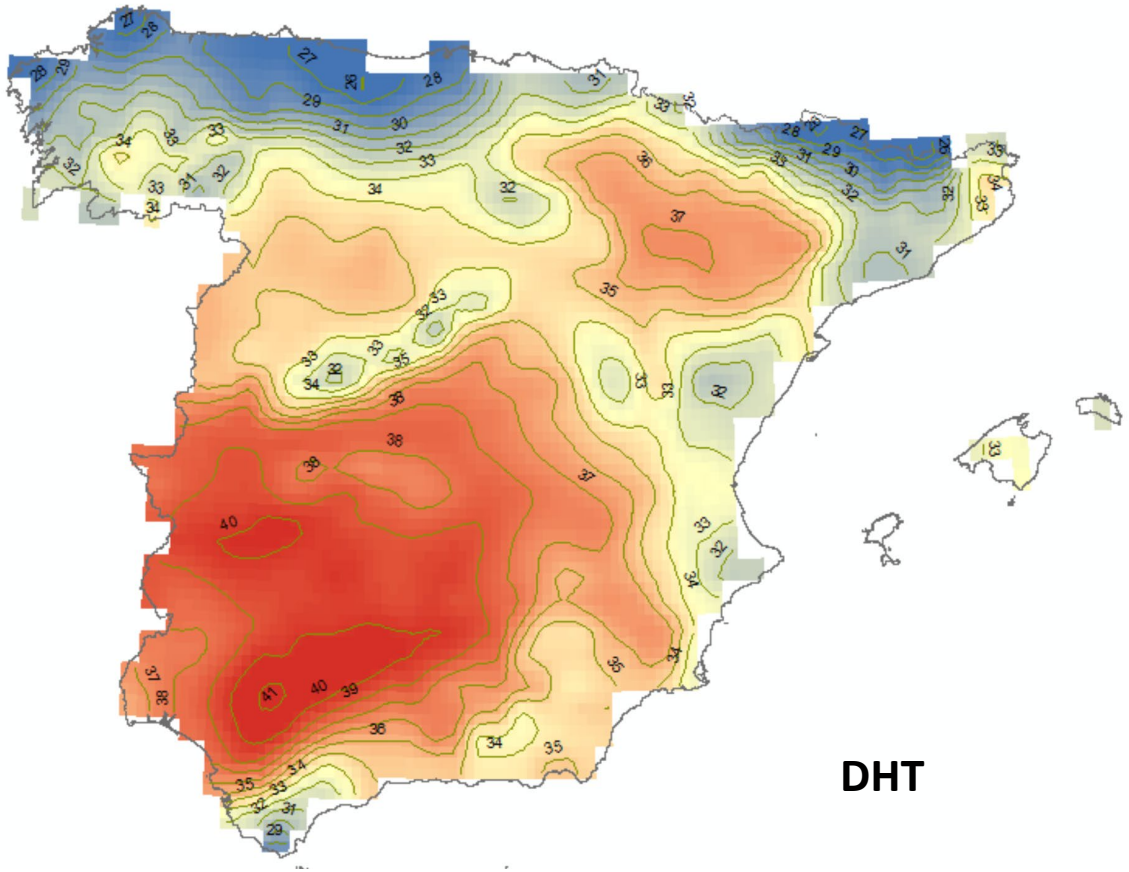
- SU have increased from 82.4 in 1971 to 117.9 in 2022. **Between 1971 and 2022, summer has increased on average across Spain by 36 days**
- TR has increased from 1.73 in 1971 to 14.12 in 2022. Faced with the increase in SU, which has been very homogeneous throughout the Spanish territory, **the increase in TR is concentrated in the Southern Plateau, the valleys of the Guadalquivir and Ebro rivers, as well as the Mediterranean coast**, with increases of more than 30 nights, between 1971 and 2022



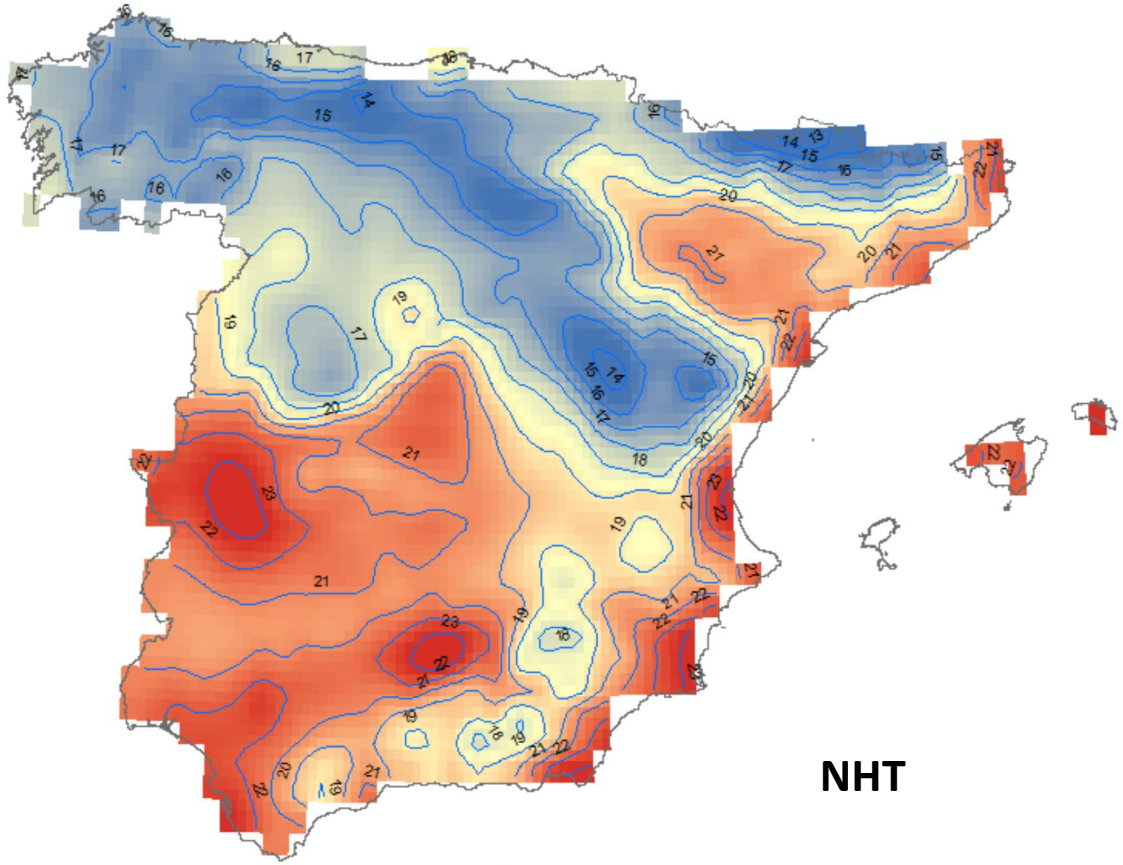
Extreme Heat Thresholds

- Extreme Daytime Heat Threshold (DHT) exceeds 35°C in the Southern Plateau, and especially the valley of the Guadalquivir river, and the valley of the Ebro river. On the Mediterranean coast, it rarely exceeds 32°C

- Night Heat Threshold (NHT) exceeds 20°C in much of the Mediterranean coast, in addition to the Community of Madrid (probably an effect of the urban heat island of the capital of Spain), and the valleys of the Guadalquivir and Ebro rivers



