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The weather behind the words. New methodologies for integrated hydrometeorological reconstruction through documentary sources.

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Abstract. The historical climatology has remarkable potentialities to produce climatic reconstructions with high temporal resolution. However, there are methodological limitations that hinder the spatial development of this discipline. This study presents a new approach to Historical Climatology that overcomes some of the limitations of classical approaches such as the Rogations Method or the Content Analysis: the Cost Opportunity for Small Towns (COST). It analyses historical documents and takes advantage of all sort of meteorological information available in the written documents, not only the most severe events, thereby overcoming the most prominent bottleneck of former approaches. COST relies on the fact that the use paper had a high cost, so its use to describe meteorological conditions is hypothesized to be proportional to the impact they had on society. To prove the validity of this approach to reconstruct climate conditions, this article uses exemplarily the Municipal Chapter Acts of a small town in Southern Spain (Caravaca de la Cruz), which span the period 1600-1900, and allow to obtain reconstructions with monthly resolution. Using the same documentary source, the three approaches have been used to derive respective climate reconstructions, which are then compared to assess the consistency of the climate signal and identify possible caveats in the methods. The three approaches lead to generally coherent series of secular variability in the hydrological conditions and that agree well with the results pointed out by previous studies. Still, COST approach is arguably more objective and less affected by changes in the societal behavior, which allows it to perform comparative studies in regions with different languages and traditions.

Keywords. Little Ice Age; Paleoclimatology; Historical Climatology; Europe; Iberian Peninsula; Documentary Sources; COST; Content Analysis; Rogations.

1 Introduction

Understanding climate variability is fundamental to put ongoing global change under a long term climatic perspective (IPCC, 2013). Meteorological observations have a prominent role in this regard, as they record such variability and enable its study. However, although few early instrumental records started in the 19th century in industrialized areas (Domínguez-Castro et al., 2013), the systematic recording of climatic data, globally coordinated by the WMO, is much more recent. This short period of time precludes establishing a robust statistical characterization of climate variability, and thus limits the understanding of the mechanisms behind longterm climate variability. Therefore, it becomes necessary the use of proxy data or direct climate descriptions that allow the reconstruction of climate series beyond the short instrumental record (Pfister et al., 2008). Such reconstructions shed light on the relationships between social processes and long term climate variability (Hsiang and Burke, 2013). Together with climate models, climate reconstructions are the two main tools available nowadays to climate researchers that enable studying climate variability. Both approaches are necessary and complementary, since their joint analysis has been shown to able to constrain uncertainties and shortcomings that otherwise would not be possible (Gómez-Navarro et al., 2015). Climate is a complex phenomenon with strong regional variability that demands a coordinated study (Izdebski et al., 2016) tackling as many regions of the world as possible (Giorgi et al., 2009). However, the availability of proxy data to be used in climate reconstructions is very heterogeneous in space and time (Consortium, 2013; Consortium, 2017). Each proxy data type has specific potential and limitations (See Pfister et al., 2008, and IPCC, 2001 Chapter 2, Section 2.3.). In some parts of the world the specific limitations of each proxy feed each other due to its socio-environmental characteristics (Huang et al., 2000). In this way, there are large areas over the world that are not represented in paleoclimatic reconstructions (Luening, 2017). Arid regions for instance are generally underrepresented due to the limited natural proxies available (Machado et al., 2011). By the way of example, to carry out climate reconstruction by speleothem a specific geological conditions must be given (Bar-Matthews et al., 1996). Regarding climate reconstruction through ancient tree rings, the existence of appropriate plant species is required (Galván et al., 2014). Finally, the correlation between the presence of ice masses and the feasibility to make reconstructions through ice cores is clear (Thompson, 2000). Most of these requirements are not met in arid and semiarid areas.

In this context, historical climatology (hereinafter HC) is a suitable alternative tool that may fill this gap, since it allows climate reconstruction in locations where natural proxies are scarce (Brázdil et al., 2005; Prieto and García-Herrera, 2009). HC is a very powerful source of insight, since historical documents recording weather-related phenomena prior to instrumental weather data collection are available in many populations around the world (Gil-Guirado et al., 2016). The documentary data is a high resolution proxy for climate reconstructions (Pfister et al., 2008). Therefore, HC is to be uniquely placed to both generate extended datasets useful for climate model validations studies, and to provide empirical evidence that might further our understanding of the changing nature of climate-society relationships over time (Nash and Adamson 2014: 132). A prominent advantage of this research field with respect to other paleoclimatology approaches is that its economic and technical requirements are minimal. Still, it requires having continuous and homogeneous written sources (Brázdil et al., 2005). In Europe, this condition limits the reconstructed period to the last 8 to 10 centuries, depending on the country (Lamb, 1965; Gagen et al., 2006; Brázdil et al., 2010). Although documentation available in Southeast Asia has allowed some researchers to perform reconstructions dating back more than 20 centuries (Ge et al., 2003; Wei et al., 2014).

Over Europe, where literature on temperatures and precipitation reconstructed through historical documents is abundant, HC is an important source of insight. Studies in Switzerland, Germany, Czech Republic, France, Hungary, Netherlands, British Isles, the Balkans, Portugal, Norway, Italy (For a more detailed analysis of HC literature in Europe see Camenisch, 2015, Brázdil et al., 2005 and 2010, and Camuffo et al., 2010) and Spain (Martín-Vide and Barriendos, 1995; Rodrigo et al., 1999;

García-Herrera et al., 2003a; Vicente-Serrano and Cuadrat, 2007 ; Domínguez-Castro et al., 2008) are examples of regions profusely analysed. Beyond Europe, other regions with a remarkable development of HC are South America (Prieto, 1985; Prieto and Jorba, 1991; Prieto et al., 2000) and Southeast Asia (Ge et al., 2003, 2005). However, most of the regional studies in HC date from the eighties and nineties decades of the last century. This period experienced a tremendous growth in terms of the emergence of series reconstructed through historical documents. Unfortunately since then there has been a stagnation in the HC studies. This stagnation can be explained by two alternative causes: either there are already sufficient locations reconstructed that enable an optimum knowledge of the variability of the climate, or HC is currently limited by methodological limitations that have prevented extending the catalogue of locations. The current proliferation of studies where new reconstructed series from natural sources are presented (Romero-Viana et al., 2011; Nieto-Moreno et al., 2013; Barreiro-Lostres et al., 2014; Tejedor et al., 2016) suggests that methodological limitations are indeed the current bottleneck of HC. Thus, new methodologies have to be developed that circumvent the current limitations of HC in order to keep it competitive with respect to other fields. Such advances would be very beneficial for Paleoclimatology as well, given the potential of HC to produce high resolution series described above. Recall that the annual and even seasonal resolved information is essential to understand how the climate variability affects societies (Hegerl et al., 2011).

Spain has one of the largest and most varied documentary heritages of the world which, unfortunately, has not been yet fully exploited for climate studies. For instance, although it has a surface of more than half a million square kilometers, there are currently just 15 reconstructed series that simultaneously span more than three centuries and overlap with the instrumental record. Catalonia (in the NE of Spain) presents a good spatial coverage (Martín-Vide and Barriendos, 1995), while the Balearic Islands, the inland and Northwest of the country have noticeable spatial gaps (See Figure 1, Panel a). Additionally to these long series, there exist initiatives that have accomplished reconstructions that span much shorter periods of time. However, they do not overlap with the instrumental data, which precludes the calibration and validation of the series against observations (Bullón, 2008; Fernández-Fernández et al., 2011; Alberola Romá, Bueno Vergara and García Torres, 2016 ; Alberola Romá, 2016 ; Cortizo, 2016). Most of the studies that overlap with instrumental data in Spain focus on capital cities (73% of the series), and specially in the episcopal see (93% of the series). This is due to the large amount of ecclesiastical and municipal sources used to produce these series, and have the side effect that small populations without a strong ecclesiastical representation remain excluded as sources of insight, a fact that contributes to the bottleneck of HC described above.

