



A Prequel to the Dantean Anomaly: The Water Seesaw and Droughts of 1302-1307 in Europe

Martin Bauch¹, Thomas Labbé^{1,3}, Annabell Engel¹, Patric Seifert²

¹Leibniz Institute for the History and Culture of Eastern Europe (GWZO), Leipzig, 04109, Germany

5 ²Leibniz Institute for Tropospheric Research (TROPOS), Leipzig, 04318, Germany

³Maison des Sciences de l'Homme de Dijon, USR 3516 CNRS, Dijon, 21066, France

Correspondence to: Martin Bauch (martin.bauch@uni-leipzig.de)

Abstract. The cold/wet anomaly of the 1310s («Dantean anomaly») has attracted a lot of attention from scholars, as it is commonly interpreted as a signal of the transition between the MCA and the LIA. The huge variability that can be observed during this decade, similarly with the high interannual variability observed in the 1340s, has been highlighted as a side-effect of this rapid climatic transition. In this paper, we demonstrate that a multi-seasonal drought of almost two years occurred in the Mediterranean between 1302 and 1304, and respectively a series of hot and dry summers north of the Alps from 1304 to 1306. We propose to interpret this outstanding dry anomaly, unique in the 13th/14th century, combined with the 1310s and the 1340s cold anomalies, as part of the climatic shift from the MCA to the LIA. Our reconstruction of the predominant weather patterns of the first decade of the 14th century from documentary and proxy data lead to the identification of multiple European water seesaw events in 1302-1307, with similarities to the seesaw conditions which prevailed in 2018 over continental Europe. It can be debated to which extent the 1302-1307 period can be compared to what is currently discussed regarding the influence of the Arctic amplification phenomenon on the increasing frequency of long-lasting stable weather patterns that occurred since the late 1980s. Additionally, this paper deals with socio-economic and cultural responses to drought risks in the Middle Ages from contemporary sources and provides evidence that there is a significant correlation between blazes that devastated cities and pronounced dry seasons.

1 Introduction & State of the Art

While Medieval studies analyzed since decades the reconstruction (Pfister et al. 1998) and the impact of cold events on premodern societies in the context of the Little Ice Age, few papers focused on droughts, notably from economic history (Stone 2014). The so-called 'Dantean Anomaly' has been highlighted since the 2000s by Brown (2001) as a wet and fresh anomaly lasting from 1315 to 1321, and leading to famine over NW Europe (Jordan 1998). This climatic anomaly has been recently described more neutrally as 'the 1310s event' (Slavin 2018). A distinctive '1300 event' has been found in proxy data even around the Pacific rim (Nunn 2007). But the focus was always on the cold and wet character of this decade and historians have clearly been fascinated by continuous rains and their impact on food security, often leading to widespread



30 famines. A lot has been written for example about the deficit of crops and thus of food supply induced by the rainy years 1315 and 1316, leading to a famine in northern Europe (Campbell 2016; Jordan 1996). Yet, in the context of current worries about global warming and its link with a potential multiplication of 2003-like drought events, dry periods have found more and more interest from pre-modern climate history (Brázdil et al. 2019; Brázdil et al. 2018; on the Middle Ages: Rohr et al. 2018). Most research deals with the early modern period though (Garnier 2019; Munzar 2004; Martin-Vide, Barriendos 1995; Weikinn 1965/66), and the ‘millenium drought’ of 1540 has been especially highlighted (Pfister 2018; Wetter, Pfister 2013; Wetter et al 2014). Concerning the medieval period, the very recent publication on the dry year 1473 (Camenisch et al. 2020) is still an exception, preceded only by case studies on medieval droughts in Hungary and modern-day Croatia (Kiss 2017; Kiss, Nikolic 2015). In fact, the socio-economic impacts of droughts on medieval societies are more difficult to conceptualize than those linked with cold-wet weather. In most parts of western Europe, droughts were basically benevolent for agricultural production based on cereals and wine (Le Roy Ladurie 2004), which easily tolerate dry weather conditions if excessive hydric stress doesn’t block vegetation growth, as in extreme cases like in 1540. Thus, droughts rarely induced socio-economic disasters similar to those frequently associated with wet anomalies. As Prybil (2017) states, warm and dry summer half years were for example not dangerous to crops in medieval England. They only show an indirect statistical correlation with epidemics, occurring with one year lag, after the introduction of *yersinia pestis* in 1348, as rodent populations exploded under such conditions. In Mediterranean regions, droughts must have been more troublesome for crops and had a direct impact on food-supply and living standards, due to a higher vulnerability to lack of water. However, few studies have been devoted to the topic.

The beginning of the 14th century is considered to be the onset of the transition period from the Medieval Climate Anomaly (MCA) towards the Little Ice Age (LIA) and the time around 1300 CE sees the nadir of the Wolf minimum in solar forcing (Steinhilber et al. 2009). Although these periods are highly disputed and maybe only regionally applicable (Andres, Peltier 2016; Grove 2001; Pfister et al 1998), this consensus prompted researchers to emphasize mainly the cold and wet conditions of the 1310s. It is beyond the scope of our contribution to add to the discussion about the question if there actually was an MCA and an LIA and when the LIA started (Bradley, Hughes, Diaz 2003; White 2014). Yet it seems worthwhile to examine at least the consistently dry decade (at least during the summers) directly preceding the wet/cold 1310s anomaly. The first decade of the 14th century actually witnessed two successive major drought events at European scale, one striking Italian regions, another impacting regions north of the Alps.

At the end of his annual report, the anonymous writer of the ‘Greater Annals of Colmar’, a Dominican monk most interested in weather phenomena, stated astonished about the cold season 1303/04: “Winter was cold in Rome, but in Alsace it was warm, and on the contrary, it was warm in Rome [the winter before, 1302/03], but cold in Alsace” (Jaffé 1861, 229). It is not only winter temperature that acted like a North-South seesaw at the beginning of the 14th century all over Europe. As we will demonstrate, an even more pronounced water seesaw happened in 1302-1307 with extremely dry conditions in the Mediterranean from the end of 1302 to early 1304 while normal humidity levels prevailed north of the Alps, and pronounced drought periods in 1304-1307 in most parts of Western and Central Europe. This double event could be by far the longest,



multi-seasonal drought in three European regions within the 13th and 14th century. We therefore want to focus our
 65 reconstruction of this period from documentary and proxy data on Northern and Central Italy (IT), Eastern France (FR) and
 Central Europe (CE) (Figure 1). Additionally, there are hardly any studies that focus on the variety of cultural impacts of
 drought on medieval societies. Especially regarding the Italian and French material, we can provide first insights.

2 Data

2.1 Narrative sources

70 Narrative texts are commonly reckoned in the field of climate history as important sources of information, and historians have
 produced for decades almost exhaustive catalogs of events from chronicles and annals. For this paper, we draw principally on
 these previous works. Alexandre (1987), Curschmann (1900) and Weikinn (1958, 2017) provide information, mostly with
 accurate source criticism, for the territories of nowadays France, Italy, and Central Europe. Additionally, Brázdil and Kotyza
 (1995, Appendix I) gathered the material for the Czech Republic, as well as Malewicz (1980) for Poland. Concerning Italy,
 75 where more urban chronicles were produced than elsewhere in Europe, we collected material ourselves, but analyzed also the
 unpublished collection of Emanuela Guidoboni (Bologna), covering the period 1000-1500 from about 200 edited narrative
 sources, some compilations and thematic articles, and few archival material. We have limited ourselves to the use of critical
 editions of contemporary chroniclers out of the Guidoboni collection. In France there are few chronicles, which almost solely
 cover the regions of Paris and Alsace during this epoch.

80 2.2 Administrative sources

Of major interest for the history of climate are cities' deliberation protocol books and accounting documentation. As far as
 extreme weather events had an impact on the organization of the communities and/or on agrarian production alike, this kind
 of documentation provides a bunch of information to the historians of climate. Cities' deliberation protocol books are kept in
 Italian archives since the middle of the 13th century. All matters of justice, economy, local policy, social order, etc., were
 85 systematically noted down after each meeting of the town council. Local governments had sometimes to deal with situations
 created by climate stress, such as organizing grain trade in case of shortfalls, resolving potential social disorders that came
 alongside, organizing processions together with ecclesiastical authorities, or dealing with the disruption of watermills in
 cases of floods or droughts. For the city of Siena, we used the unpublished protocols of the *consiglio generale* for the years
 1302-1307 (Bowsky 1981).
 90 In France and Germany, such documentation does not exist before the mid-14th century. Nevertheless, rich and unedited
 accounting documentation, similar to the one kept in English archives and repeatedly used by historians of climate (Titow
 1960; Pribyl 2012 and 2017), can be exhumed for the territory of the County of Savoy. Roll accounts produced by the
 administration of the county since the end of the 13th century provide continuous information about the impact of extreme
 weather events on local estates' agrarian profits. Wine and cereal productivity, as well as food prices, have been



95 demonstrated to react to a large extent according to climatic stress in the medieval economy (Pribyl 2017; Camenisch 2015),
and thus yields and price series give at an annual scale resolution an idea of climate trends. Moreover, the accountants who
were responsible for the production of these rolls often referred to climate events to justify any drops of revenue towards the
administration. A close chronology of events can then be drawn from this documentation, which we have been able to
reconstruct for the region of the Bresse (FR).

100 2.3 Charters

The value of charters as sources for climate history has been demonstrated for Hungary (e.g. Kiss 2016, Vadas 2010). While
not revealing any clear evidence for drought, a preliminary search within German charters editions as well as the *Regesta*
Imperii unearthed several accounts in the context of blazes: often indulgences were granted for the reconstruction of buildings
destroyed by the fire. Unfortunately, the charters normally don't give an exact date for the events and therefore only provide
105 a *terminus ante quem*.

