GIS and Geovisualization Technologies Applied to Rainfall Spatial Patterns over the Iberian Peninsula using the Global Climate Monitor Web Viewer

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Abstract: Web-based GIS and geovisualization are increasingly expanding but still few examples exist with regard to the diffusion of climatic data. The Global Climate Monitor (GCM) (http://www.globalclimatemonitor.org) created by the Climate Research Group of the Department of Physical Geography of the University of Seville was used to characterize the spatial distribution of precipitation in the Iberian Peninsula. The concern about the high spatial-temporal variability of precipitation in Mediterranean environments is accentuated in the Iberian Peninsula by its physiographic characteristics. However, despite its importance in water resources management it has been scarcely addressed from a spatial perspective. Precipitation is characterized by positive asymmetric frequency distributions so conventional statistical measures lose representativeness. For this reason, a battery of robust and non-robust statistics of little used in the characterization of precipitation has been calculated and evaluated quantitatively. The results show important differences that might have significant consequences in the estimation and management of water resources. The realization of this study has been carried out using Open Source technologies and has implied the design and management of a spatial database. The results are mapped through a GIS and are incorporated into a web geovisor (https://qgiscloud.com/Juan_Antonio_Geo/expo) in order to facilitate access to them.

1 INTRODUCTION

Current climate research benefits from the existence of large and global climate databases are produced by various international organizations. The common denominator is the availability and accessibility under the 'open data' paradigm. Very often, these new datasets cover the entire earth at a more regular spatial distribution (normally gridded), with a longer and more homogeneous time span and are built under more-robust procedures.

Many varied sources of information are at the basis of global datasets that are accessible on the reference web portals of the subject. It is important to note the wide availability of these global datasets and their quality. In most cases these datasets are distributed under *open-database licenses.* This distribution has favoured the increasingly widespread use of global data by scientists, and the emergence of countless references from studies based on these data (Folland *et al.*, 2001; Jones & Moberg, 2003; New, Hulme & Jones, 2000, etc.). However, the complexity of the very technical formats of distribution (netCDF or huge plain text files with millions of records) limits these datasets to a very small number of users, almost exclusively scientists. For non-expert users, it is important to develop and offer new environmental tools in an open and transparent manner because stakeholders, users, policy makers, scientists and regulators prefer it and demand it (Carslaw and Ropkins, 2012, Jones *et al*., 2014).

These open data and open knowledge paradigm also referred by some as 'the fourth paradigm' (Edwards *et al.*, 2011) responds, in relation to climate data, to the double challenge that climate science is currently facing; on the one hand, it has to guarantee the availability of data to permit more exploration and research and, secondly, it has to reach citizens. This leads directly to the use of Open Source technologies supported by an extensive worldwide community of users that provide tested evidence in very stressful applications. Such a large

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and proven implementation in results and experience has also motivated the use of these open technologies in our research. Particularly, the Climate Research Group of the University of Seville has a remarkable experience with PostgreSQL/PostGIS being the core of the data management and research tools.

Concerning the geovisualization, it is worth noting that it is a crucial element in applications for decision support; web services are particularly appropriate for this (Vitolo *et al.*, 2015). Also, web-mapping has become an effective tool for public access to information in general and to climate knowledge and climate monitoring in particular, specially considering the ongoing advances in web GIS and geovisualization technologies.

Despite the fact that there are some very specialized geoviewers to access and download the data (for example, the *Global Climate Station Summary* by *NCDC-NOAA)* in most cases, these viewers are very general and/or offer poor geo-displays (European Climate Assesment). The Global Climate Monitor (GCM) system belongs to this field, more precisely to the field of researching possibilities of dissemination of monitored climatic information through the use of geospatial web viewers. In this work, we focus on showing the possibilities of the GCM in climatic research by analysing the spatial distribution of precipitation in the Iberian Peninsula located in southern Europe.