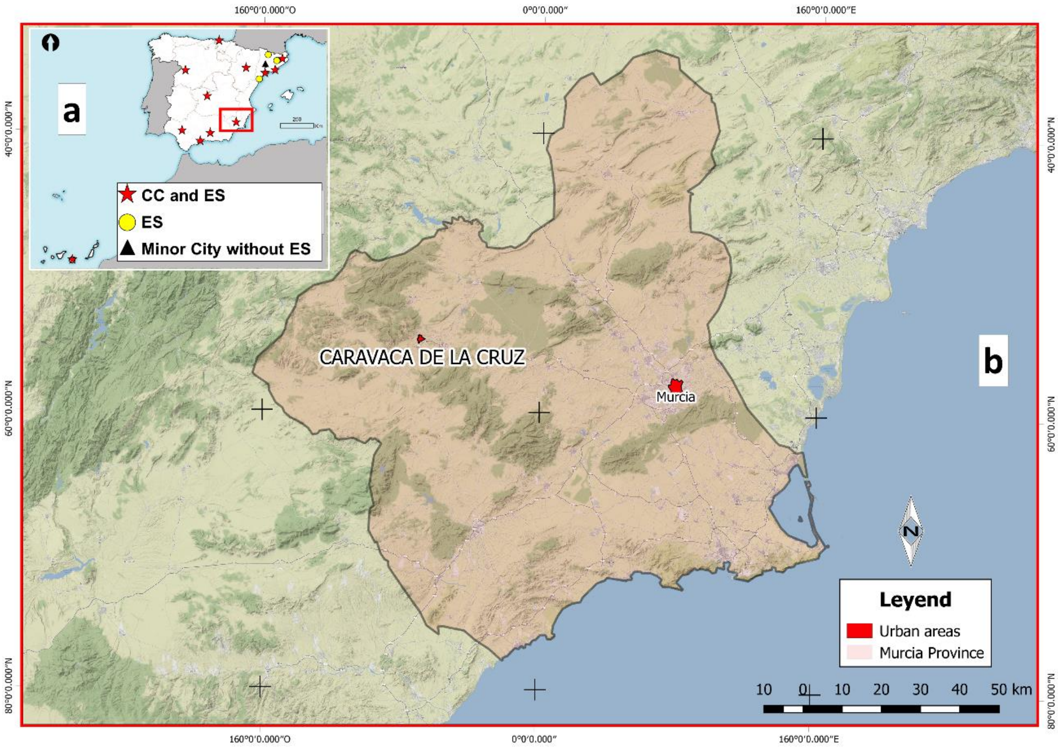

Figure 1: Location maps of reconstructed series with instrumental overlap in Spain (Panel a) and Study Area (Caravaca de la Cruz) (Panel a). Panel a show the reconstructed series in Spain that have overlap with instrumental records. The red stars identifies the reconstructed series in Capital Cities (CC) that are also episcopal sees (EP). The yellow circles identifies the reconstructed series in Cities that are Episcopal Sees (ES). Finally, the black triangle identifies the small cities that have no capital or Episcopal See. In **Panel b**, the location of the Study Area (Caravaca de la Cruz) is represented. *Sources:* Martín-Vide and Barriendos (1995); Rodrigo et al. (1999); García-Herrera et al. (2003a); Vicente-Serrano and Cuadrat (2007); Rodrigo and Barriendos (2008); Gil-Guirado (2013).

Including the sources that current HC methods do not consider requires an important quantitative and qualitative effort to develop new methodologies of reconstruction able to integrate a greater number of locations in the world (Pfister, 2014) and to make the obtained series comparable in time and space (Nash & Adamson, 2014). This is however a difficult task that raises numerous questions that need to be addressed, such as: What is the most appropriate methodology for each location? Is it dependent on the period targeted? Are there complementary and alternative methods? Answering these questions is not an easy task, but it becomes necessary to analyse the sensitivity of the different methods, since this knowledge will allow the optimization of the methods for each application. In a prominent effort in this direction, Neukom et al. (2009) used the concept of pseudo documentary source to confirm how there exists a good complementarity between series reconstructed with different kinds of historical sources, e.g. newspapers and official documents. However, this type of analysis aimed at the methodological validation for the same place using the same documentary sources, but by applying different methodologies, is infrequent in the HC literature

There exist currently two main of methods in HC that have been used to produce continuous series with the historical documentation of the old Spanish Empire. On the one hand, the rogations method (Martín-Vide, & Barriendos, 1995; Barriendos, 1997; Rodrigo and Barriendos, 2008; Domínguez- Castro et al. 2008) maps the ceremonies asking God for rain (pro-pluvia) or to stop raining (pro-serenitate) into precipitation indices. On the other hand, Content Analysis (Prieto et al. 2003; Prieto et al. 2005), which maps the precise wording used in historical documents to describe meteorological events onto numerical values (typically rain, temperature and wind). The application of these two methods is subject to an important factor, i.e. the amount of documentation available. In this sense, Spain is a good target for this type of studies, since important sources of historical documentation are nowadays available, being much higher than in South American countries for instance, where the historical vicissitudes have caused that a larger part of this documentation has been lost (Gil-Guirado, 2013). Still, when the amount of documentary sources is too large, the consultation of the full material becomes too complex and time-consuming. Therefore, the selection of the most suitable sources becomes necessary (Brazdil et al, 2005). In this circumstance, the most appropriate method is the rogations method, since it enables highly robust reconstructions using a fraction of the total documentation (Barriendos, 1997; Gil-Guirado, 2013). This condition explains why the rogations method is the most widely used in the literature of HC in Spain. Conversely, when the amount of documentary sources is scarce, it is necessary to consult the documentary sources in full detail. This forces the researchers to use documents from heterogeneous sources, with the aim to get advantage from every bit of climatic information they might contain. In this circumstance, the most appropriate method is the content analysis, since it allows analyzing documentary sources of various kinds (civil, religious, private, etc.) with a common methodology that enables obtaining robust series (Prieto et al. 2003). This situation has resulted in the content analysis method being the most widely used in South American countries (Prieto, Herrera & Dussel, 2000; García-Herrera et al. 2008; Neukom et al. 2009; Prieto & García-Herrera, 2009).

Having into account this review on the current status of HC, the objectives of this study are:

1. Describe and validate a new methodology suitable to reconstruct climatic series in small towns through historical documents (the so call Cost Opportunity for Small Towns method-COST).
2. Apply simultaneously the Rogations, Content Analysis and COST methods to the same historical document, analyzing the sensitivity of the results to the chosen method, and thus characterising the uncertainties and robustness of this new approach.
3. Determine if complementarity between methods exits so it can be used to fill gaps when the requirements for the application of one of these three methodologies is not met.

As a testbed for the application of the methods, we use the data from a small size population in the southeast of Spain (Caravaca de la Cruz, 25,633 inhabitants in 2017) (See Figure 1, Panel B) in the period 1600-1900. The semi-arid conditions (around 380 mm annual average) and the mild temperatures (around 16° C annual average) render the precipitation and water availability the determining factors for human activity (DeMenocal, 2001: 667). Therefore, the precipitation is the target variable for the reconstruction.

The structure of the paper is as follows. Section 2 presents and discusses the historical sources. Section 3 focuses on the thoughtful description of the three methodologies. Section 4 presents the reconstructions carried outs and compares the results. Finally, Section 5 concludes the paper drawing the main remarks.

2 Sources in Historical Climatology

The previous analysis of all documentary sources is a necessary step in every HC study (Brazdil et al, 2005). The next step is to objectify the information obtained, i.e. convert historical data into climate data (Glaser, 1996: 57).

For this paper, we have consulted the Actas Capitulares (Municipal Chapter Acts) of the Concejo (city council) of Caravaca de la Cruz (henceforth Caravaca). In total, we have consulted 41,385 sheets of paper for the period 1600-1900. Despite this, some documentary gaps have not been possible to cover (from 1820 to 1823 and 1891 to 1892).

The Actas Capitulares (AC) of the city councils are the most useful source for climate studies in Ibero-American countries (Metcalfe et al. 2002). After the foundation of each new town, the city council was established for its government. The Councillors and the Mayors (Capitulants) had weekly meetings where all matters relating to the management of the town were analyzed[1]. It was mandatory to leave a written record of the meetings and let the records in the municipal archive for possible future claims or consultation. A public scribe was responsible for transcribing all the information in a Chapter Acts book. In these books was recorded the date, the participants, the topics mentioned, the specific contributions of each participants, and finally the agreements reached (See Figure 2 for an example if this type of documents). This makes the AC a kind of Official Gazette, where all issues that affect the town become recorded (Barriendos, 1999). In the AC, all environmental aspects which had incidence in the population were treated comprehensively. In this way, all the anomalous events were collected in great detail. Therefore the existence of an AC without references to meteorological information implies that the climatic and environmental situation can be regarded as normal, because when climate thresholds accepted by a society are not exceeded, there is no news (Prieto, Herrera and Dussel, 1999). Taking into account these characteristics described, the AC are the council primary source that offers direct weather data, water dependent data and phenological data (Bradley & Jones, 1992: 12).

[1] These were the ordinary meetings. When there was some extraordinary event such as floods, plagues and epidemics they held an extraordinary meeting. Therefore, depending on the needs, meetings could be held on any day of the year.

