Dear editor, dear reviewers,

The manuscript has been adjusted as we indicated in our point-by-point replys to the reviewer's comments.
This document shows all changes made to the manuscript.

Best regards,
Paul Froidevaux

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\begin{document}

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\title{Flood triggering in Switzerland: the role of daily to monthly preceding
precipitation}

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\begin{abstract}
\label{floodrainabstract}
Determining the role of different precipitation periods for peak discharge
generation is crucial for both projecting future changes in flood probability
and for short- and medium-range flood forecasting. In this study, ~~We analyze ~~
catchment-averaged daily precipitation time series are analyzed prior to annual
peak discharge events (floods) in Switzerland. The high number~~amount~~ of floods
considered -more than 4000 events from 101 catchments have been analyzed- allows
to derive significant information about the role of antecedent precipitation for
peak discharge generation. Based on the analysis of precipitation times series,
~~we propose ~~a new separation of flood-related precipitation periods is proposed:
(i) the period 0 to 1 day before flood days, when the maximum flood-triggering
precipitation rates are generally observed, (ii) the period 2 to 3 days before
flood days, when longer-lasting synoptic situations generate \textquotedblleft
significantly higher than normal\textquotedblright\ precipitation amounts, and
(iii) the period from 4 days to one month before flood days when previous wet
episodes may have already preconditioned the catchment. The novelty of this
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study lies in the separation of antecedent precipitation into the precursor antecedent precipitation (4 days before floods or earlier, called PRE-AP) and the short range precipitation (0 to 3 days before floods, a period when precipitation is often driven by one persistent weather situation like e.g. a stationary low-pressure system). A precise separation of ~~Because we consider a high number of events and because we work with daily precipitation values, we do not separate the ~~"antecedent" and "peak-triggering" precipitation is not attempted. Instead, the strict definition of antecedent precipitation periods permits a direct comparison of all catchments.~~. The whole precipitation recorded during the flood day is included in the short-range antecedent precipitation. ~~\\
The precipitation accumulating 0 to 3 days before an event is the most relevant for floods in Switzerland. PRE-AP precipitation has only a weak and region-specific influence on flood probability. Floods were significantly more frequent after wet PRE-AP periods only in the Jura Mountains, in the western and eastern Swiss plateau, and at the outlet~~exit~~ of large lakes. As a general rule, wet PRE-AP periods enhance the flood probability in catchments with gentle topography, high infiltration rates, and large storage capacity (karstic cavities, deep soils, large reservoirs). In contrast, floods were significantly less frequent after wet PRE-AP periods in glacial catchments because of reduced melt.\\
For the majority of catchments however, no significant correlation between precipitation amounts and flood occurrences is found when the last three days before floods are omitted in the precipitation amounts. Moreover, the PRE-AP was not higher for extreme floods than for annual floods with a high frequency and was very close to climatology for all floods. The fact that floods are not significantly more frequent nor more intense after wet ~~weak influence of ~~PRE-AP is a clear indicator of a short discharge memory of Prealpine, Alpine and Southalpine Swiss catchments. Our study ~~nevertheless ~~poses the question whether the impact of long-term precursory precipitation for floods in such catchments is not overestimated in the general perception. The results suggest~~We conclude~~ that the consideration of a 3-4 days precipitation period should be sufficient to represent (understand, reconstruct, model, project) Swiss Alpine floods.
\end{abstract}

\introduction
\label{floodrainintro}
River flooding is one of the most devastating and costly natural hazards in Switzerland \citep[][]{hilker2009swiss} and worldwide \citep{natcat}. Damaging flood events in the Alps are often caused by high precipitation events that last for several days \citep[e.g.][]
{massacand1998Heavy,hohenegger2008cloud,stucki2012}.
However, river discharge during floods can also be influenced by both the spatial and temporal characteristics of the precipitation event and by the state of the catchment before the precipitation event, i.e. the antecedent conditions. One of the most important antecedent factors is the total water storage in the form of snow, soil water, ground water and surface water. \textcolor{black}{In particular, the importance of antecedent precipitation for floods has long been emphasized (especially for large catchments). For example, effort is invested in designing continuous hydrological simulations which allow to account for year-long antecedent precipitation time series when assessing discharge extremes \citep[see e.g.][for the Rhine and Meuse basins]{wit2007generator}. }\\
For several recent catastrophic flood events antecedent water storage was important. For example, \cite{reager2014river} point to the importance of a positive water storage anomaly for the 2011 Missouri floods. The floods in June 2013 in Central Europe were preceded by above-average precipitation during the second half of May that influenced the flood discharge by presaturating the soils \citep{grams2014atmospheric}. \cite{schroter2015what} further show that this exceptional flood event resulted from the combination of non-~~-~~extraordinary precipitation with extremely high initial wetness. For the floods of 2002 also in Central Europe, \cite{ulbrich2003central} describe several intense rainfall episodes in the first half of August that finally led~~lead~~ to the extreme discharges. In southern Switzerland, severe flooding of the Lago Maggiore in September 1993 was preceded by a series of high precipitation events in the watershed \citep{barton2014clustering}. Antecedent conditions might even be

relevant for the development of flash floods: \cite{marchi2010characterisation} found that the runoff coefficient, i.e. the fraction of the total rainfall that is routed into runoff, of 58 flash floods in Europe was statistically higher for wetter antecedent precipitation. They however also found that, although flash floods are more frequent after wet antecedent conditions in Central Europe, they primarily occur following dry conditions in the Mediterranean region and show no dependence on the antecedent conditions in the Alpine-Mediterranean region. For large Swiss lakes and streams, \cite{stucki2012} underline the importance of high soil saturation due to excessive water supply by enhanced melt and precipitation over several months for the generation of historical floods.\\

However, damages in Switzerland often occur when small rivers overflow or when surface runoff occurs outside of river beds \citep[][]{bezzola2007ereignisanalyse}. The devastating event of 1993 is a memorable example of how a local river can generate high damages \citep[][]{hilker2009swiss}. Local floods in Switzerland result from a large variety of hydrological processes \citep[depending on the region, floods may be driven by short but intense showers, continuous rainfall, rain on snow, or snow and/or glacier melt; see][]{Merz2003process,helbling2006Dauerregen,diezig2007hochwasserprozesstypen}. Defining the influence of antecedent precipitation for this large variety of flood types is a complex task. A modeling study by \cite{paschalis2014on} showed that soil saturation can play a paramount role in mediating the discharge response of a small Prealpine catchment. \textcolor{black}{The initial conditions also significantly affect flash flood forecasting in the Southern Swiss Alps \citep{liechti2013potential}. }%color

However, \cite{Norbiato.2009b} found that the impact of initial moisture conditions on the runoff coefficient during floods is important only for catchments with intermediate subsurface water storage capacity; i.e. the role of initial moisture conditions is negligible for catchments with either very large or very small storage capacity. Also, reports from \cite{ranzi2007hydrological} on observed floods in mesoscale Alpine catchments with relatively shallow and permeable soil layers conclude that \textquotedblleft...values of antecedent precipitation do not dramatically affect the resulting runoff coefficient, at least during major floods. This indicates a smaller sensitivity to initial soil moisture conditions than generally assumed...\textquotedblright.\\

~~Apart from case studies and modeling studies of single catchments, the relationship between precipitation and flooding has never been investigated in a comprehensive and systematic manner in Switzerland.\\~~

A better understanding and quantification of the role played by antecedent precipitation in the development of floods is crucial for flood hazard management for two reasons:\\

(i) Because future flood frequency changes might depend on the role of antecedent precipitation. Future changes in precipitation for Switzerland are still uncertain \citep{ch2011} but general tendencies can be derived from the projections. In summer, the most important season for Alpine floods, a clear decrease in mean precipitation (due to drier soils) is expected to be accompanied by a weak increase in extreme daily precipitation \citep[due to warmer air, see][]{rajczak2013projections}. Thus, depending on whether short-term or long-term precipitation is more important for floods, flood frequency might increase or decrease in the future.\\

(ii) Due to the relatively long residence time of water in catchments with significant moisture storage capacity, information regarding the current moisture state can help to improve medium-range flood forecasting. Identifying catchments where the amount of antecedent precipitation is particularly determinant for floods may help to determine critical regions where an efficient use of that information is primordial for flood forecasting systems. For example, it is now possible to derive water storage information from satellite data, and \cite{reager2014river} demonstrate a great potential for warning systems at weekly to seasonal lead times.\\

Here, we do not aim to quantify the role of antecedent precipitation by calculating runoff coefficients like e.g. in \cite{ranzi2007hydrological}, \cite{merz2009regional}, \cite{Norbiato.2009b} or \cite{marchi2010characterisation}. Instead, following the idea of large sample hydrology \citep[e.g.][]{gupta2014large}, ~~in previous studies. Instead,~~ we make use of two extensive~~large~~ networks of rain gauges and river discharge stations to derive robust statistics from an important~~a large~~ number of catchments and events. The underlying hypothesis is that if a period of antecedent precipitation influences the amplitude of peak discharges, floods should be significantly more frequent after wet conditions during that period provided that a sufficient sample of events is investigated. The following questions are addressed in particular for different precipitation periods before floods \textcolor{black}{(e.g. 0-1 days, 3-14 days before floods):\\}%color

(i) In the past 50 years, have floods in Switzerland been significantly more (or less) frequent after wet conditions during that period?\\

(ii) If they were more frequent, can we define catchment properties that determine whether and how strongly that period influences flood probability?\\

(iii) Did extreme floods follow wetter antecedent conditions than smaller discharge peaks?\\

(iv) Which precipitation accumulation period is most closely related to flood occurrence?\\

(v) \textcolor{black}{How many days of antecedent precipitation are relevant for floods?\\}%color

We aim to explicitly separate short-range and long-range antecedent precipitation and thus discuss the temporal separation of different precipitation accumulation periods. The analysis comprises thousands of annual maximum discharge events in a large sample of catchments representative of the various hydrological regions of Switzerland. This analysis is unique for Switzerland with~~in~~ regard to the number~~amount~~ of floods considered and, to our knowledge, also unprecedented worldwide.\\