Understanding the spatial distribution of rainfall is an important element for the management of natural resources in the Iberian Peninsula. With the exception of the northern mountain range, the Iberian Peninsula is included in the Mediterranean climate domain (De Castro *et al.,* 2005; Martin-Vide, 2011b) showing the inter-annual irregularity characteristic of the this type of climate (García-Barrón *et al*., 2011). Its main characteristics are marked fluctuations from rainy years to periods of drought together with an irregular intra-annual regime with minimum values of rainfall during the summer months (García-Barrón *et al*., 2013). Due to these characteristics decision-making in water management requires the delivery of accurate scientific information that provides objective criteria for the technical decisions in the water planning process directly affecting the environment and society (Krysanova *et al.,* 2010; Cabello *et al.*, 2015).

Furthermore, in order to advance the knowledge of rainfall regime in the Iberian Peninsula, researchers have related the annual, seasonal or monthly volume to synoptic situations mainly linked to patterns of atmospheric circulation and weather types (Muñoz-Diaz and Rodrigo, 2006; López-Bustins *et al.*, 2008; Casado *et al.,* 2010; Hidalgo-Muñoz *et al.*, 2011; Cortesi *et al.*, 2014; Ríos-Cornejo *et al*., 2015). Nevertheless, there are few studies dedicated to the analysis of the spatial variation of the rainfall for the Iberian Peninsula. The present study introduces a complementary aspect calculating a set of robust and non-robust statistics for the characterization of precipitation. Robust statistical measures are not commonly used when characterizing neither precipitation nor for the estimation of water resources in environmental management and planning despite the positive skewness of the frequency distributions. The differences between both types of measurements have also been obtained quantitatively in order to evaluate the possible bias when estimating precipitation volumes.

This work has involved the implementation of a spatial database of high volume that would allow the analysis and processing of data. Results can be viewed using GIS technologies and this information is disseminated and made accessible to final building up a new geoviewer (https://qgiscloud.com/Juan_Antonio_Geo/expo).

2 STUDY AREA AND DATA

The Iberian Peninsula is located in the southwestern end of Europe, next to North Africa, and, thereby and surrounded by the Mediterranean Sea to the East and by the Atlantic Ocean to the West. Due to transition situation between the middle latitudes and the subtropical ones, and to its complex orography, its climatic characteristics and types are very diverse due to the complex patterns of spatio-temporal variability of most climatic variables (Garcia-Barrón *et al*., 2017).

The GCM currently displayed corresponds to the CRU TS3.21 version of the Climate Research Unit (University of East Anglia) database, a product that provides data at a spatial resolution of half a degree in latitude and longitude, spanning from January 1901 to December 2012 on a monthly basis. From January 2013, the datasets that feed the system are the GHCN-CAMS temperature dataset and the GPCC First Guess precipitation dataset (Global Precipitation Climatology Centre) Deutscher Wetterdienst in Germany.

The data that are currently offered in the display come from three main datasets: the *CRU TS3.21*, the *GHCN-CAMS*, and the *GPCC first guess* monthly product. The basic features of these products are shown in table 1.

Table 1: Basic features of the datasets included in the Global Climate Monitor.

Dataset	CRU TS3.21	GHCN-CAMS	GPCC first guess
Spatial resolution	0.5°x0.5° lat by lon	0.5°x0.5° lat by lon	1°x1° lat by lon
Time span	January 1901 to December 2012	January 1948 to present expired month	August 2004 to present expired month
Time scale	Monthly	Monthly	Monthly
Spatial Reference System	WGS84	WGS84	WGS84
Format	netCDF	Grib	netCDF
Variables	Total precipitation amount Average mean temperature	Average mean temperature	Total precipitation amount

