# The process of creating the new Climate Atlas of Catalonia (1991-2020)

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2. Climate series: selection, quality control and homogenization
3. Interpolation methods and GIS
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# 1. Backgound and motivation

- Climate is a changing reality, both in space and in time.

- Climate change has introduced more variability, more rapid changes and more uncertainty when we define the "normal" climate of a region.

- We need up to date, high-quality reference data to correctly classify a period as very abnormal or not: CLIMATE NORMALS (WMO) that become CLIMATE ATLASES when the result are shown as regular and georeferenced points.

# 2. Climate series

The main source of data for the generation of climate normals, which will later feed the atlas, are the climate series. Therefore it is decisive to have high-quality, homogeneous climate series, with a wide temporal coverage, continuous and that effectively represent the climate variability of Catalonia.

## What we worked with?

Daily series of maximum (TX), minimum (TN) and mean (TM) termperature, and daily series of precipitation (P).
Then transformed into monthly, seasonal and yearly averages

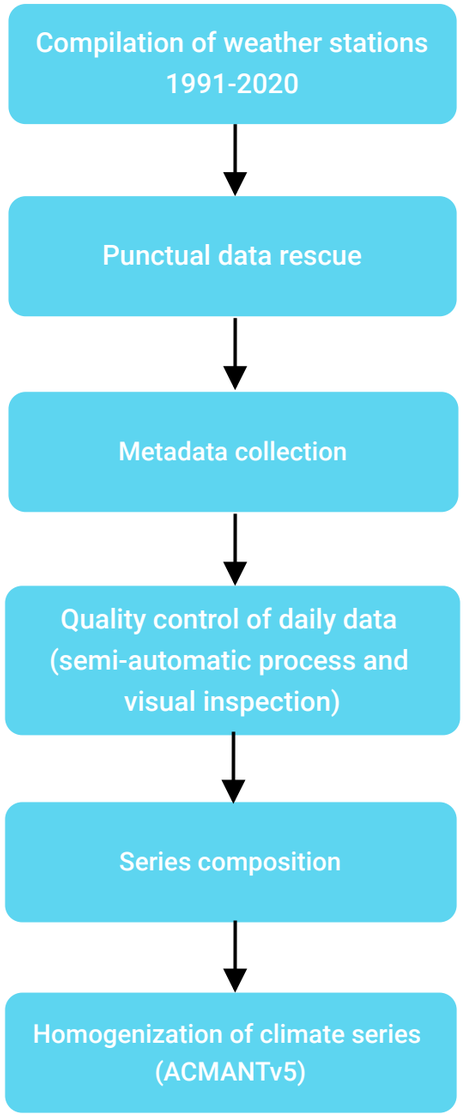
## What period we analyzed?

The thirty-year period 1991-2020

## Which analysis we applied?

Quality control of daily data and homogeneïty analysis

## Work flow

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# 2. Climate series: description of data

## Main strenghts:

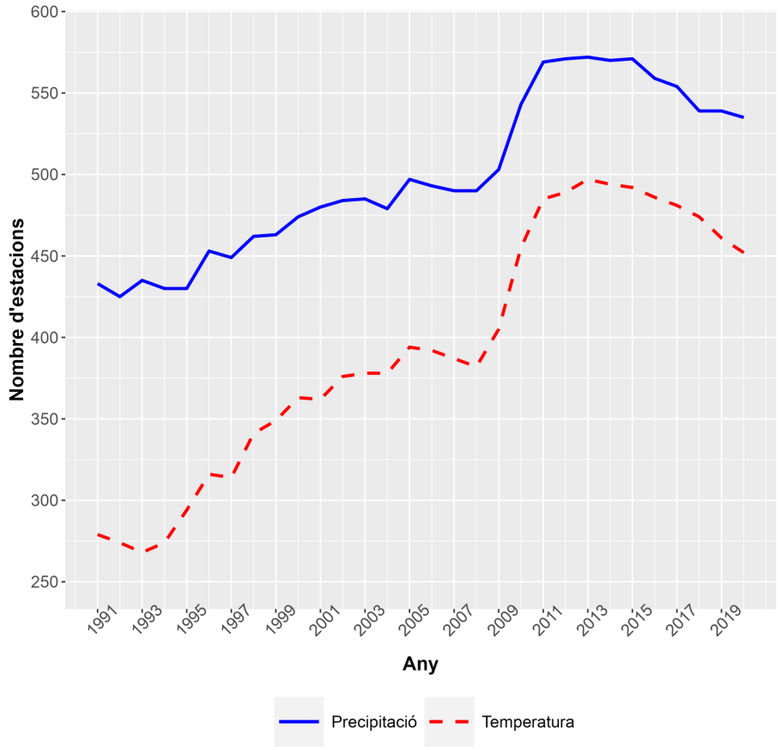
**Use of all available series from official networks: SMC, ACA and AEMET**