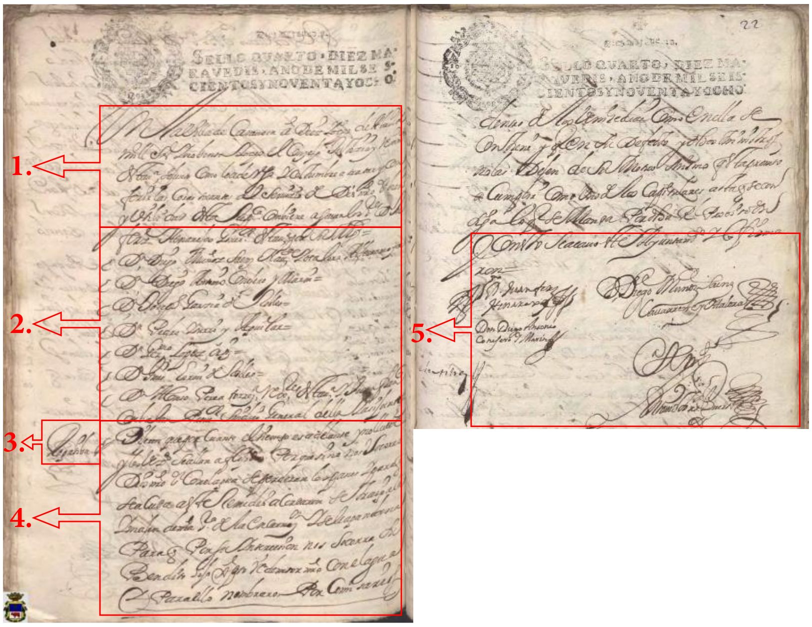

Figure 2: Caravaca city council meeting sample. AC (April 18, 1698).
The main parts of an AC are marked : 1-Date, place and type of meeting (Ordinary or Extraordinary meeting) ; 2-Full name of the meeting attendees; 3-Short summary of the topics discussed; 4- Topic memorandum and attendees contribution; 5- Attendees signatures. The text describes a ceremony to ask God for rain (pro-pluvia): "*Dijeron que por cuanto el tiempo es adelante y no llueve y los vecinos se hallan afligidos, porque si no nos socorre Dios mío con el agua se perderán los panes y para que se acuda a este remedio acordaron se traiga a la imagen de Nuestra Señora de la Encarnación y se le haga novena, para que por su intercesion nos socorra su bendito hijo con el agua y para ello nombraron por comisarios a los Señores Don Francisco de Quesada y Don Alfonso de Sajosa. Y en este estado dijeron que por cuanto Don Alfonso de Sajosa se halla en el campo y no puede venir y por no estar delante el Señor Don Francisco de Quesada parece se podrá excusar y para obviar cualquier excusa acordaron se repartan suertes entre los capitúlales que están y toco a los Señores Don Francisco de Quesada y Ginés de Gadea*". *Source:* Carmesi Project.

3 Methods for climate reconstruction derived from Hispanic Documentary Sources

Through the different methodologies used, continuous data series have been obtained from the year 1600 to 1900 at daily resolution. For the data analysis, the daily values have been aggregated at monthly, seasonal (Winter: December, January and February; Spring: March, April and may; Summer: June, July and August; and Autumn: September, October and November) and annual scale. The analysis of drought and rainfall series has been carried out separately to create seasonal and annual series for droughts and rainfall, respectively.

3.1 The rogations method

The rogations (hereinafter RO) are liturgical acts in which the Catholic Church asks God for rain (pro-pluvia rogations, hereinafter PPR) or to stop raining (pro-serenitate rogations, hereinafter PSR). Catholic countries present a high incidence of these ceremonies (Espín-Sanchez and Gil-Guirado, 2016). In Latin American countries, this historical context and the absence of more precise proxies, explain the proliferation of academic articles using rogations data to reconstruct weather patterns (Martin-Vide and Barriendos, 1995; Garza Merodio, 2002; Alcaforado et al., 2000). Spain is a country where remarkable results have been obtained following this method (Martín-Vide & Barriendos, 1995; Rodrigo and Barriendos, 2008; Domínguez- Castro et al., 2008).

Catholic rogations are religious rites performed for specific purposes such as earthquakes, droughts, heavy rains and floods. The PPR are the most extended and frequent among them. Since the 9th century, the rogations procedure has been strictly regulated by the Vatican (for more details see Espín-Sanchez and Gil-Guirado, 2016).

In this way, the implementation of the PPR has been consistent over time in all Catholic territories. The PPR process usually has the next steps (Garza and Barriendos, 1998):

i. The local government (civil authorities) receives a rogation request from the farmers and decides to ask a rogation request to the religious authorities.
ii. The religious authorities receive the rogation request of the civil authorities, and then the religious authorities decide the rogation date and the type of ceremony.
iii. The ceremony is performed.
iv. When the rain occur, the religious authorities decide to perform a thanksgiving mass.

The institutionalization of the rogations process allows us to differentiate between different rogations levels depending on the type of ceremony performed. The rogations cost has risen in line with an increase in the level of rogation (Espín-Sanchez and Gil-Guirado, 2016). We have adapted the methodology proposed by Martín- Vide and Barriendos (1995), classifying the PPR in five different levels of drought intensity. Starting in level one (the weakest drought) to level five (the most severe drought). The different levels are as follows:

1. Rogation masses inside the church.
2. Rogation masses with figures of saints or virgins exhibition inside the church.
3. Popular processions through the city streets with figures of saints or virgins.
4. Popular pilgrimages to a sanctuary outside of the city carrying the figures of saints or virgins.
5. Water body immersion (river, well or fountain) of the figures of saints or virgins.

In addition to the PPR the PSR are also recorded, although they are much less frequent, as reported below. Accordingly, the PSR are also classified in five increasing levels of rain intensity:

1. Thanksgiving masses: masses to thank God for the rain arrival.
2. Rogation masses inside the church or spells against storms.
3. Popular processions with figures of saints or virgins exhibition inside the church.
4. Popular saints or virgins exhibition from the church tower.
5. Popular processions with figures of saints or virgins exhibition and other uncommon ceremonies in PSR rogations.

In the ceremonies of level 3 or higher with two or more images (statues of the saints or virgins), we add an additional level point for each additional image (e.g. A PPR-Procession with three statues of saints have an score of 5 points. 3 points for the profession and 2 points for the additional saints). This type of strengthened ceremonies were made when the adverse situation persisted, despite they had been praying for a long time (See Figure 3).

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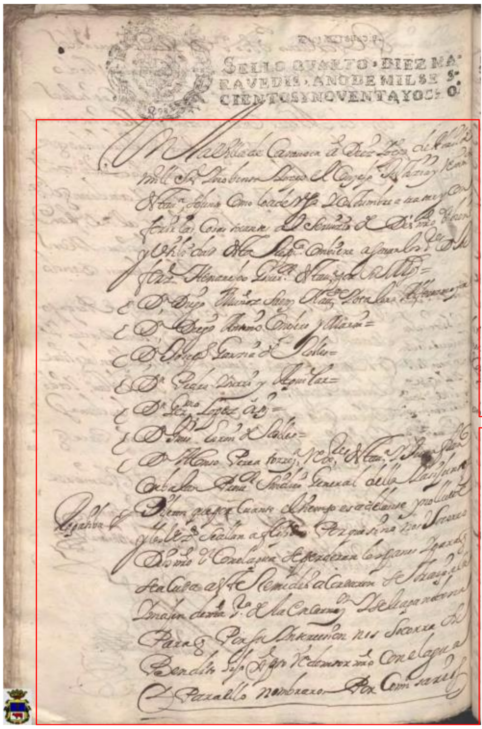

Pro-pluvia rogation transcription:

*"Rogativa: Dijeron que por cuanto **el tiempo es adelante y no llueve** y los vecinos se hallan afligidos, porque si no nos socorre Dios mío con el agua se perderán los panes y para que se acuda a este remedio acordaron se traiga a la **imagen de Nuestra Señora de la Encarnación y se le haga novena**, para que por su intercesion nos socorra su bendito hijo con el agua…".*

Pro-pluvia rogation coding:

*"…**el tiempo es adelante y no llueve** [Pro-pluvia rogation] **imagen de Nuestra Señora de la Encarnación y se le haga novena** [Level= 2]".*

Final Value:

Date	Variable	Level
April 18, 1698	Drought	2

Figure 3: Codification example of Rogations (RO) method. This particular example refers to a Pro-Pluvia Rogations on the 18th April 1698, so the variable reconstructed is drought. Source: Carmesi Project

3.2 Content Analysis

Content analysis (hereinafter CA) is a research technique used to identify the meaning given to full written texts, taking into consideration the historical, social and cultural context where they were drafted (Bardin 1986). The use of CA in climate studies is relatively recent and not yet widespread. Moodie and Catchpole (1975), and later Baron (1982) pioneered the application of content analysis in historical climatology. Recently, the works of Prieto (Prieto et al. 2003; Prieto et al. 2005) has promoted this technique, showing its validity for environmental history. Some studies have used this technique in Iberia (Domínguez-Castro, García-Herrera and Vaquero, 2015), but only for a limited number of years and without overlap with the instrumental data.

The CA studies must follow various steps in their development. Bardin (1986: 71) distinguishes the following: 1) The pre-analysis, when the documents to study are selected, the hypothesis is formulated and the objectives are marked; 2) The use of the material, when the documentation is encoded; 3) The treatment, inference and interpretation of the data.

We use the Actas Capitulares (AC) of Caravaca according to the objectives of this work and assume as hypothesis that the different linguistic expressions employed by contemporary people to describe a climate event reports the intensity, duration and direction of this event.

Documentation encode has been done on the topics in the AC which are susceptible of containing information about droughts and rainfall. Mainly, these are as follow:

- PPR and PSR topics.
- Information about crops (mainly cereals and wine).
- Information about the prices of food (bread, wine, meat, etc.).
- Topics on status of cattle.
- Measures against floods and droughts.
- Topics about non-payment of taxes and their motives.
- Information on the state of roads and communications.

As Prieto et al. (2005: 45) point out, many expressions are synonymous, so the initial number of expressions is summarized in 49 Registration Units (RU) for Droughts and 42 RU for rainfall. To identify the exact meaning of each RU, Spanish language dictionaries covering the entire period of analysis have been reviewed[2]. As can be appreciated in similar studies in Spanish language (Prieto and Jorba, 1991), there are no evident changes in the use of language to describe climate anomalies during the study period.