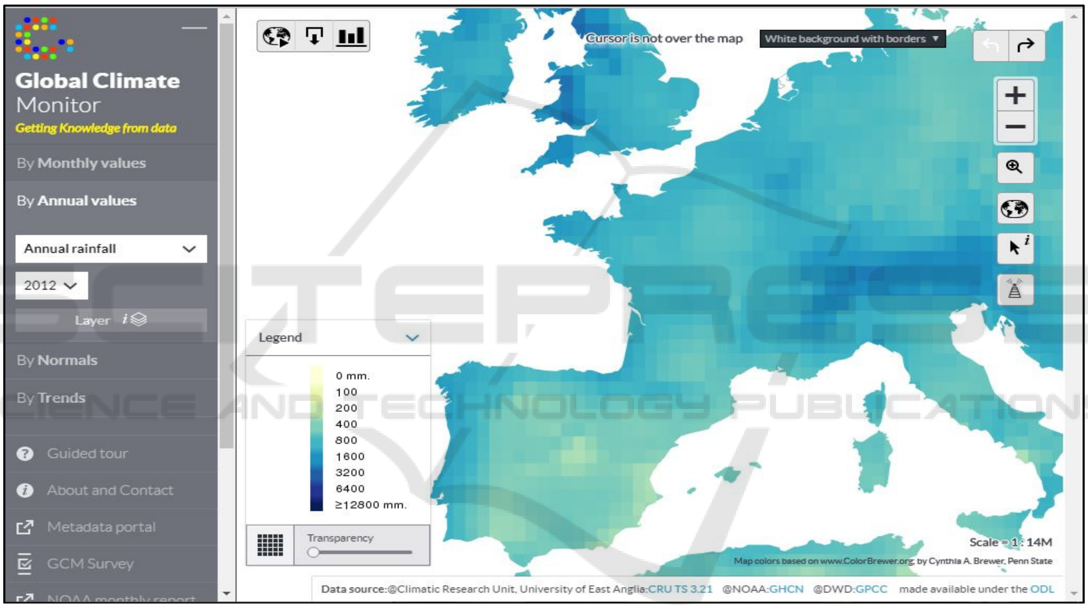

Figure 1: Global Climate Monitor view.

The CRU TS3.21 dataset is a high-resolution grid product that can be obtained through the British Atmospheric Data Centre website or through the Climatic Research Unit website. It has been subjected to various quality controls and homogenization processes (Mitchell & Jones, 2005). It is important to note that this database is also offered in the data section of their website and in their global geovisualization service (Intergovernmental Panel on Climate Change, 2014).

Apart from this organization, CRU TS is one of the most widely used global climate databases for research purposes. The GHCN and GPCC datasets are used to update monthly data. The data used for this study are historical series of monthly precipitation from January 1901 to December 2016 that covers the entire Iberian Peninsula. Visually, they are represented in the form of a grid, in an area of 0.5°x0.5° latitude-longitude (Figure 1). Therefore, the total volume of information takes into account the total months, years and cells that compose the spatial extent. The amount of information of more than 400,000 records with spatial connection requires the use of a database management system.

Given the nature of the precipitation data grid, which is not graphically adjusted to the actual physical limits of the Iberian Peninsula, it is necessary to adapt the rainfall information to the limits of the field of study. For this purpose a vector layer containing the physical boundaries of the different territorial units that make up the study area (Spain and Portugal) was also used. The 1: 1,000,000 territorial statistical units (NUTS) of the European territory for the year 2013 data have been obtained from the European Statistical Office (Eurostat, http://ec.europa.eu/eurostat/). The Coordinate Reference System through which this information is distributed is ETRS89 (EPSG: 4258), which is an inconvenience when combining this with the rainfall data projected in WGS84 Spatial Reference System used in the GCM. Therefore, through a geoprocess of coordinate transformation both systems were squared.

The assembly of the available open-source technologies used in this study is shown in table 2. The use of spatial data server, map server, web application server and web viewers allow scientists to undertake these types of macro-projects based on the use of Big Data information.

Table 2: Open-source technologies used in this study.

Software / Application	Use
PostgreSQL / PostGIS	Spatial database management system, open source, which has been used in this work
PgAdmin	Open source administration and development platform for PostgreSQL
QGIS	Free and open source desktop GIS used for export database's results
QGIS Cloud	Free geoviewer web used for results representation and facilitating their distribution

Particularly noteworthy is the role of the spatial data server PostGIS in handling spatial and alphanumeric information and charts based on a relational system PostgreSQL. The data are natively encoded in said system providing a high performance and allowing the use of any analytical functions required; but the most importantly reason for using PostgreSQL / PostGIS is its geographic relational database that make possible to carry out geoprocessing without having to leave the processing core. This allows the regionalization of data in a quasi-automatic way for any territorial scales of interest based on SQL language.

