Response to Reviewer #3.

We would like to thank the reviewer for setting aside time to read, comment and make suggestions to improve our manuscript. The impression of the manuscript being verbose was shared by another reviewer and we will do our best to improve the language and articl structure to make it better. We love the passion and the expression “amazing”. Thank you! That is how Stefan felt after completing the series. We can add an analysis that opens up the change regarding changes in the extreme. We have done an interquartile analysis for the sake of simply trying to grasp the change ourselves. This was intended for a paper on variability, but we can add it to this paper if the length is ok.

RC3

The authors present a new ice record extending back several centuries and put this new time series into context with two other rivers in the region with time series extending back centuries. It is clearly a lot of effort to assemble, revise, and validate a new record. The manuscript is quite descriptive and verbose, and could benefit from more formal quantitative analysis to support the data. The manuscript could also use better contextualization for readers outside of Finland who are not familiar with the geography and history to better follow the manuscript. Nonetheless, it is an interesting manuscript and would be a good addition to the literature.

Yes, there is a lot of work behind this series, or the dates, as the meta-data is still unused. We will add a map and a section 2.4 where we give some rough estimations on ice cover duration and ice thickness. We hope that this will make it easier to understand the change that has occurred. There is not enough data to do a comparison, but we hope that the added section will provide readers with a better understanding of the basics.

On line 36, the authors state that the “databases are not updated with observations from the first two decades of the 21st century.” This is no longer true as the database for the National Snow and Ice Data Centre have been updated in 2020 and there have been a variety of publications using ice databases that have provided their data online from the past 2 decades. Please update this sentence to reflect updated databases and recent publications.

This was a general reflection and not directed to any specific to the National Snow and Ice Data Centre. We will remove the sentence, it really does not add a lot of value.

The new time-series at Kokemäki River is amazing! Please provide some historical context of this ice time series. Who collected this time series? How was it discovered? What kinds of observations were made? Where were the observations taken? Was the same methodology used throughout the time series? How long does the breakup process take for the river?

Thank you for your kind words. That is so rare in academia, but we share the passion. I think that we answer most of your questions in the article (section 2 and 3). We do not know who did the initial observations. Most of the early series were published by the newspapers but they never reveal who made them. Therefore, we try to validate the observations by establishing that they describe the breakup in Pori and not from another section of the river. The descriptions obtained from the newspapers were made by journalists at that time.

Since one of the goals was to verify this new time-series, please provide further qualitative and quantitative evidence of how the data were verified, how closely they matched between different newspapers/records? I was also curious when there were multiple sources of ice-off, were the dates the same? Also, was the same definition used by each source over time? Did they examine breakup date at the same location and in the same way?

Regarding the ice off event from Aura River, please read our other article (Norrgård & Helama 2019).

Regarding Kokemäki River breakup dates, we describe this in section 3.1. There is very little discrepancy in Pori. For example, in the 1800s the two newspapers were published 2-3 times a week. Hence, if the ice started moving on Thursday, then both papers mention it in the Saturday paper. The only real discrepancy was in 1852, as we discuss in section 3.1. In most other cases the discrepancy may be a day or two. In this case we can assume that both observations were right, it is a question of when the ice started moving and continued moving. As with most phenological series, a day has little to no impact on the long-term trend. As with most historical observations (whether a cryophenological observation or a meteorological observation) we cannot verify the observation, we validate the dates by finding observations. We will change this use of term in our paper.

On line 107, thermal breakups were introduced. Please provide more specific details related to the thermal inputs to the river. What thermal breakups are relevant in Kokemaki River and why? This seems interesting, but much too vague for readers not familiar with the detailed geography and history of Finland to follow.

