Reply to Interactive comment Anonymous Referee #2

We want to thank the reviewer for his/her compliments about our work. In the following we will discuss the issues raised by the reviewer and hopefully answer all questions satisfactorily.

General comments:

The aim of this article is twofold: (1) to introduce two new types of drought, characterizing droughts related to ice and snow, (2) to analyze the socio-economic impacts of past droughts. The paper is both well documented and well presented.

>> Thank you.

The main weakness is the lack of link between the two points (see e.g. P10489, the authors switch abruptly from the drought typology to the socio-economic impacts). The coherence of the paper suffers from the lack of reported impact related to snowmelt/glacier droughts. The publication of this paper as it stands may be premature in the light of the current extension of the databases. At least, the 2003 event observed in Norway, (possibly) similar to the described 1949 drought, can be obtained from the EDII (Figure 11). It should be included in the discussion to ensure a minimum link between the two sections.

>> We realise that this is an important issue (also raised by reviewer #1) that we should address. We will follow your advice in discussing the causing factors of the specific events reported in the vicinity of our case study catchments. The 2003 drought in Norway can indeed be covered in both parts of the paper, and additionally we can try to find any traces of the 1972 drought in Northern Europe, the 1975-76 drought in Switzerland, the 1992 drought in Sweden, and the 2006 drought in Sweden.

Furthermore, in response to the comments of reviewer #1, we propose to restructure the first two sections of the paper (Sect.2 Theory and Sect.3 Causing factors) to include all temperature-related drought types. In these chapters we will first summarise the results of the previous study of Van Loon and Van Lanen (2012) before the new types are discussed. This will increase the coherence of the paper. We will also adapt some of the formulations in the manuscript.

We do not support the suggestion made by the reviewer that the publication of this paper is premature because the databases are still being filled. In the ideal situation there is indeed continuous extension of the databases (which is the case for DIR, but less for EDII), but for this study we already used thousands of reports (EDII: 4245 and DIR: 17195). The DIR is constantly updated, but only for current drought events. The EDII is a research database that has been set up and filled in the framework of the DROUGHT-R&SPI project (www.eu-drought.org/). In recent months there have been no major updates to the database because the DROUGHT-R&SPI project is in its final phase and large additions are also not expected in the coming months, before opening up the database to the

general public. When the database is filled with many additional reports after opening up to the public it would be very interesting to repeat this analysis.

The title should be modified (too general compared to the contents of the article).

>> We reconsidered the title to be more specific and suggest the following: "Hydrological drought types in cold climates: quantitative analysis of causing factors and qualitative survey of impacts."

In details:

P10474: how the end of the snow melt is computed?

>> The spring season ended after the flow peak in the regime, halfway the recession curve of the discharge regime. This was determined by a visual analysis of regime plots of discharge. For more information and the regime graphs used for this analysis see Ploum and Van Loon (2014).

P10474: "If needed : : : versa": the choice of the increase seems subjective. Was it applied for all the basins? If not, why? Is there any consequence on the correlation analysis? The physical meaning of the temperature is lost. In fact, the useful information is the rank of the explanatory variables. Another way would have been to use empirical non exceedance frequencies.

>> This correction was done for plotting purposes only. It was applied because without the correction, standardisation in catchments with an average temperature below zero would lead to a reverse axis and catchments could not be plotted in the same graph. The correction was applied similarly to all catchments in the same country, i.e. +10 for Austria and +15 for Norway. In this way the points in the scatterplot per country can be compared.

We did investigate other options, such as converting all temperatures to degrees Kelvin. As expected, this did not result in different correlations in the correlation analysis, but it had a large effect on the scatterplots. The conclusions drawn from the scatterplots remained the same, but they were more difficult to read because of the different axes and were less well comparable to the scatterplots of precipitation. We prefer our original conversion and propose to leave the scatterplots as they are.

P10475: are historical droughts well reconstituted? We do not know if the analyses consider either simulated or observed discharges. I suspect that observed discharges are examined. An additional analysis should consider simulated discharges. This could be a manner to verify whether the differences between the two countries and the lack of expected links between drought and meteorological conditions are due to biases in hydrological modellings.

