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Discussions

# *Interactive comment on* "The role of precipitation for high-magnitude flood generation in a large mountainous catchment (upper Rhône River, NW European Alps)" *by* Florian Raymond et al.

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The authors would like to warmly thank the anonymous reviewer for his.her useful comments and suggestions which will help to significantly improve the manuscript. Please find below our answers to the main reviewer comments:

*) It is unclear what we really learn. For example, the finding, which report correlations between floods and precipitation characteristics, these findings are only related based on the correlation of some floods of some catchment with some arbitrarily chosen P characteristics. This is potentially interesting, but does not answer any clear question to me, nor does it support the claim that "our results open new perspectives for flood



hazard assessments directly based on climate model outputs.". Sure rainfall is important in driving this floods, but this seems trivial, and I would expect some clear insight beyond this trivial statement. The provided topology of floods is an interesting way to summarize the type of flood events, but I do not see how it is really relevant beyond the case provided here.

Response:

According to your feedbacks as well as those from the 2 other reviewers, we realize that the objectives were probably not stated clearly enough in the first version of the manuscript. Please find below the clarified question and objectives.

A set of previous studies based on data series starting from the 1960s have shown that regular alpine floods (with annual/sub-annual occurrence) are complex events resulting from numerous processes in interaction like rain variability, snow/ice-melt dynamics, and soil moisture evolution (e.g. Merz and Blöschl, 2003; Sikorska et al., 2015; Brunner et al., 2017; Keller et al., 2018). On another hand, a set of studies focused on single flood cases seen as the largest historical floods and showed that these "extreme" floods mainly result from heavy precipitation accumulations (e.g. Blöschl et al., 2013; Ruiz-Bellet et al., 2015; Brönniman et al., 2018; Stucki et al., 2018).

As stated by Alfieri et al. (2015), "the assessments of the future flood hazard are commonly performed by coupling atmospheric climate projections with land-surface schemes and hydrological models". Accurate flood hazard projections are required by the decision makers in charge of flood risk reduction and water resources management at local to regional scales (Kundzewicz et al., 2016). However, expected changes in the magnitude and frequency of floods are highly uncertain, mainly due to i) the large uncertainties of extreme precipitation projections by the global and regional climate models (Sillmann et al., 2013; Kundzewicz et al., 2014; Mehran et al., 2014) and ii) the uncertainties of hydrological modelling (Dankers et al., 2014).

To overcome the uncertainties in the high-magnitude floods hazard projections, and as proposed by Farnham et al. (2018), a complementary approach that would rely on direct links between atmospheric processes and flood occurrences is used in this study. This approach assumes that i) flood events mainly result from “extreme” precipitation and ii) that atmospheric features resulting in “extreme” precipitation can be used as predictors of such events directly from climate projections (e.g. Farnham et al., 2018; Schlef et al., 2019). In this study, we explore the first point, i.e. in what extent the generation of high-magnitude flood events in a large mountainous catchment can be explained by precipitation only. We also analyse the features of precipitation, i.e. its duration and its accumulation, associated with such natural hazard.

To reach this objective, we propose a new approach, at the intersection between the study of regular alpine floods and of largest historical floods, discussed above. We study historical floods that occurred in a given large mountainous catchment and we use long discharge and precipitation datasets (almost a century) to get a “robust” sample of high-magnitude flood events.

Our key results are:

- Precipitation alone seems sufficient to explain 13 of 28 flood events (types 2 and 4). Conversely, precipitation alone is not sufficient to explain the onset of flooding of types 1 and 3, possibly associated with other processes such as snow or ice melting.

- The largest flood events (return time period > 20 years) clearly result from precipitation accumulations only.

- Precipitation accumulations resulting in these flood events are characterized mostly by the 2-day and secondly by the 8-day accumulation, all ending 1 day before the events

- In this given catchment, only flood events with return time period > 20 years or types 2 and 4 flood events could be associated with atmospheric features. - To link these flood events to atmospheric features, a link between atmospheric processes and 2 and



8-day precipitation accumulations.