Many tools in this field are more or less equivalent such as SciDB database that manages multidimensional cubes (especially suitable for satellite images processing) or some scientific libraries found in R or Python. Nevertheless these technologies present a different approach. While it is true that for raster spatial applications using time series data is the ideal environment, it can be argued that in terms of data structure the same effect can be obtained with a more conventional relational approach. Such is again the case of R and Python programming language that cover the same scientific needs with different technologies. In any case, a geographic relational database can also replace these technologies in many scenarios like the one presented in this work. Another advantage is that PostgreSQL / PostGIS can be directly coupled to R (http://www.joeconway.com/doc/doc.html) thus obtaining a geostatistical database and enlarging the possibilities of use and applications.

Through QGIS Cloud a web geoviewer was developed as an extension of the QGIS. The resulting maps of this study are represented in a geoviewer (https://qgiscloud.com/Juan_Antonio_Geo/expo). Open source systems fit the main aim of the Global Climate Monitor project: rapid and friendly geovisilization of global climatic dataset and indicators to experts and non-experts users instead of focusing in data analytics.

3 METHODOLOGY

The methodology followed in this work is presented in Figure 2. First, the data were downloaded from the GCM in csv format and converted into a database to be modelled. The proposed theoretical model defines the conceptual and relational organization which generates the physical database itself. The conceptual model is simple and consists of several tables: the meteorological stations table, the monthly precipitation table values and the table with the geographical limits of the Iberian Peninsula. Then, a series of queries are performed in SQL language on the monthly precipitation series of data in order to get the seasonal and annual values as well as the statistical measures calculated from them.

The added value and contribution of using GIS and geospatial databases is that both allow massive geospatial time and space analysis and geovisualization. The aim is to get a series of statistics that will help us characterize the spatial distribution of the precipitation gridded series. The analysis of variability, dispersion, maximum and minimum and frequency histograms of the precipitation series in the Iberian Peninsula determined the need of using adequate statistical measures to fulfil our goals.

This method of work by the management of a database system allows the analysis of precipitation

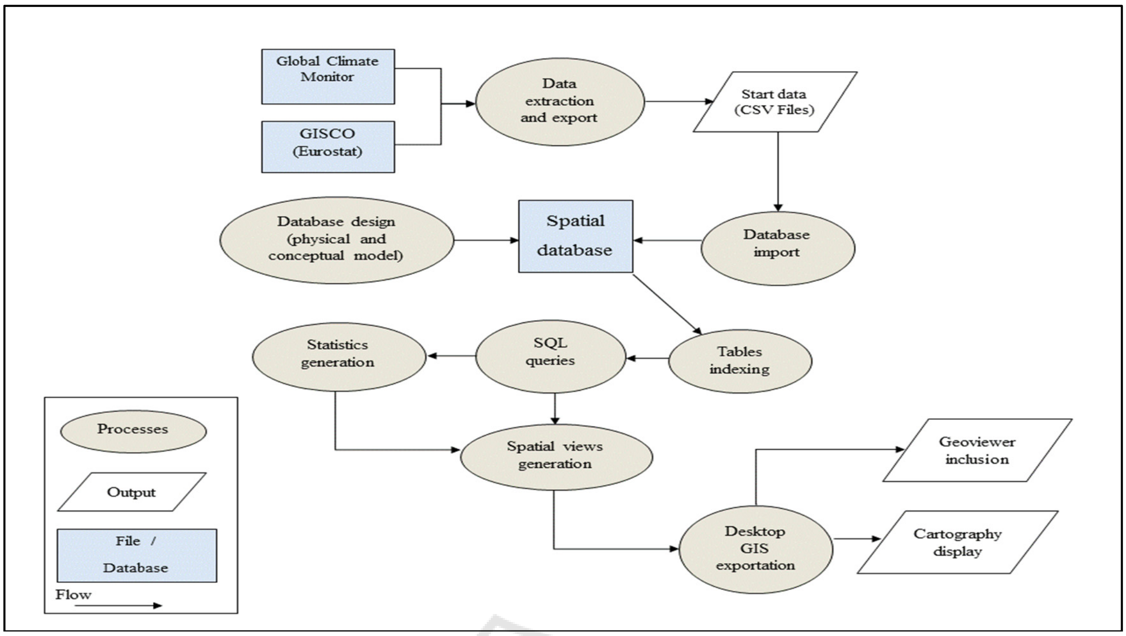

Figure 2: The methodology flow chart.