2.3 Information from manuals

In addition to information drawn directly from historical sources, for the investigation of blazes and their connection to weather
and climate we made use of existing collections in manual-like literature, as it has been done by Zwierlein (2011) for Early
Modern history, who evaluated the respective sections of the German and Austrian „Städtebücher“ (Keyser 1939-1974,
110 Knittler et al., 1968-2001). For most of the cities included, there is a list of historical blazes – unfortunately often without
information about severity or causes, and always without references. Nonetheless, this huge database is a unique source of
information, especially for the statistical evaluation of blazes and their potential connection to droughts. The „Städtebücher“
are a widely trusted and highly used standard reference for medieval urban history, making its use legitimate.
Additionally, more detailed information about blazes has been drawn from manuals on historical monasteries
115 („Klosterbücher“, e.g. Huschner et al. 2016).

3 Methodology and results

3.1 Reconstruction from narrative sources and creation of climate indices

We have created, basically according to the well-established methodology (Pfister 1999; Brázdil et al. 2013; Glaser 2013;
general overview: Pfister et al. 2018), climate indices on precipitation and temperature for the period 1290-1320 to show the
120 dry and hot episodes in the focus of this contribution within their climatical context over three decades. We adapted
established indexing methodology mainly on the temporal scale, as we chose a semi-annual approach (‘growing season’ vs.
‘non-growing season’), according to the focus of documentary records from medieval societies on the agricultural year.
Derived from these well-established climate indices (see SI 1), we closely followed Camenisch, Salvisberg (2020) and



created seasonal drought indices from the above mentioned narrative sources over the longer period 1200-1400 for all three
 125 regions (IT, FR, CE) (see SI 1). As the aforementioned sources and climate historical repositories focus on extreme events,
 we gave values of -3 (extremely dry) and -2 (very dry) if we had actual indicators for agricultural and meteorological
 drought (Brázdil et al 2019, 75) or a lack of precipitation over 2 months. We have, however, not applied the category of
 ‘socio-economic drought’ (Ibid., 75-76), as not all of its indicators are in our opinion specifically related to dry periods. To
 identify long-term droughts, these drought index values have been accumulated for single years (figs. 8-10); they confirm the
 130 extraordinary character of the 1302-1307 drought events.

If we focus on the precipitation indices only, we get for IT (Fig. 2) a dense picture demonstrating a sustained, almost 24
 months long dry period that is not at all represented by the PDSI values from the Old World Drought Atlas (OWDA, Cook et
 al. 2015). The case of Italian OWDA data is special, as only a handful of dendrochronological series from the Alps and
 Calabria are available for the period in question. This nourishes previously formulated doubts about the reliability of
 135 simulated precipitation values (Bothe et al 2019), as the OWDA is calculated for large parts of Italy on the basis of only a
 few tree-ring series.

The precipitation indices for FR (Fig. 3) are scarce, and yet they show a pronounced drought pattern in the growing seasons
 of 1304-06. In regard to IT, we lack information on the continuity of this drought over the non-growing seasons (1303/04 to
 1306/7). But the general tendency is fitting with available OWDA data, except for the summers of 1293 and 1311.

140 The most interesting results are the precipitation indices for CE (Fig. 4). They have to be stacked, as CE covers a row of
 quite different sub-regions, yet the tendency is the same in all of those regions. Furthermore, they are mostly consistent with
 OWDA data points, and if indices seem to differ (e.g. 1291/92, 1294/95, 1305/06), they provide precipitation data on the
 non-growing season which is not covered by tree-rings.

If we aim for a qualitative description of weather patterns, documentary data provides a clear, reliable and very dense picture
 145 (see SI 2) of meteorological conditions over the period in question. It all started with a rainy summer in 1302 with floods in
 CE and FR, while the second half of 1302 was already without precipitation in IT. This was followed by a cold winter with
 freezing rivers (Rhine, Doubs, Adige) and low water levels in CE, FR and IT, while more to the East (Silesia, Russia), the
 winter was mild and snowless. Spring of 1303 proved cold in CE - and while we have no information on this summer from
 north of the Alps, IT was hit by continued meteorological, agricultural and hydrological drought the whole year 1303. The
 150 following winter 1303/04 was particularly warm in FR and split in CE: warm in its Western part, cold in Bohemia. A very
 chilly winter with freezing rivers is reported for IT. Spring and summer 1304 were extremely dry and hot in FR and CE, with
 all signs of hydrological drought. IT saw strong, yet short precipitation events in late spring, interrupting the 13 months
 drought, and then again a dry summer until September 1304. Once more, a pronouncedly cold winter 1304/05 followed in
 FR and CE, strong precipitation in early 1305 in IT that continued into summer and a dry period in summer 1305 in FR. The
 155 winter 1305/06 was so chilly that the Baltic sea froze over and so did rivers in FR and CE and IT. In FR drought continued
 into spring 1306, and in CE as in IT winter 1306/07 was again very frosty, later changing to flood conditions. In Eastern CE,
 drought set in in summer 1307, and a heatwave in FR and IT.



3.2 Agricultural production in France and England

160 From the accounting documentation of the Bresse region (Eastern France), we have reconstructed wheat and wine yields for
 the period 1300-1330. For each of these reconstructions, raw data of different castellanies, i.e. administrative units under the
 control of a steward, have been extracted and then compiled in aggregate series indexed on the year 1307. Cereal yields have
 been estimated from the revenue perceived on seignorial lands located in the territories of two castellanies, i.e. Jasseron and
 Treffort. This information is indirect, as it refers only to taxes perceived on these lands which were cultivated by tenants, and
 165 not to direct indication of cereal quantity harvested each year. Being said, if that induces a limit in the interpretation, the
 reliability of the reconstructed series is not to dismiss entirely. Wine yield series are much less critical, as the accounters
 referred directly to the exact amount of wine collected in seignorial vineyards located in four castellanies. Thus, roll accounts
 allow for a reconstruction of a relevantly detailed chronology of the reaction of the local vineyard toward climate variations.
 Figure 5 plots the reconstruction of mean wheat and wine yields in the Bresse from 1300 to 1320.

170 The results show a similar pattern, namely a trend to relatively high yields before 1310 and then a downward trend reflecting
 the deteriorating weather conditions of the 1310's anomaly. Good harvests, especially for wine, clearly stand out in 1304 and
 1305, in response to the successive droughts locally described in Parisian as in Alsatian chronicles (see SI 2). Besides, the
 plentiful wine harvest of 1304 is confirmed by a contemporary chronicle (Jaffé 1861, 231). In the years 1306/07 vineyard
 production reaches average values, even if the accounts mention in both years heatwaves in June and/or July. In this case,
 175 though, temperatures reached levels so high that it prevented peasants from properly plowing the vineyard on time, which
 can explain why production is lower than in previous years. In any case, it can be inferred from the accounting
 documentation of the Bresse that from 1304 to 1307, summer temperatures certainly reached above-average values.
 Additionally, the link existing between good wine harvest and warm summer half-year stands out in 1313 too. Accounts
 mention in that year a summer dryness, which has been benevolent for the vineyard.

180 Experimental archeology demonstrated the impacts of drought on medieval-style agriculture (Kropp 2019): considerable
 damage on summer crops, but stable harvests from winter crops. A mixture of different crops guaranteed altogether a
 sufficient harvest. This can explain the average cereal yields in figure 5, especially in 1304. In contrast, excessive humidity
 in 1310 and from 1314 to 1316 clearly had a negative impact on the harvest (cereals -20/-40% and wine -80/-60%
 respectively). Methodologically it is worth noting that cold episodes are mirrored more faithfully through agricultural proxy-
 185 data than dry periods.

We then compared this reconstruction with well-studied and accessible English wheat yields (Campbell 2007). Fig. 6 plots
 the relationship between cereal productivity in Southern England and the Bresse region (FR), in comparison with East
 Anglia July-September precipitation indices reconstructed from local archival sources (Pribyl et al. 2012, Pribyl 2017).
 From 1300 to 1320 English and French yields correlate significantly (Pearson coefficient $r = 0,61$). General trends are
 190 similar in the two regions, with average or above-average harvests in the 1300s. Moreover, we find a synchronous movement



between 1304 and 1306 (Fig. 6), reflecting the precipitation trend. The low level of precipitation reconstructed in East-Anglia for these three specific years then most probably applies similarly for the Bresse region, which means that this multi-annual 1304-1306 drought occurred in a large part of NW Europe.

3.3 Identification of meteorological patterns

195 The proxy and documentary data presented in 3.1 and 3.2 provide evidence for the occurrence of an alternating large-scale weather pattern over large parts of Europe between 1300-1310. The found features are similar to the phenomenon of a water seesaw, as it was recently discussed by Toreti et al. (2019) concerning the drought events of 2018 and others of the last 500 years. A water seesaw describes a remarkable dipole of negative water (precipitation) anomalies in one part of Europe and positive ones in another part of Europe. Toreti et al. (2019) associated the 2018 drought to pronounced positive anomalies in
 200 the geopotential height of the 500-hPa level of atmospheric pressure over the continental European landmass north of the Alps. This blocking situation led to the formation of low-pressure anomalies over Northern as well as Southern Europe, with precipitation patterns associated in such a way, that Central Europe suffered a severe lack of precipitation whereas Northern and Southern Europe experienced an excess of precipitation. Thus, in the 2018 case, the water seesaw was positive over Southern Europe and negative over Central Europe.

205 Similar to what was reported by Toreti et al. (2019), the predominant weather patterns found for the period from 1302-1307 also must have originated from certain seesaw constellations and associated patterns in the geopotential height fields. A possible meteorological interpretation of the reported weather patterns (see SI 2) was found, as is illustrated in Fig. 7a-k and described in the following:

In summer 1302 (Fig. 7a), wet FR and CE and dry IT correspond to a water seesaw which was negative over IT and positive
 210 over FR and CE. Geopotential anomalies were thus positive over IT and negative over FR and CE. Winter 1302/1303 (Fig. 7b) was reported to have been dry and cold over IT, FR and CE, but warm over Western Russia. This situation can be explained by the presence of a blocking large-scale positive anomaly in the 500-hPa geopotential that covered whole IT, FR and Southern CE. A negative anomaly over Northern Europe would have provided such a constellation that warm (and - not reported - likely moist air) would have arrived in Silesia/Russia, as was reported for this season. Thus, a potential seesaw
 215 was tipping from the region CE, IT and FR (negative) towards Eastern Europe, i.e. here Silesia to Russia (positive). Due to the lack of precipitation proxies for Silesia/Russia for the period, this likely constellation can however currently not be proven.