**Use of contour series from southern France, Andorra, Aragon, and Valentia Country**

**For the first time, remarcable data from specific sites: mountain regions (Pyrenees)**

| | Total WS available | WS available for each network | % of available data (1991-2020) |
|---|---|---|---|
| TX | *664* | *393 AEMET/XOM*<br>*228 XEMA*<br>*43 Contour* | *42,8 %*<br>*56,4 %*<br>*74,1 %* |
| TN | *668* | *396 AEMET/XOM*<br>*228 XEMA*<br>*44 Contour* | *42,6 %*<br>*56,4 %*<br>*72,5 %* |
| P | *931* | *619 AEMET/XOM*<br>*230 XEMA*<br>*82 Contour* | *46,3 %*<br>*57,3 %*<br>*68,1 %* |

Main characteristics of the initial database. Period 1991-2020 (TX, Maximum temperature), TN (Minimum temperature) and P (Precipitation)

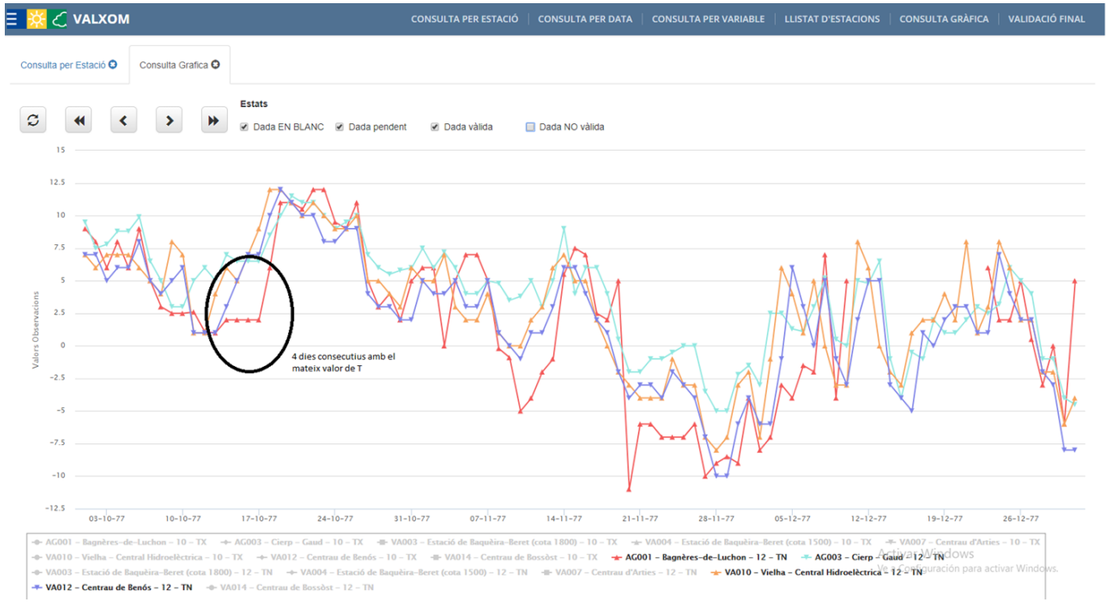



Temporal evolution of the total number of meteorological stations used in this study, within the period 1991-2020 and including contour stations