DHT



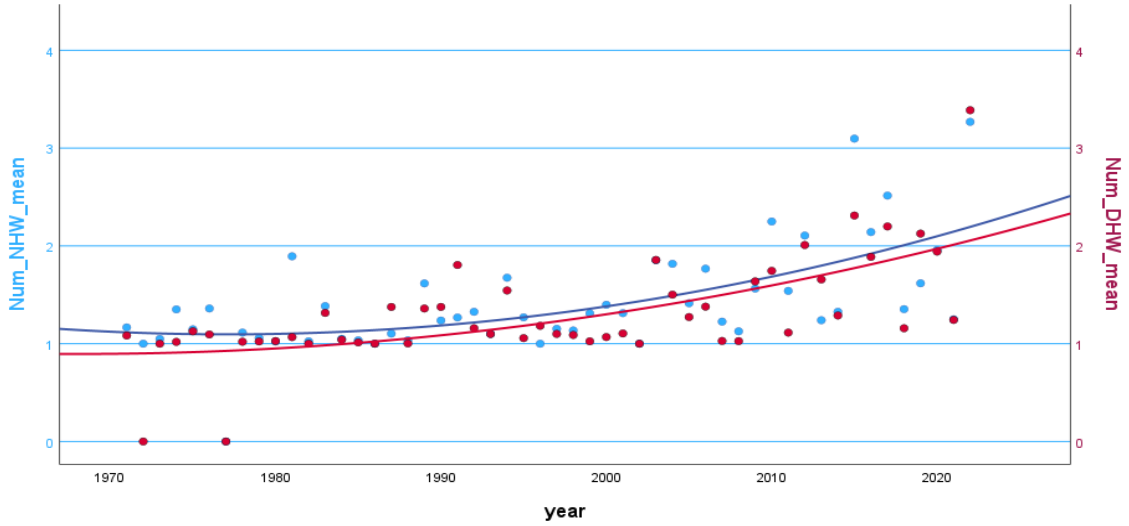
NHT

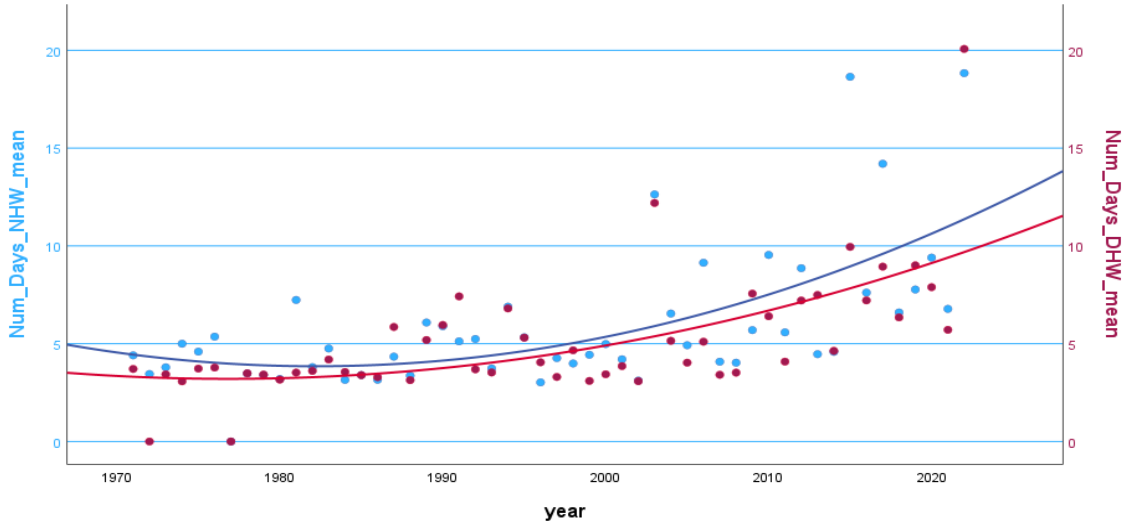
More and Longer Heat Waves

Increase in number of DHW and NHW

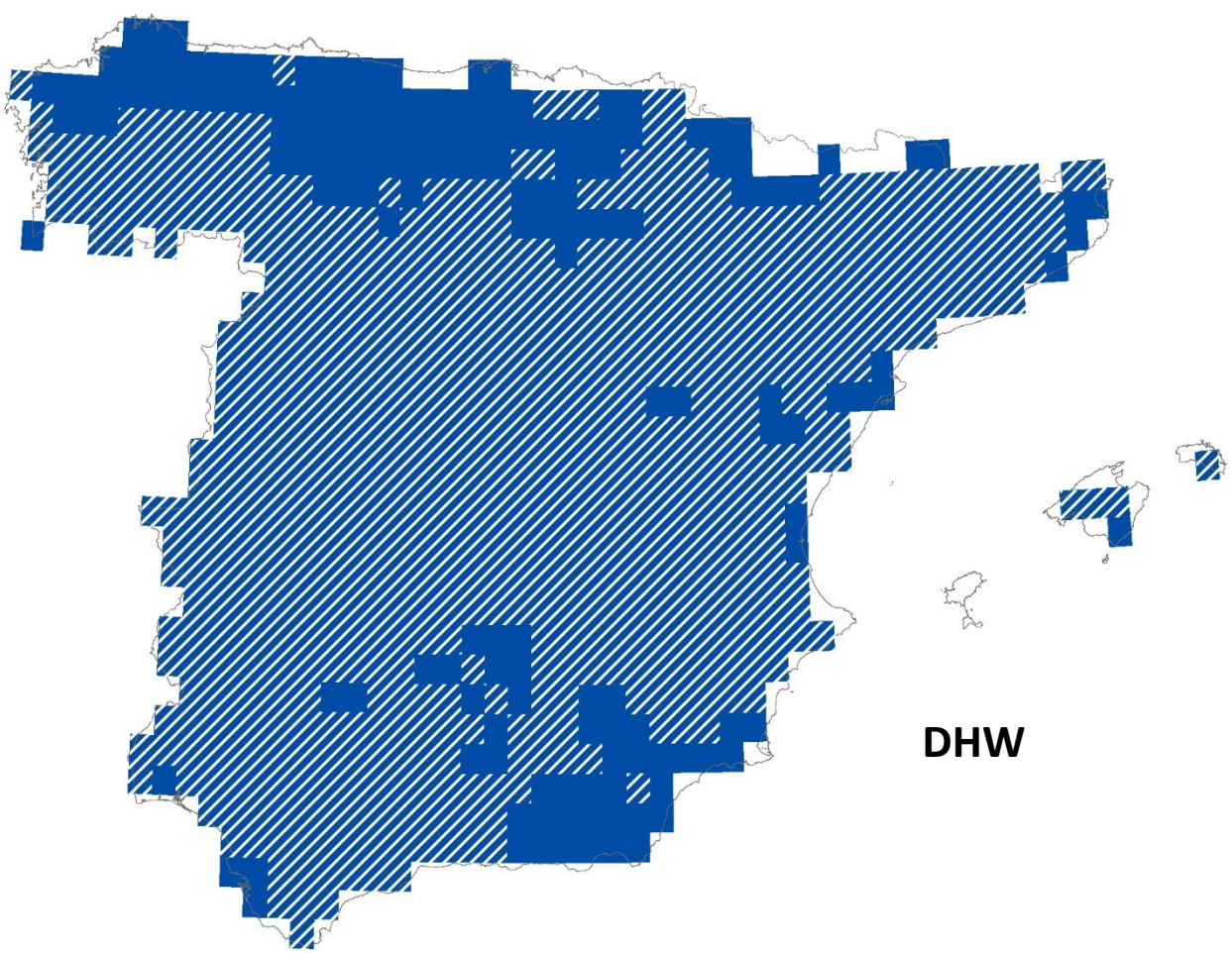
If we compare the first decade (1971-1980) with the last decade (2013-2022), *the number of DHW and NHW has gone from less than one per year to almost two*

