Response to anonymous referee #1:

Many thanks for your kind and helpful comments, we appreciate them very much.

Referee #1: 1) The authors are missing a number of recent important studies regarding historical droughts in Europe. While they are pretty well aware of the research in historical climatology, they are missing works in other fields of high-resolution palaeoclimate science.

Response: Many thanks for this useful and necessary comment. We added the following publications: Helama et al., 2009; Seftigen et al., 2017; Ljungqvist et al., 2019; Metzger and Jacob-Rousseau, 2020.

Referee #1: 2) I am lacking a quantitative comparison between the new documentary-based drought reconstructions and the tree-ring based Old World Drought Atlas. Without such a quantitative comparison it is very hard – or even impossible – to really know the nature of the similarities and disagreements.

Response: We added such a comparison by using Pearson correlation coefficients.

Referee #1: 3) Several of the figures are totally unreadable (and unpublishable). For example, the years are overlapping with each other so it cannot be read: much longer increments (say, 25 years) are needed for a clearer visualization. I also recommend the authors to look at articles in Climate of the Past for getting inspiration how to improve the graphs.

Response: The figures have been modified.

Referee #1: Minor comments: Line 7: Droughts can also be temperature-driven without a decrease in precipitation. I also would consider it an overstatement that droughts belong to the most dangerous natural hazards. ***Response: The sentence has been rephrased.***

Lines 40–42: Add citations to Seftigen et al. 2017, Helama et al. (2009) and Ljungqvist et al. (2019, ERL) here. ***Response: Done.***

Response to anonymous referee #2:

Many thanks for your kind and helpful comments, we appreciate them very much.

Referee #2: 1) I miss the general analysis and direct comparison of the two series in the Results chapter. Here only the greatest extremes are addressed and – despite the fact that the authors have made significant efforts to build up large-scale comparative series from Western Europe – only the greatest large-scale extremes are addressed in brief. Here, I think, a proper comparative analysis should be added: how different the individual series are from the regional series, what could be the reasons (e.g. source availability? Scale of events? Differences in the intensities or impacts on societies? etc.) for these differences (and the similarities).

**** Response: We removed the analyses from the discussion chapter to the results and added more analyses (see also response to referee #1).***

Referee #2: 2) The authors provide direct comparisons of the evidence derived from the two cities in the Discussion chapter. As the entire paper (so as the title) is mainly concentrated on this topic, in my opinion this part of the Discussion chapter should be moved to the Results chapter.

Response: Done.

Referee #2: 3) I think the Discussion chapter could be organised somewhat differently: here smaller but important specific topics could be discussed. I think the discussion of 1473 and 1540, and its different appearance in the two cities are a good idea for one topic (i.e. I would keep it there), but plenty of other important questions could be addressed here. For example, the authors refer to the tree-ring based OWDA as one of the applied databases in the paper: in the Discussion chapter the authors could e.g. systematically compare the OWDA with the documentary evidence and list similarities and potential differences. Other possibility could be, for example, the discussion of uncertainties.

Response: We removed parts of the discussion chapter to the results and added new information concerning a quantitative comparison of the OWDA with the DIB, DIR and SDI to the discussion chapter. We also added a paragraph on the uncertainty of dating.

Referee #2: Minor points: 1) It is rather remarkable that in Rouen only the droughts prior to summer could be detected. In the paper the authors explain this situation with source availability.
I was just wondering: is it possible that for such a large town as Rouen no source exist at all that describe any other part of the year that contains any weather-related information? No any weather(-related) information at all in narratives, no other institutional documentation (e.g. municipal accounts)? It is rather unusual, especially with regards to the later part of the study period – and if this is the case, I think, should be more emphasised in the paper – already in the Source description part. The authors explain this phenomenon mainly with the difference in documentation practice.
We wanted to use one continuous series of sources for each city, therefore we examined the proceedings of the city council. For Bern, there are much too many city accounts in order to read all of them, in the case of Rouen there are too many gaps. Therefore, we decided to analyse the proceedings. In order to get more information, also other documentary data were used, but those do not cover the whole period. We added more information about this decision to the data chapter.
However, documentation practice is always related to 2) Is it really the case that in the documentation of the two cities only and exclusively the great and extreme dry conditions are mentioned, and never even moderate dry conditions? It is true that, usually, references on moderate dry conditions in European documentation are less pronounced. Still, they appear in documentation. Thus, it is a rather interesting and unique fact that, as the authors suggested, in neither of the two cities any “dry conditions” (i.e. without referring to any extreme) have been mentioned. Or, do you mean that all cases when “dry conditions” were mentioned had to be great (i.e. no. 2) or extreme (no. 3) droughts? It is really just a question out of curiosity. The question is also addressed to understand better the level of potential uncertainties of the index values.
In the index -1 means a tendency to dry weather conditions. We did not consider this as droughts and therefore these index values are not included into the drought reconstruction. We added a few words about this.
Referee #2: Minor point: 3) The authors suggest that mainly spring and summer droughts could be detected. This is a typical characteristics in Western and Central Europe (actually, also in Eastern Europe). Does this mean that the authors found no autumn and winter drought mention at all? Or did you find some? Because if you did, it would be perhaps also interesting for a short discussion in the “Discussion” chapter. Maybe not – it is up to you (just for a further potential idea into the Discussion chapter).
Yes, we found a few autumn and winter droughts. We added some more words in order to make this point clearer.

Droughts in Bern and in Rouen from the 14th to the beginning of the 18th century derived from documentary evidence

Chantal Camenisch[1,2], Melanie Salvisberg[1,2]

[1]Oeschger Centre for Climate Change Research, University of Bern, 3012 Bern, Switzerland
[2]Institute of History, Section of Economic, Social and Environmental History, University of Bern, 3012 Bern, Switzerland

Correspondence to: Chantal Camenisch (chantal.camenisch@hist.unibe.ch)

Abstract. Droughts derive from a deficit of precipitation and can also be temperature driven. They ~~belong to the most~~ are dangerous natural hazards for human societies. Documentary data of the pre-modern and early modern times contain direct and indirect information on precipitation that allow the production of reconstructions with the methods of historical climatology. For this study, two drought indices have been created on the basis of documentary data produced in Bern, Switzerland (DIB) and in Rouen, France (DIR) for the period from 1315 to 1715. These two indices have been compared to a third supra-regional drought index (SDI) for Switzerland, Germany, France, the Netherlands, and Belgium synthesised from precipitation reconstruction based on historical climatology. The results of the study show that the documentary data from Bern mainly contain summer droughts, whereas the data from Rouen rather allow the reconstruction of spring droughts. The comparison of the three indices shows that the DIB and the DIR most probably do not contain all actual drought events, but they also detect droughts that do not appear in the SDI. This fact suggests that more documentary data from single places, such as historical city archives, should be examined in the future and added to larger reconstructions in order to obtain more complete drought reconstructions.

1 Introduction

Droughts are ~~among the most~~ threatening and ~~most~~ dangerous natural hazards for human societies. They are complex phenomena deriving from a deficit of water in comparison to normal conditions. They can also be also be temperature-driven (van Loon et al., 2016). Depending on the concerned spheres, droughts can be classified into four different types: 1. meteorological drought, which describes a lack of precipitation over a certain period; 2. agricultural drought, a consequence of the meteorological drought, which affects the growth of crops; 3. hydrological drought, which usually occurs with a time lag after the meteorological and agricultural drought and which manifests in a shortage or lack of water in the water courses such as rivers and lakes; and 4. socio-economic drought, which occurs when a society suffers from the negative economic and social impacts of drought, such as is the case during a subsistence crisis (Heim, 2002; Brázdil et al., 2018). Recent authors (van Loon et al., 2016; Brázdil et al., 2018, Metzger and Jacob-Rousseau, 2020) emphasised the importance of interactions between natural and human spheres in the occurrence and extension of droughts.

