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Observed trends and changes in Extreme Climate Indices over the Pyrenees (1959-2015)

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1. Introduction

CLIMPY *(Characterisation of the evolution of climate and provision of information for adaptation in the Pyrenees)* is a **transboundary project** that aims to perform a detailed analysis of recent trends in temperature, precipitation and snow cover in the Pyrenees, and their future projection. As a result, **changes** in the frequency, intensity, spatial extent, duration and timing **of weather and climate extremes due to climate change** are among the more relevant objectives.

This project (EFA081/15) is under the umbrella of the **Pyrenees Climate Change Observatory** (OPCC-CTP), and it has a 65% funding by the European Regional Development Fund (FEDER) through the Interreg Programme V-A Spain-France-Andorra (POCTEFA 2014-2020). More information: https://www.opcc-ctp.org/en/climpy.

2. Methodology

Present study consists in the calculation of **29 extreme climate indices** (18 indices related to air temperature and 11 indices related to precipitation), proposed by the Expert Team on Climate Change Detection and Indices (ETCCDI, WMO), all over the Pyrenees and encompassing the period from mid-twentieth century up to 2015. These indices are based on daily maximum temperature (TX), minimum temperature (TN) and precipitation (PPT) series, and results are showed for the common period 1959-2015.

These temperature and precipitation series were selected after a strict **quality control and homogenisation analysis** in order to remove artificial shifts and trends (changes in location of meteorological station, changes in instrumentation, etc.) that could mask the climatic signal. The homogenisation analysis has been performed using version 4 of **ACMANT software**, provided by Peter Domonkos (ACMANT software developer).

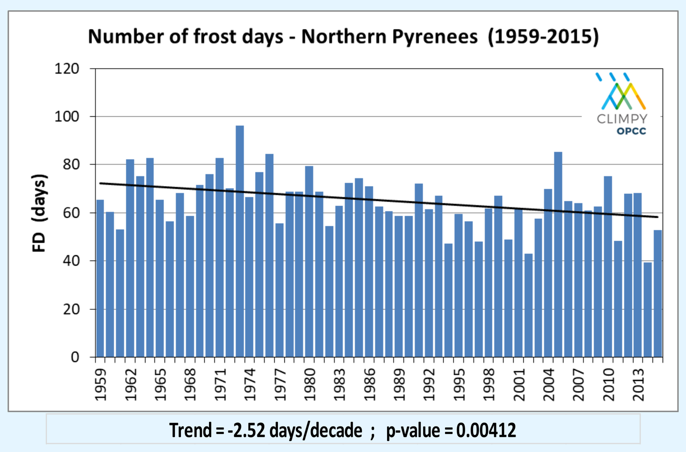
Extreme climate indices related to air temperature have been calculated at 61 locations in the Pyrenees, and those related to precipitation at 119 locations. Altitudes of these locations range from sea level up to 2,880 m asl (Pic du Midi – Observatoire). The study has been conducted with two perspectives: the **temporal evolution** of the indices and the **spatial distribution** over the Pyrenees. Moreover, a subset of the best quality series was selected to monitor the state of the climate at the Pyrenees: 12 for TX and TN (6 in Northern Pyrenees and 6 in Southern Pyrenees) and 26 for PPT (13 at each side of the mountain range). These series are representative of the whole mountain range, with different altitudes and well distributed along the massif, and their continuity in the future is assured by different National Weather Services.