The 1302/1303 winter constellation likely continued throughout the whole of 1303 (Fig. 7c). Continued positive 500-hPa geopotential anomalies over IT, FR, and CE caused a long-lasting cold period in spring north of the alps, while the blockage
 220 led to a continued lack of precipitation over IT. Also in the following winter 1303/1304 (Fig. 7d), the positive 500-hPa geopotential anomaly must have persisted over IT. However, the reported warm conditions in FR and Western CE indicate that the positive anomaly did extend less toward north compared to winter 1302/1303.



Spring 1304 seems to be a turning point for the water seesaw constellation (Fig. 7e). The dryness of FR and CE and the wetness reported for IT let it appear likely that the positive 500-hPa geopotential anomaly moved toward FR and CE (similar to what was reported by Toreti et al. 2019 for the 2018 drought), enabling precipitation systems to reach IT from the southwest via the Western Mediterranean. The dry summer reported for IT following the wet spring could have been caused by a slight positive 500-hPa geopotential anomaly over IT during this time (Fig. 7f), but in this case, summertime precipitation is rather unlikely anyway in its subtropical climate.

The weather reported for winter 1304/1305 gives a clear indication for the presence of a large-scale positive 500-hPa geopotential anomaly over Northern Europe and a negative 500-hPa geopotential anomaly over Southern Europe (Fig. 7g). Cold air masses from Eastern Europe were reported for the whole of CE and FR, while IT was reported to be wet. This constellation continued likely during summer 1305, with a slightly increased negative anomaly over eastern CE that allowed normal temperature and precipitation conditions over this region (Fig. 7h).

Cold air masses from Eastern Europe were reported for the whole of CE, FR and IT in the winter 1305/1306, which must have been caused by yet another large-scale positive 500-hPa geopotential anomaly over Northern Europe (Fig. 7i). A negative 500-hPa geopotential anomaly can thus be expected to have been present over Northern Africa. The dry air from Eastern European masses led to the reported dry conditions over FR. That situation likely continued until the winter of 1306/1307, when drought and low temperatures were reported again for CE and IT (Fig. 7j). The reported increasing flood conditions in IT in spring 1307 can be explained either by melting snow or by a slight movement of the positive 500-hPa geopotential anomaly towards the north, allowing precipitation systems to reach IT via the Mediterranean.

Finally, the CE drought and heatwave in FR and IT is likely a result of a continuing positive 500-hPa geopotential anomaly over CE (Fig. 7k). In its center, dryness prevailed while on the western (FR) and southern (IT) borders hot air was advected from Africa.

3.4 Correlation of drought periods and city fires

Medieval city fires are a topic touched upon mainly by cultural history (Jenkrift 2003, 83-100; Riegg 2003; Wolf 2015; Wozniak 2011, 2015). But a close connection between drought and fire has been made plausible for extreme years like 1540 (Pfister 2018; Wetter et al. 2014; Mauelshagen 2010, 127-129). Nevertheless, as a general phenomenon this has been put into question (Zwierlein 2011, 102-110), although the latent fire risk of wood-based pre-modern buildings with open fires to heat, cook and provide light is more than obvious (Bitterli 2015; Contessa 2000, 16-18). Already contemporaries saw a close connection between drought and blaze: “Many cities were consumed by domestic blazes because of the drought and sterility that prevailed in this year” (Wattenbach 1851b, 641).

We have been comparing accumulated drought indices, yet distinguishable by seasons, with the number of blazes we could take from the archives of societies (see sections 2.1, 2.3 and 2.4). A peak in blazes around the 1302-05 drought is visible for IT (Fig. 8), with a significant correlation of droughts and blazes ($r = 0,346$) over the whole period. The same peak is visible for FR in 1306 (Fig. 9) with an even higher correlation of fires and droughts ($r = 0,657$) over the two centuries. The



correlation of drought years and blazes in CE (Fig. 10) is still significant ($r = 0,379$). Furthermore, we have suspected from these results (Figs. 8-10) that the probability of a blaze might lag by one year the drought event, as wooden structures had dried over long periods and might ignite more easily even with a temporal distance to the drought. We have then tested in a cross-correlation if this assumed connection existed in our data and we found a very significant correlation regarding a one
 260 year lag for FR ($r=0,83$) and a significant one for IT ($r=0,59$), but none for CE ($r=-0,167$). The differing results in the case of CE can probably be explained by the non-critical use of documentary data in the ‚Deutsche Städtebücher‘, while relevant blaze information was validated by historical source-criticism for IT and FR.

As the OWDA information for CE (here broadly defined as a rectangle from the Rhine to the Alps to Novgorod in the East and all of Denmark plus Southern Scandinavia to the North, i.e. $47,34^{\circ}$ N- 58.69° N, 7.52° E - 30.88° E) is relatively dense
 265 and reliable, it has been combined with available information on blazes from documentary data. Yet, the correlation of low PDSI values and blazes in the same years (Fig. 11) is very weak, if not nonexistent ($r = -0,06$).

What is surprising, is the totally different outcome of the correlation between droughts and blazes for CE, calculated one time from the OWDA-data - with a very bad correlation - and the other time from the drought-indices based on written sources, where the correlation is much better (respectively $r = -0,06$ and $r = 0,379$). The data for blazes stayed the same in
 270 both calculations. Here, the discrepancy between the reconstruction from the OWDA on the one hand and the drought indices, on the other hand, comes into play: The OWDA (even more so the maps provided with it) shows a lot more dry periods than documentary data, that mirror mainly outstanding ones. Regarding the misleading picture the OWDA gives for Italy (in comparison with a reconstruction on the basis of written sources, see 3.1.), a general comparison with reconstructions from written sources would be advisable, especially for those regions and periods where there is a good basis
 275 of written sources and where the amount of dendrological data is at the same time rather low (like for Italy).

4 Discussion

Finally, we want to highlight aspects of societal impacts and adaptation measures to drought beyond the classical rogation ceremonies and other religious processions (overview Brázdil 2020), especially as we have only one example for them from IT: In May 1303 there were processions for rain in Parma, that indeed ‘provoked’ a one-day rain (Bonazzi 1902-04, 84). But
 280 there is more to find about how droughts impacted medieval societies, how they were perceived and how contemporaries reacted.

4.1 Drought and infrastructural responses

Italy provides a number of infrastructural responses to the drought experience of 1302-04. In 1303, the city of Parma built a new, larger and deeper fountain (Chron. Parm., 86). Something comparable happened in the Tuscan city of Siena, settled away
 285 from any larger watercourses and traditionally struggling with water scarcity. Not surprisingly, the century-old myth of an underground river below the city, the so-called Diana, was still alive in Siena. In April 1305, one year after the end of the



drought, documentary evidence reveals that the city council actively searched for this underground river by digging in a local church (Bargagli Petrucci 1903, II, 20). An even more real-time response can be found for 1303: In spring, when a dearth of grain already strangled Siena, the city council decided to import grain via the small port of Talamone, 100 km South-West of Siena (ASS, CG 62, 1303 March 26, c. 99). They had done so already the year before. But in September 1303 - after the successful grain imports that even had created an abundance of food in the city - the city council decided to buy the port for the Republic and to invest heavily in its refurbishment and expansion in the following years (Sordini 2000, 73-112). Siennese citizens were settled in the newly designed city, with infrastructures and military fortifications (Fig. 12). Although Siena had discussed buying the port years before, it was the drought experience and connected food scarcity that let the plans become real and lead to a long-term infrastructure investment, possibly the most expensive project the Republic of Siena financed outside the capital's walls.

4.2 Cultural aspects of drought

The aforementioned infrastructural responses by the city of Siena to the drought experience provoked a satirical response by Dante Alighieri. In his 'Divine comedy', the Florentine poet mocked his Siennese neighbors with a famous verse: "You will find them [some Florentines] amongst the foolish crowd [the Siennese] who put their trust in Talamone, and will lose more hope there than in their search for the Diana" (Dante, Divine Comedy, Purgatory, canto XIII). The *Purgatory*, finished during the early 1310s, makes clear that the futile Siennese efforts to search for their underground river did not go unnoticed by their neighbors. Nor did the Florentines ignore the acquisition of Talamone - they had experienced in 1303/04 how vital the port was for their food security, too. So it was just consequent to sign a trade agreement with Siena in August 1311 that guaranteed Florentine access to maritime grain trade via Talamone, although under conditions very beneficial for Siena (Banchi 1871, 126-127).

In another famous medieval text, the *De regimine principum*, a kind of manual on good governance by Thomas Aquinas and Ptolemy of Lucca, the latter starts writing from 1302 onwards and reflects on the importance of food security: "Food that is sold is not as effective for nourishment as it should be, since it is often adulterated. As Solomon says in Proverbs (Prov. 2,5): 'Drink water from your own cistern', which includes all nourishment, but especially drink, because it can more easily be adulterated. [...] There is greater security in using one's own food, since outsiders can easily poison something not kept in its proper storehouse or pantry, and it is more likely to be harmful." (Blythe 1997, 114). The whole reflection about safe access to food and drink is framed with a most striking biblical proverb, traditionally attributed to Solomon himself: "Drink waters out of thine own cistern, and running waters out of thine own well. Let thy fountains be dispersed abroad, and rivers of waters in the streets." (Prov. 5, 14-16). That Ptolemy of Lucca wrote about the drought in his chronicle (Clavuot 2009, 652) exactly the time he worked on the mirror of princes makes a connection even more plausible.