The duration of Heat Waves increased from 3 to 9 days on average

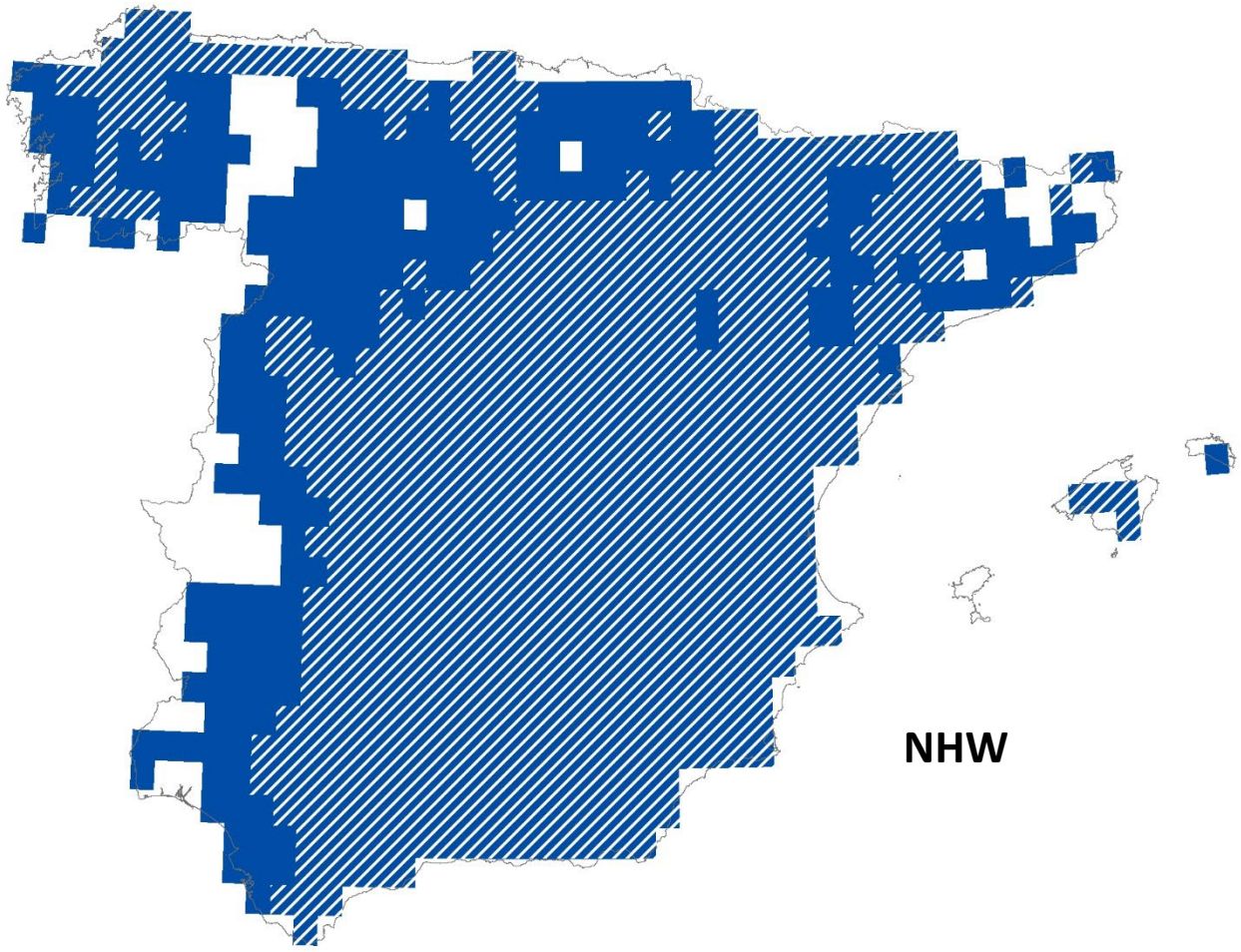




Increasing trend of Heat Waves



DHW



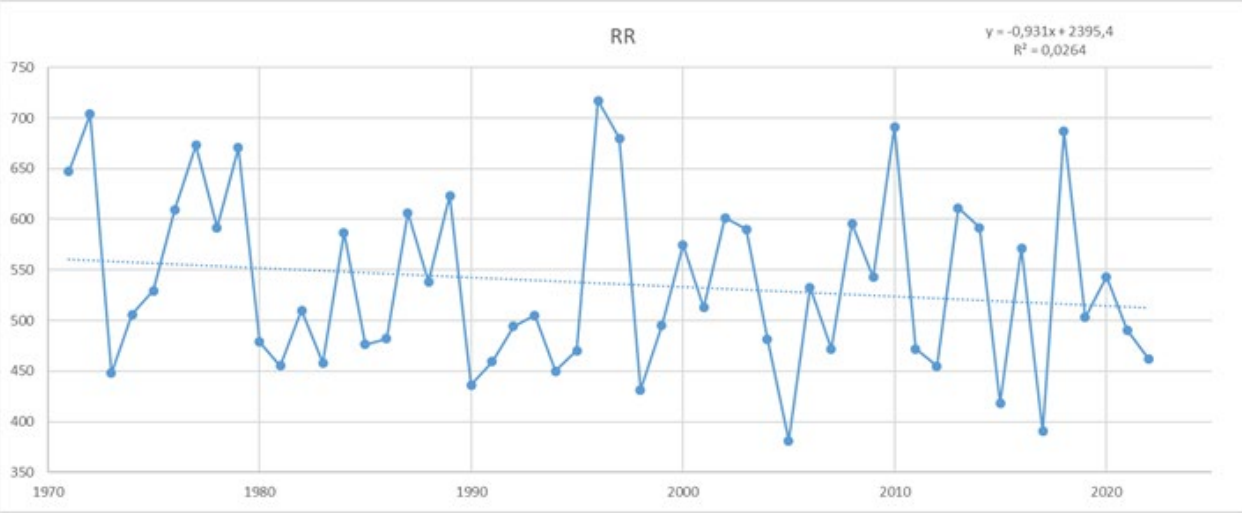
NHW

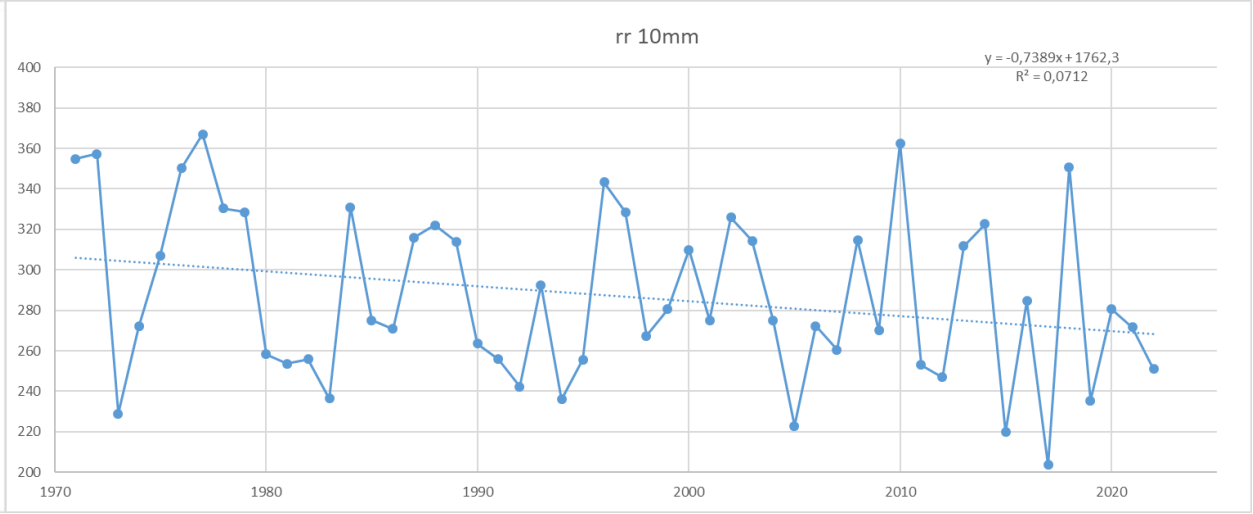
- In blue the territory with a tendency towards an increase in daytime and nighttime heat waves obtained through KTS regression models developed for the 839 points.
- With white bands show the area in which the regression coefficient is statistically representative at 95% confidence. **Almost the entire territory shows a statistically significant tendency towards an increase in both, DHW and NHW**

Towards a drier climate (1971-2022)

Average rainfall (RR) in Spain shows a trend towards greater drought, in accordance with the forecasts of climate models

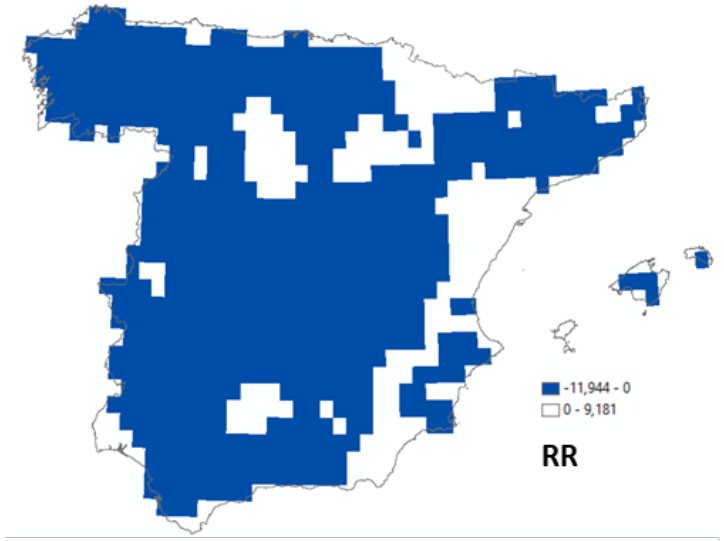
- **Between 1971 and 2022, there was a reduction in rainfall of 0.93 mm/year**
- For the entire period studied (71-22), there would have been a reduction of 48.41 mm, 8.9% of the average rainfall of the reference period 1971-2000
- **In the case of the annual sum of precipitation less than or equal to 10 mm/day (RR10mm), the saturation threshold of the thin surface layers, there has been a reduction of 0.739 mm/year**



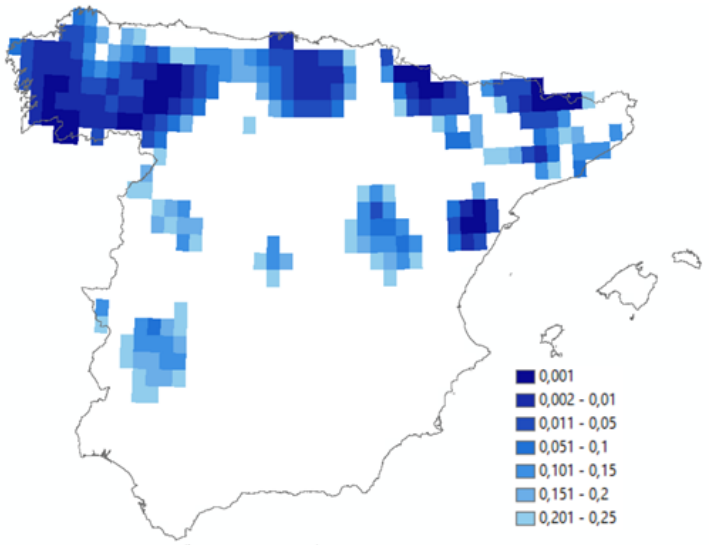


Towards a drier climate (KTS Models)

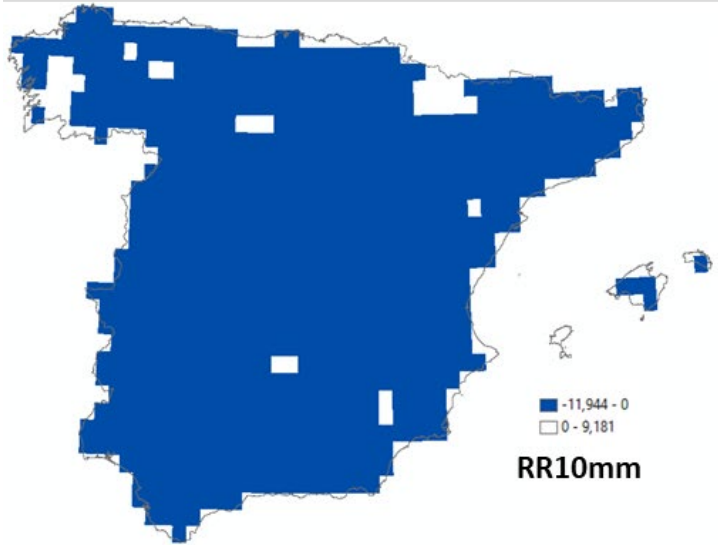
Rainfall Decrease

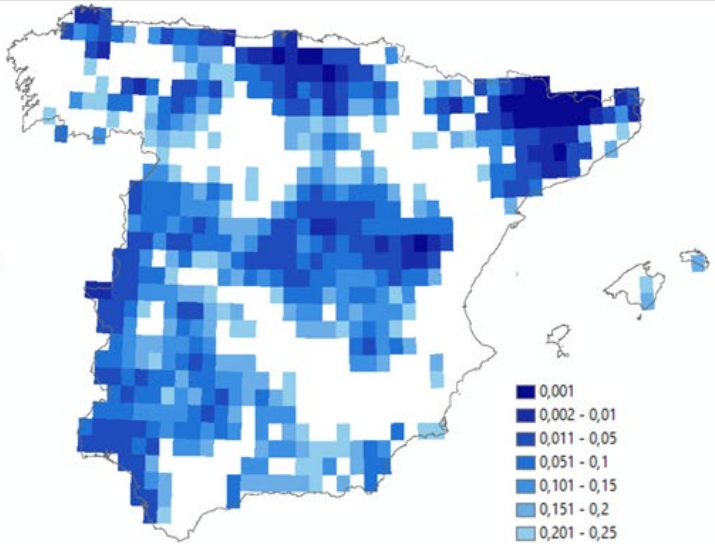


Statistical significance (p-value)