To assign a value to each RU, we have considered all the RUs for each variable (drought and rain), establishing a range between 1 and the total number of RUs of this variable. A value of 1 was assigned to the RU with less intensity of the variable and the value of the total RUs of this variable was assigned to the RU with more intensity. Between the range 1 to the total number of RUs of that variable, the rest of RUs, from less to more intensity have been classified. Finally, the values have been normalised to provide a value between 0 and 1 (See Figure 4).

To determine the position of each RU within its range of variable, we first categorise the general descriptors of the phenomenon and then we categorise the adjectives and adverbs. In this way, the descriptors determine the intensity (Prieto and Jorba, 1991: 50).

For example, we assigned value 1 to the RU "alguna falta de agua" (“some lack of water”) because it describes a very weak drought. We assigned value 49 to the RU "extrema necesidad del agua" (“extreme need of water”) as it describes the largest drought registered. Between 1 and 49, the remaining 47 RUs have been classified from less to more drought intensity.

[2] Covarrubias, Sebastián De: Tesoro de la lengua castellana o española. Madrid, Luis Sánchez, 1611. Gaspar y Roig: Biblioteca Ilustrada de Gaspar y Roig. Diccionario enciclopédico de la lengua española, con todas las vozes, frases, refranes y locuciones usadas en España y las Américas Españolas [...] Tomo I. Madrid, Imprenta y Librería de Gaspar y Roig, editores, 1853; Gaspar y Roig: Biblioteca Ilustrada de Gaspar y Roig. Diccionario enciclopédico de la lengua española, con todas las vozes, frases, refranes y locuciones usadas en España y las Américas Españolas [...] Tomo II. Madrid, Imprenta y Librería de Gaspar y Roig, editores, 1855. Real Academia Española. Diccionario de la Lengua Española, vigésima segunda edición. Available in: http://buscon.rae.es/diccionario/drae.htm.

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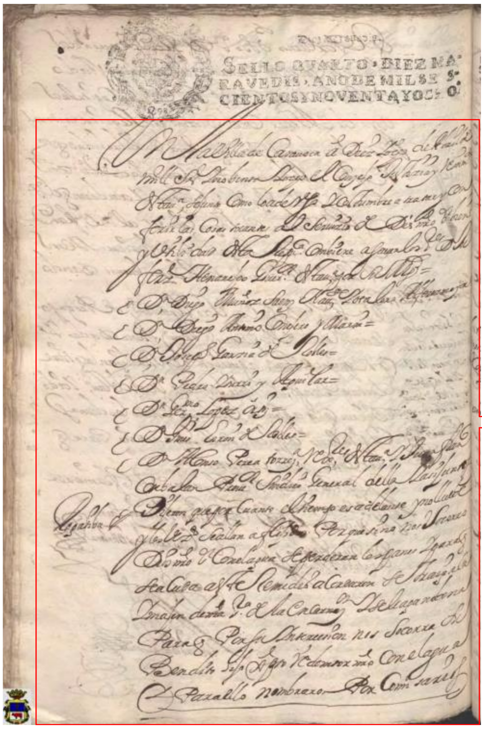


Content Analysis transcription:

"Rogativa: Dijeron que por cuanto ***el tiempo es adelante y no llueve*** *y los vecinos se hallan afligidos, porque si no nos socorre Dios mío con el agua se perderán los panes y para que se acuda a este remedio acordaron se traiga a la imagen de Nuestra Señora de la Encarnación y se le haga novena, para que por su intercesion nos socorra su bendito hijo con el agua…".*

Content Analysis coding:

"… ***el tiempo es adelante y no llueve*** *[Registration Unit 10 for Drought]…".*

Final Value:

Date	**Variable**	**RU**	**RU Rank**	**Indexed value**
April 18, 1698	Drought	Sin llover o no llueve	10/49	0.2

Figure 4: Codification example of Content Analysis (CA) method. The coded source is the same than in the Figure 2 to emphasize how the three different approaches are applied in practice. This particular example refers to a PPR on the 18th April 1698, so the variable reconstructed is drought. *Source:* Carmesi Project.

3.3 Opportunity Cost for Small Towns (COST)

We propose a new methodology applicable in small towns, the Cost Opportunity for Small Towns (hereinafter COST). This method provides results comparable with content analysis and the rogations method, since it is also based on text analysis, However, it exploits the volume occupied by the text, rather than subjective linguistic terms. In this sense, if in CA the intensity of certain key concepts is analyzed, the COST approach analyses the same key concepts, but in units of the space occupied within the document. i.e., we obtain the amount of Actas Capitulares (AC) that cover matters related to rainfall and drought.

The underlying hypothesis is that the greater the amount of paper used to describe a climate event, the greater the intensity and duration of such an event. The requirements of this methodology are as follow:

i. Availability of continuous and homogeneous documentary sources.
ii. The use of paper must have some kind of economic limitation. The latter condition implies that referring to a particular issue has an opportunity cost for not using that paper for another topic.

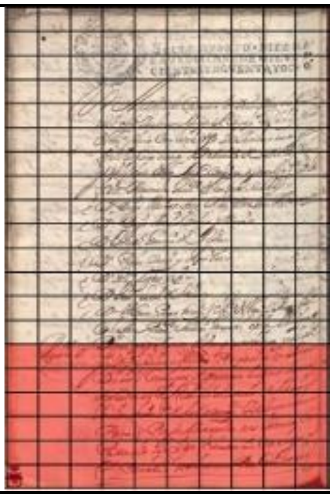
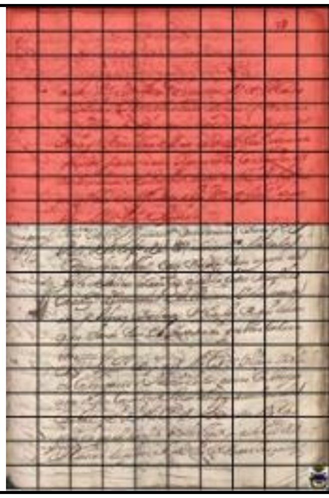
The use paper in the AC was affected by the taxes imposed by the central State through the Sealed Paper ("papel sellado"). The "Papel Sellado" in Spain was a special type of paper that contained a royal seal in order to improve the reliability of the public deeds and contribute to the cost of the monarchy (Rodriguez, 1996). On the one hand, the paper was an expensive material that supposed a significant expenditure for the City Councils. In Spain, since the 17th century an exponential increase in the needs of paper was produced, at the same time the Spanish paper industry could not meet the paper demand (Hidalgo-Brinquis, 2006). This situation forced the City Councils in small towns to be austere with the consumption of paper, therefore the second condition described above is met. On the other hand, each of the topics discussed in the City council meetings had a high cost to the town. First, a series of direct expenses at each meeting were necessary (The food and drink of the participants, wax for lighting, the displacements of the participants, paid the salary of public scribe and stewards, etc.). Secondly, each topics was preceded by a previous works to analyze the situation and collect the necessary information (Martínez, 1996).

From these requirements, we have quantified the amount of paper (percentage of AC used at City Council meeting level) which includes any information of drought and rain. Thus, the variables studied are the same as for CA. Also, the codification has been done on the same AC topics that content analysis (see previous section).

To expedite the COST implementation, it is recommended that the documentary sources are digitized. In this work, the Caravaca AC are available online on the website of the Carmesi Project[3] for the period of 1600 to 1699. For the period from 1700 to 1900, the authors have the AC photographs. This photographs were taken during a collection data campaign in the Municipal Archive of Caravaca.

The procedure is as follows (See Figure 5): We divide each AC sheet at 200 cells. In this way, each City Council meeting is broken down into a number of cells and a date. Then, we quantify the number of cells occupied by the variables studied (if there is any). At this time, we have the dates, the amount of total cells and the amount of cells occupied by each variable. Finally, for each meeting we aggregate the total cell number and the number of cells in each variable, then we calculate the percentage occupied by each variable for each meeting.

[3] Carmesi Project website: http://www.regmurcia.com/servlet/s.Sl?METHOD=

Sheet 1-200 cells= 60 cells	Sheet 2-200 cells= 90 cells	Sheet 3-200 cells= 0 cells
		
Sheet 4-200 cells= 0 cells	**Sheet 5-200 cells= 0 cells**	**Sheet 6-140 cells= 0 cells**
		

Meeting of Caravaca city council of April 18, 1698			
Total Cells:	1,140	**Occupied cells:**	150
Occupied variable:	Drought	**Occupied %:**	13.16

Figure 5: Codification example of COST method. Codification example of COST method. The coded source is the same than in the Figure 2 and 3 to emphasize how the three different approaches are applied in practice. This particular example refers to a PPR on the 18th April 1698, so the variable reconstructed is drought. *Source:* Carmesi Project.

4 Results

The number of rainfall and drought events reconstructed by the CA and COST approaches is equal, while in RO this number is always lower. This is due to the fact that whenever the documents reflect events about droughts or excess of rainfall, this

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information can be classified according to the CA and COST methodology. However, the RO method only allows gathering climatic information when these events lead to liturgical processes of rogations. Therefore, all RO data are included by CA and COST and also coincide temporarily with each other, while some of the data obtained applying CA and COST data are missed by RO. In our study, 7.1% of months between 1960 and 1900 have non-zero values in RO, whereas this value reaches 12.9% of months in CA and COST. This already informs about the larger sensitivity of RO to hydrometeorological extremes. However, this asymmetry depends on the variable being reconstructed. Thereby, there are important differences between drought events (6.4% of months in RO versus 8.5% in CA and COST) and rainfall events (0.6% of months in RO versus 4.4% in CA and COST) (See

This has two main consequences: (1) reconstructions methods are more sensitive to drought events than to rainfall. DeMenocal (2001: 667) argues that this is due to the fact that the lack of rain is the factor most strongly affecting human activities in semi-arid regions; (2) the applicability of RO to reconstruct events of rainfall is not as clearly established as for the case of drought. This is so because the religiosity associated to the climate is more tightly bind to climatic situations with stronger potentiality to produce long-term impacts in society, and in semi-arid climate zones, this is the case of droughts (Espín-Sanchez & Gil-Guirado, 2016).