In order to understand present and future droughts, it is indispensable to investigate the past and to reconstruct historical droughts. This study aims to contribute to this target with the analysis of documentary evidence from two European cities – Bern in Switzerland and Rouen in Normandy, France – for the period between 1315 and 1715 by answering the following questions: What is the potential of municipal documentary data for the reconstruction of drought in pre-instrumental periods? Which drought years or drought seasons can be found in the documentary data of the two cities? How do these drought reconstructions compare to an over-regional drought index? For this purpose, a separate drought index has been created for each city. As the number of detected droughts is limited for the two places in the pre-modern period – this due to the characteristics of the sources – a third over-regional drought index for the area of modern Switzerland, France, the Netherlands, and Germany has been developed by using a couple of already existing precipitation reconstructions or catalogues with descriptions.

As droughts belong to the most prominent natural hazards, increasing attention has been paid to this topic in recent years. Different approaches of exploring tree-ring data and other archives of nature allow the reconstruction of past droughts (e.g. van der Schrier et al., 2007, 2013; Briffa et al., 2009; Helama et al., 2009; Büntgen et al., 2010a, 2010b; Todd et al., 2013; Neukom et al., 2014; Nash et al., 2016a; van Loon et al., 2016; Haslinger and Blöschl, 2017; Seftigen et al., 2017; Dobrovolný et al., 2018; Ljungqvist et al., 2019). Moreover, with the Old World Drought Atlas (OWDA), a very comprehensive and well accessible overview for Europe over the last two millennia is available (Cook et al., 2015).

Apart from tree-ring analyses, documentary data provide another approach for drought reconstruction of the past. For instance, early instrumental precipitation measurements – often in combination with other documentary data (Hannaford et al., 2015; Brázdil et al., 2019; Erfurt et al., 2019; Harvey-Fishenden et al., 2019) – can be used for the creation of drought series. Moreover, documentary data also form the basis for the reconstruction of individual events (e.g. Dodds et al., 2009; Brázdil et al., 2013; Wetter et al., 2014, Nash et al., 2016b; Kiss, 2017; Camenisch et al., 2020). For periods and regions, where no such early measurement is available, climate indices with the methodology of the historical climatology can be made (e.g. Brázdil et al., 2013, 2016; Možný et al., 2016; Garnier, 2018).

In most cases, the reconstructions presented here either focus on a whole region or they use mainly one source sample as the basis. In this study, the focus lies on two cities – Bern and Rouen – and the documentary data produced there that are known for their satisfying source density. This paper is structured into six sections. After the introduction, the data are presented in detail. The applied methods are discussed in the next section, before the results are presented. Finally, a discussion of the results and a short conclusion follow.

2 Data

In regard to late medieval and early modern times, the weather-sensitive documentary data usually encompass at least narrative sources such as chronicles, annals, and other historiographic texts, as well as administrative sources like account books and ship log books; moreover, pamphlets as well as other early printed media and early weather diaries (Pfister et al., 1999;

Camenisch, 2015a; Garnier, 2018) are included. In general, documentary data contain either direct information or indirect (proxy) information on weather and weather impacts on human societies. In the case of direct information, this means for instance descriptions of weather conditions over a certain period. Depending on the interests of the observer, the sources focus either on descriptions of extreme weather events and natural hazards or, in lucky cases, even serial accounts of weather descriptions that include average weather conditions (Pfister, 1999; Camenisch, 2015b). If sources contain series of proxy data – which give indirect information on weather-related processes such as plant or ice phenology – further statistical analyses are necessary (e.g. Pribyl et al., 2013; Labbé et al., 2019). As the characteristics of the sources are different, it is necessary to consider the potential and the limits of the weather-related information for each source and in some cases even for each record (Camenisch, 2015b).

In this study, two different samples of historical sources are analysed, that concern either the city of Bern in today's Switzerland or the city of Rouen in Normandy, France. The reason for this choice is to examine how a comprehensive source sample of a single place – or in this case two single places – can be of use for drought reconstruction in pre-modern and early modern times. In the period from 1315 to 1715, Bern was an important city situated in the western part of the Swiss Plateau. During the 15th and 16th centuries, the city and republic of Bern was able to expand its political and territorial power and to establish the largest city state in the north of the Alps (Hesse, 2003; Camenisch, 2019). From the 14th to the 18th century, Rouen was a large and flourishing city in Normandy. The city was significant for the political administration of Normandy as well as for the trade of goods between Paris and the Norman coast (Mollat, 1979). However, over the course of the 400 years examined here, the fates of Bern and Rouen changed from time to time, and both cities suffered in certain periods of war, epidemics, and famines. Both cities possess historical archives with extensive documentary data of different origin, context, and purpose. In the case of Bern, mainly narrative sources such as the chronicles of Diebold Schilling (Schilling, 1985) or Johann Haller and Abraham Müslin (Haller and Müslin, 1800) were analysed, together with the proceedings of the city council – the so-called "Ratsmanuale" – and further sources of the cities' administration. For the earliest years, sources from nearby areas have also been taken into consideration. Moreover, drought-related entries from the climate database Euro-Climhist (Pfister and Rohr, 2015) were added to the source sample.

For the drought reconstruction in Rouen, again narrative and historiographic sources were examined, such as the chronicle of Pierre Cochon (Cochon, 1870) and the "déliberations" – the proceedings of the city council of Rouen – in addition to other administrative sources. The reason why exactly these sources were chosen is that at least the proceedings of the council of both cities cover a large part of the investigated period. Municipal accounts were not part of this analysis because for the case of Berne, there are more accounts than could be analysed in a reasonable time, while there are too many gaps for Rouen.

These sources mainly contain descriptions of extreme weather events and no frequent or serial proxies. As droughts are such extreme weather events, this is no disadvantage at all. However, as a consequence, only events remarkable to the contemporary authors appear in these sources, or when the events provoked any action of the city government. This means that most probably not all droughts can be detected with these sources.

The descriptions in the sources are often detailed and contain information regarding the weather impacts on nature, agriculture, and economy, as the following example shows (Cochon, 1870): "And in this year 1422, there was a general abundance of all goods, such as grain. There was good and strong wine, which was wonderful, and likewise an abundance of all fruit. The summer was so dry that the good people living in village in elevated altitudes had to come down to the rivers in order to get drinking water. This weather lasted until mid-October."[1]. However, shorter descriptions also exist that focus only on the weather conditions of a certain period (Schwinkhart, 1941): "In the aforesaid year [1517], a dry and hot summer and autumn occurred from the beginning onwards until the end of the last autumn month (November)."[2] The second example also shows that the authors tend to mention drought and heat together – at least for the spring, summer, and autumn season. This is the reason why it is not always easy to distinguish whether the lack of precipitation or the elevated temperatures were responsible for the impacts. In regard to the initially introduced four drought types, all four types can appear in the sources, as long as they were remarkable enough.

As argued above, it can be anticipated that not all droughts in Bern and Rouen could be detected with this source sample. In order to compare the two city-based series with a larger area, a third index was created. The data for this supra-regional index derive from other already existing climate reconstructions that are based mainly on documentary data rather similar to the already described sources (Buisman, 1996, 1998, 2000, 2006; Schwarz-Zanetti, 1998; Pfister, 1998, 1999; Glaser, 2013; Le Roy Ladurie, 2004).