Annual rainfall below 10mm/day Decrease

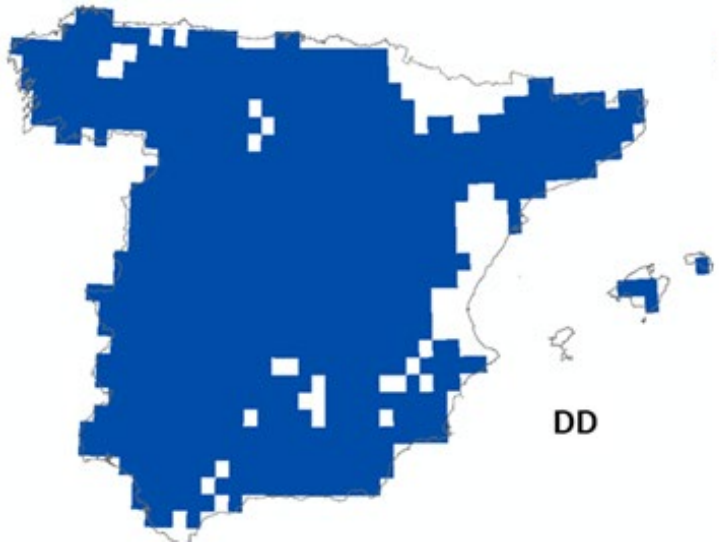




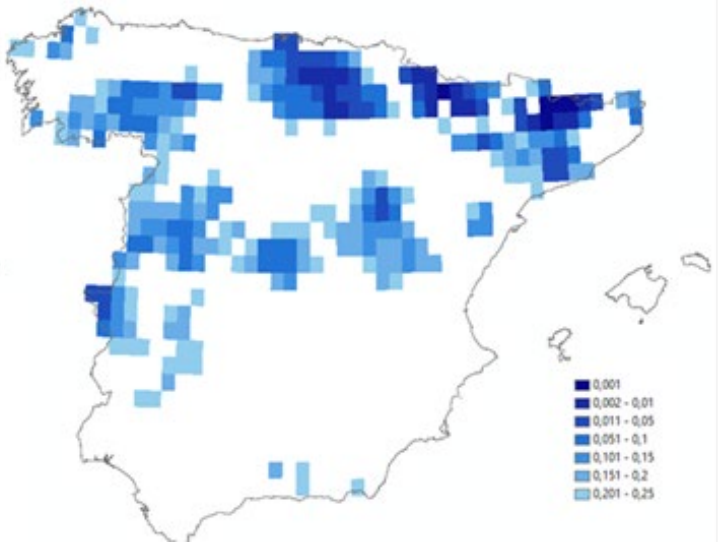
Most of the territory shows a clear tendency towards drought

Towards an increase in drought

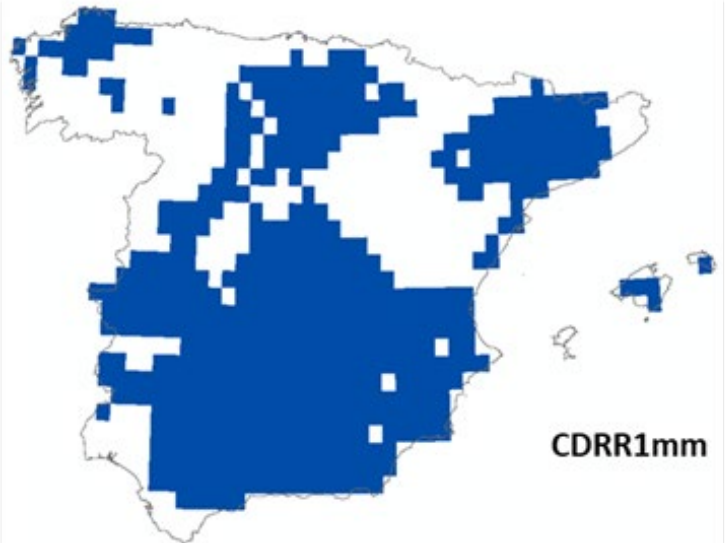
Dry Days Increase

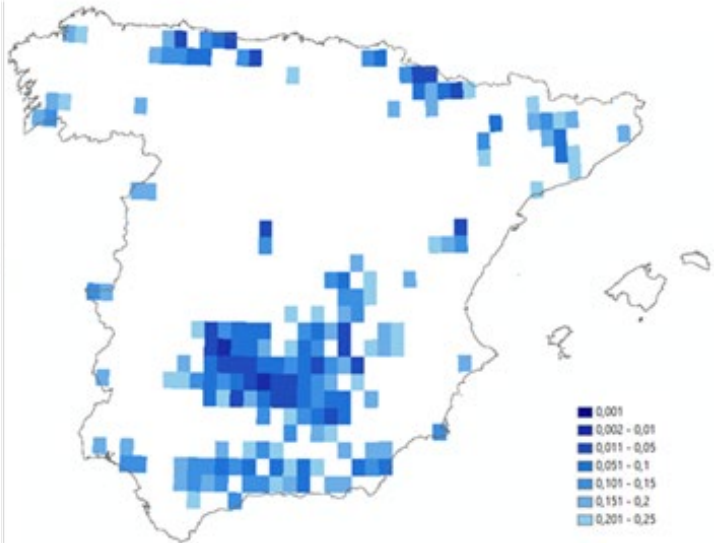


Statistical significance (p-value)



Consecutive Days of Precipitation less than 1 mm/day Increase

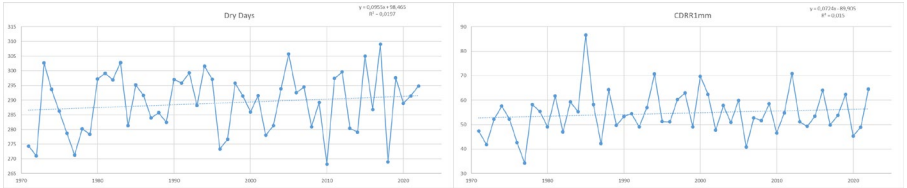




KTS models suggest a trend towards an increase in extreme drought events over time

The model for the whole territory estimates an increase of almost 1 DD per decade

Similarly, between 1971-2022 there has been an increase of almost 4 days in the number of consecutive days with precipitation less than 1mm



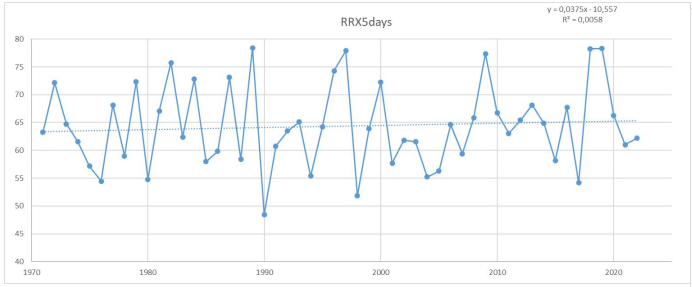
More Extreme Rainfalls

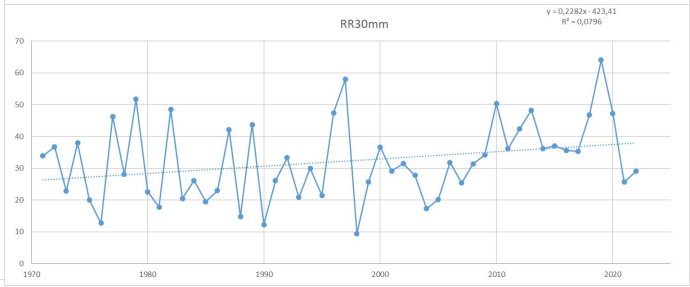
- **Regression models of extreme precipitation indicators (the highest 5-day precipitation amount, precipitation above the 99th percentile of wet days, and torrential precipitation) show an increase in this type of extreme weather events in the period under study**

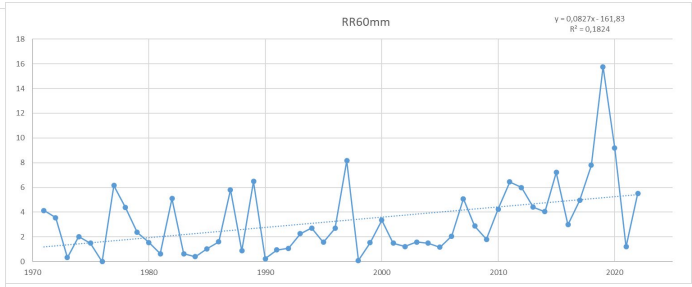
- For the highest accumulated precipitation in 5-day periods (RRX5days), the result of the regression model shows an increase of 1.95 days for the period 1971-2022, although they have a confidence level of about as likely as not 33–66% (p-value = 0.591)

- Rainfall above the 99th percentile of wet days (>30mm/day) has increased significantly between 1971 and 2022. **The annual increase of RR30mm has been 0.2282mm, representing a very high level of confidence (p-value = 0.043)**

- **The increase in torrential rainfall (RR60mm in this study) in the period 71-22 can be considered as a virtually certain fact (p-value = 0.002)**. **The regression model shows that RR60mm has increased by 0.0827 mm/year in the period studied**, representing an increase in torrential rainfall of 360%.