4.3 Societal responses to water scarcity

This worry about access to water, theoretically expressed in the *De regimine principum*, meets social reality in medieval civilization. In times of drought, one of the major problem communities affected had to cope with, in absence of any efficient water system, was actually entitlement to healthy drinkable resources. In another context, during the extreme drought of 1137, some chroniclers fully described the hardships met by some French rural communities to access water, as people had to walk miles in order to seek for non-dried sources (Labbé 2018). This aspect is complemented by the fact that water sources were frequently polluted with dangerous gastrointestinal pathogens, a situation eventually worsened by high temperatures and low levels of almost stagnant waters in summertime. Thus, in 1307, after three years of drought, a chronicler of Paris explained that, the vineyard being burnt by frost in April, citizens had to drink water instead of wine, and that an epidemic subsequently broke out during the summer (Buchon 1827, 130). The outbreak of epidemic one year after a warm half summer year, as 1306 may have been, has been emphasized by Pribyl (2017) as one of the most typical consequences of such kind of climatic conditions. The epidemic in Paris in 1307, due to warm conditions during the summer combined with a lack of ersatz drink like wine, can then most probably be interpreted as a result of the back-to-back dry vintages from 1304 to 1306.

Another side-effect of major droughts in the 14th century was eventually the temporary blockage of production and sometimes even of communication systems. If crops were generally not heavily endangered, at least in the regions north of the Alps, the lack of water induced nevertheless indirectly in some occasions a disruption of the entire food supply system. Difficulties to transform cereals into flour, and to sustain the transportation of food supply from production regions to city markets could have some economic consequences. This inconvenience was precisely exposed by the Dominican monk of Colmar in 1304: If wheat was quite affordable this year because of benevolent harvests, nevertheless bread was very expensive and scarce at the same time, just because mills settled along dried rivers could not work anymore. Likewise, if winegrowers were able to produce wine of very good quality, as the berries contained a lot of sugar, they could not benefit from it. Actually, wine prices remained very low as shipments were unable to go down the Rhine river and attain the usual city markets of Strasbourg, Köln, and Trier (Jaffé 1861, 231)

4.4 Cultural aspects of blazes in cities

The best documented of all blazes during the 1302-1307 period is the infamous city fire of Florence on 10 June 1304 that burned 1700 houses. It was interpreted by contemporaries as a conspiracy of the political opposition, the Florentine White Guelfs, which were driven out of the city in the aftermath of the blaze.

The detailed available documentation on 14th-century fires in Florence (Contessa 2000, 89-107) makes clear how unusual a large blaze of this kind was, even for a populous city like the Tuscan metropolis. The first, yet very limited fire prevention policies are known from 1325 (Contessa 2000, 21-27) and consisted of the introduction of brick-built chimneys and stoves. As early as from 1296 onwards, in Siena, the city reimbursed citizens that ruined their tools when fighting fires (Bellissima



1922), and when two blazes hit the city in November 1302, more than 200 people fought the fire in an organized way and used more than 1800 water charges (Agnolo di Tura, 265). These are strong indicators of a proto fire-guard system in Italian city-states around 1300, before official fire guards were established, e.g. 1344-48 in Florence (Contessa 2000, 31-48). One week after the fire, and again in early August 1304, the blaze was even a topic for homilies of the already mentioned Dominican Giordano da Pisa who reminded his fellow citizens that the fire only did what it should do according to God's will: bring warmth- and when it burned the city's houses, this was no sin, but God's will (Varanini, Baldassari 1993, 314). Another strategy to cope with fire threat was to oblige citizens, in case of droughts or strong winds, to arrange full water buckets at the doors of their houses, ready to be immediately used by anyone in case of fire emergency. A Parisian chronicler described this coping strategy already in 1305, when high temperatures combined with strong wind made authorities worry about a potential disaster (Buchon 1827, 116-117). This is a shared concern of other sources, too (Wattenbach 1851a, 676). That wind was crucial can also be derived from the fact that the fire was able to cross water bodies like rivers (Wozniak 2015).

Conclusion

The wet anomaly of the 1310s has attracted a lot of attention from scholars these last years (Slavin 2019), as it is commonly interpreted as a signal of the transition between the MCA and the LIA (Campbell 2016). The huge variability that can be observed during this decade, similarly with the high interannual variability observed in the 1340s, have been highlighted as side-effects of this rapid climate change. In the context of global warming, specialists now agree that periods of rapid climate change are accompanied by a probabilistic higher frequency of extreme events (Sippel and Otto 2014). To date, in the field of Medieval climate history, no efforts have been made to underline the outstanding period of drought of the first decade of the 14th century. However, we have demonstrated that two exceptional series of warm and dry summer half-year occurred respectively in the mediterranean italian regions between 1302 and 1304, and north of the Alps from 1304 to 1306. Following our indices reconstruction from narrative sources, such multi-seasonal and supraregional scale droughts did not occur during the 13th century and do not find any similar case before the 1360-1362 drought that struck all across Europe, more specifically in 1360-61 in Central Europe (Brázdil et al 2020, 82-83; Kiss 2017, 44-45; Bauch 2017, 1102-1104) and England (Pribyl 2017, 102-104), while in 1362 on the Balkan peninsula, around the Black Sea and the Aegean drought conditions prevailed (Kiss, Nikolic 2015, 13-14). As administrative data gives indicators of drought in Catalonia in 1361/62 (Fynn-Paul 2016, 137), one might even connect a major city fire in Urgell (Battle 1999, 79-82) with this continuous lack of precipitation. There are even indicators for a global dimension of the event: The years 1360 and 1362 were characterized in Japan by major droughts causing famines (Farris 2006, 109), also on the Korean peninsula (Robinson 2009, 163) and also 1362/63 in Western Rajasthan (Rao 2009, 19), which is a considerable difference to the 1302-07 event that is not traceable outside of Europe.



We propose then to interpret these remarkable conditions, combined with the 1310s and the 1340s cold anomalies, as part of the climatic transition from the MCA to the LIA. More than a last glow of the MCA, the dry anomaly of the 1300s combined with the wet-cold anomaly of the 1310s allow us to speak of a ‘long’ Dantean Anomaly: Not a new, but now a much more
385 substantiated starting point for the changing climatic pattern of this period. Our reconstruction of the predominant weather patterns for the first decade of the 14th century from documentary and proxy data likely lead to the identification of multiple European water seesaw events of 1302-1307. The series of reported meteorological conditions for this period show similarities to the seesaw conditions which prevailed in 2018 over continental Europe (Toreli et al., 2019). The period under study was characterized by a series of long-lasting, steady precipitation dipoles which lead regionally to strongly contrasting
390 precipitation and drought extremes. It can be debated to which extent the 1302-1307 period can be compared to what is currently discussed regarding the influence of the Arctic amplification phenomenon (Cohen et al., 2014) on the increasing frequency of long-lasting stable weather patterns that occurred since the late 1980s. Arctic amplification describes the decrease of the latitudinal temperature gradient between the midlatitudes and the Arctic which was found to weaken the storm tracks, shift the jet streams, and amplify quasi-stationary synoptic-scale atmospheric waves (Coumou et al., 2018).
395 Future studies should investigate whether such a scenario was also present in the early 14th century when the transition from MCA and LIA occurred. It appears plausible that such a climatological transition is temporally associated with a reduced latitudinal temperature gradient and consequences similar to the currently ongoing Arctic amplification.

Historical sources, coupled with acute source criticism, are deemed to be useful to refine the chronology of extreme events in combination with natural proxy-data. As we have demonstrated, the OWDA tree-ring reconstruction sometimes missed
400 information due to scarce raw data, especially for southern Europe. An in-depth analysis of narrative and administrative sources, which are sufficiently numerous from the 14th century onward, permits to draw a more accurate picture of this epoch’s climate, including winter conditions that must be taken into consideration to get a full image of the droughts’ extent. Finally, droughts are phenomena that offer more for a cultural history of climate than just the analysis of religious mitigation strategies. They show both in contemporary perception as in historical analysis a connection to blazes, a major threat to
405 medieval cities. We could demonstrate for the first time a correlation of droughts and blazes over 200 years, including a one-year lag in these phenomena. Furthermore, drought provokes reflections on thirst and the use of water that we otherwise hardly ever find in medieval texts.

Author contribution

Martin Bauch provided general conceptualization, curation & analysis of the Italian historical sources, the creation, evaluation,
410 and visualization of drought indices and city blazes, writing of the original draft and funding acquisition. Thomas Labbé provided conceptual input, curation & analysis of the French historical sources and visualization of other agricultural proxies. Annabell Engel provided curation & analysis of the Central European material and conceptual input on data presentation.



Patric Seifert provided conceptual input on climatological backgrounds, meteorological analysis, and interpretation of documentary data for weather patterns and geopotential maps.

415

Acknowledgments

We thank Andreas Görlitz (Siegen) for help with cross-correlation techniques and advice on statistical issues. Furthermore, we're grateful that we could use the unpublished climate historical collection of Emanuela Guidoboni (Bologna) for the Italian case studies. Finally, we are thankful for input from and discussion with colleagues from the PAGES Working Group CRIAS, esp. Chantal Camenisch, Rudolf Brázdil and Andrea Kiss during the October 2019 workshop of CRIAS in Leipzig (Germany).

420

References

Alexandre, P.: Le climat en Europe au Moyen Age: Contribution à l'histoire des variations climatiques de 1000 à 1425, d'après les sources narratives de l'Europe occidentale, Recherches d'histoire et de sciences sociales 24, Éditions de l'école des hautes études en sciences sociales, Paris, 1987.

425 Andres, H. J. and Peltier, W. R.: Regional Influences of Natural External Forcings on the Transition from the Medieval Climate Anomaly to the Little Ice Age, *J. Climate*, 29, 5779–5800, doi:10.1175/JCLI-D-15-0599.1, 2016.

Banchi, L.: I porti della Maremma senese durante la repubblica. Narrazione storica con documenti inediti, Leo S. Olschki, Firenze, 1871.

430 Bargagli-Petrucci, F.: Le Fonti di Siena e il loro acquedotti. Note storiche dalle origini fino al MDLV. Vol. II. Documenti, Leo S. Olschki, Siena, 1906.

Battle, C.: Destruições naturelles des villes de la Couronne d'Aragon au Bas Moyen Âge, in: Zerstörung durch Erdbeben, Feuer und Wasser. Destruction by earthquakes, fire and water = Destruições par des tremblements de terre, le feu et l'eau, Stadtzerstörung und Wiederaufbau = Destruction and reconstruction of towns 1, edited by Körner, M., Haupt, Bern, 67-86, 1999.