3 Methods

The characteristics of the documentary data used for this study suggest the creation of unweighted drought indices with the methods of historical climatology. In this research field, creating indices already has a long tradition. Pfister et al. (2018) proposed separate temperature and precipitation indices with a seven-degree scale (see Fig. 1). Brázdil et al. (2013) in their drought reconstruction used all three dry-index values, which gives of course a comprehensive picture.

{Figure 1: Seven-degree precipitation index (Pfister, 1999; Brázdil et al., 2013; Glaser, 2013).}

However, as the sources used here show a tendency to extreme events, only the two index points of extremely dry (-3) and very dry (-2) were used for the reconstruction. The less frequent -1 events are not included in this reconstruction because they would represent a lack of precipitation of less than a few weeks and are therefore not understood as drought. In a first step, the

[1] "Et, en celle année .cccc. xxij., fu tant habundanche de tous bienz universelement, tant blés, vinz si bonz et si fors que c'estoit grant merveille, et semblablement de touz fruytages. Et fist si sec, cet esté, que les bonnes genz des haux villagez ne povoient avoir point d'eaue, s'il n'allassent ès rivierez. Et ainssy se passa le temps jusques en la my octobre."

[2] "In dem obgenanten jare ward ein drochner vnd heyβer summer vnd herbst von anfang bys zů ende des letsten herbstmonat."

sources were searched for drought descriptions. In a second step, these drought descriptions underwent a qualitative analysis, which means the droughts were classified by comparison according to their intensity and duration (Pfister, 1999; Pfister et al., 2018; Glaser, 2013; Camenisch, 2015). To attribute an index value -2 to a drought, at least one and a half months of reduced precipitation had to have been described. These very dry weather conditions could have had either negative or positive impacts, such as a poor or good harvest. Extremely dry (-3) periods lasted at least two months, and the impacts were described as negative, such as the lack of drinking water or harvest failure. Whenever possible, the droughts were attributed to the meteorological season. This has been done for the Drought Index of Bern (DIB) and the Drought Index of Rouen (DIR).

The third index – a Synthesised Drought Index (SDI) for the area of Switzerland, Germany, France, the Netherlands, and Belgium – was created on the basis of already existing precipitation reconstructions (Buisman, 1996, 1998, 2000, 2006; Schwarz-Zanetti, 1998; Pfister, 1998, 1999; Glaser, 2013; Le Roy Ladurie, 2004). Pfister and Schwarz-Zanetti used the same seven-degree scale as that presented in the DIB and the DIR. Buisman and van Engelen used a four-degree index for precipitation and classified an extremely dry season as "- -". In the case of Buisman, Glaser, and Le Roy Ladurie, the descriptions of the different seasons were also taken into account. Because the area of Switzerland, Germany, France, the Netherlands, and Belgium is very large and precipitation patterns are often at a smaller scale with very different impacts, the SDI does not contain a further classification apart from the degrees -2 and -3, and it includes no seasonal division. A drought appears in the SDI only when at least two months were declared as very dry/-2 or extremely dry/-3 and when more than one region was affected. This simplification was necessary due to the different approaches chosen in the used reconstructions and in regard to the complex documentary data which form their basis.

4 Results

The DIB shows droughts over the whole 400 years of the analysed period (see Fig. 2). Most of them were classified as very dry (-2), and only three extremely dry (-3) periods in the years 1462, 1473, and 1540 were described in the Bernese documentary data. There are certain accumulations of drought periods at the end of the 14th century, in the second half of the 15th century, in the middle of the 16th century, and during the 1670s and early 1680s. In the DIR repeated drought periods also appear, but their number is smaller than in Bern. Again, most of them belong to the category of very dry (-2), and only in the years 1624, 1625, and 1684 were extremely dry periods reported. Accumulations of droughts are visible only in the middle of the 16th century, during the 1620s, and during the 1670s and 1680s. There are a few years when both the DIB and the DIR show drought in the same period: 1363, 1546, 1556, 1567, and 1681.

{Figure 2: Drought Index of Bern (DIB) and Drought Index of Rouen (DIR), 1315–1715.}

In regard to the seasonal distribution of the droughts (see Fig. 3), it can be stated that more about the seasonality in Bern is known than in Rouen. In Bern, the descriptions of summer droughts clearly prevail, while in Rouen more spring droughts are reported. The reason for this is that in Rouen repeated rogation ceremonies for the end of a drought are described at the end of May or the beginning of June. As no other information on precipitation is available for most of those years in Rouen, only a spring drought can appear in the reconstruction – even if it is very well possible that the drought did not end with the rogation ceremony. We can only guess as to why no rogation ceremonies are reported for late summer or other seasons, but it is probable that in Rouen the date of such religious practices is linked to the phenology of cultural plants growing in the areas around the city. Drought reports for the winter and autumn seasons are scarcer in both places, but a few examples were found in Bern as well as in Rouen.

{Figure 3: Seasonal distribution of Drought Index of Bern (DIB) and Drought Index of Rouen (DIR), 1315–1715.}

As the SID comprises a much larger area and more independent documentary data, clearly more droughts appear in this synthesised reconstruction (see Fig. 4). It is important to say that the reconstructed droughts in most cases do not concern the whole area – the indicated years only show when drought periods are reported in at least two of the examined regions. However, a cluster of repeated extreme droughts is identifiable in the first half of the 16th century and again in the first half of the 17th century. Only in three years do droughts appear in all three indices: 1556, 1567, and 1681. Between the DIR and the SDI, four years match: 1422, 1624, 1678, and 1684. However, clearly more similarities exist between the DIB and the SDI, because simultaneous drought reports are available for 13 years: 1385, 1393, 1442, 1462, 1471, 1472, 1473, 1517, 1540, 1546, 1558, 1561, and 1676.

{Figure 4: Comparison of Drought Index of Bern (DIB) and Drought Index of Rouen (DIR) with the Synthesised Drought Index (SDI) for Switzerland/Germany/France/the Netherlands/Belgium, 1315–1715.}

The comparison with the SDI also shows that not all droughts are reported in the two examined sets of documentary data. The SDI contains the years with droughts reported somewhere in Switzerland, Germany, France, the Netherlands, and Belgium, and of course it is not meant that all those drought years affected the whole area. Therefore, the number of droughts reconstructed in the SDI is certainly higher than the real occurrences in a single place, and the number is also higher than in the DIB and DIR. Among the drought years in the DIB as well as in the DIR with no corresponding counterpart in the SDI were 1333, 1382, 1549, 1560, 1586, and 1680, for the DIR in 1555 and 1583, and in 1363 for both the DIB and the DIR.

More detailed descriptions are presented below for those years which were reported as very dry or extremely dry in all three reconstructions. These are not necessarily the years with the highest number of source descriptions. For the years 1473 and 1540 many more descriptions are available (Wetter et al., 2014; Camenisch et al., 2020), but those years appear only in the DIB and the SDI.

The year 1556

A Bernese source tells us that in the year 1556 a very hot and dry summer occurred. A great quantity of good wine for low prices was available, whereas there was not much grain. This was the reason why grain prices increased, and from mid-November high prices had to be paid. In the Bernese highlands a cattle murrain raged (Haller and Müslin, 1800). In Rouen, apart from the short mention of a drought and heat period, long descriptions of governmentally organised cleaning of the streets and the river Seine appear in the proceedings of the city council. The city council also specifically prohibited throwing any garbage onto the streets or into the river during the whole summer, because it could disturb the traffic on the river. In the meantime, Rouen suffered from a terrible epidemic disease, which was linked to the heat in the eyes of contemporaries (Déliberations de la ville de Rouen, 1556). In southern Germany, the drought already started in spring and in the course of summer the extreme lack of precipitation affected the whole area. The drought lasted at least until November, only locally interrupted by downpours of rain and the following floods at the beginning of July. France was also hit by extreme heat and drought. The consequences of these weather conditions were a very early beginning of the vintage, but also poor harvest (this due to the lack of water), low water levels, and the drying up of brooks and swamps (Glaser, 2013; Le Roy Ladurie, 2004).