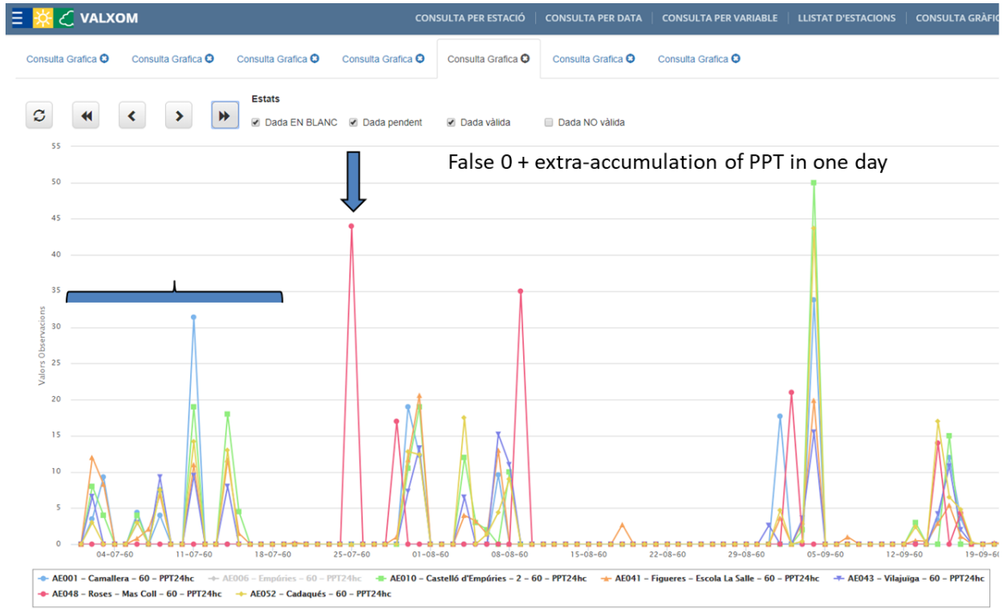
# 2. Climate series: quality control

Quality Control (CQ) is a process that allows to detect and label suspicious or potentially erroneous values in a series of data. A two-step process is applied:

a) Semi-automatic and absolute tests: tolerance, consistency, range and constrain checks (EXTRAQC, Aguilar and Prohom, 2010).
b) Visual inspection of data: allows detecting anomalous behavior of a series in context with contemporaneous and nearby series.




Flat-line error: 4 consecutive days with the same temperature




False 0 + extra-accumulation of P in one day

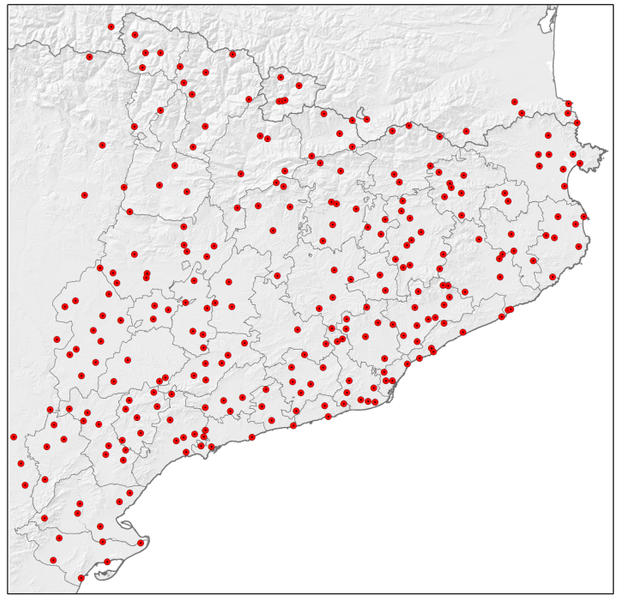
# 2. Climate series: series composition and homogenization

For the correct climatic characterization of a place, long-time series, and with few gaps are needed. As this is infrequent, it is necessary to build them from the grouping or sum of segments of more series short, and geographically and climatically similar: **blending or composition** of series. The criteria are:

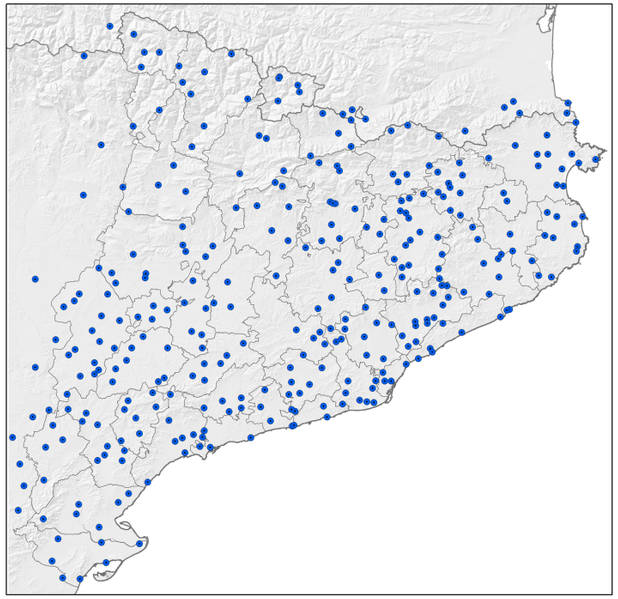
- Identification of the "mother" or candidate series: a single weather station, with sufficient temporal coverage (>10 years), with no gaps and, especially, that they are "living" series.
- Identification of the neighboring series: (1) within a radius of 10 km of distance, and (2) with a maximum difference in height of 50 m.

**266 climatic series of TX and TN, and 323 series of PPT**

Air Temperature



Precipitation



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# 2. Climate series: series composition and homogenization

Every climate series may undergo during its operational life several changes or modifications in the conditions under which the data are taken (changes in location, instrumentation, environment, observers...). Homogeneity analysis methods aims is to minimize the impact of breaks or points of inhomogeneity, through their identification and subsequent correction (Aguilar et al., 2003).

The selected daily series of TX, TN and PPT have been subjected to the **ACMANTv5 homogeneity analysis**, identified as one of the best methods in several multitest projects (Guijarro et al., 2017; Domonkos et al., 2021).

| | TN | TX | P |
|---|---|---|---|
| Number of series | 266 | 266 | 323 |
| **Average number of break points per series** | 2,4 | 2,7 | 0,7 |
| Maximum number of break points per series identified | 8 | 7 | 4 |
| **Number of series without break points** | 78 (29%) | 74 (28%) | 176 (54%) |

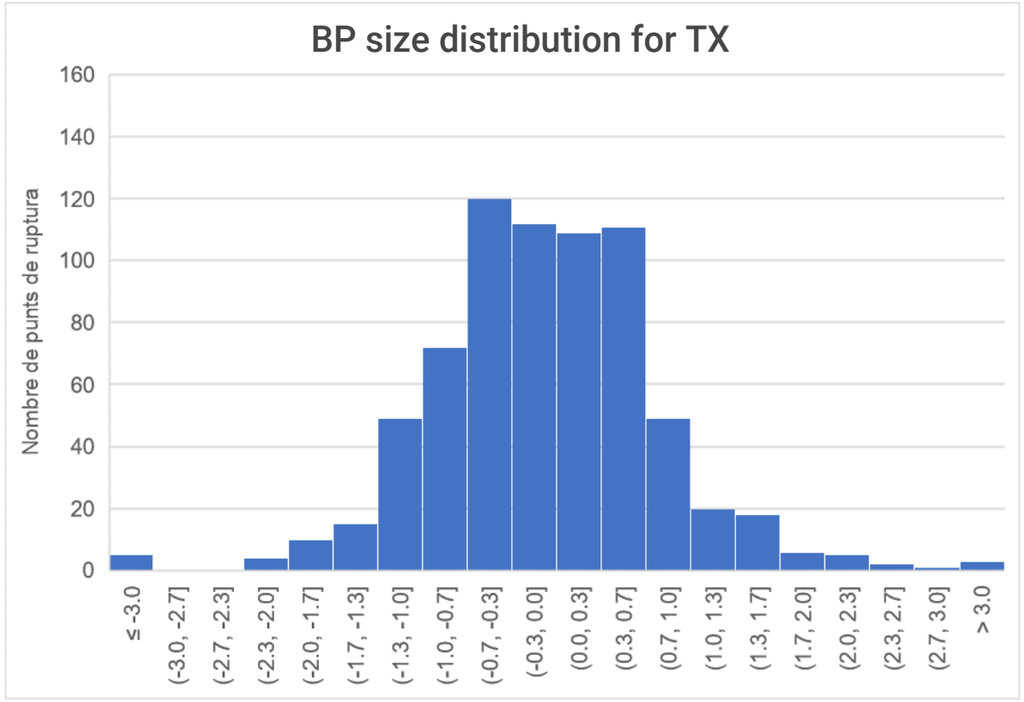
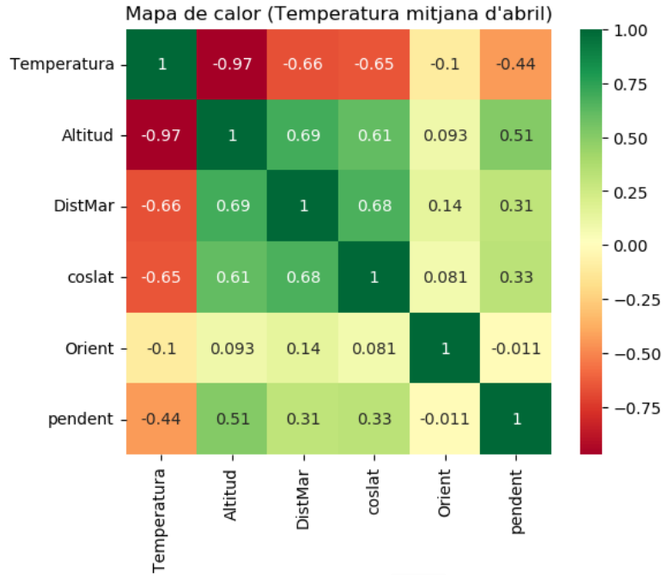