We achieve promising results since part (13 of 28 flood events) of the high-magnitude floods seem mainly associated with “extreme” precipitation accumulations only. Interestingly this includes the strongest flood events (return period > 20 years) that have the potential of greatest impacts on societies. Hence, this opens a promising avenue for complementary flood hazard projections if robust links can now be found between atmospheric processes and 2 and 8-day precipitation accumulations.

Since this approach mainly relies on the global gridded ERA-20C reanalysis, it can be applied in any part of the world. The main limitation is the need of a long flow series to get a large sample of high-magnitude flood events. A second limitation may relies on the need of meteorological station data to evaluate the precipitation series from the ERA-20C since they might encompass large biases (as suggested by the reviewer). We trust that this approach could be successfully applied in many parts of the world since we have shown that it can work for high-magnitude events in a mountainous catchment, where the flood-induced hydrometeorological processes are made even more complex by the topography, the presence of snow and ice, etc.

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*) I am unconvinced the ERA data is accurate enough to do any kind of the inferences that are performed in this study. While it is argued that the data is accurate enough (to use percentiles), as supported by Fig A2, this figure to me shows a lot of scattering

which lead to the conclusion that these data are in fact highly unreliable to use. *)L173-181: You state that "[: : :], daily precipitation percentiles from the two datasets are in a good agreement (see Fig. A2 in the Appendix); when a high percentile value of precipitation accumulation is observed for a given day in one of the datasets, a high percentile value is also observed for this day in the other dataset.". However, when I look at Figure A2 I find this difficult to conclude with so much scatter.

Response:

We fully agree that the gridded ERA-20C reanalysis is not perfect in terms of daily precipitation. In Fig.A1, ERA-20C tends to underestimate the daily precipitation in comparison with the observations, especially for the extreme values.

However, for this study, we consider that the use of the percentile value (instead of the daily accumulation) limits the impact of the weakness of ERA-20C. Indeed, as shown in the appendix section B, the flood type classification remains the same whatever the used precipitation dataset (i.e. meteorological stations or ERA-20C reanalysis). This supports the use of percentile values of the daily precipitation series from the ERA-20C dataset back to 1923, i.e. the beginning of the flow data.

*) Why is soil moisture not considered in explaining the floods? Could this be ruled out a-priori for some reason?

Response:

In this study, the main objective is to explore in what extent the precipitation, only, may explain the high-magnitude flood events. Therefore, the use of other observations (e.g. glacier mass balance to document snow-melt) are not considered. Moreover, in this region, long-term observation of soil-moisture is rare. Furthermore, Norbiato et al. (2008) showed that the impact of the initial moisture conditions in runoff is negligible for large catchments with high storage capacity. Froidevaux et al. (2015) show that Pre-Alpine and Alpine catchments have a short discharge memory because of the weak



role of the precursor antecedent precipitation on the flood triggering.

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*)L36-37: Maybe it is my limitation, but I have no idea what a "socio-ecosystem" really refers too. Can you not just replace this by a less fancy sounding, but more straightforward word?

Response:

We fully understand that this term may not be familiar for some disciplines. This work is part of the "Cross Disciplinary Program Trajectories " that aims to improving knowledge on the interactions between human societies and their environment in the Alpine regions. The concept of "socio-ecosystem" is at the core of the project and is thus used by all the disciplines to favour the interdisciplinary approach. As mentioned by Gilberto Gallopin (1994) Âń A socio-ecological system refers to any system composed of a societal (or human) component and an ecological (or biophysical) component. Socio-ecological systems may be urban as well as rural. [. . .] Socio-ecological systems exist at various levels, ranging from the local (a household in interaction with its surroundings) to the global (consisting of all mankind and the ecosphere). Âż

Gallopin G.: Impoverishment and sustainable development, A report of the International Institut for Sustainable Development (IISD) – 1994. p.19.

*)L137-142: It is unclear to me why this normalization has been performed. i.e. what do you really mean by "To reduce the influence of the marked glacio-nival or nival regime

in the analysis of the discharges"? And why would you want to do that?