The year 1567

In 1567, it is again Haller who described a dry but cold late spring (Haller and Müslin, 1800). As a consequence, the hay harvest was poor in the area of Bern. In Rouen, not much information is given about the weather conditions apart from the note that at the end of May the archiepiscopal administration organised a rogation in order to end the drought (Déliberations du chapitre de la cathédrale de Rouen, 1567). Such a procession is held only when the problems resulting from a drought are already severe. Also in Germany, spring, summer, and autumn were clearly too dry, which led at least to an above-average vintage. As a consequence of the drought, wildfires raged in the Thuringian forest and the Harz.

The year 1681

For the year 1681, the Euro-Climhist database provides us with several pieces of information about little or no precipitation in the area of Bern in late spring and summer (Pfister and Rohr, 2015). At the beginning of June, a rogation ceremony was held by the city government of Rouen. The reason for this was a drought period, as described in the council proceedings (Déliberations de la ville de Rouen, 1681). As Le Roy Ladurie (2004) described, other parts of France also suffered from this dry spell. The grain prices at least remained at a moderate level. In Germany, spring was already very dry, and in summer rain

showers occurred only on scarce occasions and never with a sufficient amount of water. These weather conditions did not change before autumn, when a wet and unsettled period started (Glaser, 2013).

The comparison between the DIB and the DIR raises the question of why such a diverging number of droughts is possible in two rather similar sets of documentary data. The answer reveals a deeper insight into the characteristics of the source types used and about the potential of these municipal documentary data. Both data sets contain administrative sources, such as the proceedings of the city council as well as narrative sources. Both source types report only very dry or extremely dry periods. In regard to the proceedings of the city council, this was only the case when the councils were forced to react to negative impacts of (extreme) droughts, while the narrative sources usually focus on outstanding events in general. It also seems that the narrative sources in Bern are more drought sensitive than those of Rouen. Moreover, for Bern more narrative sources are available. This is most probably the reason for the different frequency of drought descriptions.

5 Discussion

The information from the DIB and the DIR presented here show droughts in Bern and Rouen for a period of 400 years, there are similarities between the two and also in comparison to the SDI.

Nonetheless, it is striking that extreme drought years such as 1473 and 1540 are reported only in Bern but not in Rouen. In the case of 1473, there is a gap in the proceedings of the city council in Rouen, and the other examined sources do not mention the weather conditions of this year. However, the OWDA shows that this drought also affected Normandy (see Fig. 5a). The case of 1540 is a bit different. In this year, the source density seems sufficient, but maybe the lack of precipitation was not severe enough in Normandy to provoke any reactions by the city government. At least the OWDA suggests more precipitation in Normandy than in other European regions in that year (see Fig. 5b). These example of two extreme drought years demonstrate that, when sources such as these proceedings of the city council are examined, it is possible that even major events are not recorded. For this reason, it is advisable to investigate several locations in order to minimize errors and gaps.

{Figure 5a: Map of the year 1473 from the OWDA. Figure 5b: Map of the year 1540 from the OWDA (Cook et al., 2015).}

Moreover, a quantitative comparison of the DIB, DIR and SDI to the OWDA for approximately the same area as was examined for the SDI (45.09°N - 53.92°N, -3.91°E - -15.23°E) was made for this research. Of course, the DIB, DIR and SDI series reconstructed here only show extreme events, whereas the OWDA is a continuous series, so the quality and characteristics of the data are quite different. However, Pearson correlations show certain but not too strong similarities between the DIB and

the OWDA (r=0.32), the DIR and the OWDA (r=0.22) and the SDI and the OWDA (r=0.42) – although only the latter result is statistically significant.

A direct comparison of very dry years in the OWDA with the here presented reconstructions also shows matching years. For this purpose, all values of the Palmer Drought Severity Index (PDSI) applied in the OWDA of -2.5 or less were taken into account, which includes the drier half of moderate droughts, the severe and the extreme droughts. Most of the matching years can be found in the comparison of the OWDA to the SDI: 1325, 1326, 1360, 1385, 1397, 1420, 1422, 1434, 1442, 1447, 1462, 1473, 1504, 1517, 1540, 1590, 1603, 1616, 1624, 1636, 1644, 1653, 1666, 1676, 1681 and 1684. Also, the comparison of the OWDA to the DIB still shows a number of matches (1385, 1442, 1462, 1473, 1517, 1540, 1676, 1681) whereas the DIR and OWDA only share a few common drought years (1422, 1624, 1681, 1684). In some cases, such as 1371, 1384, 1394 1464, 1461, 1525 and 1635 droughts in the DIB, DIR or SDI occurred one year earlier or later than in the OWDA. The reason for this could be an uncertainty in the dating of the documentary data. In cases when the information derives from the proceedings of the city councils, dating errors are unlikely. However, if the data are taken from chronicles and other retrospective narrative texts uncertainty in dating should be considered. Other years do not show a congruence. In these cases, it needs to be recalled that the tree-ring-based OWDA mainly shows spring and summer droughts, while the DIB and DIR also contain autumn and winter droughts.

6 Conclusion

The DIB and DIR indices presented here show drought reconstructions of two data sets of municipal documentary data over 400 years. On the basis of the information given in the sources, it was possible to distinguish between very dry and extremely dry periods by comparing the descriptions of the weather conditions and the impacts on society. Although the sources have a tendency to report outstanding and extreme events, in both the cities of Bern and Rouen very dry periods occur clearly more frequently than do extremely dry periods. In many cases, the droughts could be attributed to certain seasons. In both reconstructions, droughts appear mostly in spring and summer. A comparison to a third drought index for the areas of Switzerland, Germany, France, the Netherlands, and Belgium shows that most probably not all droughts could be detected in the sources of Bern and Rouen. But this also shows that the DIB and the DIR contain droughts that are not known to the SDI. A last comparison to the OWDA reveals that many of the drought years reported in Bern and/or Rouen were also visible in tree-ring-based reconstructions. This means that the analysis of geographically limited source samples such as data sets of municipal sources can contribute to a more detailed understanding of the extent and severity of droughts. In some cases, these types of data sets even have the ability to detect so far unknown droughts. For future research, investigators should consider whether more drought reconstructions of single places with sufficient data density can be made and whether they can be linked to a larger grid of drought reconstructions.

Acknowledgement

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References

Brázdil, R., Dobrovolný, P., Trnka, M., Kotyza, O., Řezníčková, L., Valášek, H., Zahradníček, P., and Štěpánek, P.: Droughts in the Czech Lands, 1090–2012 AD, Clim. Past, 9, 1985–2002, https://doi.org/10.5194/cp-9-1985-2013, 2013.

Brázdil, R., Dobrovolný, P., Trnka, M., Büntgen, U., Řezníčková, L., Kotyza, O., Valášek, H., and Štěpánek, P.: Documentary and instrumental-based drought indices for the Czech Lands back to AD1501, Clim. Res., 70, 103–117, https://doi.org/10.3354/cr01380, 2016.

Brázdil, R., Kiss, A., Luterbacher, J., Nash, D. J., and Řezníčková, L.: Documentary data and the study of past droughts. A global state of the art, Clim. Past, 14, 1915–1960, https://doi.org/10.5194/cp-14-1915-20182018, 2018.