\section{Data}

The events analyzed in this study are 4257 annual maximum instantaneous discharge measurements (called floods hereafter). They were recorded at 101 stations during the period 1961 to 2011. The data is provided by the Swiss Federal Office of the Environment (FOEN)\footnote[1]{\url{http://www.bafu.admin.ch/index.html?lang=en}}. The stations measure water level from which a discharge value is obtained through a rating curve that is based on regular discharge measurements. In the case of extreme floods, the discharge values have been manually checked and, if required, have been corrected by hydraulic modeling and expert judgment. All annual maximum discharge events are denoted HQ hereafter. HQs exceeding the 5-year and the 20-year floods will be denoted HQ5 and HQ20, respectively. Note that HQs of estimated return periods of more than 100 years have been recorded in the last decades. Here those floods are simply included in the HQ20 sample (return period larger than 20 years). The distinction of higher return periods than 20 years is avoided in order to maintain a large sample size. Empirical return periods have been used for simplicity. The empirical return period of a HQ is given by the length of the time series divided by the rank of the HQ (in decreasing order of discharge).\\

We use gridded daily precipitation accumulations constructed from interpolation of a dense network of rain gauges \citep[see][]{frei1998precipitation}. The daily sums (from 6 to 6 UTC) are available on a 0.02 by 0.02 degrees grid covering the Swiss territory for the period 1961-2011 \citep[hereafter RhiresD, see][]{rhiresd}. The number of gauges varies from approximately 400 to 500 throughout this time period. The effective resolution of the dataset, given by the typical inter-station distance, is approximately 15-20 km. Some of the smallest catchments investigated here may not contain any rain gauge but the results from section \ref{res4} show that the flood-relevant precipitation is adequately captured in each catchment.\\

\section{Methods}

\label{met}

\subsection{Selection and classification of catchments}

We selected 101 catchments based on the following criteria:\\

(i) The discharge time series must cover at least 20 years during the period 1961-2011.\\

(ii) The catchment~~area~~ must be larger than 10\,km^{2} and its area must be covered $>$90\% by the precipitation dataset.\\

(iii) The possible human influence on the HQs must be minimal.\\

(iv) A homogeneous representation of the Swiss territory is ensured and multiple counting of basins, i.e. small catchments located in larger catchments, is minimized.\\

The selected catchments were subdivided according to their size into microscale catchments (Micro, 10-100\,km^{2}), mesoscale catchments (Meso, 100-1000\,km^{2}) and macroscale catchments (Macro, $>$1000\,km^{2}). Catchments within the same size category never overlap spatially, but Micro catchments can be contained in Meso and Macro catchments and Meso catchments in Macro catchments.\\

Assessment of human influence on peak discharges (e.g. hydropower dams and/or discharge regulation) requires detailed knowledge about water management in each catchment. Some of this information is available within the Hydrological Atlas of Switzerland \citep[see table of plate 5.6 from][]{Aschwanden.1995}. Only Micro and Meso catchments with no or low human influence were selected. Some human influence was tolerated for Macro catchments. Discharge is regulated at the outlets~~exits~~ of the majority of large Swiss lakes and the lake outlet~~exit~~ stations are analyzed separately (hereafter \textquotedblleft Lake Outlets~~Lakes Exits~~\textquotedblright). Karstic catchments with very complex underground flow were removed based on expert knowledge.\\

The Swiss landscape contains distinct geographical and hydrological regions: The Alps (Prealps, High Alps, Southern Alps), the Swiss Plateau and the Jura Mountains. Each region shows specific hydro-meteorological properties. In order to account for this diversity, a typical hydrological regime has been attributed to each Micro and Meso catchment (see Fig. \ref{catchsel}). This classification of hydrological regimes follows \cite{Aschwanden.1985}; see also \cite{Weingartner.1992}. A first set of separation criteria is the mean elevation and the glacier coverage. These properties allow us to distinguish between Glacial (mean altitude $>$ 1900\,m and glacial coverage $>$ 6\% or mean altitude $>$ 2300\,m and glacial coverage $>$ 1\%), Nival (mean altitude $>$1200\,m) and Pluvial regimes. The mean annual cycle of the runoff in Pluvial, Nival, and Glacial catchments is mainly dominated by rain water, snow melt, and glacier melt, respectively. Then, all catchments from the southern side of the Alps were joined in a separate~~the Meridional~~ group. The specific precipitation regime \citep{schmidli2005trends} and flood seasonality \citep{koeplin2013seasonality} of this group, as well as the specific geology (crystalline, poor infiltration rates, steep slopes, and weak soils) motivated this choice. \cite{Aschwanden.1985} called this group \textquotedblleft Meridional\textquotedblright\ to emphasize its southern location. Similarly, the catchments in the Jura Mountains were joined in the Jurassien regime type because of their shared specific morphology and geology (high plateaus, gentle slopes, high infiltration rates and important network of underground streams due to the calcareous and karstic bedrock).\\

From Glacial to Nival to Pluvial, the flood seasonality decreases but a maximum flood frequency in summer is maintained. Meridional catchments are characterized by a maximum flood frequency in fall and summer and Jurassien catchments by winter floods with rain on snow as a major flood process \citep[see e.g.][]{piock2000saisonalitatsanalyse,koeplin2013seasonality}. \\

In summary, the different catchment subsamples are: Micro (52 catchments), Meso (35 catchments), Macro (8 catchments), Glacial (19 catchments), Nival (17 catchments), Pluvial (31 catchments), Meridional (8 catchments), Jurassien (12 catchments.) and Lake Outlets~~Lakes Exits~~ (7 catchments). See Tables \ref{catchproperties1} and \ref{catchproperties2} for a brief description of each catchment.

\subsection{Derivation of precipitation time series for each catchment}
We identified catchment area boundaries for each discharge station by applying a purely topography-based approach to a digital elevation model (DEM) with a 10-meter resolution. For most of the Swiss territory, the effective drainage areas of the stations can be expected to be reasonably close to the catchments derived from the DEM. Critical regions are the highly karstic areas in the Jura Mountains and some areas of the Prealps, where the hydrological and topographical catchments tend to be significantly different because of the complex underground flow \citep[see e.g.][]{Malard.2013}. The most critical

catchments were not considered for the analysis.\\
Area-averaged precipitation time series were obtained by combining the gridded precipitation data with the topographical catchment areas.

\subsection{Definition of precipitation periods}
The first challenge is to distinguish between event and pre-event precipitation. Flood triggering precipitation can be in the form of synoptically driven precipitation (periods lasting between a few hours to several days when the synoptic situation is particularly conducive to repeated precipitation events) and/or localized and short lived high precipitation events (typically convective). Ideally, a flood-by-flood analysis using a hydrological model should be performed to determine the exact time lag between the most intense precipitation rate and the discharge peak and to merge all precipitation events that can be attributed to a particular synoptic situation, such as the passage of a cyclone. However, a case-by-case analysis is beyond the scope of this study first because the daily resolution of the data does not allow for an evaluation of precipitation rates on sub daily timescales and second because of the very large number of events considered. Instead, we search for simple indices (precipitation accumulation periods, PAPs), that will (on average) best represent the precipitation associated with all floods in Swiss rivers.\\
A set of PAPs is~~precipitation accumulation periods (PAPs) was~~ defined (summarized in Tab. \ref{precipindtable}). Most PAPs represent a precipitation sum over a particular period before the flood day and two more PAPs are based on the concept of antecedent precipitation indices (API). A detailed description of the PAPs and the motivation for choosing them is given in section \ref{res1}. For example, PAP D4-14 is the precipitation sum that occurred within the period from 14 to 4 days prior to the flood day. PAPs are calculated for each day of the catchment-averaged precipitation time series (not only for flood days). The precipitation sums corresponding to flood days are then compared to the climatological distribution of all precipitation sums. The climatological sample~~distribution~~ is defined by a 3-month moving window centered on ~~as a +/- 45 days range for~~ each day of the calendar year. For example, let us assume that a flood occurred on the 1st of June 2000. The D4-14 of that day is compared to all 11-day precipitation accumulations between April 17 and July 16 from 1979 to 2011 and the respective percentile of D4-14 is calculated. For each flood event we can thus determine the percentile value for each PAP. A 3-month moving window~~range of +/- 45 days~~ is an optimal compromise between minimizing the effects of precipitation seasonality and maximizing the climatological sample size (91 days per year times 20-50 years means that each value is compared to 1820-4550 other values).\\
Beside the simple precipitation sums, more complex indices for antecedent precipitation, i.e. APIs are used. APIs have been commonly used in hydrology for decades \citep[see e.g.][]{Kohler.1951,pui2011does}. We follow the method of \cite{baillifard2003rockfall}):\\
\begin{align}
\label{equapi}
API_{i} = P_{i}+ KP_{i-1}+K^{2}P_{i-2}+...+K^{n}P_{i-n}\\
\end{align}
where P is the daily precipitation sum, i is the day for which API is calculated, ~~ and~~ K is the decay factor, and $n+1$ is the number of days since measurements beginning. Here, a constant K value of 0.8 is used for all catchments. The decay factor K is a proxy for diverse water fluxes that lead to a reduction of the water stored in a catchment. In this study, a decay rate of 20\% per day, i.e. $K=0.8$, is chosen and reflects roughly typical conditions in Switzerland \citep{baillifard2003rockfall}. Results are insensitive to a tested range of K between 0.7 and 0.9. We use the indices API2 and API4 that include all days of the time series up to 2 and 4 days before the flood day (hereafter also called PAPs).\\

