Response to referee comment Anonymous Referee #1

We would like to thank Anonymous Referee #1 for reviewing our manuscript and the positive feedback and the suggestions for improvement. We will reply to the comments below.

The reviewer's comments are in **bold**, our response in *italic.*

General comment

This paper is an analysis on the possible causes of streamflow droughts in glacierised catchments in the context of climate change (affecting glacier geometry, melt rate, discharge regime and drought). The authors have chosen 2 different highly (more than 60%) glacierised catchments for their study. They considered 2 different approaches for modeling glacier change: (1) glacier topography remains constant, and (2) glacier topography is empirically updated every year according to surface mass balance.

First, different approaches on how taking into account changes in glacier geometry in streamflow modeling is discussed. Since the approaches used are empirical, no ice dynamics in the strict sense is considered. So I suggest to modify ''glacier dynamics'' into ''glacier changes'' in the title.

>> The approaches to take into account changes in glacier geometry are indeed empirical and complex ice flow modelling is not used. We used the term dynamics to indicate that the glacier geometry change and streamflow modelling is coupled and therefore the glacier is adjusted in a dynamical way. However we agree that this may be confusing and we can change the "glacier dynamics" into "glacier changes" in the title.

Since glacier topography always changes in a changing climate, it is in my opinion not a sound option to analyze streamflow evolution without adapting the glacier topography accordingly. A more realistic option would be to assume no glacier at all. But assuming a constant and arbitrary glacier surface area in a changing climate will produce streamflow results which can hardly be interpreted.

>> We agree that glacier geometry (in the model described by glacier area and glacier thickness in each elevation zone) always changes in a changing climate and that one should account for that in the modelling of glacierised catchments to obtain realistic predictions, as we discuss in the manuscript. The benchmark simulation with static glaciers in our study can still serve a number of interesting purposes. Most importantly, we can use the static glacier modelling to isolate the direct effect of changes in temperature and precipitation from the effect changes in glacier extent, so that we can understand the corresponding changes in seasonal streamflow variability better. While the resulting streamflow quantities might not be realistic the benchmark can still be useful for increasing our understanding of how streamflow hydrograph changes will lead to changes in the processes leading to streamflow droughts. This benchmark method has also been used many times in hydrological modelling studies (see e.g. Akhtar et al., 2008; Stahl et al., 2008; Tecklenburg et al., 2012; Sun et al., 2015. Finally, some models still only use a constant glacier cover through time, either since they only model a short period of time or since the model does not allow to model glacier change (see e.g. Singh & Kumar, 1997; Klok et al., 2001; Shabalova et al., 2003; Verbunt et al., 2003; Singh & Bengtsson, 2005; Terink et al., 2005; Horton et al., 2006; Rahman et al., 2013). We will make these points clearer in the revised manuscript.
Assuming no glacier is certainly a possible option; yet a less defendable one as the model parameters were calibrated to glacierised catchments and model parameters thus effective will reflect the typical sensitivities and relations among fluxes of glacierised catchments. Nevertheless, in our simulations for the Wolverine catchment a no glacier scenario also occurred during part of the simulation period and can happen in general in studies of future simulations of glacierised catchtments. However, no

solution to avoid this problem with calibrated model parameters and changing glaciers and long simulation periods does exist. We will improve the discussion on this point.

Furthermore, I feel that the different ways of defining a drought a bit confusing. Since I am not hydrologist, I apologize for that. But in my opinion, it would be sufficient to define a reference period (RP) (f. i. 1960-1990 as used in Switzerland for climatology), and to present streamflow results outside this RP as deviations from it. I think results presented this way will be more useful for water management purposes.

>> We used and compared two methods to define streamflow droughts in our study: the Historical Variable Threshold (HVT) and Transient Variable Threshold (TVT). For the HVT we use a fixed RP period in the past, as the reviewer describes, and deviations from this Historical Threshold in the future (below threshold values) is what we define as streamflow droughts, in the HVT method. The aim of this paper was to compare this approach with another threshold approach, the TVT. This Transient Threshold changes according to the changing regime because there is no fixed reference period (it is a moving 30-year window). The results show that using a HVT or RP in changing catchments, like glacierised catchments, may not always be the most useful method for water management purposes since this method indicates changes in the regimes but not real changes in streamflow droughts. In our study, in the Nigardsbreen catchment for example, the HVT is based on a period where the catchment was highly glacierised and using this threshold outside the reference period (in the future) where the glacier has retreated gives a large increase in drought deficit while in fact it is only a small shift in timing. The HVT method thus also leads to a strange comparison of different streamflow generation processes controlling the streamflow signal and variability (especially in the Wolverine catchment where the glacier has disappeared). We do agree that it is important to look at changes and deviations from a past RP, e.g. by looking at changes in the hydrological regime (see Fig. 5), but for water management we think it is also relevant to take these changes and adaptation into account and change the point of view and look at future streamflow variability to analyse streamflow droughts. We will clarify our reasoning for using and comparing the different thresholds in the revised manuscript.

The paper is well written and the results well presented.

I can recommend publication.

>> Thank you for this positive evaluation.

Specific comments:

p. 18 line 14: ''… in de left …'' needs correction

>> Thank you, we will correct this in the revised version.

<u>References:</u>

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