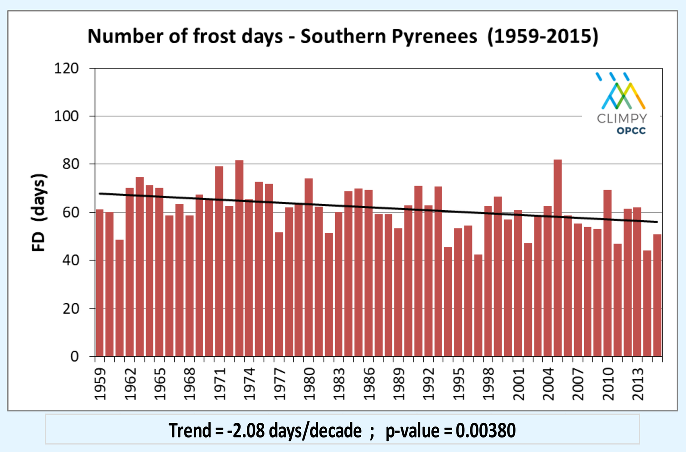
3. Results

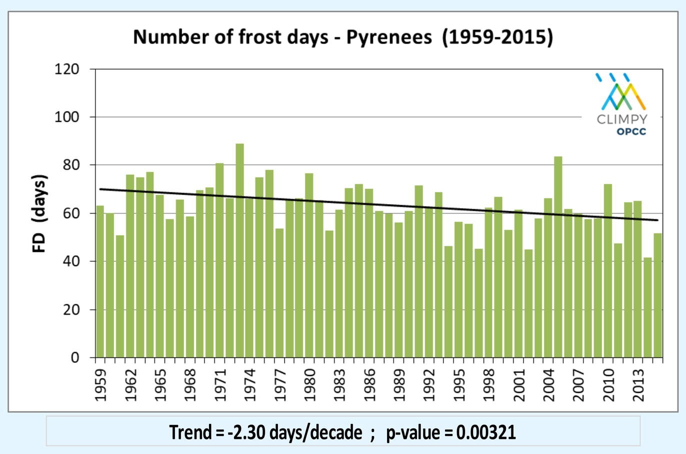
Indicator	Name	Definition	Unit	Northern Pyrenees		Southern Pyrenees		Pyrenees	
				trend (unit/decade)	Statistically significant?	trend (unit/decade)	Statistically significant?	trend (unit/decade)	Statistically significant?
FD	Number of frost days	Annual count of days when TN < 0 °C	Days	-2.52	yes	-2.08	yes	-2.30	yes
SU	Number of summer days	Annual count of days when TX > 25 °C	Days	4.35	yes	3.79	yes	4.07	yes
ID	Number of icing days	Annual count of days when TX < 0 °C	Days	-0.15	no	-0.55	yes	-0.35	no
TR	Number of tropical nights	Annual count of days when TN > 20 °C	Days	0.87	yes	0.46	yes	0.67	yes
GSL	Growing season length	Annual count between first span of at least 6 days with Tmean > 5 °C and first span after July 1st of 6 days with Tmean < 5 °C.	Days	2.53	no	2.80	yes	2.66	yes
TXx	Maximum value of TX	Annual maximum value of daily maximum temperature	°C	0.38	yes	0.38	yes	0.38	yes
TNx	Maximum value of TN	Annual maximum value of daily minimum temperature	°C	0.30	yes	0.25	yes	0.28	yes
TXn	Minimum value of TX	Annual minimum value of daily maximum temperature	°C	0.03	no	0.15	no	0.09	no
TNn	Minimum value of TN	Annual minimum value of daily minimum temperature	°C	0.24	no	0.15	no	0.19	no
TN10p	Cold nights	Percentage of days when TN < 10th percentile for the base period	%	-1.04	yes	-1.25	yes	-1.14	yes
TX10p	Cold days	Percentage of days when TX < 10th percentile for the base period	%	-1.05	yes	-1.30	yes	-1.17	yes
TN90p	Warm nights	Percentage of days when TN > 90th percentile for the base period	%	1.25	yes	1.11	yes	1.18	yes
TX90p	Warm days	Percentage of days when TX > 90th percentile for the base period	%	1.19	yes	1.39	yes	1.29	yes
WSDI	Warm spell duration index	Annual count of days with at least 6 consecutive days when TX > 90th percentile for the base period	Days	0.28	no	0.72	yes	0.50	yes
CSDI	Cold spell duration index	Annual count of days with at least 6 consecutive days when TN > 10th percentile for the base period	Days	-0.37	no	-0.96	yes	-0.67	yes
DTR	Daily temperature range	Annual mean difference between TX and TN	°C	0.08	yes	0.09	yes	0.09	yes
TMAXmean	Mean of TX	Annual mean value of daily maximum temperature	°C	0.28	yes	0.28	yes	0.28	yes
TMINmean	Mean of TN	Annual mean value of daily minimum temperature	°C	0.19	yes	0.19	yes	0.19	yes