\subsection{Logistic regression}
\label{metlg}
The underlying hypothesis of this study is that, if a PAP is important for flood generation, a significant signal can be detected using the logistic regression. A lack of significance on the other hand, implies either that the PAP has no

influence on flood probability or that this influence is too weak to be
significant during the investigated period.\\
In section \ref{res4} we assess the importance of the different PAPs for peak
discharge generation at each catchment. A test is performed for each catchment
and each PAP separately using a logistic regression model.\\
Binary daily time series of floods $y(t)$ and precipitation $\text{PAP}_T(t)$
are calculated. The time series contain approximately 7000 to 18000 days t.
For days when floods were recorded $y(t)=1$ and $y(t)=0$ for all other days. For
days when the PAP exceeded a given percentile threshold T $\text{PAP}_T(t)=1$
and $\text{PAP}_T(t)=0$ for all other days.
The model is then fitted as follows:
\begin{align}
\text{logit}(p(t)) = \beta_0 + \beta_1 \text{PAP}_T(t)
\end{align}
where $\text{logit}(x) = \log(x / (1 - x))$, and $p(t)$ is the probability of
observing a flood at day t given the predictor, i.e. $p(t) := P(y(t) = 1 |
\text{PAP}_T(t))$.\\
We are particularly interested in the value of β_1. The odds ratio
($O=\exp(\beta_1)$) is a measure for the increase (or decrease if O is below
1) of the odds, $p/(1 - ~~-~~p)$, of a flood occurring when the PAP exceeds
percentile T. Here, p is by definition small (we look at yearly discharge
maxima and even rarer events) and we can therefore set $p/(1 - ~~-~~p) \approx p$
and the odds ratio can thus be understood as a multiplicative factor for the
flood probability p. Statistical testing can assess the significance of the
predictor PAP_T. %, i.e. we can test the hypothesis $H_0: \beta_1 = 0$
through the computation of a p-value. When the p-value is small (typically,
lower than 5%) the hypothesis is rejected which means that β_1 is
significantly different from 0 and that the predictor has hence a significant
influence on the probability of floods.
A significant p-value implies that \textquotedblleft the exceedance of a given
precipitation threshold significantly changes the flood
probability\textquotedblright.\\
Note that working with binary predictors is not mandatory in logistic
regression. Here this choice offers the advantage of avoiding the assumption
that $\text{logit}(p)$ is proportional to the percentile of the precipitation
period; an assumption for which no particular argument could be found. A
drawback is however that the regression can only be performed with predefined
thresholds. Here, the logistic regressions are tested for 5 different thresholds
(P50, P75, P90, P95, P99) and the p-value of the most significant test is
selected (the corresponding thresholds and odd ratios are not discussed).\\

\section{Results}
\label{res}
Hereafter, we will use percentiles to describe precipitation
quantities~~intensities~~. To simplify the language, we define a set of expressions
(see Tab. \ref{intexpr}).
\subsection{Defining different precipitation periods preceding Swiss floods}
\label{res1}
~~The first challenge is to distinguish between event and pre-event precipitation.
Flood triggering precipitation can be in the form of synoptically driven
precipitation (periods lasting between a few hours to several days when the
synoptic situation is particularly conducive to repeated precipitation events)
and/or localized and short lived high precipitation events (typically
convective). Ideally, a flood-by-flood analysis using a hydrological model
should be performed to determine the exact time lag between the most intense
precipitation rate and the discharge peak, as well as to merge all precipitation
events that would be attributed to a particular synoptic situation, such as the
passage of a cyclone. However, a case-by-case analysis is beyond the scope of
this study first because the daily resolution of the data does not allow for an
evaluation of precipitation rates on sub daily timescales and second because of
the very large number of events considered. Instead, we search for simple
indices, i.e. PAPs that will (on average) best represent the precipitation
associated with all floods in Swiss rivers.\\~~

In order to determine the optimal separation of precipitation periods for the sample of events considered, the precipitation distribution is first investigated day by day. Figure \ref{boxplot}a shows the distributions of daily precipitation sums for every day prior to and after all floods. For example, the boxplot at x=-10 represents the distribution of precipitation sums recorded 10 days before all floods (4257 values of daily precipitation recorded 10 days prior to the 4257 flood days). Moderate to high~~intense~~ precipitation is most often recorded one day before floods when the 80th local seasonal percentile is exceeded in 75\% of the cases and the median precipitation sum corresponds to the 98th climatological percentile. During flood days, the median precipitation only amounts to percentile 93. The days -2 and -3 also show high precipitation sums with medians amounting to climatological percentiles 75 and 60, respectively. From day -4 backwards, the precipitation distribution is very close to climatology, although it tends to be slightly enhanced up to 10 to 15 days before floods. Similar results are observed when subsamples of catchments are analyzed (Fig. \ref{boxplot}b-d). The maximum median daily precipitation is recorded 0-1 days before HQ days at Micro catchments and 1-2 days before HQ days at Lake Outlets~~Lakes Exits~~. A clearly enhanced median precipitation prior to 4 days before HQ days is only found at Lake Outlets~~Lakes Exits~~.\\

Daily precipitation sums correspond to the 06 UTC to 06 UTC accumulations and are therefore shifted by 5 hours compared to discharge peaks recorded on calendar days. This partly explains the one-day shift between maximum precipitation and HQ occurrence, especially for the floods in Micro catchments. The response time of catchments, i.e. the time between precipitation and registration of the related runoff at the gauge, plays a role as well. We therefore group the flood days and the preceding days together (hereafter the PAP called D0-1; see also Tab. \ref{precipindtable}). This is the time range when high precipitation quantities~~intense precipitation rates~~ are most likely. As shown in Fig. \ref{boxplot}b-c, this assumption is valid for Micro and Macro catchments whereas for Lake Outlets the highest~~Lakes Exits the most intense~~ precipitation occurs 2 days before floods (because of longer response times due to lake retention). Intense precipitation events responsible for flood peaks might be very short (hours or minutes in the case of flash floods) but the daily resolution of the data and the shift between precipitation and floods does not allow for a further separation of the time windows.\\

Precipitation 2 to 3 days before floods is also greater than climatology in all catchments and, interestingly, precipitation remains also greater than climatology 2 days after floods in Fig. \ref{boxplot}a. An explanation for this phenomenon can be found in Fig. \ref{boxplot}e, which shows the results of an analysis similar to the one of Fig. \ref{boxplot}a but applied to maximum precipitation days instead of flood days. In Fig. \ref{boxplot}e, the precipitation distribution is similarly enhanced +/- 2 days around high precipitation events like it is enhanced around flood events. The typical time scale of precipitating weather systems over Europe leads to some persistence of the daily weather situations so that daily precipitation time series are autocorrelated. Figure \ref{boxplot}a thus highlights a time window centered between day -1 and day 0 and ranging from day -3 to day +2 when precipitation is clearly higher than usual. We identify it as the time range when the flood-producing weather situations generate high precipitation. Two more PAPs are thus defined which range back to 3 days before floods in order to capture precipitation associated with longer-lasting weather events (periods D0-3 and D2-3). The \textquotedblleft precursor antecedent precipitation\textquotedblright (PRE-AP) is subsequently defined as the period finishing 4 days before floods. PAPs representing PRE-AP are D4-6, D4-14 and D4-30. To complete the set of PAPs, a similar separation is also applied to APIs (see API2 and API4, stopped 2 and 4 days before floods, respectively).

Hereafter, the analysis is based on seasonal percentiles of the PAPs. For comparison, precipitation sums [mm] corresponding to percentiles of different PAPs are shown in Fig. \ref{suppl1}. For example, the P99.9 of D0-1 in summer is summarized for all Macro catchments by the rightmost orange boxplot in Fig. \ref{suppl1}a. The P99.9 exceeds 94\,mm for 50\% of the Macro catchments and reaches 156\,mm at one catchment. The P99.9 of D0-1 at Macro catchments is in general lower in winter than in summer (compare the orange and the blue boxplot). Note that API2 and API4 result from the same calculation (see equ. 1)

applied at different days i. Their climatology is therefore the same and Fig. \ref{suppl1}c,f are valid for both API2 and API4.\\
In hydrology, \textquotedblleft antecedent precipitation\textquotedblright\ typically implies all the precipitation preceding the very last flood-triggering event. Here we separate flood-preceding precipitation into the short-range antecedent precipitation and what we define as the precursor antecedent precipitation PRE-AP. Although this sharp separation (between days -3 and -4) is only based on averaged statistics and although flood-triggering events can be defined over a wide range of time scales; we choose this simple formulation to distinguish explicitly long range antecedent precipitation from a period when unusual precipitation is obvious in rainfall time series. We strongly emphasize that hereafter PRE-AP excludes the last 3 days before floods (see Tab. \ref{precipindtable}).

\subsection{Overview of the precipitation associated with Swiss floods}
\label{res2}
We start the analysis with an overview of the variability of the precipitation associated with Swiss floods (event and pre-event precipitation).
\subsubsection{The 2-days precipitation}
Figure \ref{allev01} shows the 2-day PAP (D0-1) associated with each annual maximum discharge (HQ) of each catchment. The return periods of D0-1 vary by several orders of magnitude between different events. Very high precipitation (with a ~~Extreme or very intense precipitation (~~return period longer than ~~$>$~~100 days) is frequently associated with floods, but a majority of catchments also experience HQs during low or moderate precipitation~~D0-1~~. A return period of D0-1 longer than ~~$<$~~ 10 days corresponds to a percentile lower than 90 ~~$<$ P90~~ and thus to less than 20-30\,mm in 2 days (see Fig. \ref{suppl1}a,d). There are more floods without high~~intense~~ D0-1 in Nival and Glacial regimes as compared to the Pluvial regime. The D0-1 in Jurassien and Meridional groups is comparable to the Pluvial group. D0-1 is slightly lower in Macro catchments and clearly the weakest for Lake Outlets~~Lakes Exits~~. HQ5s and HQ20s tend to be associated with longer return periods of D0-1 than HQs, although they can also be triggered by weak or moderate ~~non-intense~~ precipitation (return periods shorter ~~of less~~ than 10 days), especially at Lake Outlets~~Lakes Exits~~, as well as in Glacial and Nival catchments. Interestingly, extreme D0-1s often occur simultaneously in several catchments, indicating widespread events. Most of them correspond to extraordinary flood events in 1978, 1987, 1990, 1999, 2002, 2005, and 2007 and involve several HQ20s.\\
\subsubsection{Precursor antecedent precipitation}
Figure \ref{allev414} is similar to Fig. \ref{allev01} but shows the PAP D4-14, i.e. the accumulated precipitation between day -4 and day -14 (PRE-AP). The large majority of floods are associated with return periods of PRE-AP shorter~~lower~~ than 10 days, i.e. not unusually wet. In general HQ5s and HQ20s are not associated with higher PRE-AP than HQs and the rare cases of unusually wet PRE-AP typically occur simultaneously at many catchments (like in 1972, 1993, 1999 and 2006).\\
The logarithmic scale of return periods in Figures \ref{allev01} and \ref{allev414} underlines the fact that return periods of D4-14 are several orders of magnitude shorter~~lower~~ than those of D0-1. However, one cannot expect D4-14 to be systematically extreme as this 11-day period often excludes the heavy precipitation (which happens just before the flood)~~. We will now move on to further quantify these qualitative observations~~.

