Dear Editor,

Thank you very much for giving us an opportunity to revise and resubmit the article entitled *Droughts in the area of Poland in recent centuries in the light of multi-proxy data*. We are grateful also for all the opinions and suggestions given by the reviewers. All changes in the article were marked using red fonts. We would kindly like to inform you that the following alterations have been made to the text regarding the reviewers' comments, suggestions and opinions. For clarity the reviewers' texts are in black and our answers in blue and red.

General Remarks

Anonymous Referee #2

Received and published: 09 Jan 2020

I have now reread the revised version of the articles and I consider it suitable for publication now. The authors have implemented must, albeit far from all, of the reviewer recommendations. See also my response to the authors.

The revision is much improved compared to the original submission and I can, hence, recommend publication now. I still think that a longer discussion could be make regarding whether the few droughts in in the first half of the 17th century in Poland was because of less evapotranspiration due to lower temperatures during the Little Ice Age.

The following explanation was added: Summer and winter air temperature reconstructions for Poland for the period 1401–1800 (see Przybylak 2011, 2016) indicate that thermal conditions were more favourable for the occurrence of droughts in the first half of the 17th century than in the period 1751–1800, which was colder. Only in the second halves of the 15th and 16th centuries were conditions better for the occurrence of summer droughts than in the first half of the 17th century. This means that the low number of droughts in the latter period is not the result of climate but is of the significantly smaller number of available sources, as we mentioned earlier.

Moreover, the Abstract could still be shortened and streamlined more. The Introduction reads considerably better now.

Answer: The text was shortened according to the Reviewer's suggestion.

Fig. 7 could still be improved graphically.

Answer: The Figure 7 was changed, and we hope that now its quality is better.

A very minor comment: I would recommend to write the "Medieval Climate Anomaly" with capitals.

Answer: Was corrected according to the Reviewer's suggestion.

Anonymous Referee #3

Received and published: 13 Jan 2020

This paper written by a team of geographers, climatologists, historians and dendro-climatologists convincingly highlights the rich legacy of valuable (paleo-) climatic evidence that is available for Poland. The authors present the main features of more than 100 droughts over the last millennium including their frequency of occurrence, spatial dimension, duration and intensity. The study is based on:

• documentary data for the period 1451 to 1800, originating mostly from Pomerania and Silesia

• 22 local chronologies of tree-ring width (996 to 2015)

• 8 long-term precipitation series (1722-2015).

Droughts with the instrumental period were defined using the Palmer Drought Severity Index.

An index approach was used differentiating between extreme droughts, severe droughts and minor droughts according to duration and intensity (taking from observed hydrological and vegetative effects) at assess long term frequencies.

It is worth improving this important paper in the following respects

• A short overview over the climate of Poland is missing

Answer: A short review was added. See text below:

The climatic conditions of Poland have been characterized many times by different authors such as Paszyński and Niedźwiedź 1991; Woś 1999 and Lorenc 2005. For many years The Polish National Meteorological and Hydrological Service IMGW-PIB has presenting the fruits of their monitoring (www.klimat.pogodynka.pl), allowing analyses and assessments to be made.

The climate of Poland is in general temperate. Due to its location in the central part of the continent and being considerably affected by oceanic features in the western part of the country and a pronounced continental impact in the east, the area of Poland is diverse in terms of climatic conditions. An important geographic feature of Poland is the latitudinal course of its natural landscape types – from its sea coast in the north to its lakelands, lowlands, uplands and mountains located southward.

The mean annual air temperature in particular regions of the country varies between almost 7°C to nearly 10°C (as for the period 1981-2010) with lowest temperatures in January (from -3.5°C to 0.5°C) and highest temperatures in July (from 16.5°C to 19.5°C) (IMGW 2020). The whole country is experiencing a systematic considerable increase in air temperature with rates of increase of 0.3°C every 10 years occurring since the second half of

the 20th century. The largest increases have taken place in northern and western parts of Poland. In 2019, mean annual air temperature reached 10°C, translating into the warmest year in Poland since the beginning of instrumental measurements of air temperature. Annual precipitation ranges from 450mm in the central belt to 700 mm in the uplands and 1500-1700 mm in the highest mountain ranges in southern Poland (IMGW 2020). February is the driest month in Poland and July is the month when the highest monthly precipitation totals occur. During the last number of decades symptoms of the systematic drying of climate in Poland can be observed. Westerly and south-westerly winds predominate and only in northern, coastal parts of the country is there a considerable amount of north-westerly winds.

• The scientifically most valuable result concerns the mega-droughts, which are only partly presented and climatically not interpreted though a rich literature is known to exist.