435 Bauch, M.: Jammer und Not. Karl IV. und die natürlichen Rahmenbedingungen des 14. Jahrhunderts, *Český Časopis Historický*, 115/4, 983-1016, 2017.

Bellissima, G.: L'estinzione degli incendi secondo lo Statuto del Comune di Siena del XXI dicembre MCCLXXXVI, Stab. Tip. S. Bernardino, Siena, 1922.

440 Bitterli, M.: Es brennt ein Licht in der Hütte. Beleuchtungseinrichtungen im mittelalterlichen Alltag - ein Überblick, in: Feuernutzung und Brand in Burg, Stadt und Kloster im Mittelalter und in der Frühen Neuzeit, edited by: Wagener, O., Dr. Imhof, Petersberg, 330-339, 2015.



- Blythe, J. M. (ed.): *On the Government of Rulers / De Regimine Principum*. Ptolemy of Lucca with portions attributed to Thomas Aquinas, University of Pennsylvania Press, Philadelphia, 1997.
- Bonazzi, G. (ed.): *Chronicon Parmense. Ab Anno MXXXVIII usque ad Annum MCCCXXXVIII., Rerum Italicarum Scriptores (RIS²)*, 9/9, Città di Castello: Lapi, 1902.
- Bowsky, William Marvin: *A medieval Italian commune. Siena under the Nine, 1287-1357*. Berkeley: University of California Press, 1981.
- Bothe, O. Wagner, S. and E. Zorita, Inconsistencies between observed, reconstructed, and simulated precipitation indices for England since the year 1650 CE. In: *Clim. Past* 15 (1), S. 307-334. DOI: 10.5194/cp-15-307-2019, 2019.
- Bradley, R. S., Hughes, M. K., and Diaz, H. F.: Climate Change: Climate in Medieval Time, *Science*, 302, 404–405, doi:10.1126/science.1090372, 2003.
- Brázdil, R. and Kotyza, O.: *History of Weather and Climate in the Czech Lands I: Period 1000-1500*, Zürcher geographische Schriften 62, Geographisches Institut ETH, Zürich, 1995.
- 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., 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-14-1915-2018>, 2018.
- Brázdil, R., Kiss, A., Řezníčková, L. and Barriendos, Droughts in Historical Times in Europe, as Derived from Documentary Evidence, in: *Palaeohydrology: Traces, Tracks and Trails of Extreme Events*, edited by: Herget, J. and Fontana, A., Springer, Cham, 65-96, https://doi.org/10.1007/978-3-030-23315-0_4, 2019.
- Brown, N.: *History and climate change. A eurocentric perspective*, Routledge, London, 2001.
- Buchon, J. A. (ed.): *Chronique métrique de Godefroy de Paris, suivie de la taille de Paris en 1313*, in: *Collection des chroniques nationales françaises*, 9, Verdère, Paris, 1-304, 1827.
- Camenisch, C.: *Endlose Kälte. Witterungsverlauf und Getreidepreise in den Burgundischen Niederlanden im 15. Jahrhundert*, Schwabe, Basel, 2015.
- Camenisch, C. and Salvisberg, M.: Droughts in Bern and in Rouen from the 14th to the beginning of the 18th century derived from documentary evidence, *Clim. Past Discuss.*, <https://doi.org/10.5194/cp-2019-114>, in review, 2019.
- Camenisch, C., Brázdil, R., Kiss, A., Pfister, C., Wetter, O., Rohr, C., Contino, A. and Retsö, D., Extreme heat and drought in 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.



- Campbell, B. M. S.: Three centuries of English crops yields, 1211-1491 [WWW document]. URL <http://www.cropyields.ac.uk> [accessed 20/02/2020], 2007.
- Campbell, B. M. S.: The great transition: Climate, disease and society in the late-medieval world, Cambridge University Press, Cambridge, 2016.
- 475 Clavuot, O. (ed.): Tholomeus von Lucca. Historia ecclesiastica nova nebst Fortsetzungen bis 1329, Hahnsche Buchhandlung, Hannover, 2009.
- Cohen, J., Screen, J., Furtado, J. et al. Recent Arctic amplification and extreme mid-latitude weather. *Nature Geosci* 7, 627–637 (2014). <https://doi.org/10.1038/ngeo2234>
- Contessa, M. P.: L'Ufficio del fuoco nella Firenze del Trecento, Le Lettere, Firenze, 2000.
- 480 Cook, E. R., Seager, R., Kushnir, Y., Briffa, K. R., Büntgen, U., Frank, D., Krusic, P. J., Tegel, W., van der Schrier, G., Andreu-Hayles, L., Baillie, M., Baittinger, C., Bleicher, N., Bonde, N., Brown, D., Carrer, M., Cooper, R., Čufar, 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.,
- 485 Svoboda, M., Thun, T., Timonen, M., Touchan, R., Trotsiuk, V., Trouet, V., Walder, F., Ważny, T., Wilson, R., and Zang, C.: Old World megadroughts and pluvials during the Common Era, *Science advances*, 1, 10,e1500561, doi:10.1126/sciadv.1500561, 2015.
- Coumou, D., Di Capua, G., Vavrus, S. et al. The influence of Arctic amplification on mid-latitude summer circulation. *Nat Commun* 9, 2959 (2018). <https://doi.org/10.1038/s41467-018-05256-8>
- 490 Curschmann, F.: Hungersnöte im Mittelalter: Ein Beitrag zur deutschen Wirtschaftsgeschichte des 8. bis 13. Jahrhunderts, Leipziger Studien aus dem Gebiet der Geschichte 6,1, B. G. Teubner, Leipzig, 1900.
- Di Tura del Grasso, A.: Cronache senese attribuita ad Agnolo di Tura del Grasso detta la Cronica Maggiore, in: *Cronache senese*, vol. 1, *Rerum Italicarum Scriptores (RIS²)*, 15,6:1-2, edited by: Lisini, A. and Iacometti, F., Zanichelli, Bologna, 253-564, 1939.
- 495 Farris, W. W.: Japan's medieval population. *Famine, fertility, and warfare in a transformative age*, Univ. of Hawai'i Press, Honolulu, Hawaii, 2006.
- Fynn-Paul, J.: The rise and decline of an Iberian bourgeoisie: Manresa in the later Middle Ages, 1250-1500, *Cambridge studies in medieval life and thought*, 4th ser., 103, Cambridge University Press, Cambridge, 2016.
- Garnier, E.: Historic drought from archives: beyond the instrumental record, in: *Drought. Science and Policy*, edited by: Iglesias, A., Assimacopoulos, D., Van Lanen, H. A. J., Wiley, Hoboken, 45–67, 2019.
- 500



- Glaser, R.: Klimageschichte Mitteleuropas, 1200 Jahre Wetter, Klima, Katastrophen: Mit Prognosen für das 21. Jahrhundert, 3rd Edn., Primus, Darmstadt, 2013.
- Grove, J. M.: The Initiation of the "Little Ice Age" in Regions Round the North Atlantic, *Climatic Change*, 48, 53–82, doi:10.1023/A:1005662822136, 2001.
- 505 Huschner, W., Münch, E., Neustadt, C., and Wagner, W. E. (Eds.): Mecklenburgisches Klosterbuch: Handbuch der Klöster, Stifte, Kommenden und Prioreien (10./11.-16. Jahrhundert), Hinstorff, Rostock, 2 Vols., 2016.
- Jaffé, P. (ed.): *Annales Colmarienses maiores a. 1277-1472*, in: *Monumenta Germaniae Historica, Scriptores (in folio)* 17, edited by Pertz, G. H., Hahnsche Buchhandlung, Hannover, 202-232, 1861.
- Jankrift, K. P.: Brände, Stürme, Hungersnöte. Katastrophen in der mittelalterlichen Lebenswelt, Jan Thorbecke Verlag,
 510 Ostfildern, 2003.
- Jordan, W. C.: *The great famine: Northern Europe in the early fourteenth century*, Princeton University Press, Princeton, 1998.
- Keyser, E. (ed.) (1939-1974), *Deutsches Städtebuch. Handbuch städtischer Geschichte*, 12 vols., Kohlhammer, Stuttgart, 1939-1974; revised editions: Stoob, H., Johannek, P., Engel, E., Enders, L., Heinrich, G., Schich, W. and Post, F. J. (eds.):
 515 1995-2003.
- Kiss, A.: Weather and Weather-Related Natural Hazards in Medieval Hungary III: The Fourteenth Century, *Medium Aevum Quotidianum*, 73, 5–55, 2016.
- 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, *Journal of Environmental Geography*, 10, 43–56,
 520 doi:10.1515/jengeo-2017-0012, 2017.
- Kiss, A. and Nikolić, Z.: Droughts, Dry Spells and Low Water Levels in Medieval Hungary (and Croatia) I: The Great Droughts of 1362, 1474, 1479, 1494 and 1507, *Journal of Environmental Geography*, 8, 11–22, doi:10.1515/jengeo-2015-0002, 2015.
- Knittler, H., Deák, E., Baltzarek, F., Pradel, J., Goldmann, F., Oberhammer, E., Hye, F.-H., Hausmann, R. F. and Reisinger,
 525 N. (eds.): *Österreichisches Städtebuch*, Verlag der Österreichischen Akademie der Wissenschaften, Wien, 1968-2001.
- Kropp, C.: Die Dürre des Jahres 2018 aus der Perspektive mittelalterlicher Subsistenzwirtschaft. Erste Erfahrungen aus dem experimentalarchäologischen Freilichtmuseum Lauresham, in: *Laureshamensia*, 2, 6-17, 2019.
- Labbé, T.: Europe, 1137 AD: Drought, fires and thirst, online: The Dantean Anomaly Project. *Climate, History and Society in the Middle Ages* [WWW document]; URL <https://dantean.hypotheses.org/645>, [accessed 26/02/2020], 2018.