\subsection{Quantification of the precipitation ~~intensity~~ during different periods preceding Swiss floods}
\label{res3}
The overview of flood-precipitation in the last 50 years revealed that precipitation during PAP D0-1 was high~~intense~~ or extreme for a majority of floods but PRE-AP (during PAP D4-14) was not. This raises the question of whether D4-14, although not extreme before floods, still tends to be wetter than climatology.\\
Figure \ref{relative_frequ} shows the distribution of PAPs for different flood samples (deviations from climatology significant at the 99\% level are outside of the gray zones). The gray zones are based on binomial distributions and

represent the 99\% level of significance of the variations of~~\\~~ relative frequency in case of independent events. In the case investigated, the independence of events cannot be assessed in a purely quantitative way but the flood events are likely dependent, i.e., there are more simultaneous flood occurrences than expected from a random process, because floods in neighboring catchments can be triggered by the same weather event. The significance shown is hence likely too high (the zones too small) but the gray zones are still drawn as indicators of the minimum amount of random noise that can be expected. Note that it is strongly dependent on the sample size, i.e. on the number of flood events.\\

For HQ5s in Micro catchments (Fig.\ref{relative_frequ}a), precipitation during D0-1 was very high (higher than ~~intense ($>$~~P99) for 61\% of the floods and high (higher than ~~intense ($>$~~P90) for 90\% of the events~~ (6\% P90-95 + 23\% P95-99 + 61\% $>$P99 = 90\%>P90)~~. Only 10\% of the floods were preceded by no or moderate precipitation (lower than ~~$<$~~P90). For D2-3, high~~intense~~ and very high~~intense~~ precipitation was also significantly more frequent than usual although the deviation from climatology is very weak compared to D0-1. Drier percentiles of D2-3 were also significantly less frequent than usual (only 35\% of the cases are below ~~$<$~~P50). On the other hand, no significant departure from climatology is found for the PRE-AP PAPs (D4-6, D4-14, D4-30). This means that, as a general rule, the conditions were not significantly wetter than usual earlier than 3 days before floods in Micro catchments.\\

The statistics of Meso and Macro catchments (Fig.\ref{relative_frequ}b-c) resemble the ones of Micro catchments.\\

In contrast, HQ5s at Lake Outlets~~Lakes Exits~~ (Fig.\ref{relative_frequ}d) were triggered by significantly higher than usual precipitation during all PAPs (and not only during D0-1 and D2-3). For example, a percentile~~the P$>$99~~ of D4-14 higher than 99 is as frequently observed as a percentile lower than ~~P$<$~~50.\\

Figure \ref{relative_frequ}e-f show the results for HQs and HQ20s in all catchments. During D0-1, very high~~intense~~ precipitation is twice as frequent prior to HQ20s (80\% of all floods) as it is prior to all annual HQs (45\% of all floods). However, the precipitation prior to HQs and HQ20s is surprisingly similar during the other periods (D2-3 is only slightly higher for HQ20s than for HQs and PRE-AP is basically the same).\\

In summary, the flood events considered in this study, with the exception of Lake Outlets~~Lakes Exit~~ floods, frequently co-occur with high~~intense~~ precipitation during the flood day and/or the day before (D0-1). Longer-lasting multi-day events also generate high precipitation during D2-3. The slightly larger departure from climatology during D2-3 at Macro~~Marco~~ compared to Micro catchments indicates a higher importance of longer-lasting events. \cite{helbling2006Dauerregen} already showed that larger catchments are more sensitive to longer-lasting precipitation at the sub-daily scale; here we can extend those findings to multi-day events. Regarding precipitation 4 or more days before HQ days, a significantly enhanced frequency of wet weeks is only found for Lake Outlets~~Lakes Exits~~. For other catchments, floods did not happen after significantly wetter nor drier PRE-AP in general.\\

Although no significant signal is found, PRE-AP was nevertheless slightly wetter than climatology before floods in Switzerland. Consequently, more detailed analyses are presented in the next sections to explore the correlation between PRE-AP and floods for particular catchments, particular flood types, and particular flood seasons.

\subsection{Catchment by catchment analysis}
\label{res4}
Here, we use logistic regression to address the following question for each PAP and each catchment: is the occurrence of HQs influenced by the amount of precipitation? Or in other words: are floods more (or less) frequent after wet periods? We thereby aim to investigate whether the large variety of Swiss basins is associated with different flood responses to PAPs. Previous studies showed that typical flood-triggering precipitation depends not only on catchment size (investigated in the previous section), but also on various catchment properties \citep[e.g.][]
{Merz2003process,Weingartner.2003,helbling2006Dauerregen,diezig2007hochwasserpro

zesstypen}. Potentially important properties include mean elevation, slope, land cover, soil type, geology and reservoirs (lakes, underground cavities). The hydrological regimes encompass some of this variability and serve as a framework for interpreting the following analysis.\\

Figure \ref{logregregtyp} shows the results of the logistic regression for the different PAPs (see details in section \ref{metlg}). For example, triangles (P-value $<$ 0.001) in Fig. \ref{logregregtyp}a indicate that, in every catchment investigated, floods were significantly more frequent when a particular threshold of D0-1 was exceeded. In other words, the amount of precipitation that falls during D0-1 has a significant impact on flood frequency. The amount of precipitation that falls during D2-3 (Fig. \ref{logregregtyp}b) also significantly impacts the flood frequency in most catchments, with the exception of most Glacial and few Nival and Pluvial catchments. With regard to PRE-AP in D4-6, D4-14 and D4-30 (Fig. \ref{logregregtyp}c-e), clear regional patterns can be distinguished. Wet antecedent periods significantly enhance the flood frequency mainly in the northwest and northeast Switzerland, as well as at the outlet~~exit~~ of all lakes except Lake Thun (no~~nb~~.111). In contrast, floods were significantly less frequent after wet periods in some Glacial catchments. Indeed, six catchments show a significant P-value with an odd ratio smaller than 1 for D4-14. These are the exact 6 catchments with more than 25\% glacial coverage. For the rest of Switzerland, the amount of PRE-AP does not significantly affect the flood probability. By comparing the results of D0-30 with D4-30, it emerges that floods are significantly associated with wet months (D0-30) in a large majority of catchments only because heavy precipitation 3-4 days before floods lead to high monthly accumulations. Indeed, D4-30 indicates that precipitation during the rest of the month has no significant impact on the flood probability for most catchments.\\

A reduced flood frequency following wet periods (like found for the glacial catchments) seems counterintuitive. The most significant negative correlation is found for the most glaciated catchment (the Aletsch glacier catchment, no~~nb~~. 865). The highest significance is obtained in this case with the threshold P75 because none of the 51 HQs recorded correspond to the 25\% wettest D4-14. The expected value is 51/4; i.e. approximately 12-13 HQs. It is almost impossible to get 0 HQs just by chance and an explanation must therefore be found. Glacial catchments are typically small and located at high elevations, exhibit steep slopes and lack deep soils. They are characterized by very short response times and a large runoff contribution from melt during the flood season \citep[summer, see e.g.][]{Verbunt.2003,koeplin2013seasonality}. The negative correlation is probably due to the fact that prolonged periods of wet weather (lower temperature, reduced sunshine and hence reduced melt) can lead to a lower baseflow in those catchments so that contributions from short and intense precipitation events would be less likely to generate annual discharge peaks. Indeed, discharge time series of glacial catchments are typically characterized by a pronounced diurnal cycle in summer, revealing the importance of high temperature and sunshine for melt and discharge generation. The baseflow continuously rises from day to day in case of extended periods of nice weather which are therefore particularly conducive to floods. Hence, floods are less frequent after precipitation at Glacial catchments, probably because of the reduced glacier melt.\\

Enhanced flood frequency after wet periods is less surprising. The Swiss Plateau, especially the western part, is a relatively flat area characterized by deep soils that need to be saturated before large runoff in the main streams is recorded. Soils in the Jura are typically thinner but very permeable and this region is well known for its underground karstic cavities. A karstic underground network can contain important reservoirs, the water level of which influences the flow response in surface streams \citep[see e.g.][]{ball2012spring}.\\

In summary, the role of long-term antecedent precipitation for flood generation depends strongly on the region and/or on the hydrological regime considered. Wet PRE-AP periods enhance HQ probability where soil saturation and reservoir filling are important processes and decrease HQ probability where melt water is an important contributor to the floods discharges.

\subsubsection{Antecedent precipitation indices (APIs)}

We also tested the power of APIs (see Tab. \ref{precipindtable}) for statistically predicting floods as compared to simple precipitation sums. API2, like D2-3, omits information about the flood day and the day preceding the flood but accounts for the whole antecedent precipitation instead of for only 2 days. The results for both periods are similar in most catchments. D2-3 is a better (more significant) flood predictor than API2 for 12 catchments, and a weaker predictor for 11 catchments. API2 allows us to distinguish the relevance of dry periods for flooding in Glacial catchments but D2-3 is too short and too close to the flood to capture this signal.