Brázdil, R., Demarée, G. R., Kiss, A., Dobrovolný, P., Chromá, K., Trnka, M., Dolák, L., Řezníčková, L., Zahradníček, P., Limanowka, D., and Jourdain, S.: The extreme drought of 1842 in Europe as described by both documentary data and instrumental measurements, Clim. Past Discuss., https://doi.org/10.5194/cp-2019-77, in review, 2019.

Briffa, K. R., van der Schrier, G., and Jones, P. D.: Wet and dry summers in Europe since 1750: evidence of increasing drought, Int. J. Climatol., 29, 1894–1905, https://doi.org/10.1002/joc.1836, 2009.

Buisman, J.: Duizend jaar weer, wind en water in de Lage Landen, 2 (1300–1450), edited by: van Engelen, A. F. V., Van Wijnen, Franeker, Netherlands, 1996 (in Dutch).

Buisman, J.: Duizend jaar weer, wind en water in de Lage Landen, 3 (1450–1575), edited by: van Engelen, A. F. V., Van Wijnen, Franeker, 1998 (in Dutch).

Buisman, J.: Duizend jaar weer, wind en water in de Lage Landen, 4 (1575–1675), edited by: van Engelen, A. F. V., Van Wijnen, Franeker, Netherlands, 2000 (in Dutch).

Buisman, J.: Duizend jaar weer, wind en water in de Lage Landen, 5 (1675-1750), edited by: van Engelen, A. F. V., Van Wijnen, Franeker, Netherlands, 2006 (in Dutch).

Büntgen, U., Brázdil, R., Frank, D., and Esper, J.: Three centuries of Slovakian drought dynamics, Clim. Dynam., 35, 315–329, https://doi.org/10.1007/s00382-009-0563-2, 2010a.

Büntgen, U., Trouet, V., Frank, D., Leuschner, H. H., Friedrichs, D., Luterbacher, J., and Esper, J.: Tree-ring indicators of German summer drought over the last millennium, Quaternary Sci. Rev., 29, 1005–1016, https://doi.org/10.1016/j.quascirev.2010.01.003, 2010b.

Camenisch, C.: Endless cold: a seasonal reconstruction of temperature and precipitation in the Burgundian Low Countries during the 15th century based on documentary evidence, Clim. Past, 11, 1049–1066, doi:10.5194/cp-11-1049-2015, 2015a.

Camenisch, C.: Endlose Kälte. Witterungsverlauf und Getreidepreise in den Burgundischen Niederlanden im 15. Jahrhundert (Wirtschafts-, Sozial- und Umweltgeschichte 5), Schwabe Verlag, Basel, 2015b (in German).

Camenisch, C.: "We did not eat bread for two or three months." Subsistence crises in the town and republic of Berne from 1315 to 1715, Food and History, 17, in print, 2019.

Camenisch, C., Brázdil, R., Kiss, A., Pfister, C., Wetter, O., Rohr, C., Contino, A., and Retsö, D.: Extreme heat and drought of 1473 and their impacts in Europe in the context of the early 1470s, Reg. Environ. Change, 20, 19, https://doi.org/10.1007/s10113-020-01601-0, 2020.

Cochon, P.: Chronique normande de Pierre Cochon, notaire apostolique à Rouen, edited by: de Robillard de Beaurepaire, C., A. Le Brumet, Rouen, 1870 (in French).

Cook, E. R., Seager, R., Kushnir, Y., Briffa, K. R., Büntgen, U., Frank, D., Krusic, P. J., Tegel, W., van der Schrier, G., Andreu-Heyles, L., Bailie, M., Baittinger, C., Bleicher, N., Bonde, N., Brown, D., Carrer, M., Cooper, R., Cŭfar, K., Dittmar, C., Esper, J., Griggs, C., Gunnarson, B., Günther, B., Gutierrez, E., Haneca, K., Helama, S., Herzig, F., Heussner, K.-U., Hofmann, J., Janda, P., Kontic, R., Köse, N., Kyncl, T., Levanič, T., Linderholm, H., Manning, S., Melvin, T. M., Miles, D., Neuwirth, B., Nicolussi, K., Nola, P., Panayotov, M., Popa, I., Rothe, A., Seftigen, K., Seim, A., Svarva, H., Svoboda, M., Thun, T., Timonen, M., Touchan, R., Trotsiuk, V., Trouet, V., Walder, F., Wazny, T., Wilson, R., and Zang, C.: Old World megadroughts and pluvials during the Common Era, Sci. Adv., 1, e150061, https://doi.org/10.1126/sciadv.1500561, 2015.

Déliberations de la ville de Rouen, Archives départementales de Seine-Maritime, Rouen, 003E001/ANC/A17, 1556.

Déliberations de la ville de Rouen, Archives départementales de Seine-Maritime, Rouen, 003E001/ANC/A28, 1681.

Déliberations du chapitre de la cathédrale de Rouen, Archives départementales de Seine-Maritime, Rouen, G/2168, 1567.

Dobrovolný, P., Brázdil, R., Trnka, M., Rybníček, M., Kolář, T., Možný, M., Kyncl, T., and Büntgen, U.: A 500-year multi-proxy drought reconstruction for the Czech Lands, Clim. Past Discuss., https://doi.org/10.5194/cp-2018-160, 2018.

Dodds, S. F., Burnette, D. J., and Mock, C. J.: Historical accounts of the drought and hurricane season of 1860, in: Historical Climate Variability and Impacts in North America, Springer ScienceCBusiness Media B.V., edited by: Dupigny-Giroux, L.-A., and Mock, C. J., Dordrecht, Heidelberg, London, New York, 61–77, 2009.

Erfurt, M., Glaser, R., and Blauhut, V.: Changing impacts and societal responses to drought in southwestern Germany since 1800, Reg. Environ. Change, https://doi.org/10.1007/s10113-019-01522-7, 2019.

Garnier, E.: Historic drought from archives. Beyond the instrumental record, in: Drought. Science and Policy, edited by: Iglesias, A., Assimacopoulos, D., and Van Lanen, H. A. J., Wiley, Hoboken, 45–67, 2018.

Glaser, R.: Klimageschichte Mitteleuropas, 1200 Jahre Wetter, Klima, Katastrophen: Mit Prognosen für das 21. Jahrhundert, 3rd Edn., Primus, Darmstadt, 2013 (in German).

Haller, J., and Müslin, A.: Chronik aus den hinterlassenen Handschriften des Joh. Haller und Abraham Müslin von 1550 bis 1580, D. Sutermeister, Zofingen, 1800 (in German).

Hannaford, M. J., Jones, J. M., and Bigg, G. R.: Early-nineteenth-century southern African precipitation reconstructions from ships' logbooks, Holocene, 25, 379–390, https://doi.org/10.1177/0959683614557573, 2015.

Harvey-Fishenden, A., Macdonald, N. and Bowen, J.P.: Dry weather fears of Britain's early 'industrial' canal network, Reg. Environ. Change, https://doi.org/10.1007/s10113-019-01524-5, 2019.

Haslinger, K. and Blöschl, G.: Space-time patterns of meteorological drought events in the European Greater Alpine Region over the past 210 year, Water Resour. Res., 53, 9807–9823, https://doi.org/10.1002/2017WR020797, 2017.

Heim, R. R.: A review of twentieth-century drought indices used in the United States, B. Am. Meteorol. Soc., 83, 1149–1165, 2002.

Helama, S., Merilainen, J., and Tuomenvirta, H.: Multicentennial megadrought in northern Europe coincided with a global El Nino-Southern Oscillation drought pattern during the Medieval Climate Anomaly, Geology, 37, 175–178, https://doi.org/10.1130/g25329a.1, 2009.