Figure 7. Histograms showing the distribution of the proposed adjustments to the TX series

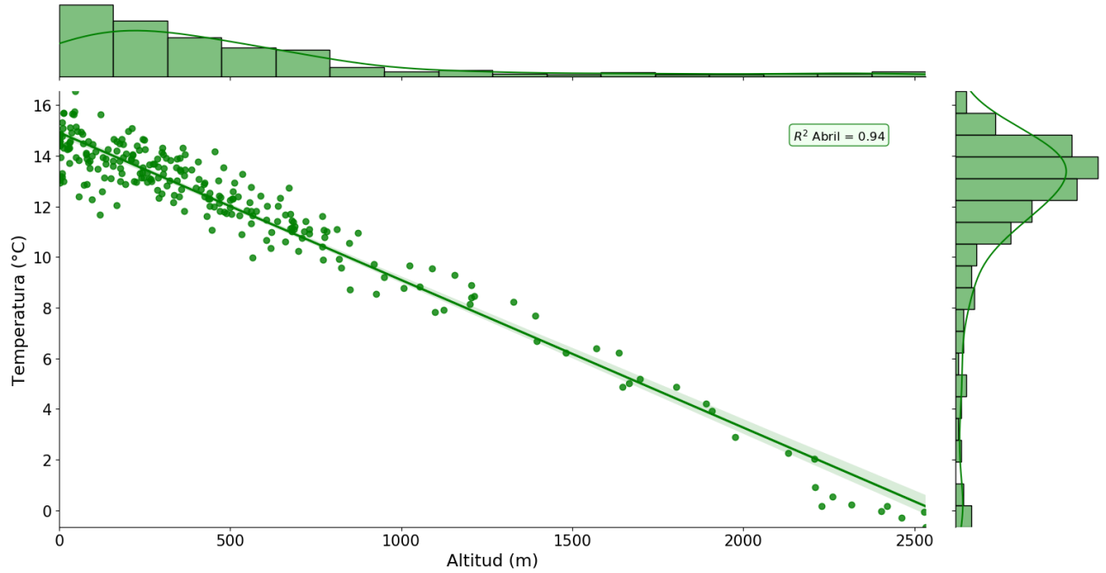
# 3. Interpolation methods and GIS: Temperature

For the generation of the temperature maps, the method mainly used has been **multiple linear regression**, combined with **kriging of the residuals**. This method is based on the relationship between the variable you want to interpolate (dependent variable Y) and other variables (called independent X1, X2,...), and the knowledge you have about these latter in a more continuous way in space.