However, combining D2-3 and D4-6 indicates that dry conditions followed by wet conditions are important for flood formation in the L\"{u}tschine in Gsteig (no~~nb~~. 387), for example. Both periods cancel out in API2 and no significant signal is found. Searching for the best period also appears to be complex with regard to PRE-AP. Each of the 4 periods (D4-6, D4-14, D4-30, API4) is the most significant flood predictor at several catchments. D4-30 is rarely the best predictor, indicating that the precipitation sum over a monthly period is not a powerful measure for flood probability.

API4 is slightly more often a better measure than D4-6 and D4-14, although this is not systematic. APIs are widely used in hydrology \citep[see e.g.][]{Kohler.1951,Fedora.1989,Heggen.2001,Tramblay.2012} but our integrative study cannot confirm that they explain flood frequency better than simple precipitation sums.\\

\subsection{Impacts of short range precipitation and PRE-AP on flood magnitude}
\label{res5}

In the previous sections, the impact of PAPs on HQ probability was discussed (i.e. whether floods are more frequent after wet periods). Here, the impact on the flood magnitude is investigated as well (i.e. whether larger floods follow wetter periods than smaller floods).\\

In Fig. \ref{xysummary}, the flood-precipitation is simply summarized by the median return period of the PAPs for a flood sample. This allows us to compare various flood samples (different flood magnitudes, different catchment groups, different flood seasons). Assuming that the precipitation distribution is equal to climatology before floods, the median return period should be equal to 2 days (delimited by solid lines in the graphs).\\

For the Micro, Meso and Macro catchments in Fig. \ref{xysummary}a, larger floods correspond to higher D0-1 than smaller floods (HQ20s are associated with a median return period of D0-1 of 400-1000 days=1-3 years while HQ1s correspond to a median D0-1 of only 60 days). In contrast, HQ20s are related to clearly higher D2-3 only at Macro catchments. At those catchments, as much precipitation falls 2 to 3 days before the HQ20s as falls 0 to 1 days before all HQs. At Lake Outlets~~Lakes Exits~~, D2-3 is more extreme than D0-1 because of the long time delay between precipitation and gauged discharge (see section \ref{res1}).\\

Figure \ref{xysummary}a can be directly compared to Fig. \ref{xysummary}b. For Micro, Meso and Macro catchments, the return periods of D0-3 in Fig. \ref{xysummary}b are similar to the ones of D0-1. On the other hand, the median PRE-AP is remarkably close to normal for each catchment size (close to the climatological median). Moreover, the PRE-AP was not higher before HQ20s than before HQ1s. A change in PRE-AP with flood magnitude is only found at Lake Outlets~~Lakes Exits~~.\\

Figure \ref{xysummary}c-f investigates different hydrological regimes and different flood seasons. For no regime and no season is the amount of PRE-AP precipitation linked to the flood amplitude. Even at Jurassien catchments, where we found that floods are significantly more frequent after wet periods, HQ20s are not associated with wetter periods than HQ1s.

\subsection[Triggering events and antecedent precipitation]{Can weaker precipitation trigger floods if PRE-AP is higher?}

In the previous sections, the PAPs were investigated separately. Here we show the combinations of PRE-AP and short-range precipitation events for single floods. If the runoff coefficient is enhanced by wetter PRE-AP (and thus more saturated soils), floods might happen in association with weaker triggering events.\\

Figure \ref{xyregtyp} shows D0-3 and D4-14 of all flood events for different catchment samples. As already inferred from Fig. \ref{allev01}, precipitation accumulations before floods vary remarkably between single events and the portion of floods lacking high~~intense~~ triggering precipitation is highest in

Glacial and Nival catchments. The green lines in Fig. \ref{xyregtyp} show the linear regression between D0-3 and D4-14 for HQ5 events (only HQ5s are shown for clarity). The regression lines address the following question: did wet periods of PRE-AP allow weaker weather events to generate HQ5s? Indeed, it seems that for the Jurassien, Meridional and Lake Outlets~~Lakes Exit~~ catchments, HQ5s that were triggered by weaker weather events tend to be associated with higher values of PRE-AP. This is in contrast to Glacial catchments where weaker events trigger HQ5s after drier periods. Regarding flood forecasting, it would be interesting to define which~~a~~ minimum threshold ~~: what amount~~ of event precipitation is required to trigger a HQ5 given that PRE-AP is known, similarly to the flash flood guidance (FFG) approach \citep[see e.g.][]{mogil1978nws}. ~~?~~ The scatter in observations shows that defining such a threshold is impossible for Switzerland because floods can occur in association with all types of precipitation. The only flood sample for which such a threshold would be realistic is the set of HQ20s at Lake Outlets~~Lakes Exits~~. There, a HQ20 occurred without precipitation in the last 3 days but after an exceptionally wet period of PRE-AP. In contrast, all HQ20s occurring after not unusually wet periods of PRE-AP required at least a D0-3 of return period of 100 days. There might be a minimum threshold of D0-3 for HQ20s in Macro and Meridional catchments as well but it does not seem to depend on PRE-AP. The lack of a minimum threshold of D0-3 for floods is probably due to the very simple definition of precipitation used here and to the fact that the precipitation thresholds vary between catchments. Finer and catchment-specific approaches \citep[see e.g.][]{norbiato2008flash} are required to formulate an FFG system for the catchments considered.\\

\section{Discussion}

~~Our results are based on a synoptic and statistical approach that emphasizes the common signature of antecedent precipitation to a large sample of flood events in Switzerland. In this section, we comment on the specific limitations of this approach and of our data and put our results in the context of previous work.\\~~

~~We call weekly to monthly precipitation periods preceding floods by more than 3 days \textquotedblleft PRE-AP\textquotedblright\ (PREcursor Antecedent Precipitation) periods. The comprehensive statistical analysis shows that the occurrence of annual floods is differently related to PRE-AP in different regions. (i) Annual floods are significantly more frequent after wet PRE-AP periods in most Jurassien catchments, in some Pluvial catchments of northwestern and northeastern Switzerland, and at lakes exits. (ii) Annual floods are significantly less frequent after wet PRE-AP periods in glacial catchments. (iii) The amount of PRE-AP is not significantly related to the occurrence of annual floods in the rest (the majority) of Swiss catchments. Also, PRE-AP is absolutely not related to flood magnitude except at lakes exits (for all catchment sizes, all hydrological regimes and during all seasons). The precipitation outside of a 4-day period is not related to the amplitude of discharge peaks. Our results thus highlight that long precipitation periods, if at all, only weakly influence floods (occurrence and amplitude) in the Swiss Alps. We emphasize that their role should not be overestimated and that a 4 day period must be considered as most relevant.\\~~

~~The lack of correlation between precipitation during PRE-AP and the occurrence of annual floods at the majority of catchments may appear surprising given that the influence of soil saturation on runoff formation is well established. Indeed, models showed that for the same triggering precipitation event, variations in antecedent moisture can lead to strong differences in discharge \citep[see e.g.][]{berthet2009crucial,pathiraja2012continuous}. Also, artificial rainfall experiments showed that the runoff coefficient changes strongly with the amount of antecedent precipitation for various soil types in Switzerland \citep[e.g.][]{spreafico2003hochwasserabschatzung}. Moreover, weekly to monthly precipitation anomalies have been described as important factors for the development of extreme European floods \citep[see e.g.][]{ulbrich2003central,grams2014atmospheric,schroter2015what} and was found to affect flood probability in Australia \citep[see e.g.][]{pui2011does}.\\~~

~~Our findings are not necessarily in contradiction with these studies. We find that the role of PRE-AP is very dependent on the hydrological regime of the catchments so that the absence of link between PRE-AP and flood occurrence is specific to the Swiss Prealpine, Alpine (except glaciers) and southern Alpine~~

~~catchments.\\~~

~~Moreover, several limitations inherent to the statistical experiment must be considered in order to correctly appreciate the results:\\~~

~~The statistical results do not mean that the runoff coefficient is independent on the amount of PRE-AP. Our analysis simply shows that this dependence is too weak to generate a significant signal when 20-50 floods per catchment are investigated. We nevertheless expect to be on the safe side when stating that a PRE-AP has no significant influence on the flood occurrence at a particular catchment. Indeed, we performed 5 tests for each catchment and each PAP, (we tested if the exceedance of the P50, P75, P90, P95 or P99 of the PAP significantly changes the flood probability). Significance was established even if only one of these 5 tests lead to a flood probability change with a P-value of 5\%.\\~~

~~Antecedent precipitation is not antecedent moisture. Extending the results to the role of antecedent moisture would require to use land surface models which is beyond the scope of this study given the large number of events considered. We thus must emphasize that our results are limited to the role of antecedent precipitation amounts and that the moisture state may better represent the disposition of a catchment to generate discharge peaks, especially at the time scale covered by PRE-AP.\\~~

~~The small-scale time and space distribution of precipitation is an important determinant of the runoff coefficients of some catchments \cite[e.g.][]{paschalis2014on}. Precipitation events can be very local and imply rapidly varying rainfall rates. Some short and/or localized precipitation events can thus be smoothed out or missed in the daily- and point measurement-based precipitation dataset used here. The PAPs are with this regard very coarse representations of real precipitation events. While this limitation prevents us from describing the sub-daily flood-triggering precipitation characteristics, it is unlikely to impact the main findings of our study; namely the role of PRE-AP.\\~~

~~Our results could be refined by including information about the precipitation phase. We chose not to distinguish between snowfall and rainfall because of uncertainty arising from the strong variations of the snowline on the sub-daily time scale. Future work involving hourly precipitation data may offer new opportunities with this regard. Also, the presence of a snow cover strongly influences the flow response to precipitation but a high-resolution snow cover dataset is not available for the period of investigation. Snow was therefore not considered.\\~~

~~In summary, the small scale distribution of precipitation, the precipitation phase and the land surface state (soil moisture, snow cover) are other contributors to the final peak discharges which are not addressed in this study. Our results are strictly limited to the role of antecedent precipitation amounts on a supra-daily scale. The statistics presented here cannot be directly related to specific hydrological processes. Instead, they give general and robust indications on the relevance of different precipitation periods for the occurrence and amplitude of peak discharges in the different Swiss hydrological regions.~~