La Table 1 summarises the amount of months when there are events of droughts and rainfall in the period 1600-1900 for each of the three methodologies. The average and standard deviation values are also shown for descriptive purpose only. RO shows an average PPR of level 2.4, whereas for PSR it is of level 1.5. CA shows an average intensity of 8.7 RU for drought, and an average intensity of 11.3 RU for rainfall. Finally, COST leads to 0.9% and 1% of paper dedicated to discuss each type of event on average, respectively. This way, it can be appreciated how average values for rainfall are above those for the lack of it in CA and COST, whereas this situation is reversed in the case of RO. This further illustrates the lower sensitivity of the latter approach for the detection of rainfall discussed above. The variability of the indices obtained with the three methods differs and depends on the variable being reconstructed. While average deviation in droughts indicates similar values across all methods, in the case of rainfall this value is lowest for COST and highest for CA. In this regard, it seems that CA presents a tendency to overestimate rainfall events.

	Drought			**Rainfall**		
	RO	**CA**	**COST**	**RO**	**CA**	**COST**
N	228	301	301	22	154	154
%	6.44	8.50	8.50	0.62	4.35	4.35
$\bar{X}$	2.39	8.72	0.85	1.50	11.33	0.96
S	1.84	7.82	0.80	0.96	10.08	1.09
Average deviation	0.74	0.71	0.71	0.71	0.80	0.61

Table 1: Basic statistics of the reconstructed series with the three methods for both lack and excess of rain, respectively.
N refers to the number of months where the series differ from zero in the period 1600-1900 excluding data gaps (1820-1823 and 1891-1892). Percentage (%) indicates the fraction of months including an event. $\bar{X}$ and S represent the mean and the standard deviation of the series, respectively. Average deviation is a dispersion metric calculated as the average of the absolute difference between a given month and the mean of the series.

4.1 Annual cycle and agroclimatic context

Relating the annual cycle of the reconstructed series with the hydric variability of the agricultural system allows to analyse their robustness. In this sense, strong decoupling between the reconstructed series and the water agricultural requirements could invalidate the use of historical documents to reconstruct climate (Gil-Guirado et al., 2016), as it would indicate that social demand of water is not related to water scarcity.

In the case of droughts, the averaged frequency and intensity present both an absolute maximum in spring, together with a secondary one in autumn, and a minimum in summer (more clearly in RO) (See Figure 6, a). This annual cycle can be directly related to the distribution of precipitation in Caravaca due to its Continental Mediterranean character. Spring is the rainiest season, followed by autumn, whereas it presents dry summers. The agricultural specialization in this region, based on the cultivation of cereals (mostly wheat and barley)[4], is the result of adaptations to this seasonality. Autumn rainfalls are especially critical to plant cereals, while spring rain is important to allow an optimal growth. Conversely, summer is the harvesting season, so that rainfall is not necessary in these months, and can become inconvenient when it is excessive. The latter explains why references to droughts in summer are rare in historical documents. Still, when a severe drought occurs in spring, summer could suffer issues derived to the lack of water in the former season. This can explain why the differences between RO and the other two approaches are especially large in summer. During these months, the dry conditions may lead to water management requirements that are recorded in the historical documents, although they did not produce any rogation ceremony. In summary, the intensity and frequency of the annual cycle implicit in the documents nicely reflect the actual precipitation regime in Caravaca. This indicates that water demand occurs in the months where water deficit can produce the biggest social impact, and therefore demonstrates the ability of these reconstructed series to reflect actual past climate conditions, particularly drought variability.

For rainfall, there are important differences between the frequencies of RO and the other two methods (See Figure 6, b). RO shows a clear spring maximum, which is the counterpart of the season with the strongest rains in Caravaca, whereas CA and COST do not exhibit such a clear maximum. However, the few events related to rainfall in RO (N=22) reduce the reliability of the frequencies reconstructed with this approach. It is important to note that in the case of rainfall, the reconstructed series reflect the inherent heterogeneity of precipitation in the Southeast of the Iberian Peninsula. Thereby, in spring and winter precipitations are associated to frontal systems that have the potential to cause damage due to the accumulation of water across several days, whereas in autumn severe flash floods associate to convective storms are frequent and lead to severe impact (Martin-Vide, 2004). Although during summer convective precipitations are not exceptional, what determines that CA and COST increase the intensity of rainfall in June is the fact that this is the cereal harvesting month, and therefore excessive rain can lead to important economical loses that are reflected in the documents. Still, CA and COST points to high average intensities in the most rainy months of spring and autumn. Nevertheless, the absence of a clear annual cycle suggest

[4] The Cadastre of the Marques de la Ensenada in 1756 pointed out that the main agricultural products of Caravaca were wheat, barley and rye. Ref. General File of Simancas: AGS-CE-RG-L463-324.

that the reconstructed precipitation spectrum is mostly limited to flash flood episodes, as well as events associated to the presence of frontal systems.

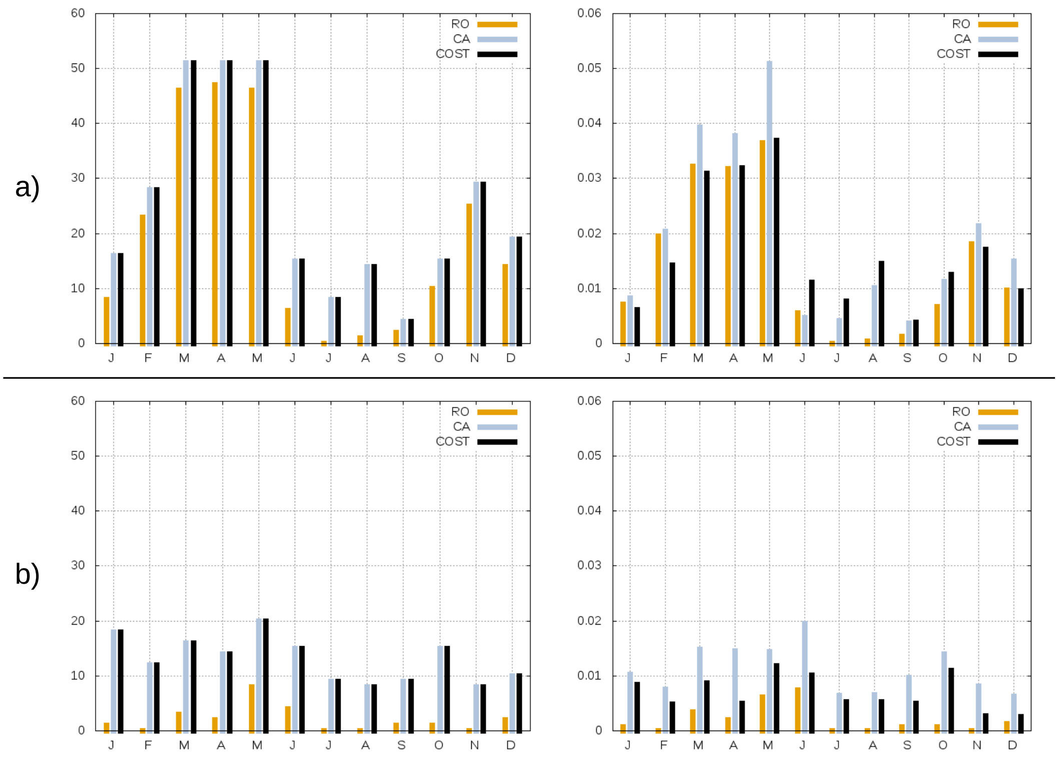

Figure 6: Annual cycle of the values in the series associated to RO, CA and COST. Panel a shows droughts, whereas **panel b** is for rainfall extremes. Left figures represent the frequency (number of months with non-zero values), whereas right figures show the normalised intensity. Intensity is normalised by dividing each data by the maximum value of each serie.

4.2 Seasonal variability and coherence of hydrometeorological extremes

In terms of seasonal and annual drought variability (See Figure 7), the three reconstruction methods coincide in pointing to the same large periods of drought. However, the years of greatest intensity of droughts differ. While for RO the 5 driest years were 1683, 1605, 1655, 1756 and 1606 (being the fifth position shared among with the years 1749, 1765 and 1774), for CA this ranking consists of the years 1627, 1606, 1628, 1660 and 1756. Finally, for COST the five driest years were 1756, 1627, 1879, 1689 and 1628, respectively. In this way, there is a clear inter-method agreement that the years 1606, 1627, 1628 and, especially 1756 were the driest. These droughts are consistent with the results of other works. Corona et al. (1988) detected a severe drought between 1602 and 1606 in the Southwest of the Iberian Peninsula based on dendroclimatic evidence. On the other hand, Martín-Vide and Barriendos (1995: 212) identify 1628 as one of the four driest years in Barcelona in the period between 1525 and 1825. The year 1756 underwent great climatic variability in the Iberian Peninsula, characterized by severe droughts (Cuadrat et al., 2016: 72), aggravated by torrential rains and an important locust plague (Alberola Romá, 1996).