The independent variables that have been considered are those that can have a greater impact on temperature variations: **altitude, distance to the sea, latitude, orientation and slope.**



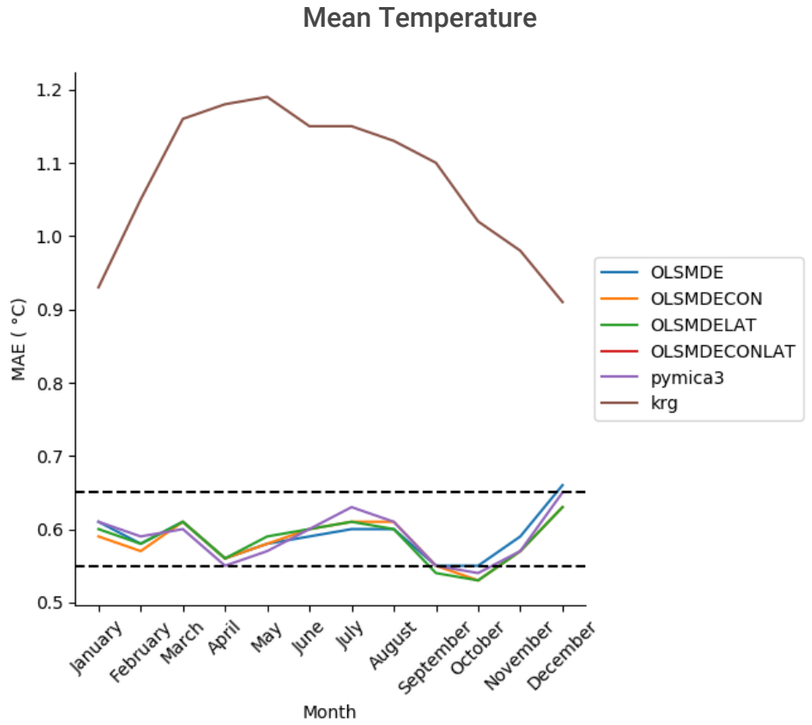

Exploratory analysis of the data. Example for April.



# 3. Interpolation methods and GIS: Validation of T

In order to evaluate the best method to perform the interpolation, a cross-validation of 10 iterations has been carried out for each of them. This method consists of dividing the data sample into two subsets, one with the data with which the interpolation is done (called training) and the other with which the results given by the model are compared with measured values (called test). The statistic used to evaluate which is the best method has been Mean Absolute Error (MAE).

Several methods were tested (Ordinary Least Squares)
- Atltitude (OLSMDE)
- Altitude and distance to the sea  (OLSMDECON)
- Altitude and latitude cosinus (OLSMDELAT)
- Altitude and all the others (OLSDETOTES)
- The cluster method developed at the SMC with three clusters (pymica3)
- krigging metthod (kgr)




Monthly Mean Absolute Error (MAE) values of the TM, and for the different methods tested.