A synoptic and statistical approach is used to separate event precipitation and antecedent precipitation for several thousand of floods. We define weekly to monthly precipitation periods preceding floods by more than 3 days \textquotedblleft PRE-AP\textquotedblright\ (PREcursor Antecedent Precipitation) periods. Flood-triggering events are distinguished by D0-1, D2-3 and D0-3.\\

The relation between flood occurence and the precipitation amount during D0-1 is stronger for Pluvial catchments than for Nival and Glacial catchments. We attribute this observation to the fact that rain-on-snow events are more common in Nival and Glacial catchments. During such events, the transformation of precipitation into runoff is strongly influenced by the presence of a snow cover through snow melt and complex snowpack runoff dynamics, \citep[see e.g.][]{wever2014model}. The Nival and Glacial catchments are also at higher altitudes and typically smaller than Pluvial catchments. They consequently react to shorter and more intense precipitation events which do not necessarily correspond to high 2-days sums.\\

We attribute the weak relationship between the precipitation amount during D0-1 and the occurence of floods at lake outlets to the relatively strong influence of the PRE-AP. PRE-AP is indeed significantly related to flood occurences at these catchments. This is most probably due to the large reservoir capacities of the lakes; i.e. the lakes must first be filled before floods can be recorded at their outlets.\\

The majority of the lake outlets is regulated. Small HQs after wet PRE-AP may be triggered by the lake regulation itself (if the gates are opened after long periods of precipitation resulting in high lake levels). However, we expect the extreme discharge peaks after wet PRE-AP to be damped due to the lake regulation. Despite the lake regulation, HQ20s at lake outlets are the floods that are proportionally the most frequent after wet PRE-AP. Lake regulation is often a compromise between the need to protect settlements adjacent to the lake but also the downstream areas; its effect on extreme floods is thus complex.\\

While PRE-AP is important at lake outlets, it is only weakly linked to flood probability at the other catchments and its influence is region-specific: (i) Annual floods are significantly more frequent after wet PRE-AP periods in most Jurassien catchments, in some Pluvial catchments of northwestern and northeastern Switzerland, and at lake outlets. (ii) Annual floods are significantly less frequent after wet PRE-AP periods in glacial catchments. (iii) The amount of PRE-AP is not significantly related to the occurrence of annual floods in the rest (the majority) of Swiss catchments. The fact that PRE-AP is only weakly related to floods compared to D0-1 or D0-3 is not astonishing. Indeed, we expected the highest precipitation amounts to fall during and just before the flood days, rather than 4 to 30 days before.\\

More unexpected is the fact that more precipitation during PRE-AP is, in the majority of catchments, not related to a significantly higher flood probability, nor to a higher flood amplitude. For most catchments, floods and precipitation amounts are not significantly related if we ignore precipitation during the last 4 days. This observation may be most convincingly reflected by Fig. \ref{xysummary}b which shows that the median PRE-AP of HQ20s is very close to the climatological median (except at lake outlets). The idea that the flood risk remains enhanced for several days after long periods of precipitation is strongly anchored in the general perception. The influence of soil saturation on runoff formation is indeed well established. Models showed that for the same triggering precipitation event, variations in antecedent moisture can lead to strong differences in discharge \citep[see e.g.][]{berthet2009crucial,pathiraja2012continuous}. Also, artificial rainfall experiments showed that the runoff coefficient changes strongly with the amount of antecedent precipitation for various soil types in Switzerland \citep[e.g.][]{spreafico2003hochwasserabschatzung}. Moreover, weekly to monthly precipitation anomalies have been described as important factors for the development of extreme European floods \citep[see e.g.][]{ulbrich2003central,grams2014atmospheric,schroter2015what}. Contrastingly, our results show that, in the majority of Swiss catchments and for the period investigated, flood days are not significantly different than other days regarding the amount of precipitation that fell earlier than 3 days before.\\

Our findings are, however, not in contradiction with the studies cited above. First, we find that the role of PRE-AP is very dependent on the hydrological regime of the catchments so that the absence of significant relationship between PRE-AP and flood frequency/magnitude is specific to the Swiss Prealpine, Alpine (except glaciers) and southern Alpine catchments. Second, several limitations inherent to the statistical experiment must be considered in order to correctly appreciate the results:\\

The statistical results do not mean that the runoff coefficient is independent on the amount of PRE-AP. Our analysis simply shows that this dependence is too weak to generate a significant signal when 20-50 floods per catchment are investigated. We nevertheless expect to be on the safe side when stating that PRE-AP has no significant influence on the flood occurrence at a particular catchment. Indeed, we performed 5 tests for each catchment and each PAP, (we tested if the exceedance of the P50, P75, P90, P95 or P99 of the PAP significantly changes the flood probability). Significance was established even if only one of these 5 tests lead to a flood probability change with a P-value of 5\%.\\

Antecedent precipitation is not antecedent moisture. Extending the results to the role of antecedent moisture would require to use land surface models and/or extensive observations of soil moisture and ground water. This is beyond the scope of our study given the large number of events considered. We thus must emphasize that our results are limited to the role of antecedent precipitation amounts and that the moisture state may better represent the disposition of a catchment to generate discharge peaks, especially at the time scale covered by PRE-AP.\\

The small-scale temporal and spatial distribution of precipitation is an important determinant of the runoff coefficients of some catchments \cite[e.g.][]{paschalis2014on}. Precipitation events can be very local and imply rapidly varying rainfall rates. Some short and/or localized precipitation events can thus be smoothed out or missed in the daily- and point measurement-based precipitation dataset used here. The PAPs are with this regard very coarse representations of real precipitation events. While this limitation prevents us from describing the sub-daily flood-triggering precipitation characteristics, it is unlikely to impact the main findings of our study; namely the role of PRE-AP.\\

Finally, the PAPs have a constant formulation for all catchments, regardless of their diverse sizes and hydrological regimes. This limitation is inherent to the nature of the experiment. The consideration of more than 100 catchments and several thousands of discharge peaks limits obviously the possibilities of refinement. A catchment-specific formulation of the PAPs and the APIs (a calibration of the K factor in equ. \ref{equapi} For e.g.) would allow for a finer distinction of the triggering events and the antecedent precipitation. Such a refinement would however require to determine typical response times for all catchments. Moreover, a dynamical formulation of PAPs and APIs would reduce the possibilities of comparing different catchment types. Instead, a strict and simple formulation of PAPs like the one used here maintains the experiment to an affordable level of complexity. This is to our opinion primordial when investigating very large samples.\\

Thanks to its relative simplicity, the method developed here can easily be used anywhere on the globe provided than extensive observations are available. Minimum requirements are multidecadal observations of discharge peaks and daily precipitation, as well as an accurate digital elevation model. The precipitation information may be the most critical to retrieve and potentially useful datasets must guarantee a sufficient homogeneity in space and time as well as a sufficient space resolution and coverage. The recent daily precipitation dataset from \cite{isotta2014climate} offers an interesting opportunity to extend the method developed here to the whole Alpine range. The high station density of the dataset should also allow the analysis of Meso- to Micro-scale catchments. Over areas of sparse raingauges networks, satellite or satellite-gauge daily precipitation climatologies may alternatively be used \citep[see e.g.][]{huffman2007trmm}.

\conclusions

We quantify statistically the influence of different precipitation periods for the generation of thousands of annual floods in Switzerland. In contrast to previous studies that define antecedent precipitation as all the water that fell before the very last flood-triggering precipitation event, we explicitly separate antecedent precipitation into the short-range and long-range antecedent precipitation based on the autocorrelation of daily precipitation time series and reflecting the synoptic time scale. The short-range encompasses the 0-3 days period before floods and the long range the earlier period (called PRE-AP). This novel distinction allows to specifically address the role of several antecedent precipitation periods for flood generation.\\

At the short range, we do not separate antecedent precipitation from the precipitation event directly triggering the discharge peak. Instead, we consider accumulations over several days and address~~adress~~ the following question: over which preceding~~preceeding~~ period is the amount of precipitation related to flood frequency and flood magnitude?\\

The 2-day sum (0-1 days before floods) is clearly the best correlated with both the flood frequency and the flood magnitude. The precipitation 2 to 3 days before floods also significantly affects flood frequency everywhere except in the high Alps. It is moreover related to flood magnitude at lake outlets~~lakes~~

~~exits~~ and in large catchments. Regarding earlier periods however, we find that PRE-AP has had no significant impact on flood frequency for the majority of Swiss catchments in the last 50 years. Moreover, the magnitude of floods was also independent on the magnitude of PRE-AP in all catchment types except at lake outlets~~lakes exits~~. The influence of PRE-AP is thus overall weak. We thus suggest that researchers focus on 2 to 4 days precipitation periods when reconstructing antecedent precipitation of past Alpine floods or when inferring future Alpine flood risk from climate projections. Long range antecedent precipitation periods preceding the last three days before floods are in contrast only relevant in~~for~~ the Jura Mountains, in~~for~~ the western and eastern Swiss Plateau, as well as at lake outlets. The results presented here may thus also motivate particular efforts to refine flood warning systems with information about the antecedent precipitation for the areas where antecedent precipitation significantly influences flood probability~~for lakes exit areas~~.\\

Our findings are derived from extensive observations and can be expected to be robust and representative of the various flood types encountered in the Swiss territory. Although our results are specific to Swiss catchments, the method presented here could be applied to other regions given that sufficient data is available.\\

~~Although our results are specific to Swiss catchments, the method presented here could be applied to other regions given that sufficient data is available.\\~~

The large differences in return periods of precipitation prior to floods of a similar magnitude indicate that catchment-averaged daily precipitation sums only explain a limited part of the flood variability. Future work is required to better characterize the short flood-triggering precipitation events at a hourly and kilometer scale. The advent of a new gridded precipitation dataset at a hourly resolution (combining rain gauges and radar) will offer new potential with this regard although the use of radar data to achieve this goal limits the time coverage to the 21st century. This analysis may also be further expanded by including information about snow line, snow cover and soil moisture.

\begin{acknowledgements}

The authors gratefully acknowledge the Swiss Federal Office of the Environment (FOEN) for monitoring Swiss rivers, post-processing extreme discharge values and contributing to this study by providing data on annual maximum discharge events. This study would not have been possible without the high-end interpolation of rain gauges made available by the Swiss Federal Office of Meteorology (MeteoSwiss). We are thankful to Claudia Brauer and Massimiliano Zappa for their pertinent and constructive comments.