at three different levels; a joint analysis of the historical series, where all the monthly values recorded in the database are collected; seasonal analysis obtained by grouping months with a theoretically similar behaviour that allows the comparison between them; and finally intra-seasonal analysis, which gives the possibility of studying the statistically behaviour and variability of precipitation within the months of each season.

In the Mediterranean area climate variables, and particularly precipitation, present an extremely variable and irregular behaviour, so the frequency distributions tend to be asymmetrical. Typically, non-robust statistics (mean, standard deviation and variation coefficient) are commonly used in this type of climatic studies. But these measures are susceptible to extreme values that may detract their statistical representativeness. For this reason we decided to incorporate robust statistics to eliminate this effect and to be able to assess the differences between them (robust and non-robust) in both absolute and relative statistics that are shown in table 3.

It is important to note that, despite the relative simplicity of these calculations many results can be obtained due to the potential offered by the use of spatial databases.

Table 4 shows the statistical measures calculated at different time scales (annual, seasonal and monthly) for each precipitation series. The result has provided a total of 136 outcomes, which were viewed using GIS, each with their corresponding cartographies for the entire Iberian Peninsula.

Table 3: Statistical measures calculated for each series.

	Centrality statistical	Absolute statistical dispersion	Relative statistical dispersion
Not Robust	Mean ($\bar{x}$)	Standard deviation (s)	Coefficient of variation (CV)
Robust	Median (Me)	Interquartile range (IRQ)	Interquartile coefficient of variation (ICV)
Difference	($\bar{x}$ – Me)	(s – IRQ)	-

Table 4: Statistical measures calculated at different time scales.

Time scale	Measures of central tendency	Absolute measures of variation	Relative measures of variation
Annual	3	3	2
Seasonal	12	12	8
Monthly	36	36	24
Total	51	51	34

The statistics obtained for each of the cells are incorporated into the open source Geographic Information System QGIS. This is very useful when carrying out multitude of analysis processes or simply performing a cartographic representation of the results. Finally, each map outcome is included in a new web geoviewer (https://qgiscloud.com/Juan_Antonio_Geo/expo).

4 RESULTS

The management of large volumes of precipitation information through spatial-temporal databases has made possible to obtain products of relevant climatic interest related to the spatial estimation of precipitation in the context of water resources management. The main results are presented first focusing on statistical measures of central tendency and measures of variability. The comparison and quantification of non-robust and robust statistical measures spatially represented in maps by means of GIS allow the evaluation of the effect produced when incorporating non-robust statistics rarely used. Relative dispersion statistical measures are also calculated to diminish the effect of the very different amounts of rain recorded in the Iberian Peninsula.

Concerning measures of central tendency the picture obtained by calculating the mean or the median perfectly identified the three large homogeneous climatic zones traditionally described for the Iberian Peninsula. The first, called the Atlantic or humid region, corresponds to the Mesothermal climates, which extend over most of the North coast from Galician to the Pyrenees; the second, corresponding to semi-arid or sub-desert region, occupies the southeast of the peninsula around the province of Almeria; and the third is the most extensive region with Mediterranean climate that occupies the greater part of the Iberian Peninsula. The spatial division basically matches the 800-mm isohyet separating the humid zone from the Mediterranean ones and 300-mm that delimit the southeast semi-arid area.

Comparing the robust (median) to the non-robust (mean) measures it can be stated that there is a general overestimation of precipitation. The map of the difference between mean and median shows the predominance of greenish tonalities which represent mean precipitation values above medium precipitation (Figure 3c). This is a consequence of the positive symmetry of the annual precipitation distributions due to the presence of very rainy years with respect to the rest of the series. The areas where precipitation is overestimated are mainly located in the south normally characterized by low levels of precipitation.