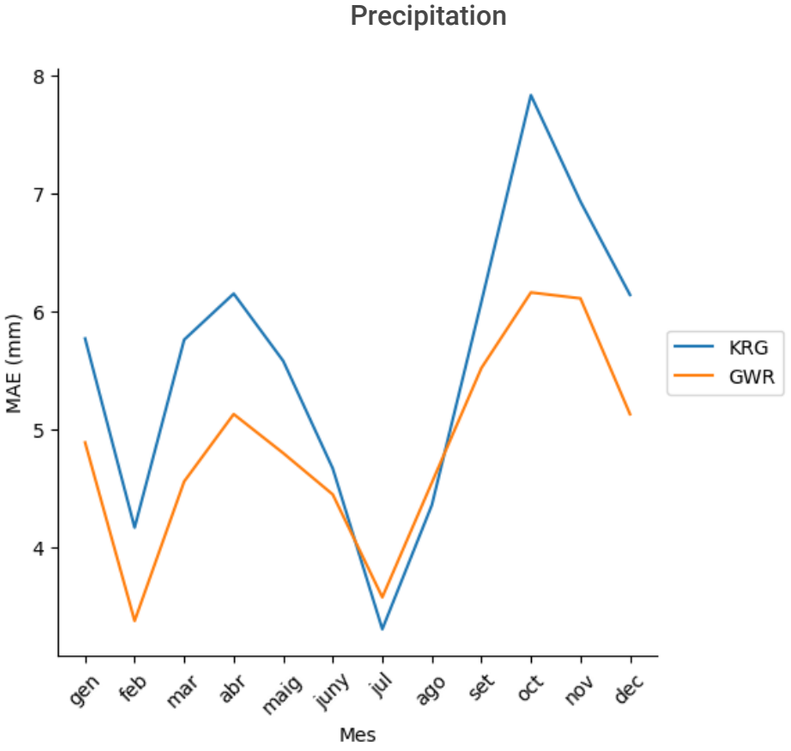
For TX, all The MAE results provide a more scattered fork, with the best ones ranging from 0.51 to 0.69. And for TN, the MAE values are higher, and on average being slightly below 1.0.

# 3. Interpolation methods and GIS: Validation of P

Precipitation is a more complicated variable to interpolate than temperature. Although it has a certain dependence on altitude, this is not as obvious, and it has a much more pronounced spatial variability. Two methods has been tested: kriging and geographically weighted regression (GWR).

| Method | JAN | FEB | MAR | APR | MAI | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| GWR | **4,89** | **3,38** | **4,56** | **5,13** | **4,80** | **4,45** | 3,58 | 4,55 | **5,52** | **6,16** | **6,11** | **5,13** |
| KRG | 5,77 | 4,17 | 5,76 | 6,15 | 5,58 | 4,67 | **3,31** | **4,36** | 6,08 | 7,83 | 6,93 | 6,14 |

Validation results for precipitation (P). The values indicate the MAE calculated for all cases, and monthly, between the series value and the interpolated value at that same point for the two methodologies. In bold, the lowest MAE values in each case.