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The seasonal drought values within each year also shows great temporal variability, as well as notable differences between methods. In general, the agricultural model of Caravaca, based on cereal production, magnifies the impact of spring droughts. Winters are however less sensitive, although between 1600 and 1615 winters were especially dry. On the other hand, the autumns of the second half of the 17th century and the 18th century increased the relative weight of droughts in the annual computation. Although the society in Caravaca is adapted to the lack of precipitation in summer, COST, and to a lesser extent CA, indicate very dry summers during the 17th century and in the second half of the 19th century. However, RO is not able to provide any information about droughts during these months due to the lack of rogation ceremonies.

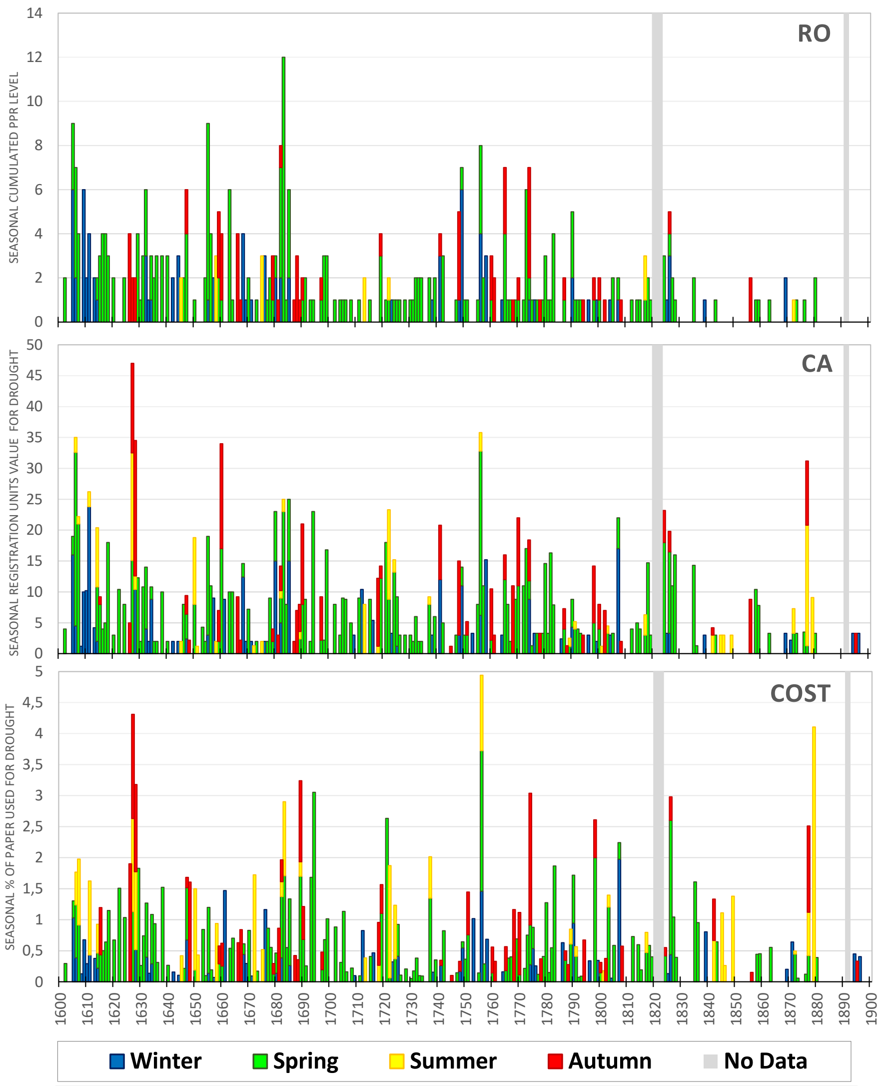

Figure 7: Seasonal values are accumulated for each year. In this way, the annual value is defined as the sum of the four seasonal values for the given year. The values in the y axis are in the unit corresponding to each methodology, i.e. the sum of the Pro-Pluvia Rogations levels for each station in RO, the sum of the values of RU for drought in CA, and the percentage of paper used for drought in each season in COST. *Data gaps (from 1820 to 1823 and 1891 to 1892) are show in grey color.

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The annual and seasonal series of indices associated to rainfall show some interesting aspects (Figure 8). The rarity of rainfall reconstructed by RO is remarkable, with only 4 months with rainfall events throughout the 19th century. This situation reduces the reliability of this method to reconstruct precipitation. Note that this factor does not affect the CA and COST methods, which are able to record a large number of rainfall extremes events throughout the study period. Both CA and COST report wet winters at the end of the 17th century. This period is consistent with the coldest and wettest winters detected for this same period by Alcoforado et al. (2000) in the south of the Iberian Peninsula, and might indicate an strengthening of the zonal circulation associated with the polar front during the late Maunder Minimun (Luterbacher et al., 2001), which is also consistent with climate simulations (Gómez- Navarro, et al., 2011). In the second half of the 18th century, and specially between 1855 and 1870, several wet winters are also detected, being coincident with wet winters in Andalusia (Sánchez-Rodrigo et al., 2000). Spring season shows generally a more homogeneous behavior, without obvious anomalous periods. In autumn and summer, there are notable differences between the CA and COST method. CA tends to exaggerate the intensity of several humid summers and autumns, especially in the seventeenth century. Still, both methods coincide in indicating the autumns of 1740 to 1775 as very humid, such as the autumns of the second half of the 19th century. Barriendos and Llasat (2009) highlight the severity of autumnal rains during the second half of the 19th century, and associate them to a period of strong climatic variability in the east of the Iberian Peninsula, identified as the Maldá Anomaly. Additionally, there are numerous historical studies and testimonies of the epoch[5] that point out the great intensity of autumn rainfall in the Spanish Mediterranean region during the second half of the 19th century (Barriendos and Martín-Vide, 1998; Gil-Guirado, 2013) (Figure 8). In this regards, a strong source of evidence about the intensity of rains in this period is the fact that 5 out of the 10 rainiest years detected by CA and COST are included in the period from 1829 to 1888, including 3 of such years just between 1650 and 1685.

[5] In this climate context, and after the notable damages caused by the continuous floods of the late 19th century in the Southeast of Spain, a number of studies were conducted to try to mitigate the negative impacts of floods. In this regard, the work of Hernandez Amores (1885) entitled: "*Inundaciones de la huerta de Murcia: juicio sobre su frecuente repetición de pocos años a esta parte, sus terribles desastres, sus causas y remedios*" is a prominent example.

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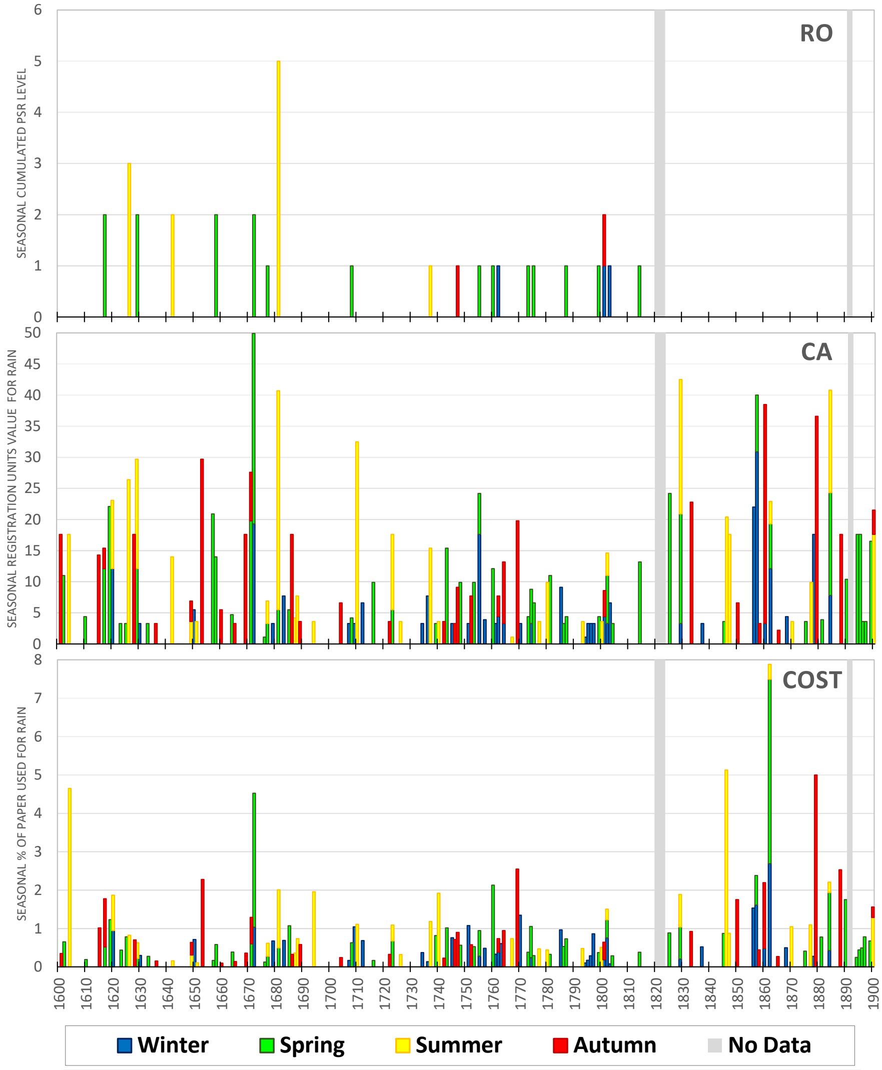

Figure 8: Seasonal extreme rainfall in Caravaca between 1600 and 1900. Seasonal values are accumulated for each year. In this way, the annual value is defined as the sum of the four seasonal values for the given year. The values in the y axis are in the unit corresponding to each methodology, i.e. the sum of the Pro-Serenitate Rogations levels for each station in RO, the sum of the values of RU for drought in CA, and the percentage of paper used for drought in each season in COST. *Data gaps (from 1820 to 1823 and 1891 to 1892) are show in grey color.