Hesse, C.: Expansion und Ausbau. Das Territorium Berns und seine Verwaltung im 15. Jahrhundert, in: Berns grosse Zeit. Das 15. Jahrhundert neu entdeckt (Berner Zeiten 2), edited by: Beer, E. J., Gramaccini, N., Gutscher-Schmid, C., and Schwinges, R. C., Stämpfli Verlag, Bern, 330–348, 2003 (in German).

Kiss, A.: Droughts and low water levels in late Medieval Hungary II: 1361, 1439, 1443–4, 1455, 1473, 1480, 1482(?), 1502–3, 1506: Documentary versus tree-ring (OWDA) evidence, J. Environ. Geogr., 10, 43–56, https://doi.org/10.1515/jengeo-2017-0012, 2017.

Labbé, T., Pfister, C., Brönnimann, S., Rousseau, D., Franke, J., and Bois, B.: The longest homogeneous series of grape harvest dates, Beaune 1354–2018, and its significance for the understanding of past and present climate, Clim. Past., 15, 1485–1501, https://doi.org/10.5194/cp-15-1485-2019, 2019.

Le Roy Ladurie, E.: Canicules et glaciers (XIIIe-XVIIIe siècles), Histoire humaine et comparée du climat, 1, Fayard, Paris, 2004 (in French).

Ljungqvist, F. C., Seim, A., Krusic, P. J., González-Rouco J. F., Werner, J. P., Cook, E. R., Zorita, E., Luterbacher, J., Xoplaki, E., Destouni, G., García-Bustamante, E., Melo Aguilar, C. A., Seftigen, K., Wang, J., Gagen, M. H., Esper, J., Solomina, O., Fleitmann, D., Büntgen, U.: European warm-season temperature and hydroclimate since 850 CE, Environ. Res. Lett., 14/7, 084015. doi: 10.1088/1748-9326/ab2c7e, 2019.

Metzger, A. and Jacob-Rousseau, N.: The 1857–1858 drought in Alsace: from water shortage to a socio-political extreme event, Reg. Environ. Change, 20, 48, 2020.

Mollat, M. (Ed.): Histoire de Rouen, Privat, Toulouse, 1979 (in French).

Možný, M., Brázdil, R., Dobrovolný, P., Trnka, M., Potopová, V., Hlavinka, P., Bartošová, L., Zahradníˇcek, P., and Žalud, Z.: Drought reconstruction based on grape harvest dates for the Czech Lands, 1499–2012, Clim. Res., 70, 119–132, https://doi.org/10.3354/cr01423, 2016.

Nash, D. J., De Cort, G., Chase, B. M., Verschuren, D., Nicholson, S. E., Shanahan, T. M., Asrat, A., Lézine, A.-M., and Grab, S.: African hydroclimatic variability during the last 2000 years, Quaternary Sci. Rev., 154, 1–22, https://doi.org/10.1016/j.quascirev.2016.10.012, 2016a.

Nash, D. J., Pribyl, K., Klein, J., Neukom, R., Endfield, G. H., Adamson, G. C. D., and Kniveton, D. R.: Seasonal rainfall variability in southeast Africa during the nineteenth century reconstructed from documentary sources, Clim. Change, 134, 605–619, https://doi.org/10.1007/s10584-015-1550-8, 2016b.

Neukom, R., Nash, D. J., Endfield, G. H., Grab, S. W., Grove, C. A., Kelso, C., Vogel, C. H., and Zinke, J.: Multi-proxy summer and winter precipitation reconstruction for southern Africa over the last 200 years, Clim. Dynam., 42, 2713–2716, https://doi.org/10.1007/s00382-013-1886-6, 2014.

Pfister, C.: Raum-zeitliche Rekonstruktion von Witterungsanomalien und Naturkatastrophen 1496–1995 (unter Mitarbeit von Daniel Brändli. Schlussbericht zum Projekt 4031-33198 des NFP 31), vdf Hochschulverlag AG an der ETH, Zürich, 1998.

Pfister, C.: Wetternachhersage. 500 Jahre Klimavariationen und Naturkatastrophen (1496–1995), Haupt Verlag, Bern, 1999 (in German).

Pfister, C., and Rohr, C. (eds.): Euro-Climhist. Information System on the History of Weather and Climate (http://www.euroclimhist.unibe.ch, doi:10.7892/boris.73059), 2015.

Pfister, C., Brázdil, R., Glaser, R., Barriendos, M., Camuffo, D., Deutsch, M., Dobrovolný, P., Enzi, S., Guidoboni, E., Kotyza, O., Militzer, S., Rácz, L. and Rodrigo, F.: Documentary evidence on climate in sixteenth-century Europe, Clim. Change, 43, 55–110, doi:10.1023/A:1005540707792, 1999.

Pfister, C., Camenisch, C., and Dobrovolný, P.: Analysis and interpretation: temperature and precipitation indices, in: The Palgrave Handbook of Climate History, edited by: White, S., Pfister, C., and Mauelshagen, F., Palgrave Macmillan, London, 115–129, 2018.

Pribyl, K., Cornes, R. C., and Pfister, C.: Reconstructing medieval April-July mean temperatures in East Anglia, 1256–1431, Climatic Change, 113, 393–412, 2012.

Schilling, D.: Textedition, edited by: Ladner, P., in: Die grosse Burgunderchronik des Diebold Schilling von Bern "Zürcher Schilling". Kommentar zur Faksimile-Ausgabe der Handschrift Ms. A5 der Zentralbibliothek Zürich, edited by: Schmid, A. A., Faksimile Verlag, Luzern, 93–288, 1985.

Schwarz-Zanetti, G.: Grundzüge der Klima- und Umweltgeschichte des Hoch- und Spätmittelalters in Mitteleuropa, Ph.D. thesis, University of Zurich, Zurich, 1998 (in German).

Schwinkhart, L.: Chronik 1506 bis 1521, edited by: v. Greyerz, H., and Schlaepfer, R., H. Lang & Co., Bern, 1941 (in German).

Todd, B., Macdonald, N., Chiverrell, R. C., Caminade, C., and Hooke, J. M.: Severity, duration and frequency of drought in SE England from 1697 to 2011, Clim. Change, 121, 673–687, https://doi.org/10.1007/s10584-013-0970-6, 2013.

Seftigen, K., Goosse, H., Klein, F., Deliang, C.: Hydroclimate variability in Scandinavia over the last millennium – insights from a climate model-proxy data comparison, Clim. Past, 13, 1831–1850, https://doi.org/10.5194/cp-13-1831-2017, 2017.

Van der Schrier, G., Efthymiadis, D., Briffa, K. R., and Jones, P. D.: European Alpine moisture variability 1800–2003, Int. J. Climatol., 27, 415–427, https://doi.org/10.1002/joc.1411, 2007.

Van der Schrier, G., Barichivich, J., Briffa, K. R., and Jones, P. D.: A scPDSI-based global dataset of dry and wet spells for 1901–2009, J. Geophys. Res., 118, 4025–4048, https://doi.org/10.1002/jgrd.50355, 2013.

Van Loon, A. F., Stahl, K., Di Baldassarre, J., Clark, J., Rangecroft, S., Wanders, N., Gleeson, T., Van Dijk, A. IJ. M., Tallaksen, L. M., Hannaford, J., Uijlenhoet, R., Teuling, A. J., Hannah, D. M., Sheffield, J., Svoboda, M., Verberein, B., Wagener, T. and Van Lanen, H. A. J.: Drought in a human-modified world: reframing drought definitions, understanding, and analysis approaches, Hydrol. Earth Syst. Sci., 20, 3631–3650, doi:10.5194/hess-20-3631-2016, 2016.