Response:

As shown in the Fig.1 below, the discharge series of Rhône@Bognes and of the three sub-catchments are affected by a marked seasonality.

Figs. 5 and 7 present the anomalies of discharge associated with the flood type (from D-7 to D+3). By using the deseasonalised anomalies, we obtained the "real" anomalies of the discharges, with respect to the season in which they occur. For a river affected by a strong seasonality as Rhône@Bognes is, the classical anomalies computed as the difference of the discharge with the mean annual discharge will be less representative of the "real" discharge anomalies values associated with the floods. The anomalies values depend on the seasonal mean base level of the river (here mainly higher during summer and lower during winter).

*)L186-189: I do not understand the description and meaning of Figs 2 and 3.

Response:

Figs 2 and 3 are indeed a bit difficult to understand, we therefore need to be clearer in the text to better guide the reader.

To capture the main flood characteristics (e.g. "short-rain" or "long-rain" floods from Merz and Blöschl, 2003), we tested different time sequences of precipitation occurring prior to the floods. This allows to highlight the time sequences that have the main influence on the 28 observed flood events.

We focus on two aspects: the precipitation duration (number of consecutive days) and the occurrence of the precipitation sequence (with respect to the flood day). In total, we studied 10 precipitation durations (from 1 to 10 consecutive days). The mean percentile is thus computed for these 10 durations. Then, to analyse the signature of the occurrence of the precipitation sequence on the flood day, we compute the mean percentile of the 10 precipitation sequences for 11 ending times (from 10 to 0 days prior



to the flood).

To illustrate this approach, Fig. 2 is proposed as a conceptual graphic illustrating the 10 precipitation sequences, i.e. from 1 to 10 consecutive days (y-axis) which end from 10 days to 0 day before the flood day (x-axis).

Fig.3 displays the mean percentile values associated with each of the precipitation duration (colours) and for each ending time (Up to...). Fig.3 aims at identifying the durations that have the greatest influence on the 28 flood events. The higher the percentile value is, the more the precipitation sequence is related to high precipitation accumulation, compared to the entire period studied. From Fig.3, the following comments can be made: the precipitation accumulation has the greatest influence on the floods when we consider the precipitation durations until the day before the flood whatever the precipitation durations. Therefore, for the rest of the study, the 10 precipitation durations that end one day before the flood events (up to D-1) are kept and analysed to then select which durations are the more informative.

Merz, R. and Blöschl, G.: Regional flood risk âĂŤ what are the driving processes?, Water resources research, 39 (12), 1340, doi:10.1029/2002WR001952, 2003.

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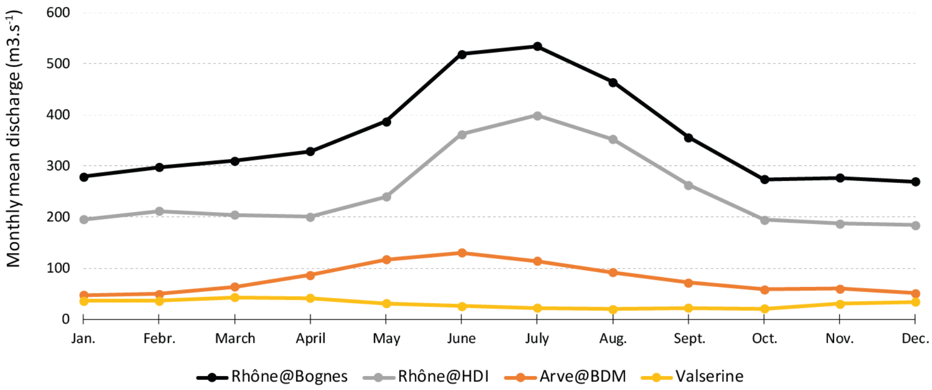


**Fig. 1.** hydrograms of the Rhône@Bognes, Rhône@HDI, Arve@BDM and for Valserine catchment for the 1923-2010 period.