\end{acknowledgements}

\bibliographystyle{copernicus}
\bibliography{flood_rain_refs.bib}

\begin{figure*}[t]
\includegraphics[width=12cm]{pics/fig1.pdf}
\caption{Swiss river discharge stations selected for this study. Colors refer to the hydrological regimes in the legend. Stations at lake outlets~~lakes exits~~ are shown by triangles to highlight the strong anthropogenic influence on the discharge (lake outlets~~lakes exits~~ are thus analyzed separately). The numbers refer to Tab. \ref{catchproperties1} and \ref{catchproperties2} which provide brief descriptions of the catchments.}
\label{catchsel}
\end{figure*}

\begin{figure*}[t]
\includegraphics[width=12cm]{pics/fig2.pdf}
\caption{The distribution of daily precipitation before and after all flood events is shown in (a). For example, the boxplot at $x=-10$ represents the distribution of daily precipitation percentiles 10 days prior to the 4257 annual flood events analyzed in this study (all HQs from all catchments). The middle line of the boxplots shows the median, the boxes comprise the 25-75 percentile range, and the whiskers end at a deviation from the mean of 1.5 the interquartile range. (b-d) Same as (a) but for floods in Micro catchments, Macro

catchments and Lake Outlets~~lakes exits~~. (e) The same procedure as in (a), but applied to annual maximum precipitation days instead of annual flood days.}
\label{boxplot}
\end{figure*}

\begin{figure*}[t]
\includegraphics[width=12cm]{pics/fig3.pdf}
\caption{Absolute values of the climatological percentiles for the different PAPs. Statistics from Macro (a-c) and Micro (d-f) catchments are shown on the top and bottom row, respectively. Accumulations over 2 days which correspond to the PAPs D0-1 or D2-3 are shown in (a,d). Accumulations over 11 days corresponding to D4-14 are shown in (b,e). APIs are shown in (c,f). Variation between catchments is visualized in boxplots.}
\label{suppl1}
\end{figure*}

\begin{figure*}[t]
\includegraphics[width=12cm]{pics/fig5.pdf}
\caption{Overview of all flood events. All river discharge stations (numbers on the y axis, see Tab. \ref{catchproperties1}) cover at least 20 years in the 1961-2011 period. For each annual discharge peak, the return period of the two-days precipitation sum (D0-1) is indicated by colors. HQ5s and HQ20s are marked with squares and triangles, respectively. The catchments are sorted by regime type and by increasing size from top to bottom. Hydrological regimes are indicated by colors: blue=Glacial, cyan=Nival, green=Pluvial, orange=Jurassien, red=Meridional, magenta=Macro, brown=Lake Outlets~~Lakes Exits~~.}
\label{allev01}
\end{figure*}

\begin{figure*}[t]
\includegraphics[width=12cm]{pics/fig6.pdf}
\caption{Same as Fig. \ref{allev01} but for PRE-AP (D4-14).}
\label{allev414}
\end{figure*}

\begin{figure*}[t]
\includegraphics[width=12cm]{pics/fig7.pdf}
\caption{Relative frequency of precipitation percentiles for several PAPs before floods. Each colored line represents a PAP. (a-d) HQ5s in (a) Micro catchments, (b) Meso catchments, (c) Macro catchments and (d) Lake Outlets~~Lakes Exits~~ catchments. (e) All HQs and (f) HQ20s in all catchments. Gray shadings represent the 99\% level of significance of the frequency of each percentile bin.}
\label{relative_frequ}
\end{figure*}

\begin{figure*}[t]
\includegraphics[width=12cm]{pics/fig8.pdf}
\caption{The relevance of the different precipitation periods for the occurrence of annual floods is tested using logistic regression for each precipitation period and each catchment (a) D0-1, (b) D2-3, (c) D4-6, (d) D4-14, (e) D4-30, (f) D0-30, (g) API2, and (h) API4. ~~For each precipitation period and each catchment, the following question is addressed using logistic regression: does the exceedance of a given precipitation threshold significantly change the flood probability?~~ Several thresholds are tested (P50, P75, P90, P95, P99) and the most significant P ~~-~~value is displayed symbolically (squares, dots and triangles indicate a non-, weakly-, and strongly ~~-~~significant influence, respectively). The colors of the symbols refer to the hydrological regimes of the catchments. Circles denote a negatively significant correlation, i.e. the exceedance of a given precipitation threshold significantly reduces flood probability~~. Negative correlations are almost exclusively found in Glacial catchments~~.}
\label{logregregtyp}
\end{figure*}