- 530 Le Roy Ladurie, E.: Histoire humaine et comparée du climat. I. Canicules et glaciers (XIIIe-XVIIIe siècles), Paris, Fayard, 2004.
- Malewicz, M. H.: Zjawiska przyrodnicze w relacjach dziejopisarzy polskiego średniowiecza, Monografie z dziejów nauki i techniki, 123, Zakł. Nar. im. Ossolińskich, Wrocław, 1980.
- Martn-Vide, J. and Vally, M. B.: The use of rogation ceremony records in climatic reconstruction: a case study from Catalonia (Spain), *Climatic Change*, 30, 201–221, doi:10.1007/BF01091842, 1995.
- 535 Mauelshagen, F., *Klimageschichte der Neuzeit. 1500-1900*. Darmstadt: WBG, 2010.
- Munzar, J.: Extreme droughts in Central Europe in the preinstrumental period, *Morav Geogr Rep* 12, 13–23, 2004.
- Nunn, P. D., *Climate, Environment and Society in the Pacific during the last Millenium*, Elsevier, Amsterdam u.a., 2007.
- Pfister, C., Schwarz-Zanetti, G., and Wegmann, M.: Winter severity in Europe: The fourteenth century, *Climatic Change*, 34, 91–108, doi:10.1007/BF00139255, 1996.
- 540 Pfister, C.: *Wetternachhersage. 500 Jahre Klimavariationen und Naturkatastrophen (1496–1995)*, Haupt Verlag, Bern, 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, 365 115–129, 2018.
- 545 Pfister, C.: The “Black Swan” of 1540. Aspects of a European megadrought, in: *Climatic change and cultural transition in Europe*, edited by Leggewie, K. and Mauelshagen, F., Brill, Leiden, 156–196, 2018.
- Pribyl, K., Cornes, R. and Pfister, C.: Reconstructing Medieval April–July Mean Temperatures in East Anglia, 1256–1431, *Climatic Change*, 113, 393–412, 10.1007/s10584-011-0327-y, 2012.
- Pribyl, K.: *Farming, Famine and Plague. The Impact of Climate in Late Medieval England*, Cham, Springer, 2017.
- 550 Rao, A.S.: Climate and Microclimate Changes Influencing the Fauna of the Hot Indian Arid Zone, in: *Faunal Ecology and Conservation of the Great Indian Desert*, edited by C. Sivaperuman, C., Baqri, Q. H., Ramaswamy, G. and Naseema, M., Springer, Berlin; Heidelberg, 13-24, 2009.
- Riegg, E.: Brandkatastrophen und stadtbürgerliche Identität, *traverse*, 10, 130–141, 2003.
- Robinson, D. M.: *Empire's twilight: Northeast Asia under the Mongols*, Harvard-Yenching Institute monograph series, 68, Harvard Univ. Press, Cambridge, Mass., 2009.
- 555 Rohr, C., Camenisch, C., and Pribyl, K.: European Middle Ages, in: *The Palgrave handbook of climate history*, edited by White, S., Pfister, C. and Mauelshagen, F., Palgrave Macmillan, London, 247–263, 2018.



- Slavin, P.: The 1310s event, in: The Palgrave handbook of climate history, edited by: White, S., Pfister, C., Mauelshagen, F., Palgrave Macmillan, London, 495–516, 2018.
- 560 Slavin, P.: Experiencing famine in Fourteenth-Century Britain. Turnhout: Brepols, 2019.
- Sippel, S., Otto, F.E.L.: Beyond climatological extremes - assessing how the odds of hydrometeorological extreme events in South-East Europe change in a warming climate, *Climatic Change*, 125, 381–398, 10.1007/s10584-014-1153-9, 2014.
- Sordini, B.: Il Porto della “Gente vana”. Lo scalo di Talamone tra il secolo XIII e il secolo XV, Protagon Editori Toscani, Siena, 2000.
- 565 Steinhilber, F., Beer, J., and Fröhlich, C.: Total solar irradiance during the Holocene, *Geophys. Res. Lett.*, 36, 2130, doi:10.1029/2009GL040142, 2009.
- Stone, D.: The impact of drought in early fourteenth-century England, *The Economic History Review*, 67, 435–462, doi:10.1111/1468-0289.12035, 2014.
- Titow, J.: Evidence of weather in the accounts of the Bishopric of Winchester 1209–1350, *The Economic History Review*, 570 12, 360–407, 1960.
- Toreti, A., Belward, A., Perez-Dominguez, I., Naumann, G., Luterbacher, J., Cronie, O., Seguni, L., Manfron, G., Lopez-Lozano, R., Baruth, B., Berg, M., Dentener, F., Ceglar, A., Chatzopoulos, T., and Zampieri, M.: The Exceptional 2018 European Water Seesaw Calls for Action on Adaptation, *Earth's Future*, 7, 652–663, doi:10.1029/2019EF001170, 2019.
- Vadas, A.: Weather Anomalies and Climatic Change in Late Medieval Hungary: Weather events in the 1310s in the 575 Hungarian Kingdom, VDM Verlag, Saarbrücken, 2010.
- Varanini, G. and Baldassarri, G.: Racconti esemplari di predicatori del Due e Trecento, vol. 2, I novellieri italiani, 4, Salerno, Roma, 1993.
- Wattenbach, W. (ed.): *Continuatio Novimontensis a. 1329–1396*, in: *Monumenta Germaniae Historica, Scriptores (in folio)* 9, edited by Pertz, G.H., Hahnsche Buchhandlung, Hannover, 669–677, 1851.
- 580 Wattenbach, W. (ed.): *Continuatio Sancrucensis II a. 1234–1266*, in: *Monumenta Germaniae Historica, Scriptores (in folio)* 9, edited by Pertz, G.H., Hahnsche Buchhandlung, Hannover, 637–646, 1851.
- Weikinn, C.: *Quellentexte zur Witterungsgeschichte Europas von der Zeitwende bis zum Jahre 1850: Hydrographie, Quellensammlung zur Hydrographie und Meteorologie*, 1,1, Akad.-Verl., Berlin, 1958.
- 585 Weikinn, C.: Katastrophale Dürrejahre während des Zeitraums 1500–1850 in den Flußgebieten der heutigen Deutschen Demokratischen Republik, *Acta Hydrophysica*, 10, 33–54, 1965/66.



Weikinn, C.: Weikinn'sche Quellensammlung zur Witterungsgeschichte Europas (Meteorologischer Teil), doi: 10.6094/UNIFR/11658, 2017.

Wetter, O. and Pfister, C.: An underestimated record breaking event - why summer 1540 was likely warmer than 2003, *Clim. Past*, 9, 41–56, doi:10.5194/cp-9-41-2013, 2013.

Wetter, O., Pfister, C., Werner, J. P., Zorita, E., Wagner, S., Seneviratne, S. I., Herget, J., Grünwald, 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., Nordl, 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, *Climatic Change*, 125, 349–363, doi:10.1007/s10584-014-1184-2, 2014.

White, S.: The Real Little Ice Age, *Journal of Interdisciplinary History*, 44, 327–352, doi:10.1162/JINH_a_00574, 2013.

Wolf, T.: ... incensus est ignis. Wormser Stadtbrände des 13. Jahrhunderts in der chronikalischen Überlieferung, in: *Feuernutzung und Brand in Burg, Stadt und Kloster im Mittelalter und in der Frühen Neuzeit*, Studien zur internationalen Architektur- und Kunstgeschichte 129, edited by: Wagner, O., Michael Imhof Verlag, Petersberg, 228-233, 2015.

Wozniak, T.: Brände im mittelalterlichen Nowgorod, *Neues Osteuropa*, 4,2, 8–23, 2011.

Wozniak, T.: Kirchen und Feuerschutz in Novgorod im Mittelalter, in: *Feuernutzung und Brand in Burg, Stadt und Kloster im Mittelalter und in der Frühen Neuzeit*, Studien zur internationalen Architektur- und Kunstgeschichte 129, edited by: Wagner, O., Michael Imhof Verlag, Petersberg, 234-243, 2015.

Zwierlein, C.: *Der gezähmte Prometheus: Feuer und Sicherheit zwischen Früher Neuzeit und Moderne*, Umwelt und Gesellschaft 3, Vandenhoeck & Ruprecht, Göttingen, 2011.

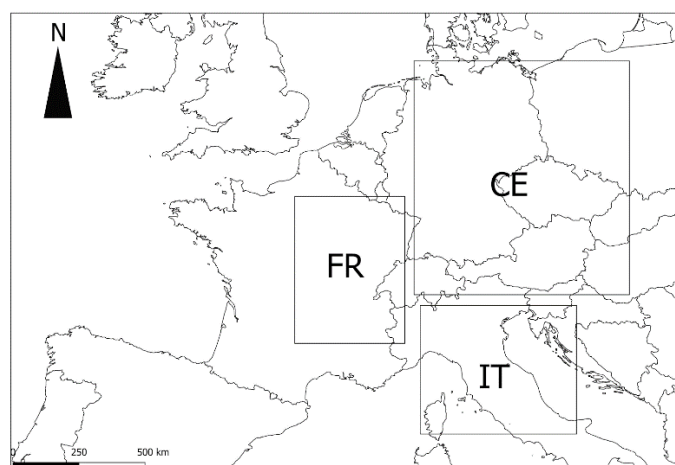
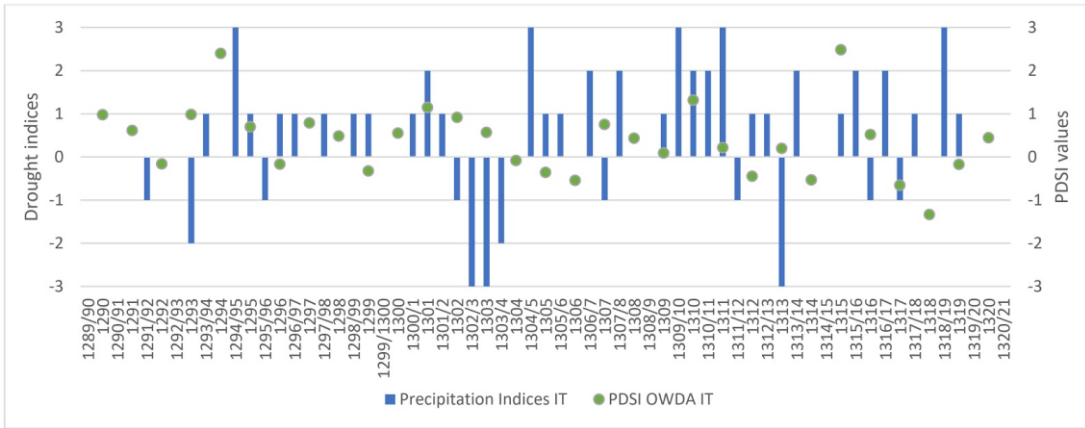


Figure 1: Geographical zones delimited for documentary researches (Map: Thomas Labbé).