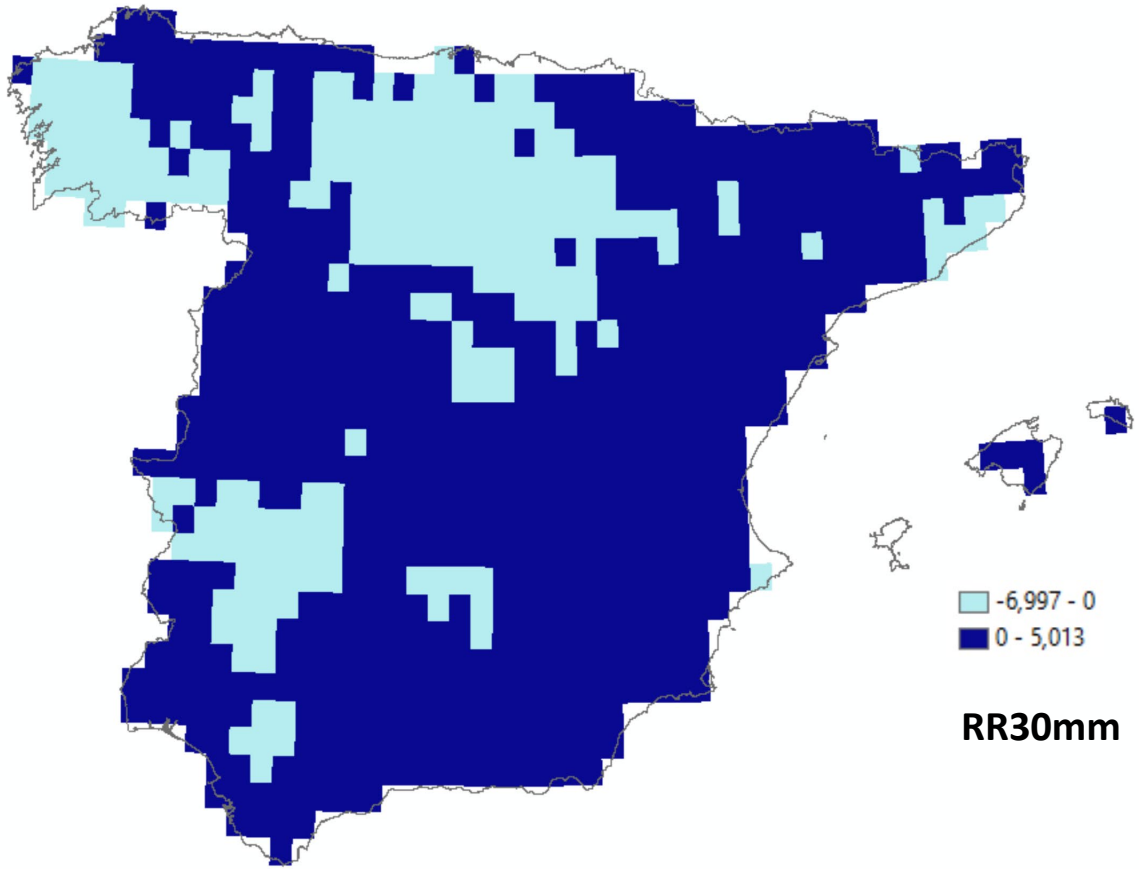


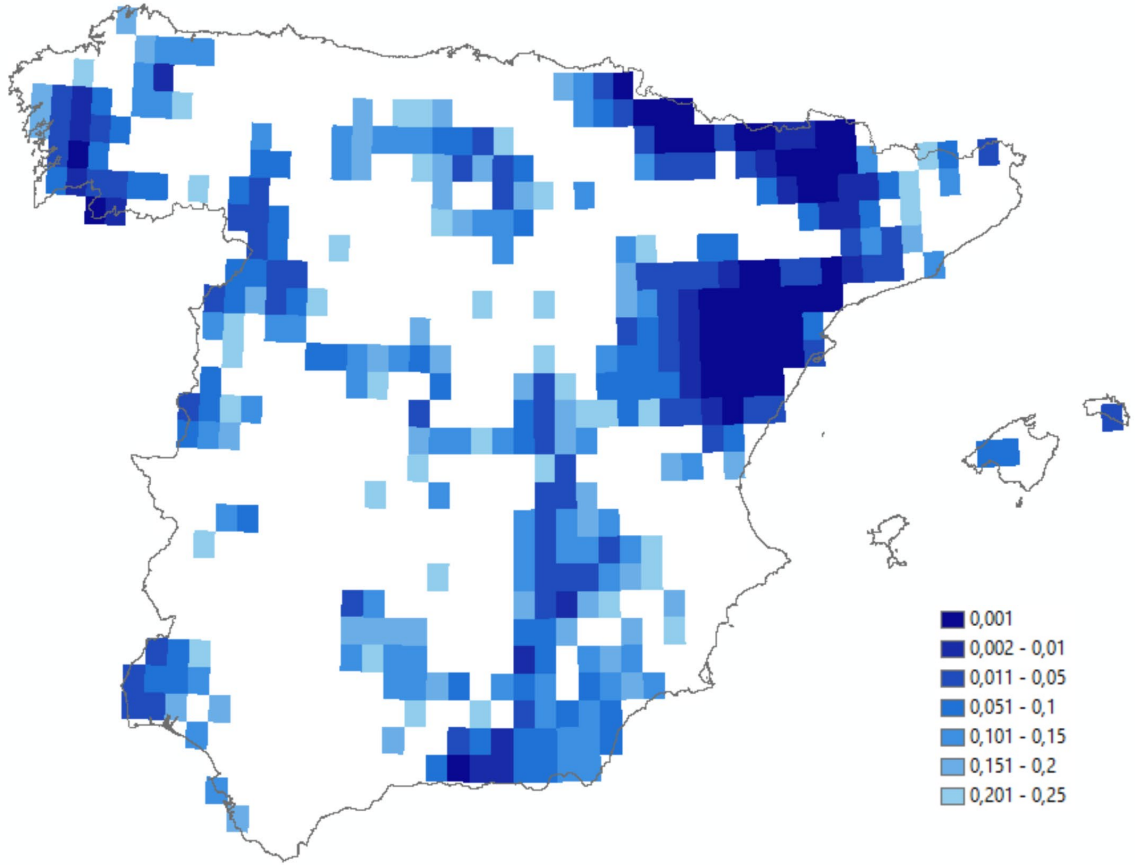




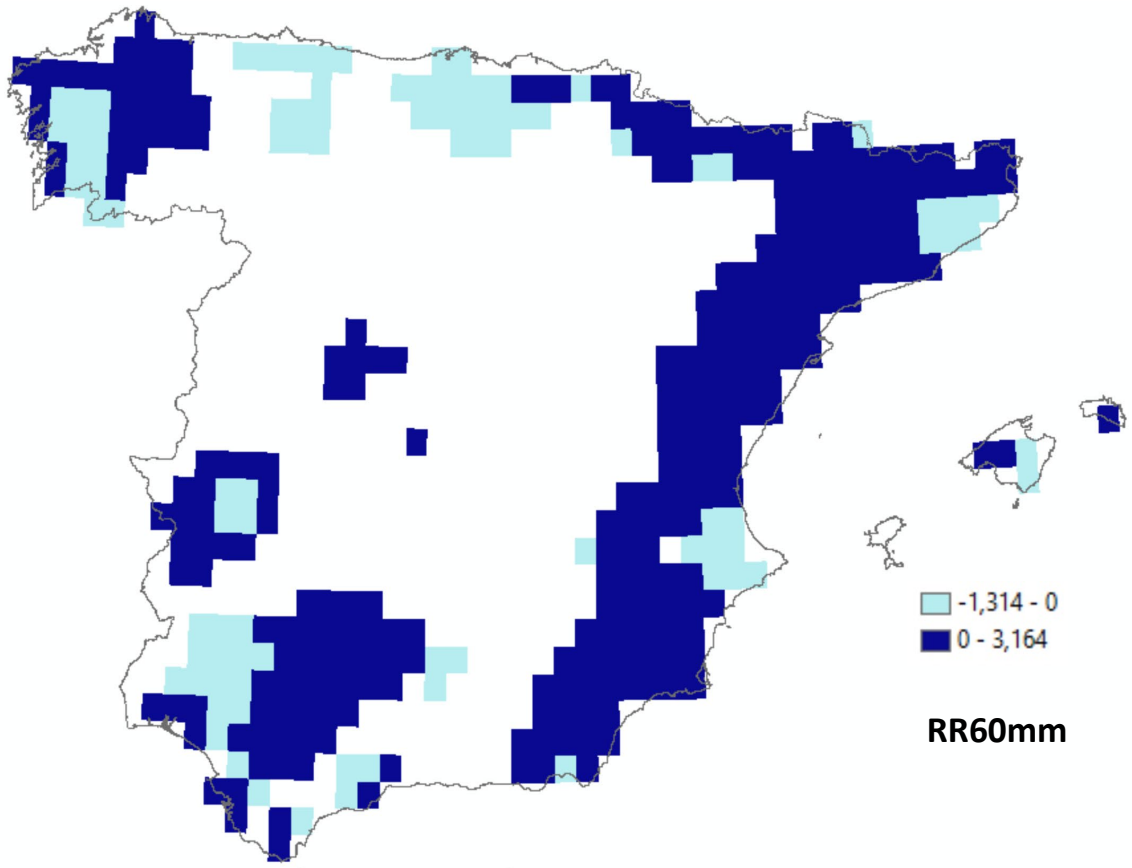
Extreme Rainfall (1971-2022)

- The increase in extreme rainfall (RR30mm) is relatively widespread (dark blue), but not unanimous (light blue is the area where RR30mm decreases).
- In Andalusia, Castilla La Mancha, Murcia, Valencia, southern Catalonia, Balearic Islands, Aragon, Navarre, Basque Country and Asturias, torrential rainfall increased between 1971 and 2022.
- In Extremadura, Cantabria, part of Castilla-León, part of Catalonia and Galicia, there has been a decrease in episodes of extreme rainfall