To gain insight on the intra-annual differences of variability across the three methods, it is necessary to take into account several considerations. Regarding droughts, it is important to have into account their continuous nature. In this sense, droughts show their social impacts cumulatively over time, which makes it difficult to define clear boundaries (Logar, & van den Bergh, 2013). This can be appreciated in our results counting the number of dry summers that were immediately preceded by a dry spring (See Table 2). More than 50% of summers with a drought were preceded by a spring that was also dry. However, these correlative droughts do not occur as frequently in winter, spring, or autumn. This allows us to infer additional information about the severity of a spring drought when the CA and COST method indicate dry summers. A

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similar analysis reveals clear differences in the case of events related to rainfall. Unlike droughts, rainfalls manifest their impact immediately, and therefore the documents reflect them without delay or references to previous events. This explains the lack of autocorrelation between consecutive seasons. Still, the CA and COST methods detect correlation between wet summers and previous wet springs, (See Table 2).

	CA and COST	RO
Drought		
Dry summer preceded by dry spring	54.55%	28.57%
Dry spring preceded by dry winter	13.95%	12.61%
Dry autumn preceded by dry summer	15.91%	0.00%
Dry winter preceded by dry autumn	16.98%	12.50%
Rain		
Rainy summer preceded by rainy spring	25.81%	0.00%
Rainy spring preceded by rainy winter	16.00%	0.00%
Rainy autumn preceded by rainy summer	6.45%	0.00%
Rainy winter preceded by rainy autumn	10.81%	0.00%

Table 2: Temporal coincidence of drought and rainfall extreme values between consecutive seasons. Each cell shows the percentage the dry/rainy seasons that were preceded by dry/rainy seasons. *The different colours simbolise how much the values deviate above (from white colours to red colours) or below (from blue colours to white colours) from the 50th percentile of the data, respectively.

4.3 Breakpoints and series consistency

The analysis of the consistency of the data involves homogeneity tests that allows to find abrupt changes, as well as to discern whether such changes have either a climatic or a methodological origin. This analysis is carried out for the drought and rainfall reconstructed series separately. For each variable we have applied standard homogenization tests to both, the frequencies of appearance, and the intensities of annual values. We use several non-parametric tests to determine possible changes in the data. Although robust, they all have the disadvantage of being able to identify a single jump in the series. The homogeneity tests include the Pettitt Test (Pettitt, 1979), the Standard Normal Homogeneity Test (SNHT) by Alexandersson (1986) and the Buishand rank test (Buishand, 1982). Due to their similarities, the results are very similar among tests. However, the Pettitt test is the most widely disseminated, while the SNHT has a mathematical predisposition to detect jumps near the beginning and end of the series. On the other hand, the Buishand rank test is more sensitive to inhomogenities in the middle of the series (Renom Molina, 2009). The XLSTAT software (Addinsoft, 2018) has been used for the application of these tests.

For the drought data, the Pettitt test, the SNHT test and the Buishand test identify breakpoints both in intensity and frequency (See Table 3). For RO and COST, the Pettit and Buishand test identify a decrease in the drought intensity towards the end of the 17th century. The Buishand test points to 1783 as a year that marks changes towards lower drought severity conditions. However, all three methods agree in identifying the year 1828 as the one when an abrupt change towards less intense and specially less frequent droughts occurred. We have tried to determine whether this jump is related to an actual change in the climatic conditions, as opposed to a methodological artifact. In this regard, it is important to keep in mind that during this period Spain underwent important social changes and continuous conflicts between the public authorities that invite to be

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overly cautious, not completely ruling out the possibility that the detected breakpoints can be related consistency issues in the documentary sources. The joint analysis of the data and the existing scientific literature discussed in the previous section are consistent with a reduction of droughts from the first third of the 19th century (Barriendos and Martín-Vide, 1998). Further, the Buishand test detects a remarkable increase in rainfall intensity for the COST method after 1844. This increase in rainfall intensity is consistent with the higher rainfall detected in the literature (Sánchez Rodrigo y Barriendos, 2008; Barriendos and Llasat, 2009; Benito, Rico et al., 2010). All these independent sources of insight indicate that the points of rupture identified by the tests are not due to documentary sources. Instead, the changes detected have a climatic nature, which validates the methodology implemented to reconstruct droughts, and render the COST approach the most consistent one to analyze the variability of rainfall.

		Intensity				Frequency			
		T	*p-value*	*1st* $\bar{X}$*	*2nd* $\bar{X}$*	*T*	*p-value*	*1st* $\bar{X}$*	*2nd* $\bar{X}$*
		Pettit Test							
RO	Drought	**1685**	0.0012	2.349	0.943	**1828**	< 0.0001	0.689	0.171
	Rain	1681	0.2408			1814	0.0900		
CA	Drought	**1828**	0.0102	6.862	1.974	**1828**	< 0.0001	0.756	0.329
	Rain	1855	0.2002			1893	0.3477		
COST	Drought	1694	0.0654			**1828**	< 0.0001	0.756	0.329
	Rain	1844	0.1003			1893	0.3812		
		Buishand Range							
RO	Drought	**1783**	< 0.0001	1.837	0.550	**1828**	< 0.0001	0.689	0.171
	Rain	1681	0.0655			**1814**	0.0430	0.102	0
CA	Drought	**1783**	< 0.0001	7.204	3.212	**1828**	< 0.0001	0.756	0.329
	Rain	1855	0.2260			1733	0.2744		
COST	Drought	**1694**	0.0062	0.780	0.446	**1828**	< 0.0001	0.756	0.329
	Rain	**1844**	0.0248	0.328	0,799	1733	0.2744		
		SNHT							
RO	Drought	**1828**	< 0.0001	1.702	0.229	**1828**	< 0.0001	0.689	0.171
	Rain	1814	0.0992			1814	0.0900		
CA	Drought	**1828**	< 0.0001	6.862	1.974	**1828**	< 0.0001	0.756	0.329
	Rain	1735	0.9766			1733	0.5618		
COST	Drought	**1828**	< 0.0001	0.639	0.278	**1828**	< 0.0001	0.756	0.329
	Rain	1735	0.9766			1733	0.5618		

Table 3: Results of the homogenization tests for breackpoint detection.
T refers to the year in which an inhomogeneity is detected in the data. For the calculation of the p-value, 10,000 Monte Carlo simulations are run. Years where the p-value is below the alpha=0.05 level of confidence are highlighted with bold character.
* The 1st $\bar{X}$ refers to the average over the period previous to the breaking point, while the 2nd $\bar{X}$ corresponds to the average for the period after it.

4.4 Secular variability and temporal space coherence of reconstructions

We analyse now the low frequency variability of the reconstructed indices through the analysis of 10, 20 and 30-year running means in Fig. 9. First, it is important to note that all reconstruction methods indicate a significant decline in the number and severity of droughts at the end of the study period, as discussed in the previous section. This decrease is significant (95% level with the Mand-Kendall test) in the summer, autumn and annual series, both in frequency and intensity. Second, the CA and COST methods identify a concurrent increase in rainfall in this period, which is climatically consistent with a decrease in droughts severity, while the RO method shows a decrease in rainfall. Regarding this difference with respect to the other two methods, it is noteworthy that the last PSR is celebrated in 1814, which suggests a loss of homogeneity of the documentary sources, therefore questioning the ability of the RO approach to reconstruct rainfall with this data.

We note that the timing of droughts and rainfall in these series agrees qualitatively with independent paleoclimatic evidence in locations close to the study area (Barriendos, 1996-1997, Barriendos, 1997, Zamora Pastor, 2002, Sanchez Rodrigo & Barriendos, 2008 Benito, Rico et al., 2010, Machado, Benito, Barriendos & Rodrigo, 2011). Regarding droughts, the three methods have a high secular covariability, highlighting the consistency of the three methods to reconstruct the low frequency variability of this variable. Still, RO exhibits periods of decoupling with CA and COST, especially at the end of the series. The periodicity of the droughts presents cycles of approximately 30 years (See Figure 9: a_1 and a_2). Regarding rainfall, the differences among methods are more evident, partly due to the scarcity of RO data from the 19^{th} century. Further, although CA and COST are coherent in wet periods, the differences are more marked than in the case of droughts (See Figure 9: b_1 and b_2). CA tends to exaggerate the intensity of wet periods respect to COST. This can be attributed to the fact that historical documents tend to overstate the description of the effects of heavy rains, since it was customary the application of tax reductions as compensation measure for the catastrophe, therefore introducing a non-climatic bias into the documentary evidence (Gil-Guirado, 2013). Contrarily to this, the COST method is not affected by this subjective bias, therefore becoming a more objective methodology.