Indicator	Name	Definition	Unit	Northern Pyrenees		Southern Pyrenees		Pyrenees	
				trend (unit/decade)	Statistically significant?	trend (unit/decade)	Statistically significant?	trend (unit/decade)	Statistically significant?
RX1day	Maximum 1-day precipitation	Annual maximum value of 1-day precipitation	mm	1.30	no	-2.16	yes	-0.43	no
RX5day	Maximum consecutive 5-day precipitation	Annual maximum value of consecutive 5-day precipitation	mm	-0.41	no	-4.39	yes	-2.40	no
SDII	Simple precipitation intensity index	Quotient of annual amount on wet days (R ≥ 1,0 mm) and annual number of wet days	mm/day	-0.12	no	-0.30	yes	-0.21	yes
R10	Number of days with R ≥ 10 mm	Annual count of days when R ≥ 10 mm	Days	-0.32	no	-1.16	yes	-0.74	no
R20	Number of days with R ≥ 20 mm	Annual count of days when R ≥ 20 mm	Days	-0.01	no	-0.57	yes	-0.29	no
R50	Number of days with R ≥ 50 mm	Annual count of days when R ≥ 50 mm	Days	0.02	no	-0.15	yes	-0.07	no
CDD	Maximum length of dry spell	Annual maximum number of consecutive days with R < 1,0 mm	Days	-0.80	yes	0.40	no	-0.20	no
CWD	Maximum length of wet spell	Annual maximum number of consecutive days with R ≥ 1,0 mm	Days	0.13	no	-0.09	no	0.02	no
R95p	Precipitation in very wet days	Annual total precipitation considering days with R > 95th percentile for the base period	mm	3.00	no	-17.10	yes	-7.05	no
R99p	Precipitation in extremely wet days	Annual total precipitation considering days with R > 99th percentile for the base period	mm	3.70	no	-6.53	yes	-1.41	no
PRCPTOT	Precipitation in wet days	Annual total precipitation in days with R ≥ 1,0 mm	mm	-7.04	no	-36.46	yes	-21.75	no

Results for 18 extreme climate indices related to temperature (left of this text) and 11 related to precipitation (above this text). For each index, it is shown: indicator, name, definition, unit and value of trend for the period 1959-2015 in Northern and Southern Pyrenees and the mean value for the whole mountain range, taking into account the subset of the best quality series mentioned in the methodology. The statistical significance is calculated by Mann-Kendall test using a confidence level of 95% (p-value < 0.05).