>> We indeed only examined observed discharges in this research. We do agree that it is very interesting to do a similar analysis on simulated discharges to verify the influence of the hydrological model on our results. We did a preliminary analysis and found quite remarkable differences in the

correlations for simulated discharge. We propose to add some results of the analysis of simulated discharges to the paper.

P10476: statistics may be wrong (see comments on Figure 5)

>> The plotting error in Figure 5 did not have any results on the correlations. In the statistical analysis the entire dataset was used.

P10481: how was this selection made? Which proportion of the inventoried events do they represent?

>> The events were extracted from the French and English archives. The list includes droughts beginning in winter or including winter. For the majority, archives indicate clearly their wintry character when they mention snow (in 1614, 1731, 1921) and/or frost (1740, 1742). In the English case, 5 wintry events quoted in table 5 are included in a British series counting 50 droughts between 1539 and 2013. In the French case, 5 wintry events quoted in table 5 are included in a French series counting 63 droughts between 1500 and 2014.We will mention these numbers in the manuscript.

Table 4: can you define what rogations are.

>> The Roman Catholic Church ordered these ceremonies called 'rogations' (rogativas) in Spain or processions in Portugal and in France to avoid endangering the established order or the socioeconomic balance. In the case of the droughts, processions were organised 'pro pluvia' (latin word), literally 'for the rain'. The ceremony gathered elits, clergy and people of the village or the city. We will add a short explanation in the paper.

Table 5: droughts of type C are of type A in Figure 11. This is confusing.

>> We will change this.

Figure 2 and Figure 3: the way drought is defined, is not consistent with the way events are defined in section 3.3

>> We do not completely understand what the reviewer means with this comment. The definition of events mentioned in Section 3.3 reads: "A drought event was classified as snowmelt drought *if the centre point of the drought was within the snowmelt period (spring) and no precipitation deficit in spring occurred with similar magnitude as the discharge deficit. A drought event was classified as* glaciermelt drought *if the centre point of the drought was within the glaciermelt period (summer) and no precipitation deficit in summer occurred with similar magnitude as the discharge deficit." This corresponds to the conceptual figures of* snowmelt drought *and* glaciermelt drought *in Figure 3. The*

conceptual figures of the other drought types sketched in Figure 2 do not correspond to this description because for example cold and warm season droughts *have a hydrological drought in winter and not in spring/summer like* snowmelt and glaciermelt droughts*.*

Figure 5: two dots are missing in the graph Pwinter against Qspring. These two dots are located around (1, 1) in the graph Twinter against Qspring. Why? Does it mean that some of the figures in Table 3 are wrong?

>> Thank you for pointing out this error (well spotted!). The points are missing because the axes are defined to strictly. We will correct this.

Figure 11: there is a gap between 1800 and 1920. Why? Why is the dashed line used for 1921? No automatic procedure is available (yet) for applying the hydrological drought typology (P 10486). Does it mean that by default, events that do not fully respect criteria defined in Section 3.3 are not snowmelt/glaciermelt droughts?

>> The gap and the dashed line are caused by the same plotting choice, namely to make the upper and lower axis as similar as possible. There is a large gap in the drought impacts reported in the historical sources between 1779 and 1921 (see Table 5) and we decided not to include the 19th century in the figure for reasons of readability. The 1921 event on the lower axis in Figure 11 is dashed because it originates from historical sources instead of from the EDII like the other events on the lower axis, and the 1921 event actually belongs to the upper axis of Figure 11. We will explain the special position of the 1921 event in the caption.

Indeed, drought events that do not meet the criteria of any drought type are classified as "unidentifiable". This applies to only a few events in our database.

References:

Ploum, S. and Van Loon, A.: Investigating seasonal variables for droughts in cold climates: a comparative study in Austria and Norway, DROUGHT-R& SPI Technical Report No. 15, available at: http://www.eu-drought.org/technicalreports, Wageningen University, Wageningen, the Netherlands, 2014.

Van Loon, A. F. and H. A. J. Van Lanen. A process-based typology of hydrological drought. Hydrology and Earth System Sciences, 16(7):1915{1946, 2012. doi: 10.5194/hess-16-1915-2012.