In relation to the non-robust dispersion statistics (standard deviation) and robust (interquartile range) the most characteristic of both maps is the presence of a marked NW-SE gradient (Figure 4). Inside the Iberian Peninsula and great part of the south and southeast dispersion values are less than 150 mm linked to lower precipitation records. Therefore, where the annual totals are higher, a greater dispersion is observed in the precipitation values. Standard deviation values are markedly higher than the interquartile range except for the humid zones of the north Atlantic coast. In the map of the differences between standard deviation and interquartile range it can be seen the latter concentrating the greatest differences in the Atlantic coast. These differences indicate the heterogeneity of the precipitation values as a function of their mean and median, which shows the high irregularity in certain areas of the Iberian Peninsula. This is a surprising result since these zones are usually characterized by their pluviometric regularity.

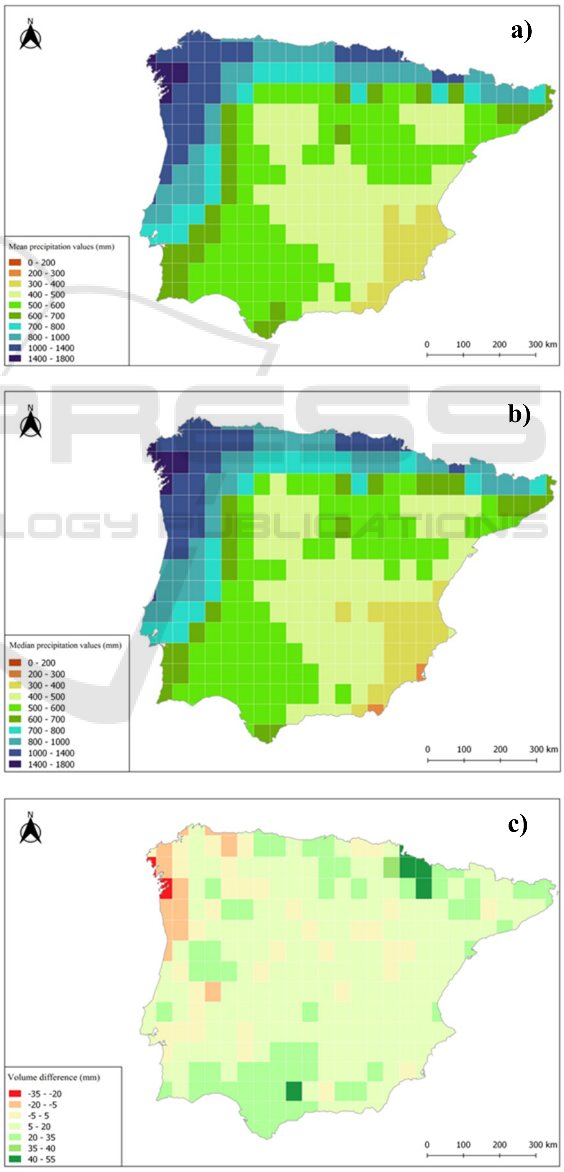

Figure 3: Cartography of annual centrality statistical (1901-2016); a) Mean precipitation, b) Median precipitation, c) Difference between mean and median.