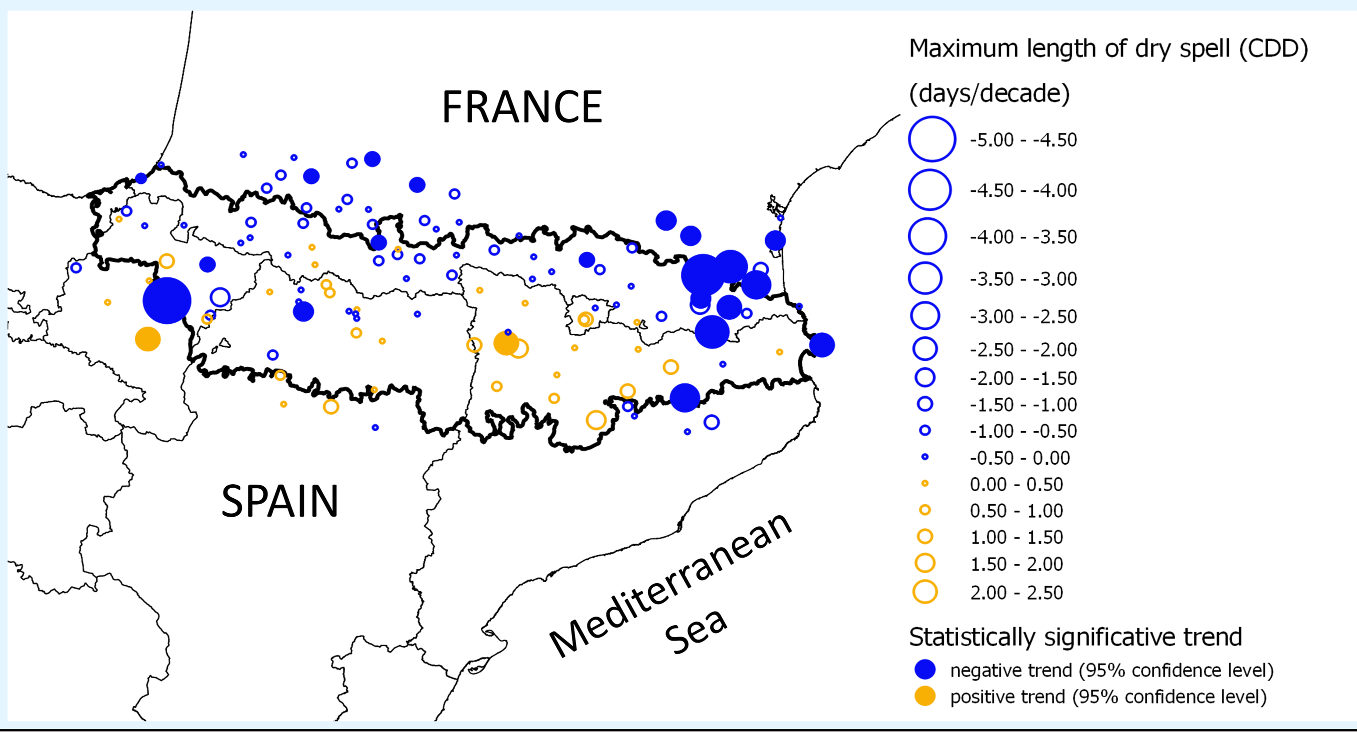






Temporal evolution of "Number of frost days (FD)" for the period 1959-2015 in Northern Pyrenees (top left), Southern Pyrenees (top right) and the whole Pyrenees (left), showing the linear regression (black line), the trend and p-value.

Map on the right. Spatial distribution of "Maximum length of dry spell (CDD)" trend over the Pyrenees for the period 1959-2015. Negative values (blue) predominate in Northern Pyrenees and positive values (orange) predominate in Southern Pyrenees. On the other hand, the greatest negative values are obtained at the Eastern Pyrenees, area with a clear Mediterranean influence.



4. Conclusions

- ✓ It is critical in a climate change analysis to obtain long-time quality controlled and homogeneous series, so it can be assured that any observed change is due to the evolution of climate, and not to "external and non-climatic" behaviours.
- ✓ The value of trend for indices related to temperature shows a much greater statistical significance than for indices related to precipitation.
- ✓ There are 3 indices with a negative (decrease) and statistically significant trend in the Pyrenees: "Number of frost days", "Cold nights" and "Cold days". On the other hand, there are 9 indices with a positive (increase) and statistically significant trend detected over the whole mountain range: "Number of summer days", "Number of tropical nights", "Maximum value of TX", "Maximum value of TN", "Warm nights", "Warm days", "Daily temperature range", "Mean of TX" and "Mean of TN". These results reinforce the idea of an increase of temperature in the Pyrenees during, at least, the last 70 years.
- ✓ The "Simple precipitation intensity index (SDII)" is the only one that presents a statistically significant trend for the whole Pyrenees (a negative (decrease) trend), but it is not statistically significant for the Northern Pyrenees. Indexes related to precipitation present trends of different sign and statistical significance depending on the side of the Pyrenees, with a predominance of statistically significant trends in the Southern Pyrenees (all of them indicating a decrease in precipitation).
- ✓ About the spatial distribution of the value and statistical significance of the trend of calculated indices, there are not only differences between Northern and Southern Pyrenees, but also between Eastern (Mediterranean influence) and Western (Atlantic influence) Pyrenees.

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