Wetter, O., Pfister, C., Werner, J. P., Zorita, E., Wagner, S., Seneviratne, S. I., Herget, J., Grünewald, U., Luterbacher, J., Alcoforado, M.-J., Barriendos, M., Bieber, U., Brázdil, R., Burmeister, K. H., Camenisch, C., Contino, A., Dobrovolný, P., Glaser, R., Himmelsbach, I., Kiss, A., Kotyza, O., Labbé, T., Limanówka, D., Litzenburger, L., Nordli, Ø., Pribyl, K., Retsö, D., Riemann, D., Rohr, C., Siegfried, W., Söderberg, J., and Spring, J.-L.: The year-long unprecedented European heat and drought of 1540 – a worst case, Clim. Change, 125, 349–363, https://doi.org/10.1007/s10584-014-1184-2, 2014.

Figures

-3	-2	-1	0	1	2	3
Extremely dry	Very dry	Dry	Normal	Wet	Very wet	Extremely wet

Figure 1: Seven-degree precipitation index (Pfister, 1999; Brázdil et al., 2013; Glaser, 2013).

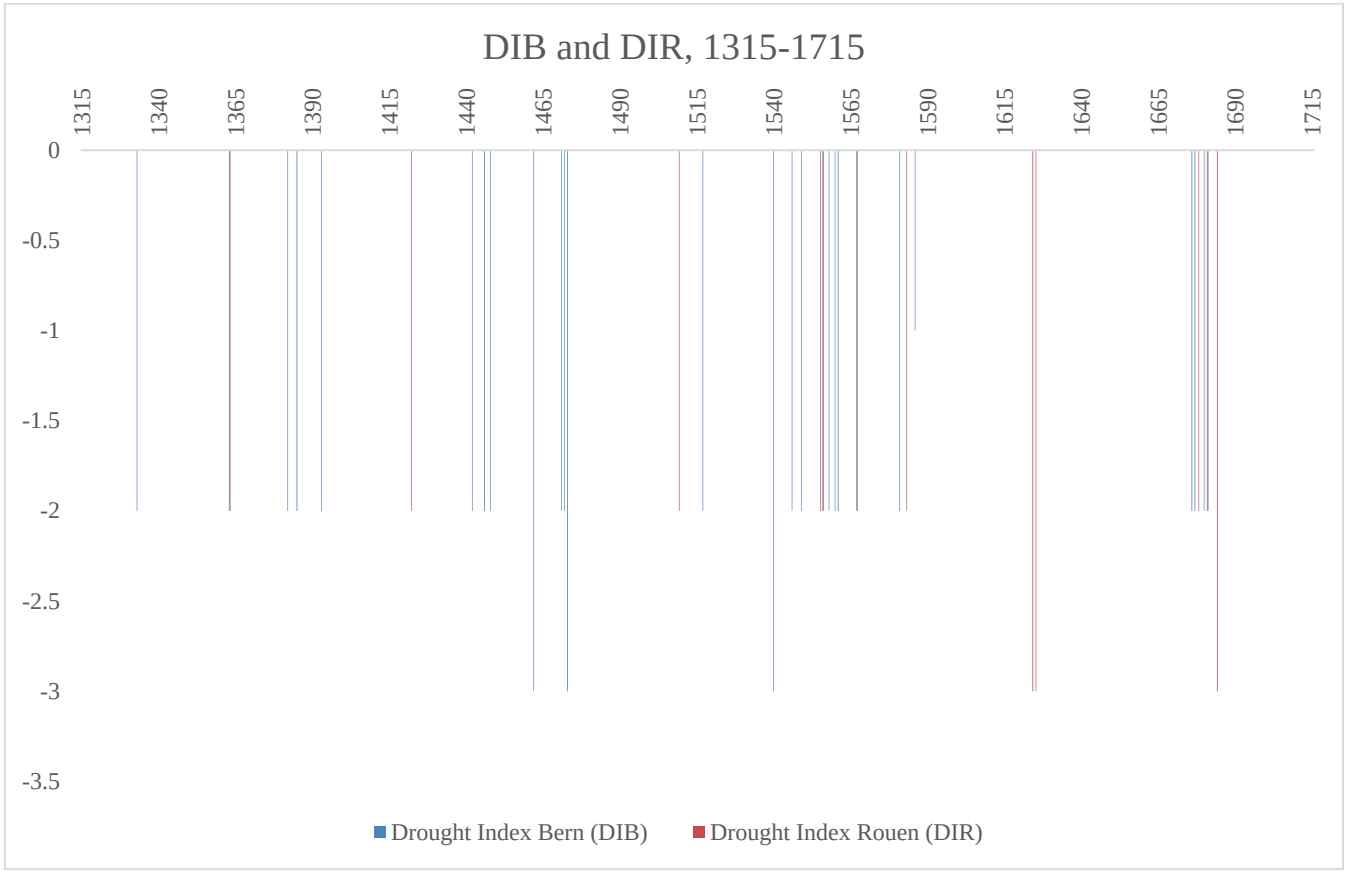

Figure 2: Drought Index of Bern (DIB) and Drought Index of Rouen (DIR), 1315–1715.