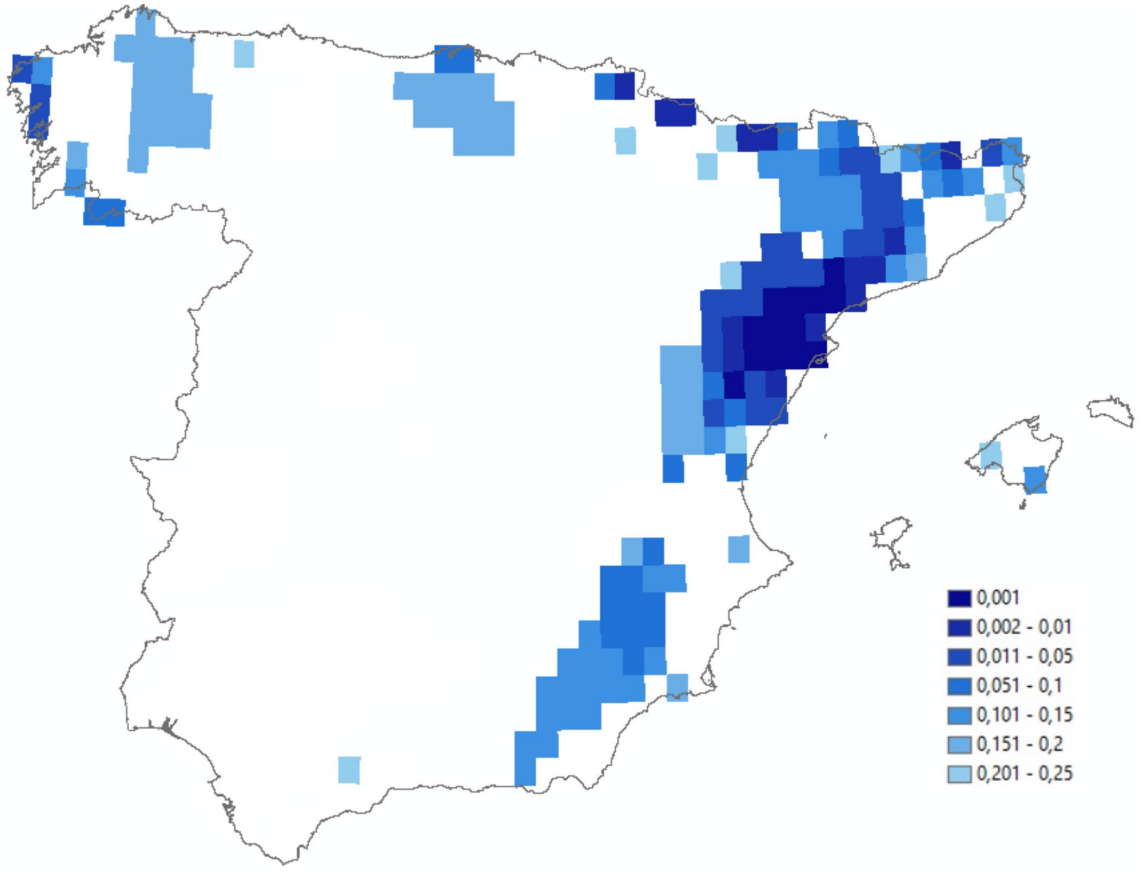




Torrential rainfall (1971-2022)



Statistical significance (p-value)



- Dark blue, areas where there has been an increase in torrential rainfall (>60 mm/day)
- Light blue, areas where torrential rainfall has decreased; in white, the areas where there is no rainfall greater than 60 mm/day)

The distribution of torrential rainfall is concentrated on the Mediterranean coast, inland Galicia, and the Guadalquivir valley and Extremadura.

Interaction between Temperatures and Precipitation

The maximum temperature (TX) is the temperature indicator that shows the highest correlation, both in the case of total precipitations (RR), and the drought indicators (RR10mm and DD)

In the case of extreme precipitation, the most pronounced correlation occurs with the minimum temperature (TN).

- The warmest years at night are those that show a greater tendency towards extreme precipitation (RRX5days, RR30mm and RR60mm).
- Torrential rains are more correlated with year variable than temperatures

		RR	RR10mm	Dry_days	RRX5days	RR30mm	RR60mm
year	Pearson corr.	-0.163	-0.267	0.14	0.076	.282*	**.427****
	Sig.	0.25	0.056	0.322	0.591	0.043	0.002
TG	Pearson corr.	-.275*	-.401**	.304*	0.048	0.209	.386**
	Sig.	0.049	0.003	0.028	0.735	0.137	0.005
TX	Pearson corr.	**-.413****	**-.530****	**.439****	-0.037	0.141	.362**
	Sig.	0.002	<.001	0.001	0.793	0.319	0.008
TN	Pearson corr.	-0.051	-0.185	0.079	0.157	**.317***	**.411****
	Sig.	0.717	0.189	0.578	0.265	0.022	0.002

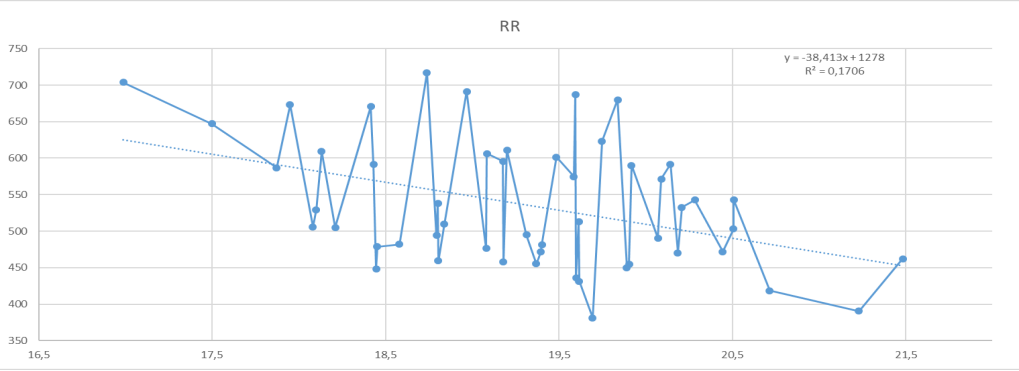
** The correlation is significant at the 0.01 level (two-tailed).

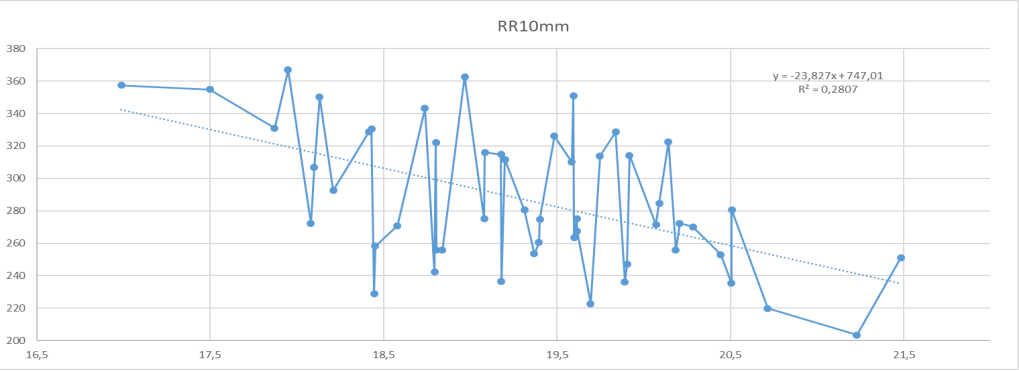
* The correlation is significant at the 0.05 level (two-tailed).

TX Increase ➔ RR Decrease

- The regression models between the total annual rainfall and the rainfall <= 10mm with the annual average of maximum temperatures confirm the strong link between the increasing evolution of temperatures and the decrease in rainfall in mainland Spain and the Balearic Islands
- **An increase of 1°C in TX represents a reduction in annual rainfall of 38,413mm/year, as well as 23,83 mm/year, in the case of rainfall less than or equal to 10mm/day**

Considering the increase in temperatures in Spain, the precipitation regime decreases and the periods of drought increase



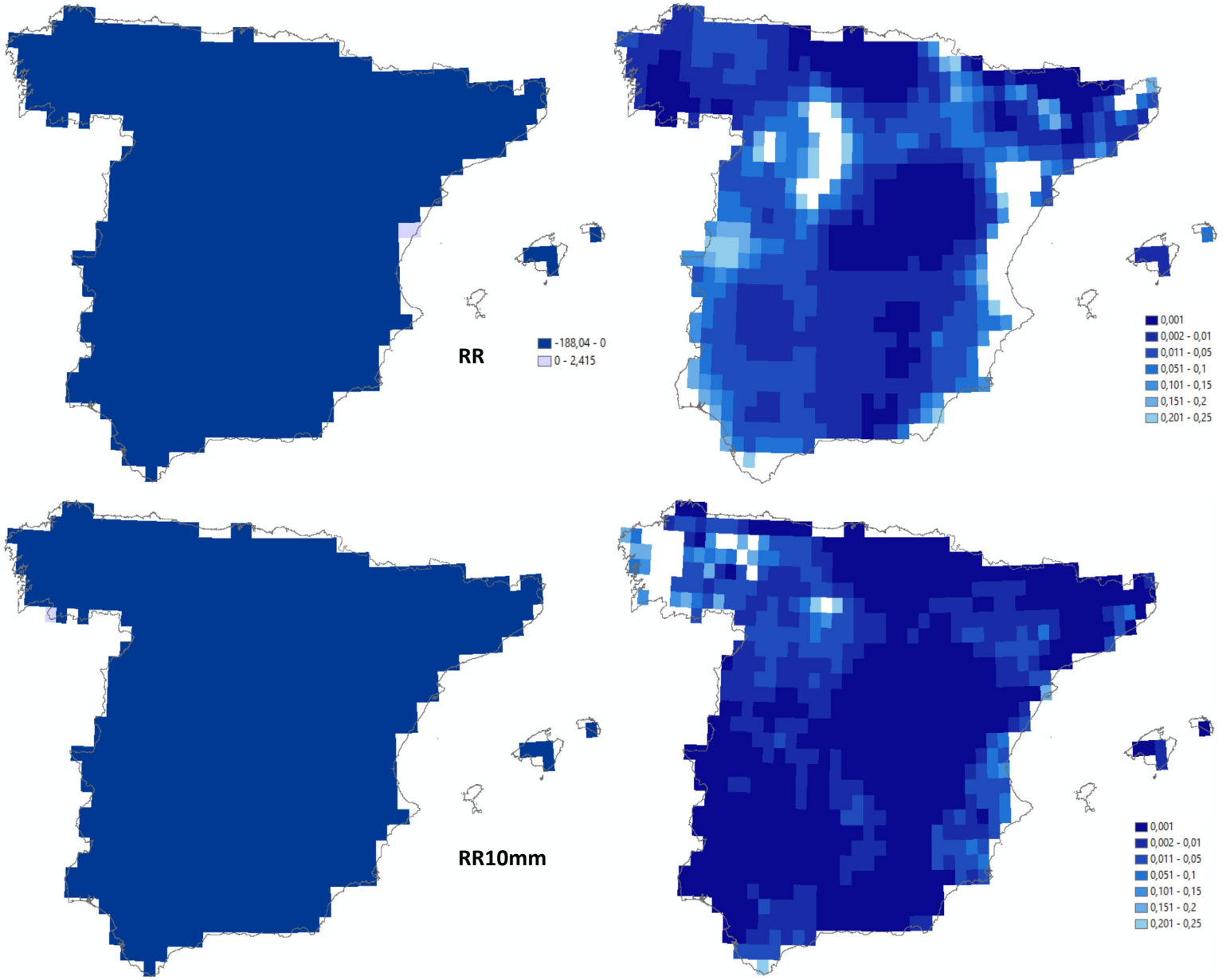


Interaction between precipitation and maximum temperatures

Top left (in dark blue, models with a negative regression coefficient), annual precipitation. Bottom left, annual precipitation >= 10mm.