610 **Figure 2: Reconstructed semi-annual drought indices and OWDA PDSI data for JJA from tree-rings (Cook et al. 2015) for IT, 1290-1320.**

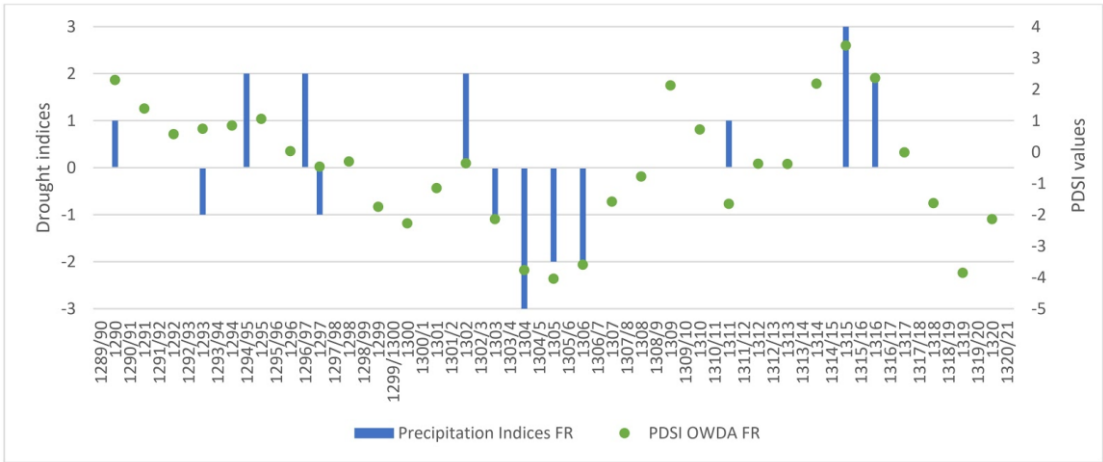


Figure 3: Reconstructed semi-annual drought indices and OWDA PDSI data for JJA from tree-rings (Cook et al. 2015) for FR, 1290-1320.

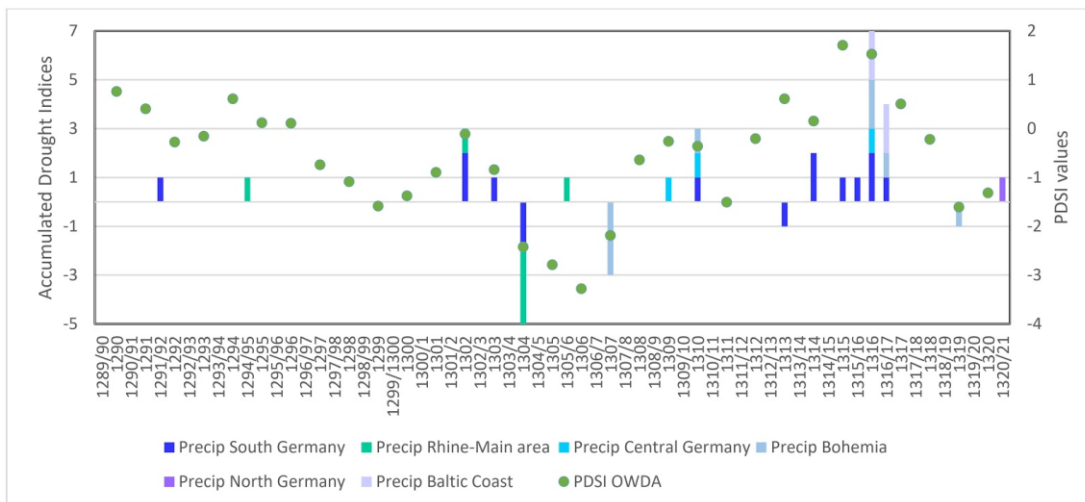


Figure 4: Reconstructed semi-annual drought indices and OWDA PDSI data for JJA from tree-rings (Cook et al. 2015) for CE, 1290-1320.

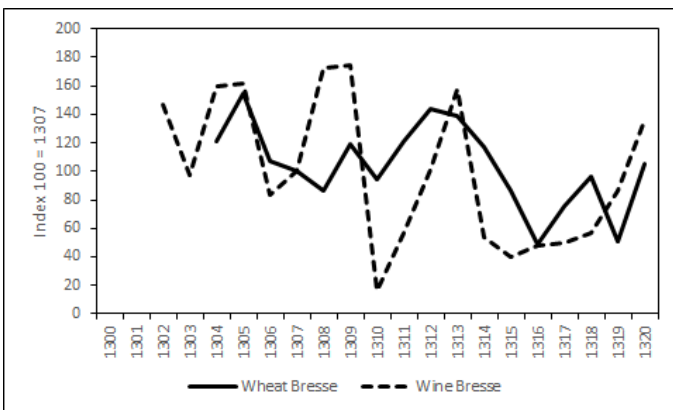


Figure 5: Mean wheat and wine yield in the region of the Bresse (FR), 1300-1320.

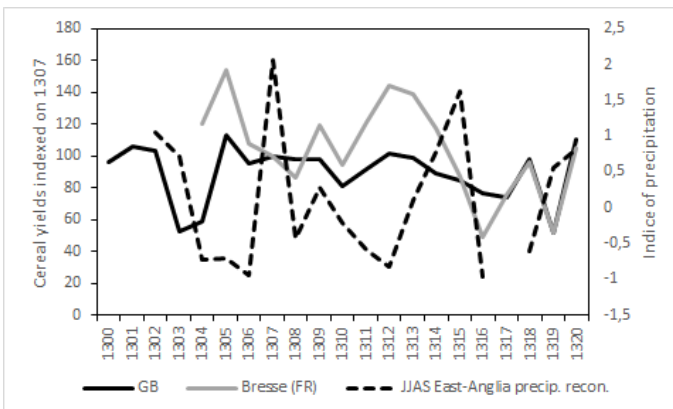
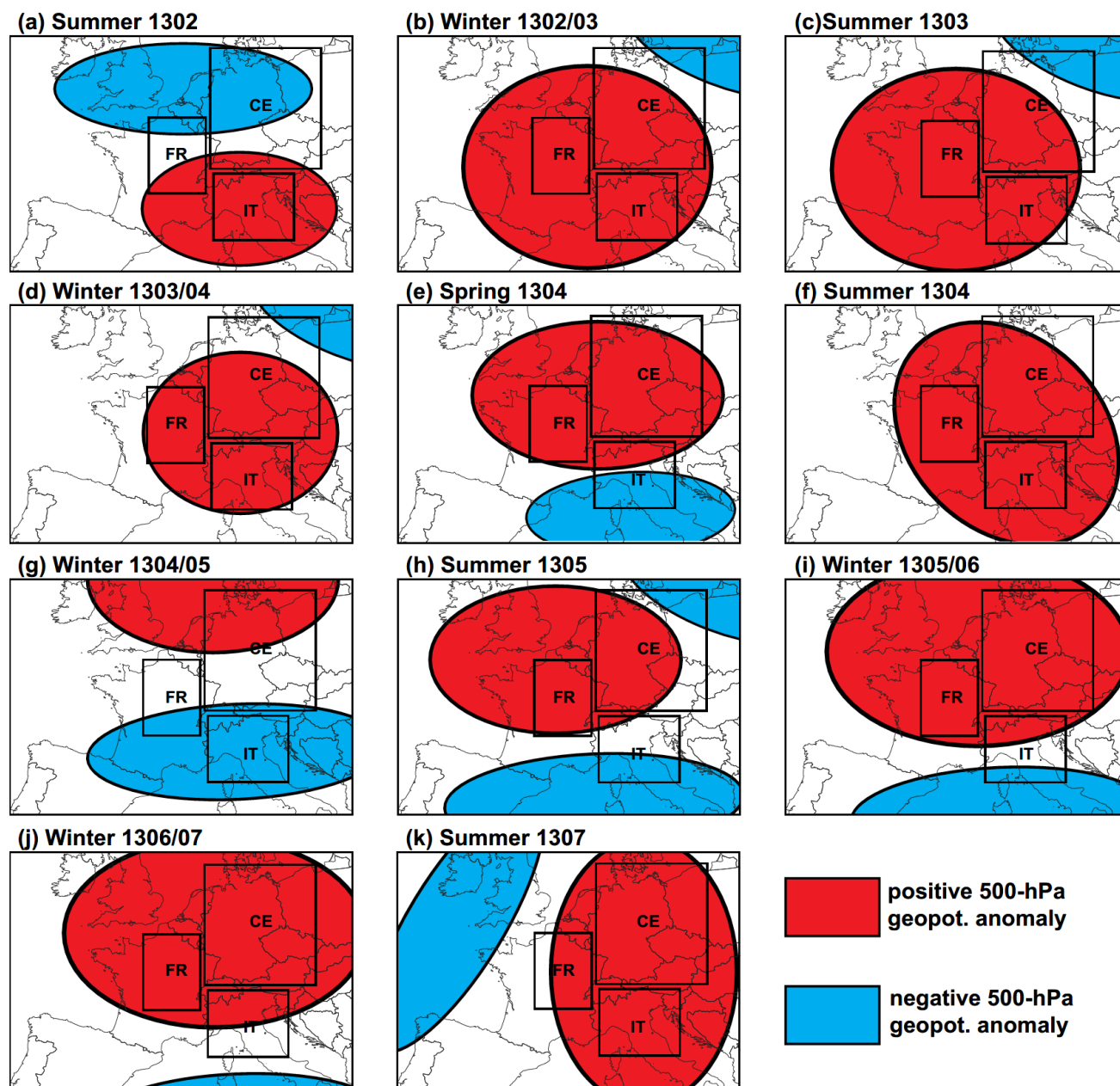


Figure 6: Comparison of cereal productivity in Southern England and in the Bresse region (FR). Data: Southern England wheat yields (Campbell 2007); Bresse wheat yields (this article); East-Anglia JJAS precipitation reconstruction (Pribyl 2017).