Answer: The new information was added. See the text below and the revised version of the paper (Table 3):

The megadrought year of 1473 was detected in the Baltic Province on the basis of an oak chronology from Eastern Pomerania (Ważny, 1990). Narrow rings were observed in 80 percent of the samples for this year. The effect of the drought in 1473 can also be shifted and observed in southern Poland in 1474 (Szychowska-Krąpiec, 2010). Reconstruction based on dendrochronological data (OWDA, Cook et al. 2015) shows that, in this year, severe droughts were common in almost the entirety of Europe (but particularly in southern Germany, western Czech Republic and Austria) excluding only its northern and north-eastern parts and Spain. The drought in 1540 was observed in different parts of Europe; particularly strong evidence is available in documentary sources (Wetter et al., 2014; Pfister et al., 2015; Brázdil et al., 2016). Additionally, many dendrochronological data confirm the existence of strong droughts in much of Europe, in particular from France to Latvia, Belarus and Ukraine and from the southern Scandinavian Peninsula to northern parts of Italy (OWDA, Cook et al., 2015). Čufar et al. (2008) identified the existence of droughts in Slovenia in 1540 based on tree rings. The scale and intensity of the 1540 megadrought in Europe described by Wetter et al. (2014) as "an unprecedented 11-month-long Megadrought" (more severe than the 2003 drought in Western Europe and the 2010 drought in Russia) was, however, recently questioned by Büntgen et al. (2015), who analysed this year in light of 24,303 individual tree-ring-width measurement series. It is also worth adding here that in different parts of Europe the effect in tree rings was shifted and observed in 1541 (Büntgen et al., 2011). Analysis of our 22 dendrochronologies reveals the occurrence of narrow rings in trees growing in the Baltic Province and in the Lesser Poland Province, and thus not in the whole of Poland as shown in

the OWDA (Cook et al., 2015). In 1590, narrow rings were observed in the Baltic Province, but the decidedly strongest droughts in Europe in view of this proxy were those occurring in France and Germany (Cook et al., 2015). Narrow rings were also noted in most sites in central and eastern Europe, as well as in Scandinavia. The megadroughts occurring in Poland in the 17th century (1676 and 1683–84) were the least territorially extensive of all the megadroughts analysed here (see Fig. 13). Analysis of tree-ring reconstructed droughts (Cook et al. 2015) generally confirms this, except for the year 1684. In all those years strong droughts were common in Europe also, but their greatest intensity was observed in Germany, France, the Low Countries and England (1676 and 1684), but in southern Europe in 1683. The year 1748 seems to have a somewhat regional character; narrow rings were noted in the Greater Poland and Pomerania Province and in the Lesser Poland Province. There is no information about tree reaction for this drought in selected sites in central Europe (Büntgen et al., 2011). Looking at OWDA we see the occurrence of droughts in this year mainly in northern and western parts of Poland (although their severity is not so large). Evidently more severe droughts in this year in Europe were particularly observed in southern Germany, the whole of Austria and the western borders of the Czech Republic (Cook et al., 2015).

• Attempts to extrapolate the regional results to the whole of Poland are not convincing. They may be omitted.

Answer: We did not extrapolate the regional results to the whole of Poland. When information about droughts was available for all of Poland, we also count these cases for each region. Thus, the strategy is opposite to that which the reviewer suggests.

• Statistics for winter droughts should perhaps be calculated separately

Answer: After discussion we decided not to extend the article by adding further calculations, this time related only to winter droughts. However, considering the valuable opinion of the Reviewer we recognized the need to explain the conditions leading to the establishment of winter droughts in a wider context by adding the additional explanation as follows:

For comparison against the number of droughts delimited using documentary evidence, 50-year frequencies of the three categories of droughts were calculated for climatological seasons (Fig. 10). It comes as little surprise that the frequency of all-category droughts was greatest in winter. Other seasons show more-or-less similar frequencies. In winter, droughts evidently dominated in the study period in the second half of the 19th century, this is particularly well seen in the case of severe droughts, and slightly less so for moderate droughts, which were also quite frequent in the first half of the 20th century. Extreme droughts in winter do not show any significant changes over time, but it should be emphasised here that they were slightly more frequent in 1951–2000 than in 1851–1900. Moreover, in addition to winter droughts it should be pointed out the deficit in precipitation during this season is usually connected to temporarily increasing continentality of climate conditions which are related to

the advection of very cold and dry polar continental air masses from the east, sometimes even with the mixture of very cold arctic air masses. During such conditions deep soil frost increases which does not allow the water infiltration into deeper layers. Thus, almost all melting snow is transformed into spring surface run-off volume and only the negligible part of this volume is transformed into groundwater. Such conditions may lead to the occurrence of very dry spell in spring. In spring, moderate droughts prevailed still in the period 1851–1950 (usually 4–6 cases), with a greater frequency in the first 50-year period. Both severe and extreme droughts were most frequent (usually 1–3 cases) in 1851–1900, and in particular in 1951–2000 (Fig. 10). In summer there is a clear change in the time pattern of drought occurrence: drought frequency rises in the 20th century (except severe droughts), and in the case of moderate droughts particularly in its second half. Frequency of extreme droughts is evidently higher in the 20th century compared to pre-1900 period. In autumn, moderate droughts do not show great changes in the last two centuries, while severe and extreme droughts were most frequent in the 20th century (Fig. 10).

Fig. 11 is dominated by droughts with a duration of 2 months. Which is the criterion for "extreme" in this case?

Answer: The information is given on page 22, lines 9–13, see in particular the last sentence in red:

„Secondly, a drought was considered to be at least two consecutive months during which the SPI1 value was ≤-0.50. Thus identified, a drought was determined both in terms of duration and by category. Thirdly, drought category was determined by the dry month of lowest SPI1 value. A drought was thus considered extreme if the SPI1 value for at least one of the drought months was ≤-2.00."