On the right, the statistical significance of the RR and RR10mm models

In practically the entire territory, the association between progressive warming (TX) and the tendency towards reduced rainfall is highly significant

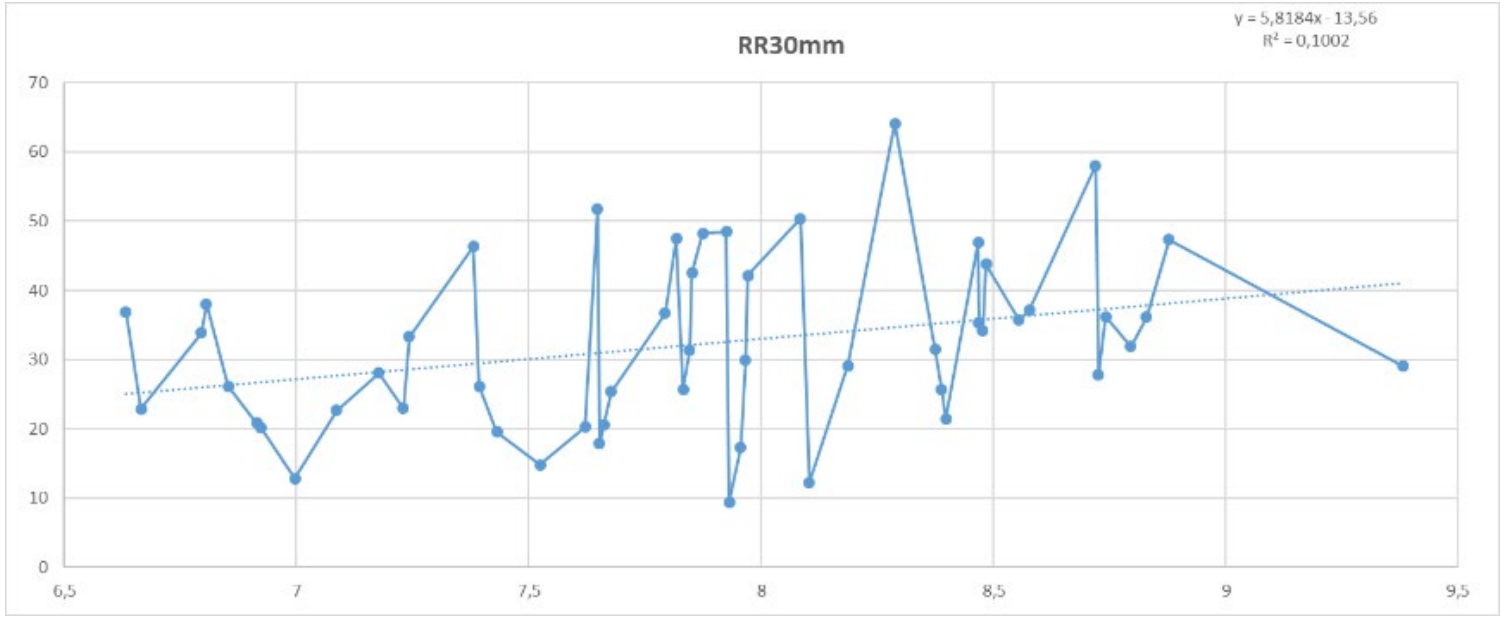


TN increase ➔ extreme rainfall increase

Clear positive correlation between RR30mm and TN

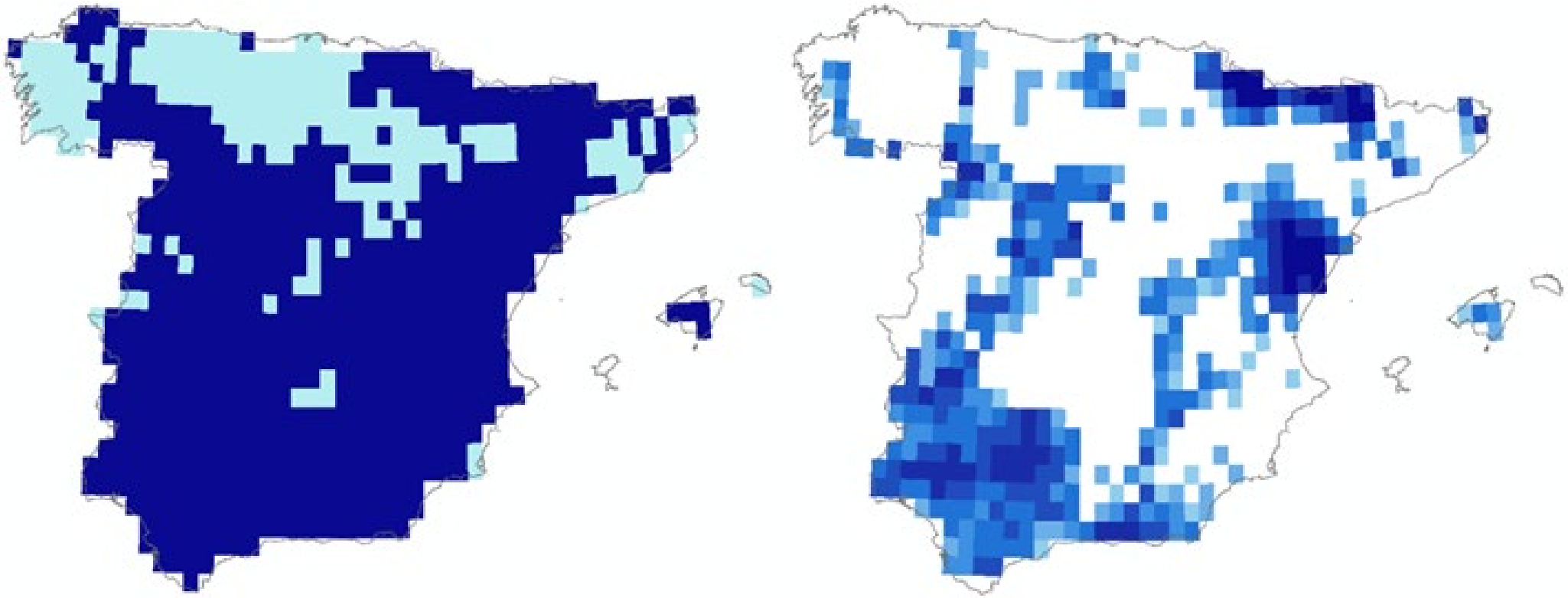
- **As minimum temperatures rise, extreme precipitation increases (at a rate of 5.8184 mm/year)**

- **The model is significant at 95% confidence (p-value = 0.022), which confirms with a high level of confidence the hypothesis that the warming process that Spain is experiencing is associated with an increase in extreme precipitation**



Extreme rainfall vs minimum temperatures

Statistical significance



Most of peninsular and insular Spain have a positive association between extreme precipitation and the increase in minimum temperatures (dark blue represents a positive sign of the OLS models and light blue the negative sign).

Discussion: Horizon 2050

The regression models allow a relatively robust forecast of the climate of mainland Spain and the Balearic Islands in a relatively close scenario (2050)

- ➔ **TG would most likely reach 15.84°C in 2050, 1.43°C higher than the average temperatures of the last 10 years (2013-2022)**
- ➔ Equally significant increase in TX (1.77°C) and TN (1,20°C).
- ➔ Summer days (SU) would be extended by 22.7 and tropical nights (TR) by 7.2 nights on average throughout Spain, compared to the period 2013-2022
- ➔ **The average annual rainfall in mainland Spain and the Balearic Islands in 2050, will be well below 500mm/year (417mm)**, 126.3mm less than the period 1971-2000, as well as almost 109.6mm less than in the last 10 years
- ➔ **The periods of drought will be longer.** The RR10mm will most likely be around 214mm in 2050, almost 80mm less than in the period 1971-2000.
- ➔ **Extreme rainfall will increase** in the horizon year (2050), reaching around 43 mm accumulated throughout the year. An increase of almost 45% compared to 1971-2000

	1971-2000	2013-2022	2050	71-20 Change	13-22 Change
TG	13.1381	14.4123	15.8412	2.7031	1.4289
TX	18.7875	20.3542	22.1292	3.3417	1.7749
TN	7.4984	8.5706	9.7658	2.2674	1.1952
SU	92.4033	114.3392	137.0396	44.6363	22.7004
TR	5.2269	13.0089	20.1763	14.9494	7.16744

	1971-2000	2013-2022	2050	71-00 Change	13-22 Change
RR	543.5778	526.9043	417.2818	-126.2960	-109.6225
RR10mm	293.5095	273.1846	213.8925	-79.6170	-59.2921
RR30mm	29.6981	40.5644	43.0275	13.3294	2.4631