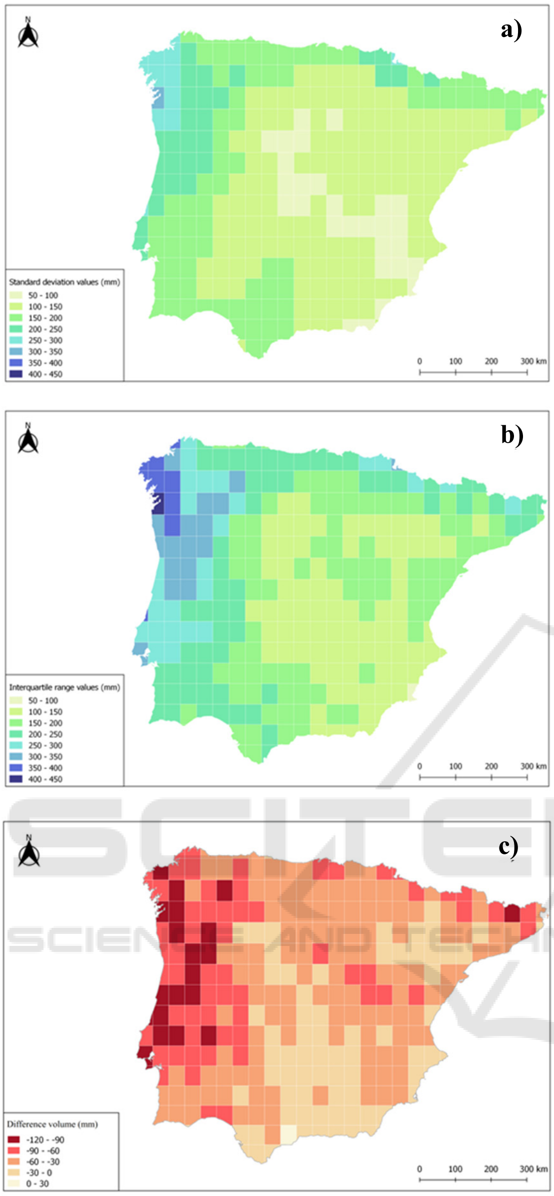

Figure 4: Cartography of annual absolute statistical dispersion (1901-2016); a) Annual standard deviation, b) Annual interquartile range, c) Difference between standard deviation and interquartile range.

Finally, in order to remove the effect con magnitude of precipitation totals, relative dispersion statistics (Pearson Coefficient of Variation and Coefficient of Interquartile Variation) were calculate to compare different zones of the peninsula. In the first map (Figure 5) it can be observed a considerable decrease from north to south and even in most of the Mediterranean coast.

The maps evidence considerable geographic coherence and identify the areas with most rainfall contrast. The country becomes distinctly divided into the northern coast, where the stronger influence of Atlantic disturbances produces more regular daily rainfalls, and the rest of the territory. The Mediterranean depressions produce highly contrasting amounts (sometimes very large) especially the Mediterranean side of the Peninsular due to its scarce annual precipitation.

Though the Pearson Coefficient of Variation (CV) has been already used for precipitation studies in the Iberian Peninsula (Martín-Vide, 2011a), the Coefficient of Interquartile Variation has not been used previously (Figure 5b). It shows a less defined pattern than the CV and with much higher values of variation. The most notable is the low variability, with respect to the rest of the territory registered in the northern part as well as the presence of higher levels in the Mediterranean coast and the Southwest area of Atlantic influence decreasing as it penetrates the interior of the peninsula.

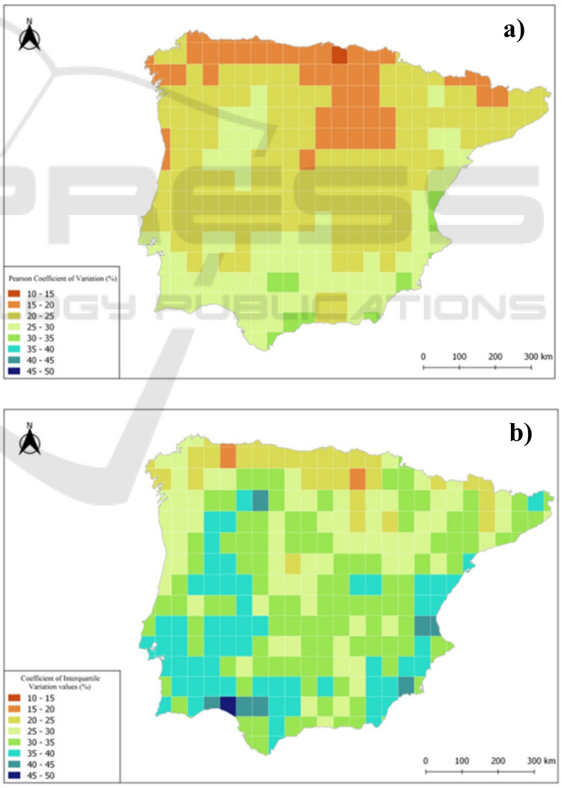

Figure 5: Cartography of annual relative statistical dispersion (1901-2016); a) Annual coefficient of variation, b) Annual interquartile coefficient of variation.