625 Figure 7: Illustration of the possible constellations of 500-hPa geopotential anomaly that can explain the weather patterns retrieved from the proxy and documentary sources for the years 1302-1307.

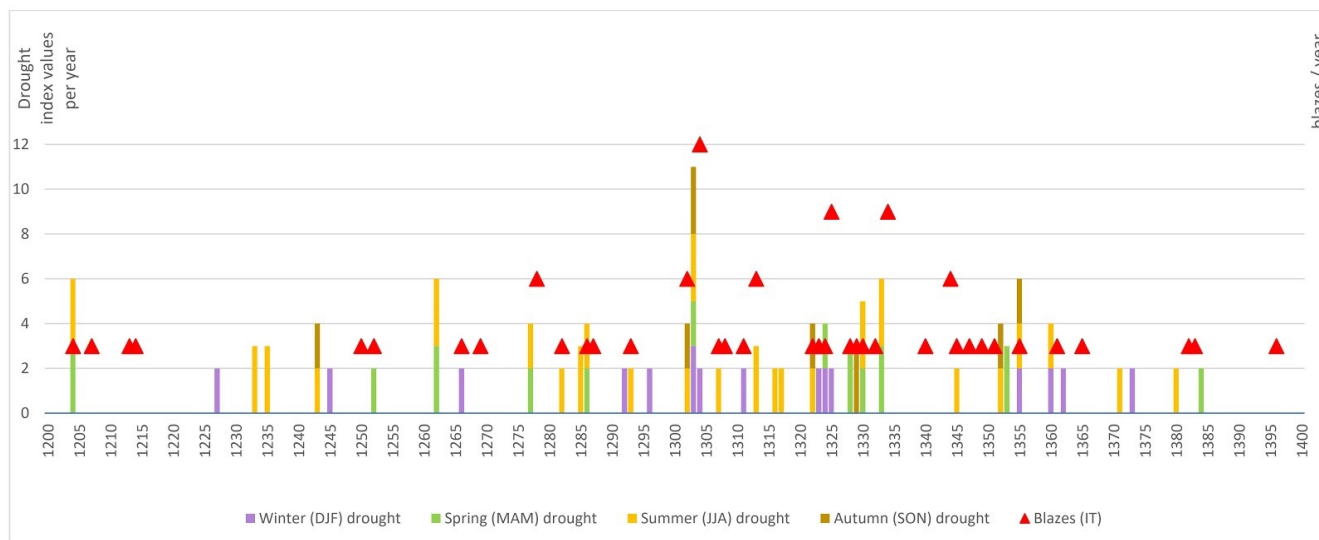


Figure 8: Reconstruction of drought indices compared with a chronology of blazes for IT, 1200-1400. Data is available for 64 years out of 200 (32% coverage).

630

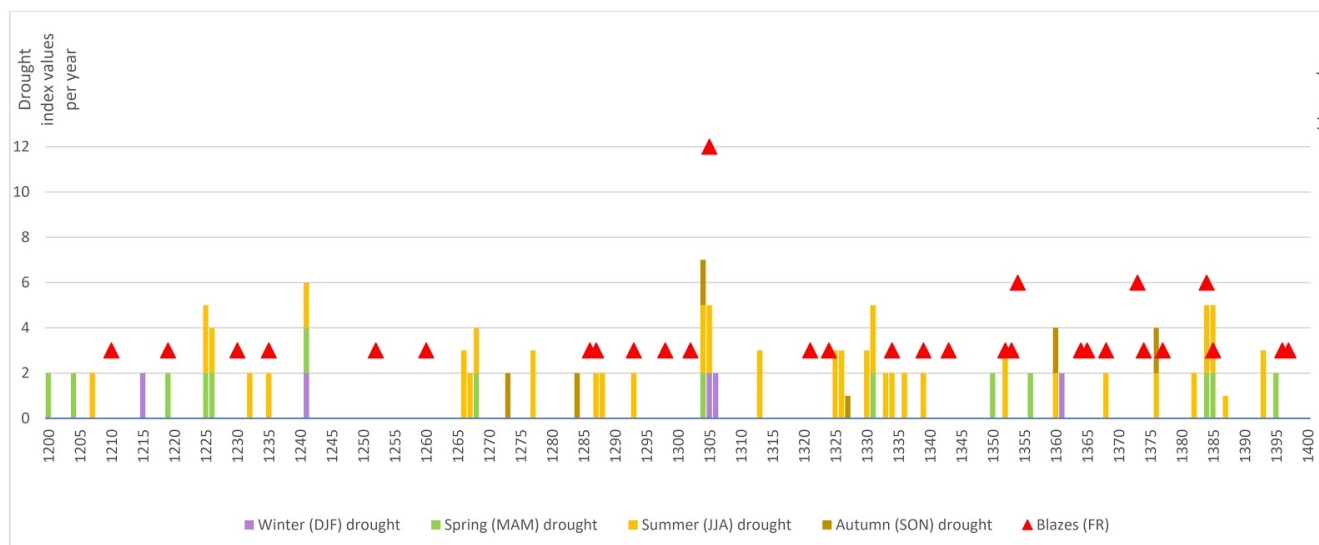
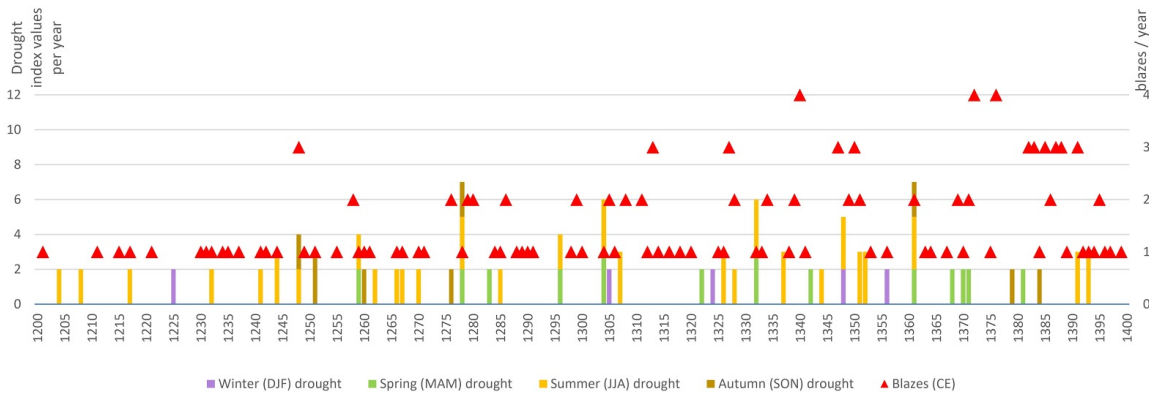
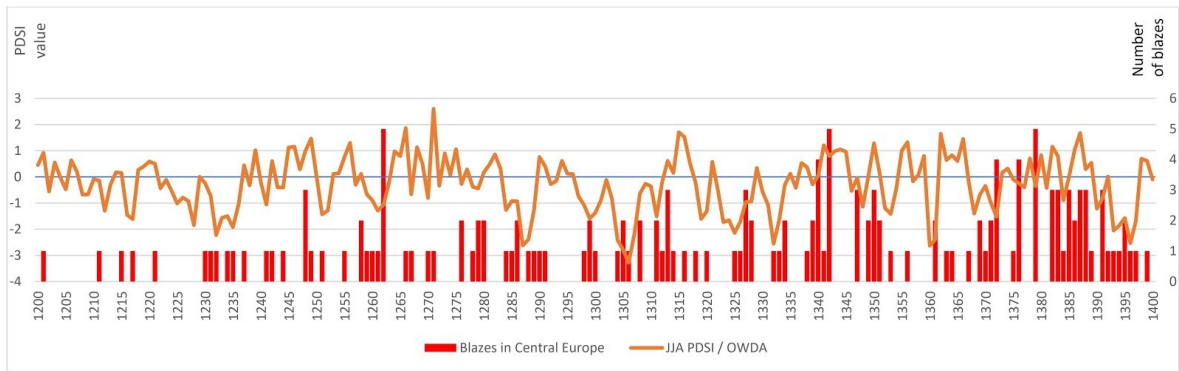


Figure 9: Reconstruction of drought indices compared with a chronology of blazes for FR, 1200-1400. Data is available for 67 years out of 200 (33,5% coverage).



635

Figure 10: Reconstruction of drought indices compared with a chronology of blazes for CE, 1200-1400. Data is available for 125 years out of 200 (62,5% coverage).



640

Figure 11: Reconstruction of JJA precipitation in tree-rings for CE and information on blazes from documentary data for the same region.

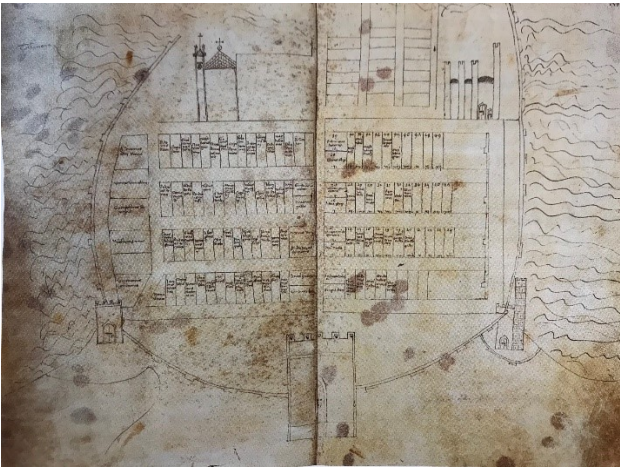


Figure 12: New city layout of Talamone with plots for new settlers from the mother city. Source: Archivio di Stato di Siena, Caleffo Nero, cap 3, 21 December 1306.