\begin{figure*}[t]

```
\includegraphics[width=12cm]{pics/fig9.pdf}
\caption[Precipitation and flood magnitude]{Median return periods of flood-
associated precipitation for different flood samples. The rows show different
catchment sizes (a-b), different hydrological regimes (c-d) and different flood
seasons (e-f). The left column shows D0-1 in $x$ and D2-3 in $y$ and the right
column D0-3 in $x$ and D4-14 in $y$. The numbers 1, 5 and 20 indicate median
return periods associated with all HQs, with all HQ5s, and with all HQ20s,
respectively. They are joined together by a line.}
\label{xysummary}
\end{figure*}

\begin{figure*}[t]
\includegraphics[width=12cm]{pics/fig10.pdf}
\caption[Triggering events versus antecedent precipitation]{Flood-associated
precipitation for different catchment samples: a) Glacial, b) Nival, c) Pluvial,
d) Jurassien, e) Meridional, f) Macro and g) Lake Outlets~~Lakes Exits~~. For each
discharge peak, D0-3 is shown in $x$ and D4-14 in $y$. Annual floods are shown
by gray dots (shadings indicate the density of dots), HQ5s by green dots and
HQ20s by red triangles. Green lines show the linear regression of the HQ5s.}
\label{xyregtyp}
\end{figure*}





\begin{table*}[t]
\caption{The different precipitation accumulation periods (PAPs) used in this
study.}
\begin{tabular}{cccccc}
\tophline
D0-1& climatological percentile of the&2-days&precipitation sum&(from 0 to 1
days&before the flood day)\\
D2-3& '' &2-days& '' &2 to 3 days& '' \\
D0-3& '' &4-days& '' &0 to 3 days& '' \\
D4-6& '' &3-days& '' &4 to 6 days& '' \\
D4-14& '' &11-days& '' &4 to 14 days& '' \\
D4-30& '' &27-days& '' &4 to 30 days& '' \\
D0-30& '' &31-days& '' &0 to 30 days& '' \\
API2& '' & API &&(2 days&before the flood day)\\
API4&''&API &&(4 days&''\\
PRE-AP&\multicolumn{5}{l}{all precipitation accumulation periods excluding the
last three days before the flood day (here D4-6, D4-14, D4-30 and API4)}\\
\bottomhline
\end{tabular}
\label{precipindtable}
\end{table*}

\begin{table}[t]
\caption{Expressions used to define different quantities~~intensities~~ of
precipitation.}
\centering
\begin{tabular}{lll}
\tophline
expression&percentile&return period\\
\middlehline
extreme&$>$P99.9&$>$ 1000 days\\
very high~~intense~~&P99.9-P99&100-1000 days\\
high~~intense~~&P99-P90&10-100 days\\
moderate&P90-P75&4-10 days\\
unusually wet&$>$P90&$>$10 days\\
wetter&$>$P50&$>$ 2days\\
drier&$<$P50&$<$ 2 days\\
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\bottomhline
\end{tabular}
\label{intexpr}
\end{table}

\begin{table*}[t]
\caption[Summary of catchments properties]{Summary of catchment properties for
the selected stations. Catchments are sorted based on hydrological regime and
increasing size from top to bottom. Locations are given in Swiss coordinates
(CH1903).}
\resizebox{1.99\columnwidth}{!}{
\begin{tabular}{ccccccccc}
Number&Name&coord X&coord Y&Area [km$^{2}$]&Station Height [m]&Avg. Height
[m]&Glacier coverage [\%]&Hydro. Regime\\
\tophline
844&Ferrerabach - Trun&717795&179550&12.5&1220&2461&17.3&Glacial\\
821&Alpbach - Erstfeld. Bodenberg&688560&185120&20.6&1022&2200&27.7&Glacial\\
945&Rein da Sumvitg - Sumvitg.
Encardens&718810&167690&21.8&1490&2450&6.7&Glacial\\
751&Gornernbach - Kiental&624450&155130&25.6&1280&2270&17.3&Glacial\\
838&Ova da Cluozza - Zernez&804930&174830&26.9&1509&2368&2.2&Glacial\\
803&Witenwasserenreuss - Realp&680950&160130&30.7&1575&2427&12.7&Glacial\\
735&Simme - Oberried/Lenk&602630&141660&35.7&1096&2370&34.6&Glacial\\
792&Rhone (Rotten) - Gletsch&670810&157200&38.9&1761&2719&52.2&Glacial\\
1250&Goneri - Oberwald&670520&153830&40&1385&2377&14.2&Glacial\\
753&Kander - Gasterntal. Staldi&621080&144260&40.7&1470&2600&43.5&Glacial\\
848&Dischmabach - Davos. Kriegsmatte&786220&183370&43.3&1668&2372&2.1&Glacial\\
740&Hinterrhein - Hinterrhein&735480&154680&53.7&1584&2360&17.2&Glacial\\
778&Rosegbach - Pontresina&788810&151690&66.5&1766&2716&30.1&Glacial\\
922&Chamuerabach - La Punt-Chamues-ch&791430&160600&73.3&1720&2549&1.5&Glacial\\
793&Lonza - Blatten&629130&140910&77.8&1520&2630&36.5&Glacial\\
782&Berninabach - Pontresina&789440&151320&107&1804&2617&18.7&Glacial\\
1064&Poschiavino - Le Prese&803490&130530&169&967&2170&6.5&Glacial\\
865&Massa - Blatten bei Naters&643700&137290&195&1446&2945&65.9&Glacial\\
387&L{\"u}tschine - Gsteig&633130&168200&379&585&2050&17.4&Glacial\\
\middlehline
890&Poschiavino - La R{\"o}sa&802120&142010&14.1&1860&2283&0.35&Nival\\
765&Krummbach - Klusmatten&644500&119420&19.8&1795&2276&3&Nival\\
948&Chli Schliere - Alpnach. Chilch Erli&663800&199570&21.8&453&1370&0&Nival\\
750&Allenbach - Adelboden&608710&148300&28.8&1297&1856&0&Nival\\
799&Grosstalbach - Isenthal&685500&196050&43.9&767&1820&9.3&Nival\\
826&Ova dal Fuorn - Zernez. Punt la
Drossa&810560&170790&55.3&1707&2331&0.02&Nival\\
822&Minster - Euthal. R{\"u}ti&704425&215310&59.2&894&1351&0&Nival\\
916&Taschinasbach - Gr{\"u}sch.
Wasserf.Lietha&767930&206420&63&666&1768&0.04&Nival\\
862&Saltina - Brig&642220&129630&77.7&677&2050&5.1&Nival\\
852&Thur - Stein. Iltishag&736020&228250&84&850&1448&0&Nival\\
720&Grande Eau - Aigle&563975&129825&132&414&1560&1.8&Nival\\
1143&Engelberger Aa - Buochs. Flugplatz&673555&202870&227&443&1620&4.3&Nival\\
1017&Plessur - Chur&757975&191925&263&573&1850&0&Nival\\
284&Muota - Ingenbohl&688230&206140&316&438&1360&0.08&Nival\\
637&Simme - Oberwil&600060&167090&344&777&1640&3.7&Nival\\
1117&Kander - Hondrich&617790&168400&496&650&1900&7.9&Nival\\
1127&Landquart - Felsenbach&765365&204910&616&571&1800&1.4&Nival\\
\middlehline
1252&Sellenbodenbach - Neuenkirch&658530&218290&10.5&515&615&0&Pluvial\\
882&Steinenbach - Kaltbrunn.
Steinenbrugg&721215&229745&19.1&451&1112&0&Pluvial\\
831&Steinach - Steinach&750760&262610&24.2&406&710&0&Pluvial\\
1240&Biber - Biberbrugg&697240&223280&31.9&825&1009&0&Pluvial\\
932&Sionge - Vuippens. Ch{\^a}teau&572420&167540&45.3&681&862&0&Pluvial\\
1251&Alp - Einsiedeln&698640&223020&46.4&840&1155&0&Pluvial\\
833&Aach - Salmsach. Hungerb{\"u}hl&744410&268400&48.5&406&480&0&Pluvial\\
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1022&Goldach - Goldach&753190&261590&49.8&399&833&0&Pluvial\\
789&Bibere - Kerzers&581280&201850&50.1&443&540&0&Pluvial\\
1118&Rot - Roggwil&630260&231650&53.6&436&586&0&Pluvial\\
1128&G{\"u}rbe - Burgistein.
Pfandersmatt&605890&181880&53.7&569&1044&0&Pluvial\\
863&Langeten - Huttwil. H{\"a}berenbad&629560&219135&59.9&597&766&0&Pluvial\\
1231&Worble - Ittigen&603005&202455&60.5&522&679&0&Pluvial\\
1151&Veveyse - Vevey. Copet&554675&146565&62.2&399&1108&0&Pluvial\\
\bottomhline
\end{tabular}
}
\label{catchproperties1}
\end{table*}

\begin{table*}[h]
\caption[Summary of catchments properties (continued)]{Table
\ref{catchproperties1} continued.}
\centering
\resizebox{1.99\columnwidth}{!}{
\begin{tabular}{ccccccccc}
Number&Name&coord X&coord Y&Area [km$^{2}$]&Station Height [m]&Avg. Height
[m]&Glacier coverage [\%]&Hydro. Regime\\
\tophline
834&Urn{\"a}sch - Hundwil.
{\"A}schentobel&740170&244800&64.5&747&1085&0&Pluvial\\
528&Murg - W{\"a}ngi&714105&261720&78.9&466&650&0&Pluvial\\
1066&Lorze - Baar&683300&228070&84.7&455&866&0&Pluvial\\
911&Necker - Mogelsberg. Aachs{\"a}ge&727110&247290&88.2&606&959&0&Pluvial\\
1140&Lorze - Zug. Letzi&680600&226070&101&417&825&0&Pluvial\\
898&Mentue - Yvonand. La Mauguettaz&545440&180875&105&449&679&0&Pluvial\\
888&Langeten - Lotzwil&626840&226535&115&500&713&0&Pluvial\\
650&G{\"u}rbe - Belp. M{\"u}limatt&604810&192680&117&522&837&0&Pluvial\\
977&Murg - Frauenfeld&709540&269660&212&390&580&0&Pluvial\\
549&T{\"o}ss - Neftenbach&691460&263820&342&389&650&0&Pluvial\\
978&Sense - Th{\"o}rishaus.Sensematt&593350&193020&352&553&1068&0&Pluvial\\
962&Wigger - Zofingen&637580&237080&368&426&660&0&Pluvial\\
883&Broye - Payerne. Caserne d'aviation&561660&187320&392&441&710&0&Pluvial\\
938&Glatt - Rheinsfelden&678040&269720&416&336&498&0&Pluvial\\
1100&Emme - Emmenmatt&623610&200420&443&638&1070&0&Pluvial\\
944&Kleine Emme - Littau. Reussb{\"u}hl&664220&213200&477&431&1050&0&Pluvial\\
825&Thur - Jonschwil. M{\"u}hlau&723675&252720&493&534&1030&0&Pluvial\\
\middlehline
854&Bied du Locle - La
Ran\c{c}onni{\`e}re&545025&211575&38&819&NA&NA&Jurassien\\
1254&Scheulte - Vicques&599485&244150&72.8&463&785&0&Jurassien\\
959&Aubonne-Allaman. Le Coulet&520720&147410&91.4&390&890&0&Jurassien\\
1173&Promenthouse - Gland. Route Suisse&510080&140080&100&394&1037&0&Jurassien\\
972&Seyon - Valangin&559370&206810&112&630&970&0&Jurassien\\
829&Suze - Sonceboz&579810&227350&150&642&1050&0&Jurassien\\
946&D{\"u}nnern - Olten. Hammerm{\"u}hle&634330&244480&196&400&750&0&Jurassien\\
1150&Allaine - Boncourt. Fronti{\`e}re&567830&261200&215&366&559&0&Jurassien\\
960&Venoge-Ecublens. Les Bois&532040&154160&231&383&700&0&Jurassien\\
915&Ergolz - Liestal&622270&259750&261&305&590&0&Jurassien\\
1139&Areuse - Boudry&554350&199940&377&444&1060&0&Jurassien\\
380&Birs - M{\"u}nchenstein. Hofmatt&613570&263080&911&268&740&0&Jurassien\\
\middlehline
879&Riale di Calneggia - Cavergno.
Pontit&684970&135960&24&890&1996&0&Meridional\\
975&Magliasina - Magliaso. Ponte&711620&93290&34.3&295&920&0&Meridional\\
1255&Riale di Pincascia - Lavertezzo&708060&123950&44.4&536&1708&0&Meridional\\
871&Breggia - Chiasso. Ponte di Polenta&722315&78320&47.4&255&927&0&Meridional\\
843&Cassarate - Pregassona&718010&97380&73.9&291&990&0&Meridional\\
1287&Vedeggio - Agno&714110&95680&105&281&898&0&Meridional\\
769&Calancasca - Buseno&729440&127180&120&746&1950&1.1&Meridional\\
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1241&Verzasca - Lavertezzo. Campi�i&708420&122920&186&490&1672&0&Meridional\\
\middlehline
67&Ticino - Bellinzona&721245&117025&1515&220&1680&0.7&Macro\\
785&Inn - Tarasp&816800&185910&1584&1183&2390&5.1&Macro\\
136&Thur - Andelfingen&693510&272500&1696&356&770&0&Macro\\
764&Limmat - Baden. Limmatpromenade&665640&258690&2396&351&1130&1.1&Macro\\
51&Reuss - Mellingen&662830&252580&3382&345&1240&2.8&Macro\\
942&Rhein - Bad Ragaz. ARA&757090&209600&4455&491&1930&1.9&Macro\\
32&Rh{\^o}ne - Porte du Scex&557660&133280&5244&377&2130&14.3&Macro\\
47&Aare - Brugg&657000&259360&11726&332&1010&2&Macro\\
\middlehline
527&Lorze - Frauenthal&674715&229845&259&390&690&0&Lake Outlet~~Exit~~\\
656&Tresa - Ponte Tresa. Rocchetta&709580&92145&615&268&800&0&Lake Outlet~~Exit~~\\
377&Linth - Weesen. Bi{\"a}sche&725160&221380&1061&419&1580&2.5&Lake Outlet~~Exit~~\\
917&Reuss - Luzern. Geissmattbr{\"u}cke&665330&211800&2251&432&1500&4.2&Lake Outlet~~Exit~~\\
111&Aare - Thun&613230&179280&2466&548&1760&9.5&Lake Outlet~~Exit~~\\
1253&Rh{\^o}ne - Gen{\`e}ve. Halle de l'Ile&499890&117850&7987&369&1670&9.4&Lake Outlet~~Exit~~\\
1170&Aare - Br{\"u}gg. {\"A}gerten&588220&219020&8293&428&1150&2.9&Lake Outlet~~Exit~~\\
\bottomhline
\end{tabular}
}
\label{catchproperties2}
\end{table*}

\end{document}
```