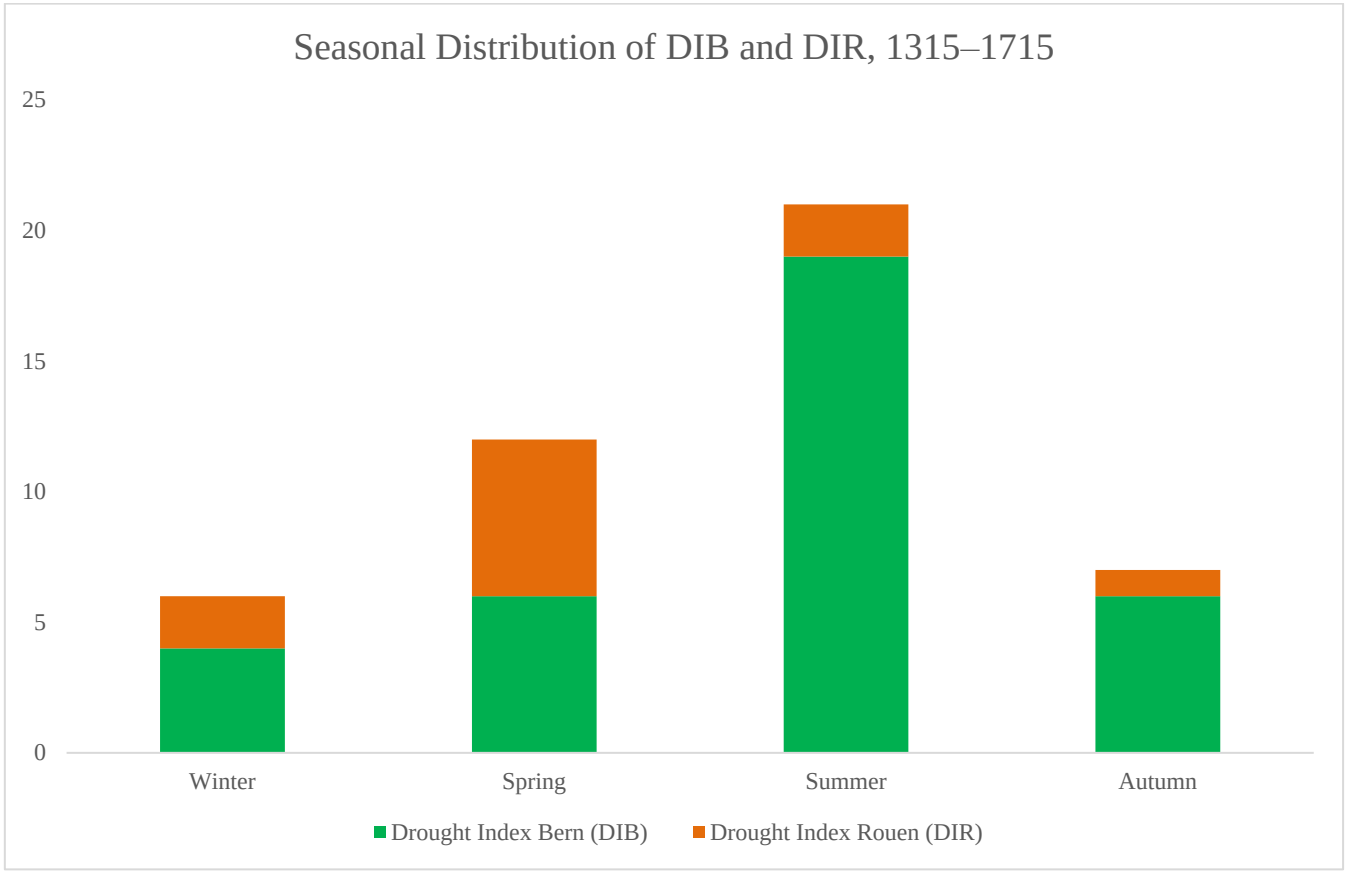

Figure 3: Seasonal distribution of Drought Index of Bern (DIB) and Drought Index of Rouen (DIR), 1315–1715.

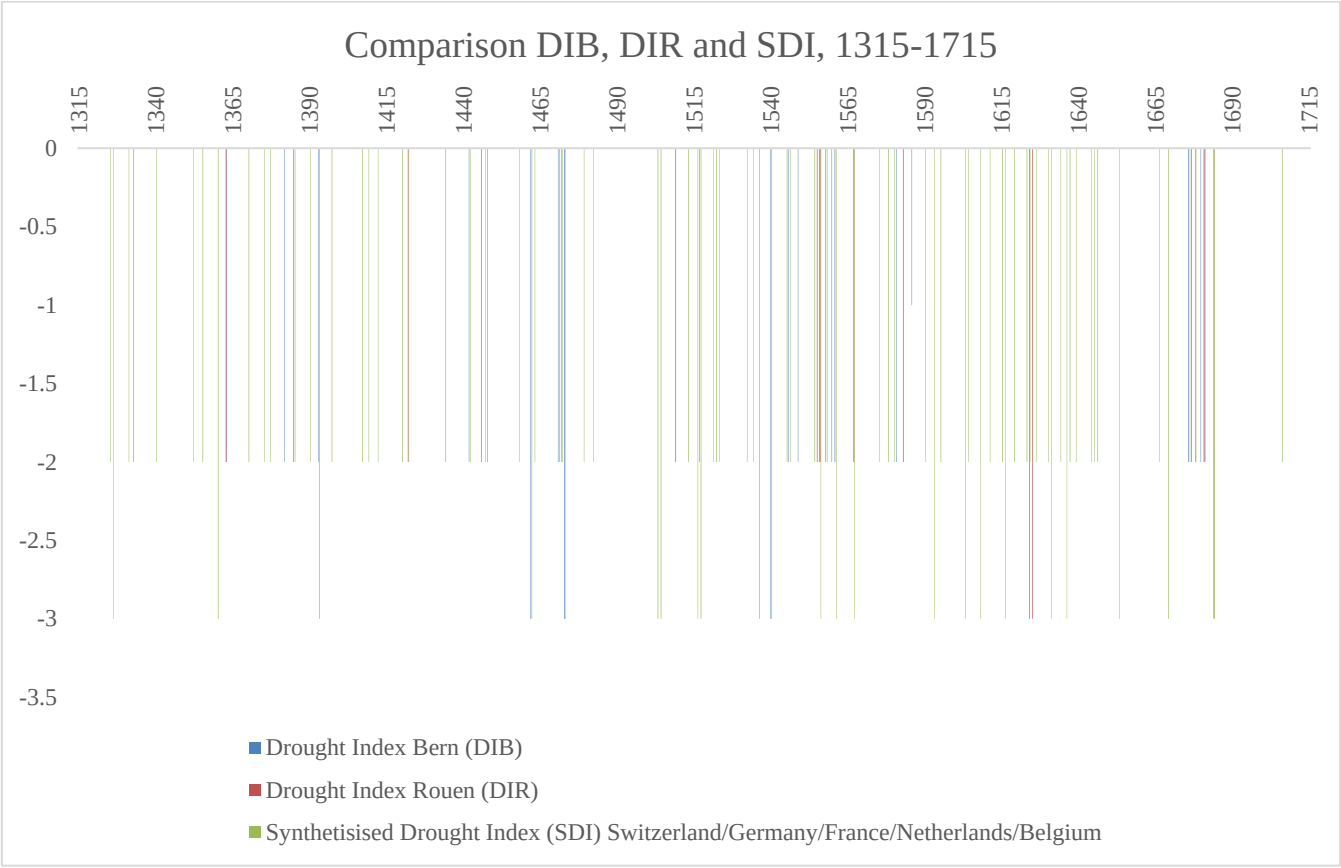

Figure 4: Comparison of Drought Index of Bern (DIB) and Drought Index of Rouen (DIR) with the Synthesised Drought Index (SDI) for Switzerland/Germany/France/the Netherlands/Belgium, 1315-1715.

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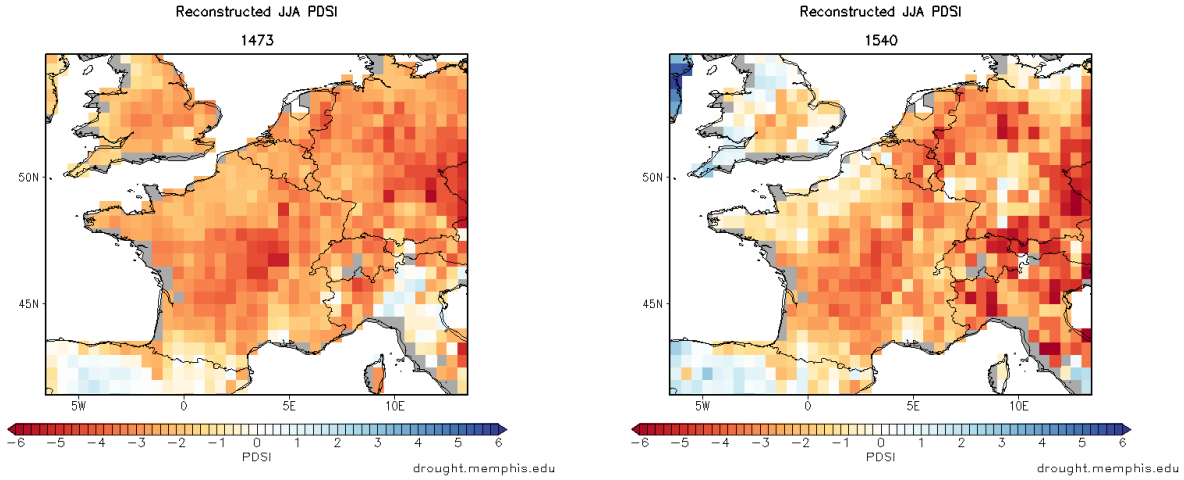

Figure 5a: Map of the year 1473 from the OWDA. Figure 5b: Map of the year 1540 from the OWDA (Cook et al., 2015).