The driest period the 17^{th} century is from 1620 to 1630, also reported by dendroclimatic evidence in Southeast Spain (Creus Novau & Saz Sánchez, 2008). The following dry phase takes place during the fourth quarter of the same century, in the Maunder Minimum, and is also reported in the bibliography (Barriendos, 1997, Creus Novau & Saz Sánchez, 2008). The generally low temperatures during this period could be related to a decrease in the Mediterranean Sea temperature, which is the main contributor of moisture to the autumn rains in the East of the Iberian Peninsula (Luterbacher et al., 2001). The 18^{th} century is generally less dry than the previous one, although it presents two important dry periods. The first one around the decade of 1720, and the second one between 1755 and 1785. Some authors have identified a cold phase in the first decades of this century (Mann et al., 2000) as the driver of a northern displacement of the storm fronts associated to the polar front with western flow, which in turn can be related to a positive phase of the NAO index (Creus Novau & Saz Sánchez, 2008, Sánchez Rodrigo and Barriendos, 2008). The 19^{th} century, however, is the least dry of the full period analysed. Still, there are two short-duration arid periods (from 1825 to 1830 and from 1875 to 1880).

A high rainfall period occurred between 1750 and 1800, during the so-called Maldá anomaly, characterized by the consecutive occurrence of drought episodes followed by extraordinary floods with catastrophic consequences (Barriendos & Llasat, 2009; 2010). From all humid periods, the one during the second half of the 19^{th} century stands out. It can be described as the wettest of the studied period, and is a distinct feature of the final phase of the Little Ice Age in the Mediterranean lands of the Iberian Peninsula (Benito, Rico et al., 2010, Machado, Benito, Barriendos & Rodrigo, 2011, Zamora Pastor, 2002, Sánchez Rodrigo y Barriendos, 2008).

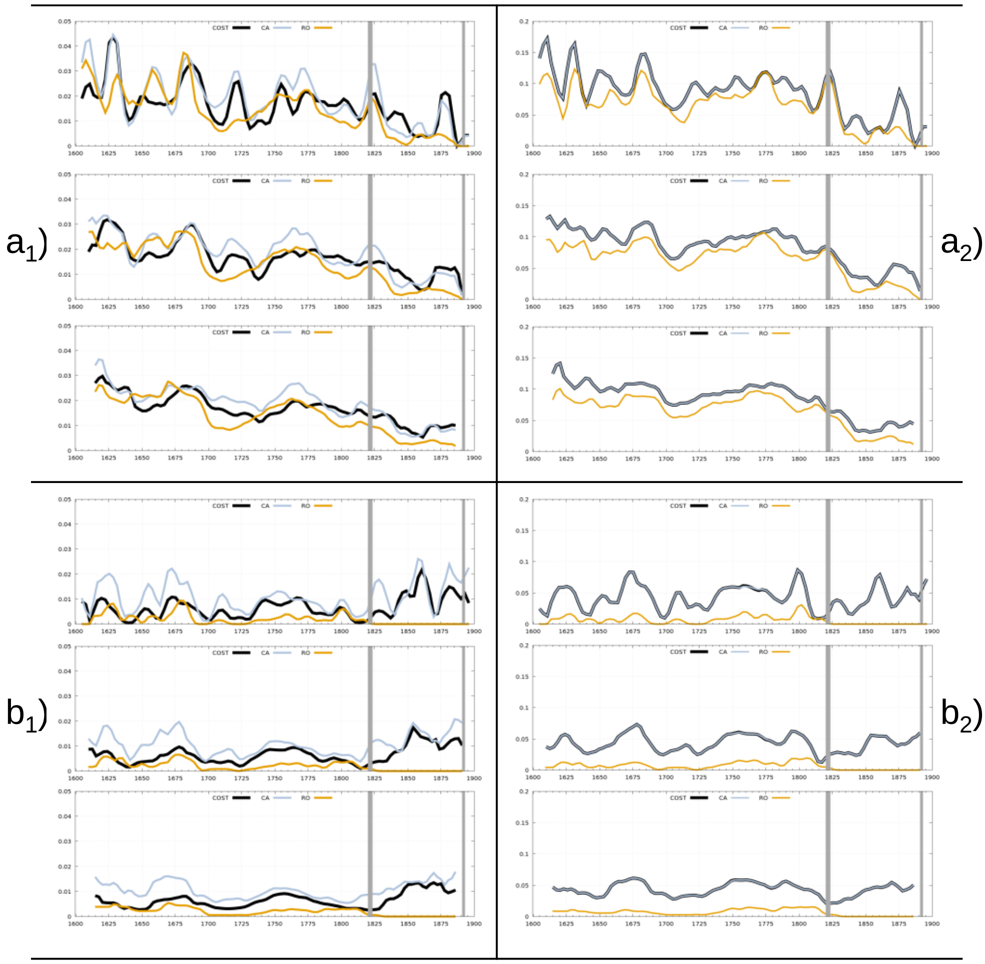

Figure 9: Normalized intensity and occurrence of droughts and rainfall in Caravaca between 1600 and 1900. Series are normalized by dividing each data by the maximum value of each series. The intensity is defined as the normalized monthly value, while the occurrence is defined in a dichotomous way, differentiating between the months when there exist an event, 1, from the months when there is no event, 0. **Panel a_1** shows the running mean of the intensity of droughts, while **Panel a_2** shows the running mean of their occurrence. **Panels b_1** and **b_2** depict the same information, but for the rainfall reconstruction. All panels show the running mean with a temporal window of size 10, 20 and 30 years, respectively. *Data gaps (from 1820 to 1823 and 1891 to 1892) are shown in grey color.

5 Results

Historical climatology has some methodological limitations that make it difficult to produce climatic reconstructions in sparsely populated areas, leading to an important geographic bias in the reconstruction of past climate variability. The richness of documentary heritage worldwide calls for the development of new methodologies that are able to overcome such methodological limitations, allowing the development of new high-resolution multi-secular reconstructions. In this paper we propose a new methodology (the COST method) and compare it with a newly approach of Content Analysis (CA). Both methodologies are identified as robust alternatives to a more classic method consisting on the analysis of Rogations Ceremonies (RO). An improvement of CA and COST, compared to RO, is that the first two are capable of capturing a larger number of drought events than the latter. But the greatest novelty of these approaches is that they allow a reliable reconstruction of events associated to rainfall, while classical methods are limited to reconstruct situations associated to water deficit. This work also demonstrates that the methods implemented enable a reconstructions carried out at monthly basis. In this regard, the validation of the robustness of the monthly results can be established by comparing the output of the reconstructions with the observed annual cycle of rainfall and the progress of agricultural work in the region under analysis.

These three approaches are applied exemplarily to produce the reconstruction of hydrometeorological extremes in a small town in Southern Spain, Caravaca. The three proposed methods identify a decrease in the droughts in the Southeast of the Iberian Peninsula which is compatible with the results of other studies. However, the COST method is the only one able to detect a change towards more intense rains since the middle of the 19th century. This fact indicates that such trends are due to actual climatic variability, rather than to data inhomogenities. All methods detect anomalous key periods during the Little Ice Age that mirror those reported in previous studies. In this regard, a dry phase takes place during the fourth quarter of the 17th century during the Maunder Minimum, related to a decrease in the Mediterranean Sea temperature. Another dry phase occurs around the decade of 1720, and the second one between 1755 and 1785, which can be related with a positive phase of the NAO index. The CA and COST methods also detected a number of wet phases. In this regard, a period of high rainfall occurred between 1750 and 1800, during the so-called Maldá anomaly. From all humid periods, the one during the second half of the 19th century stands out. This period can be described as the wettest of the studied period, and is a distinct feature of the final phase of the Little Ice Age in the Mediterranean lands of the Iberian Peninsula.

Historical climatology techniques are often affected by lack of objectivity, which remains a problem to be taken into account when assessing the reliability of the reconstructions. In this regard, the COST method is a significant step forward in the achievement of more objective approximation to the analysis of historical documents. This method bases its implementation on an economic variable, therefore limiting biases associated to non-climatic matters. Thereby, while RO and the CA can overstate situations of excess or water deficits due to non-climatic motivations, i.e. paying lower taxes as compensation measure, the values of COST present greater homogeneity, being more closely related to the climatic reality of the moment. As COST is based on the amount of discourse around a climatic variable, it enables the possibility to carry out comparative exercises in regions with different languages and ways of understanding the natural environment. Finally, COST has the advantage of begin a simpler approach to the decoding of the documentary information than RO and CA.

In this way, CA, but especially COST, allow the use of currently underexploited documentary evidence, thereby multiplying the potential number of regions where historical techniques can be used to produce new climate reconstructions. We believe this may open new opportunities of field work which to motivate follow up investigations.

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Data availability. The systematic data are not publicly accessible because they are currently being used in an ongoing research project. However, research data required to reproduce the work can be obtained by request addressed to the corresponding author (salvagil.guirado@ua.es).

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