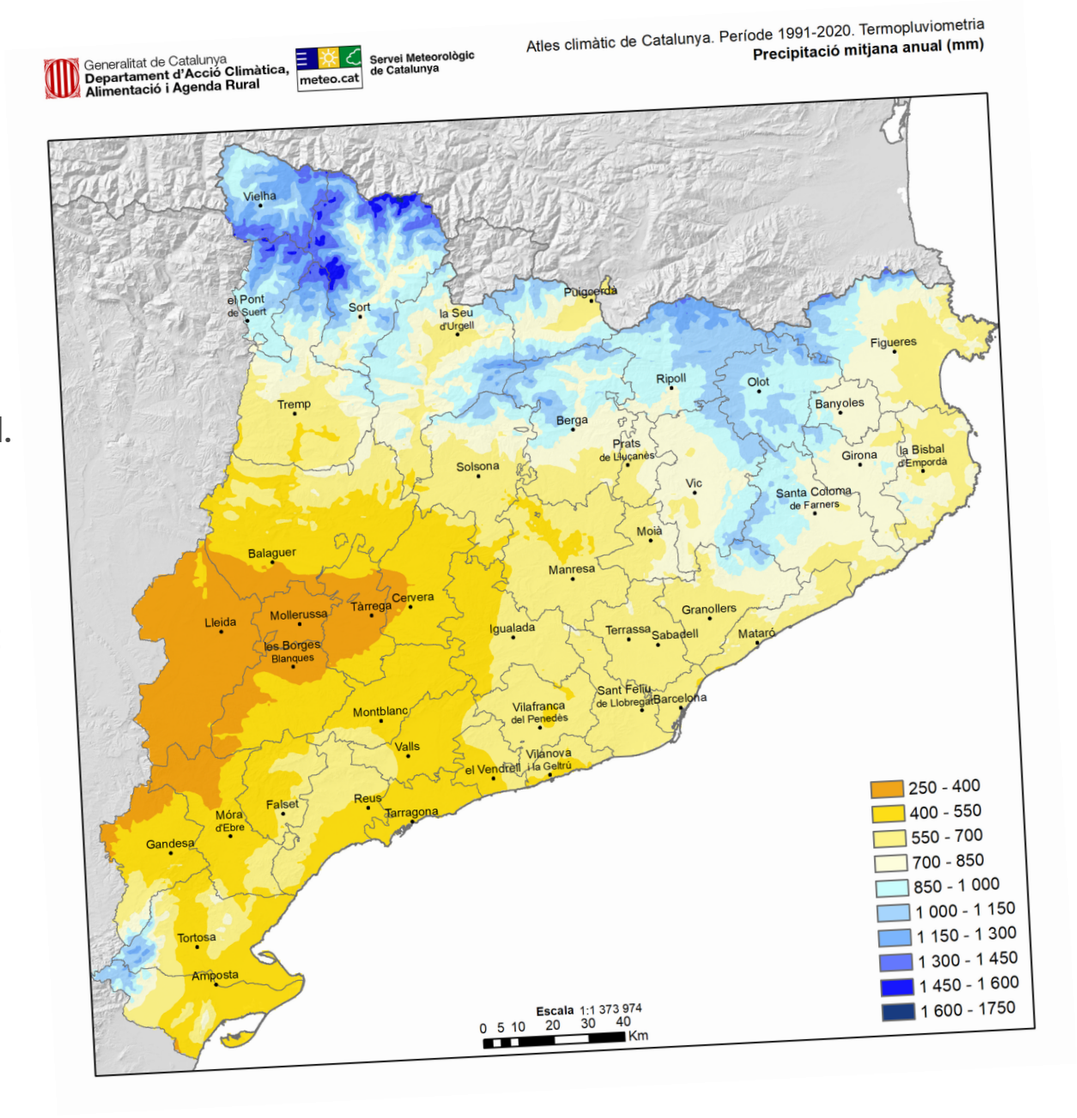

Monthly Mean Absolute Error (MAE) values of the P, and for the two methods tested.

# 4. Results

69 digital maps have been obtained:

- 17 average temperature maps: 12 monthly, 4 seasonal, and 1 annual
- 17 maps of average maximum temperature: 12 monthly, 4 seasonal and 1 annual.
- 17 average minimum temperature maps: 12 monthly, 4 seasonal and 1 annual.
- 18 precipitation maps: 12 monthly, 4 seasonal, 1 annual and 1 rainfall regime.

The rasters can be viewed and downloaded at the Corporate GIS of the Generalitat de Catalunya: HIPERPAMA (https://sig.gencat.cat/).




Annual mean precipitation (1991-2020)

# 4. Results: climatic interpretation

The main climatic characteristics that are appreciated are:

## Altitude

The main factor that explains the temperature distribution in Catalonia is altitude, and to lesser extent latitude.

## Warming

The footprint of climate change is beginning to become evident, if the results of the current atlas are compared with 1961-1990. Especially the heat islands of the cities of Barcelona and Tarragona are more evident.

## Rainfall variability

The average annual precipitation map shows extreme values of 1.563 mm in Espot (NW Pyrenees), and 324 mm in the Riba-roja marsh (SW corner), which means that the average annual precipitation from the driest place to the rainiest is almost a factor of five.

## Rainfall reduction

A slight expansion of the semi-arid surface (< 400 mm annual P) is detected, as well as some average lower than 350 mm, which in the 1961-1990 period was unknown. In summer, rainfall totals are more reduced in the more recent period.

# 5. Conclusions

- One of the most needed climate services is to have georeferenced and up-to-date and high-quality **climate normals** (1991-2020).
- The new version of the climate atlas of Catalonia, updates the knowledge of the climate in this **complex region**, where climate change is introducing very rapid changes.
- The new atlas introduces appreciable **improvements** compared to previous editions: an increase in the number of series (with more and better information on mountain locations), a deeper daily quality control, and the application of a homogeneity analysis.
- The generation of **digital cartography** has been tested by comparing different methods, minimizing bias as much as possible.
- Thanks to this product, some changes in Catalonia's climate related to **global warming** are already noticeable.
- NEXT, the generation of a new product: the Climate Atlas based on **indices of precipitation and temperature extremes**.


MANY THANKS FOR YOUR ATTENTION !!