We added some descriptions to improve clarity. For example, in March 1992, one newspaper claimed that the ice in Kokemäki River melted in situ for the fourth year in a row. The city employee conducting the observations claimed that he would not record an official breakup date because a 'proper' breakup date could not be determined. We will add this description, and this is why we highlight thermal breakups. We are not doing the series a favour, but it important for future research. We highlight thermal breakups because 1) the process of determining the breakup date is affected by changes in the breakup process. We do not know what causes this change (climate change or the power plant) and it is need of further research. Another way of expressing the change is that intense mechanical breakups have become rare. Moreover, if thermal breakups are becoming more common, then this is 2) a methodological aspect that has not been addressed before.

On line 234, could you please clarify what is meant by previously published ice breakup dates and which river is this referring to? Changed to improve clarity.

In the methods, it has become clear that there were changes in the location and observations for ice breakup over the years? How were the changes in location and definitions reflected in the dates and patterns of ice-off? Did they coincide with extreme events or breakpoints in the data? And how else could they have impacted the uncertainty around ice-off dates?

It seems as if the reference point changed in Kokemäki River. This is explained in section 3.1. Why they made the change is unclear. It might be the construction of the new bridge caused a change of place as it then would have seemed a better option to determine the breakup date

before the bridges than after. But this is something that could be expected when series continues for over 200 years.

I liked the introduction of extreme events, but I was hoping to see a more quantitative analysis than simply identifying the 30 most extreme years. Perhaps more formal analysis could be done here to quantify if there are more extreme years in certain decades/periods than others or expected by chance. Also have the number of extreme events increased over time? Further quantitative analysis would be appreciated here.

Identifying the 30 most extreme events might not seem refined. However, by simply identifying the 30 earliest breakups, our analysis shows something that quantitative analyses in previous research has not been able to identify. (Of course, Torne River was for a long time the only series available so there was no reason to identify extreme years (cold springs) because there was nothing no other series to compare with. Now there is.)

Nonetheless, we have done an interquartile analysis for 30-year non-overlapping periods which shows how variability has changed. This was meant for another paper, but it was based on the information attained from the tables and could be added if there is room. In this analysis we take the average of the three earliest/latest breakup dates to show how the extreme events have developed.

Have the number of extreme events increased over time:
yes and no. The frequency of early extremes has, as shown in table 1, increased. However, we have not specifically investigated the frequency of early events. This is a tricky question that we have given some thought, i.e. how to analyze and visualize changes in frequency in a way that reflects the results in Table 1. Breakup variability in Torne River has been analyzed before, but standard methods seem to fail to register the changes we discuss in the article. As mentioned above, we have an interquartile analysis that we could add if there is enough room.

On line 283, the analysis with the hydroelectric plant was introduced. Is this power plant only relevant to Kokemaki? It doesn't seem so as earlier it was stated that there are 4 power plants on this river. Are there any other power plants in the other rivers? Why was only 1 power plant included in this analysis and not the others?

We mention this in the paper. There is one power plant in a tributary to Torne River (section 2.1) but no power plants in Aura River (2.2.). We only included the power plant in Harjavalta because a tributary river (Loimijoki River) connects to Kokemäki River before the power plant built in 1919. It would be impossible to distinguish which affects the breakup in Pori more, the powerplant or the discharge from the tributary river.

I was curious how far these rivers and sites are from one another? If the sites are more than a grid cell apart, I was curious why air temperatures were used from the same station.
We included distances between the rivers. There are no measurements available from Pori.

Please provide a map of these rivers and also include some of the features that were discussed in the manuscript. Will do.

The impact of the power plant is much too descriptive. Please provide some more formal quantitative analysis to illustrate whether findings were significant. Earlier in the manuscript, many other factors that have contributed to land use changes and warming were discussed, but not included in the analysis, including urbanization, land use change, and climate change. How have these factors contributed to the ice-off dates?

It is impossible to quantify and assess how urbanization or land use has impacted the ice off or breakup. However, we must acknowledge these factors because the series stretch over several centuries and derive from urban environments. The series may be affected by these factors, but it is impossible to quantify them. We write this out more clearly now.