Discussion: Horizon 2050

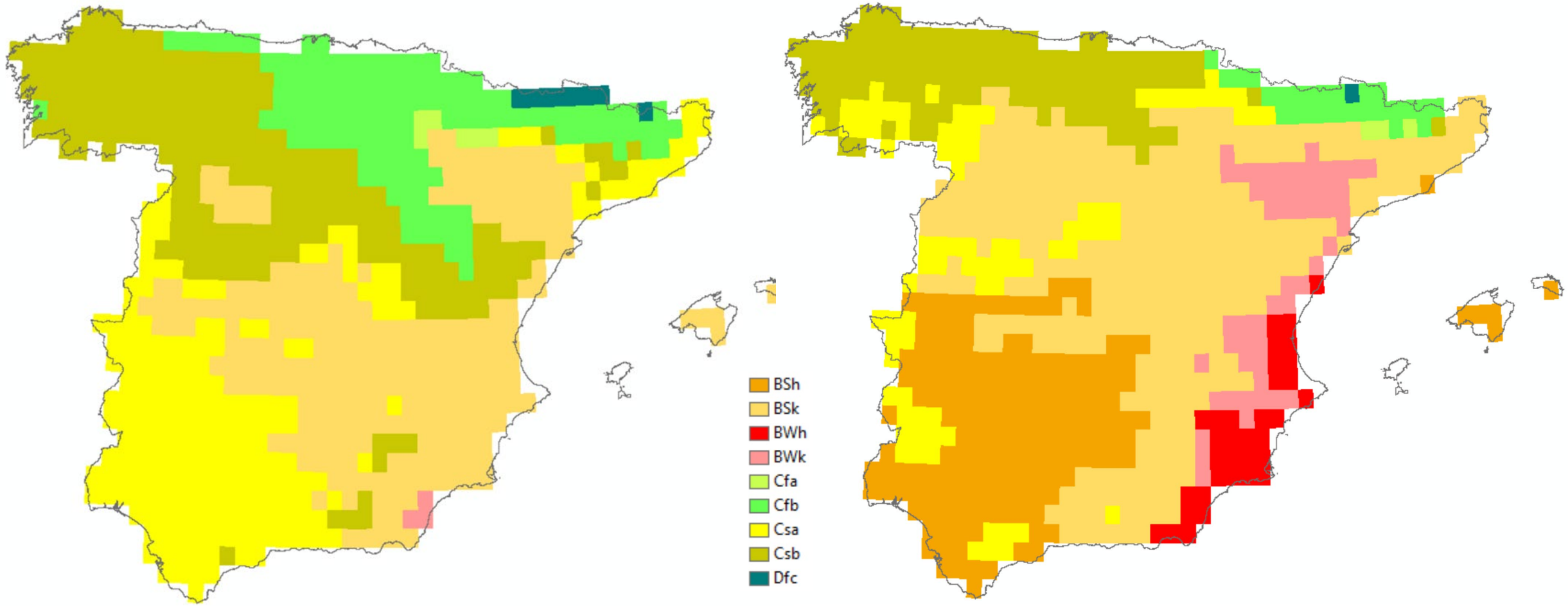
For 2050, the average climate of peninsular and insular Spain (Balearic Islands) will experience a fundamental change when compared with the reference period 1971-2000. If we consider the dominant climate in the whole territory, table presents the most relevant information to determine the type of climate (Köppen) in Spain in 1971-2000 and 2041-2060

By 2050 (moving average 2041-2060), the KTS model (with maximum temperature as independent variable) predicts a marked change in the Köppen climate classification. **The climate of mainland Spain and the Balearic Islands would change from Csa (hot-summer Mediterranean climate) to BSk (cold semi-arid climate), with average annual temperatures below 18°C and rainfall below the dryness threshold.**

The model predicts a significant increase in average temperatures (TG) by 2050, which will lead to an increase in the drought threshold (Dt). Also, the KTS model predicts a significant reduction in rainfall, with a tendency to decrease rainfall below the drought threshold (Dt), which would significantly compensate the trend towards an increase in extreme rainfall (RR>30 mm)

	TG	RR	RRs/RR	Dt	Köppen
1971-2000	13.138	543.58	1/3-2/3	403.76	Csa
2041-2060	15.863	416.4	1/3-2/3	457.25	Bsk

Discussion: Comparison Köppen 1971- 2000 vs. Köppen 2041-60



The geographic distribution of climate change is clearly observed through detailed modelling for the 839 study points.

Climate classification 1971-2000 vs. 2041-2060

In the near future, the dominant climate in mainland Spain and Balearic Islands will evolve towards a steppe-type climate, with the expansion of "brown" Spain.

More than 40% of the territory will probably change from a C climate (temperate) to a B climate (dry), confirming the trend towards a progressive decrease in rainfall

Particularly notable, as indicated, is the dramatic reduction of the typical Mediterranean climate (Csa), which would go from representing 24.43% of the peninsular and island territory in the reference period 1971-2000 to 10.13% in the period 2040-2060

The "cold" steppe climate (BSk) will represent the dominant climate in mainland Spain by 2050 (39.81%), progressively displacing the typical Mediterranean climate

		BSh	BSk	BWh	BWk	Cfa	Cfb	Csa	Csb	Dfc	Total
Koppen_71_00	BSk	64	109	33	52	0	0	0	0	0	**258**
	BWh	0	0	2	0	0	0	0	0	0	**2**
	BWk	0	0	3	0	0	0	0	0	0	**3**
	Cfa	0	6	0	0	0	0	0	0	0	**6**
	Cfb	0	41	0	0	3	19	12	54	0	**129**
	Csa	109	65	0	1	0	0	30	0	0	**205**
	Csb	0	113	0	1	0	0	43	70	0	**227**
	Dfc	0	0	0	0	0	7	0	0	1	**8**
Total		**173**	**334**	**38**	**54**	**3**	**26**	**85**	**124**	**1**	**839**

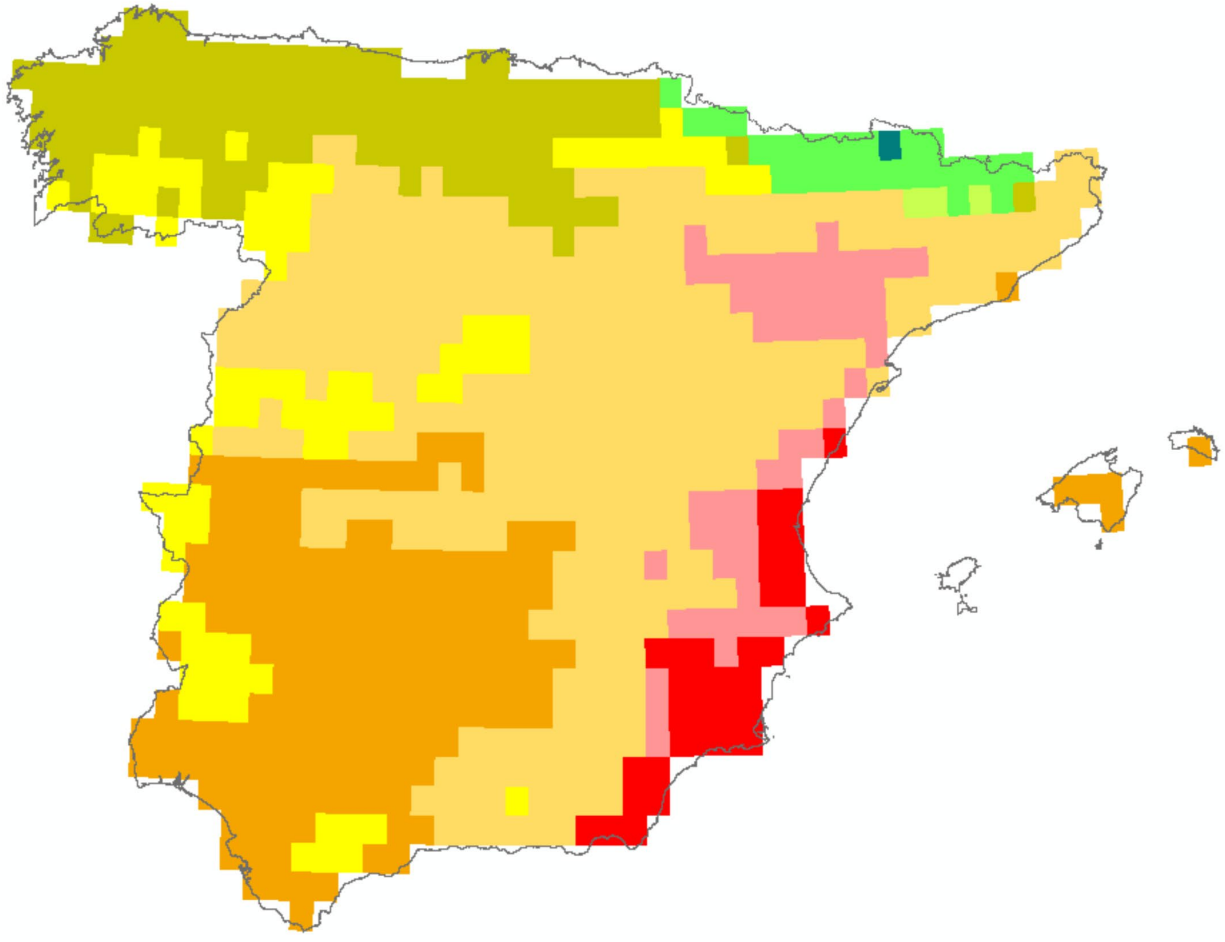
Conclusions

- The warming affecting the Iberian Peninsula and the Balearic Islands is significantly affecting the rainfall regime

- **There is a clear interaction between temperatures (especially maximum) and rainfall**

- This interaction, however, occurs in the opposite way, depending on the thresholds that mark the drought processes (<=10mm/day) of extreme rainfall (>=30mm/day)
  - ➔ Increasing temperatures (especially TX) significantly reduce the rainfall that marks the drought threshold
  - ➔ This increase in temperatures (especially TN) determines an increase in extreme rainfall.
  - ➔ **The joint result of both opposing processes (RR) is the predominance of the tendency towards drought, determining a progressive aridification of the Iberian climate. It can therefore be concluded with a high level of confidence that climate change is leading to a clear tendency towards a reduction in rainfall**

- **Prospective models, if the trends of the 1971-2022 period continue, suggest that by the middle of this century the climate will be noticeably drier and warmer, with steppe and even desert Spain dominating**



Thanks for your attention and take care!

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