These differences are not depreciable since in many areas, such as the southwest of the Peninsula corresponding to the Guadalquivir river valley, 80% of the water resources are destined to the demand of irrigated agriculture. So far, the presence of many reservoirs manages to satisfy and balance changes in the availability of water, but the expected changes due to climate change, with increasing temperatures, evapotranspiration and extreme events threaten a management system that has already exceeded the natural limits of the resource. For this reason our results are particularly relevant in these areas where major imbalances and drought problems occur. There should be a precise estimation of water resources in order to be preparing for climate change adaptation and mitigation measurements.

In addition, the simpler and more efficient way to show all the results obtained in this work is to make them accessible in a geovisor. This was made by using QGIS Cloud, a web geovisor developed as an extension of the QGIS that allows the publication in a network of maps, data and geographic services. This geovisor has all the potential of a cloud storage and broadcast system that provides such a spatial data infrastructure.

In short, it is a platform through which all information and data capable of owning a geographic component can be shared, according to the standards of the Open Geospatial Consortium (OGC), represented on the web through WMS services and downloadable in WFS. Results of this study can be viewed in https://qgiscloud.com/Juan_Antonio_Geo/expo.

5 CONCLUSIONS

The complexity of the spatial rainfall pattern in the Iberian Peninsula determined by many factors was such as the relief, the layout, orientation or altitude atmospheric circulation. All of them make even more difficult a generalized characterization of the Iberian precipitation spatial distribution.

Using the data from the Global Climate Monitor it is possible to carry out this type of studies. This climatic data geo-visualization web tool can greatly contribute to provide an end-user tool for climatic spatial patterns discovery. Compared to other geo-viewers it hast objective advantages such as the easy way to access and visualize climatic past and present (near real-time) data, fast visualization response time, variables and climatic indicators selection in a unique client environment. The fast and easy way for data downloading and exportation in some different accessible formats facilitates the development of climatic studies such as the one presented here.

Using the precipitation data series provided by the GCM, robust and non-robust statistics were calculated for the period 1901-2016 at an annual and seasonal scale. Robust statistical measures provided different and complementary knowledge of precipitation spatial distribution and patterns in the Iberian Peninsula revealing a general significant overestimation of precipitation. The consequences of this for water resources estimation and allocation are noteworthy for environmental management and water planning and should be taken into account. The two coefficients of variation used emphasized the high irregularity behaviour more than it has been traditionally considered and reveals different zones of maximum variability.

The most novel contribution of this work is to incorporate non-robust statistical measures and the comparison with the most comely used ones. The results show important variations in the estimation of the amount of available water resource coming from precipitation. The estimation of the differences between statistics at monthly scales and by river basins is to be achieved. All this results can be useful in the knowledge spatial and temporal distribution of precipitation and, therefore, in the initial computations of the available water resources of river basins for water management (commonly estimated by few meteorological stations and not updated periods of time). Nevertheless, the effect of mountain ranges on the GCM data needs to be evaluated when considering river basins.

In addition, web-based GIS and geovisualization enable that the results obtained can be displayed in maps and seen in a new web geovisor (https://qgiscloud.com/Juan_Antonio_Geo/expo). This is largely novel since usually obtained results in this type of studies are not shared by means of any tool to give greater diffusion through the web. Improving the interface and making it more user-friendly based on the experience of users is a constant goal of the Global Climate monitor project.

In future work we would also like to evaluate the statistics used in this study at a global level and for large areas relating the results with climatic typologies. We will also like to compare the evolution and changes of precipitation amounts between different standard periods (climatic normal) and other climatic indicators. Other climatic variables will be also estimated and incorporated into the Global Climate Monitor geoviewer. This is an added value to this work concerning not only about the generation of quality climate information and knowledge, but also making it available to a large audience.

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