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Climate change and flood types

GEO 511 Master's Thesis

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Abstract

Floods are one of the most significant natural hazards in Switzerland and according to recent climate simulations (CH2018), an increase of extreme precipitation events, which could lead to more floods, is expected. However, it is also important to know that floods can be classified into different types, according to flood event characteristics, such is duration, precipitation amount or snowmelt amount. These are in particular, flash floods (FF), short-rainfall floods (SRF), long-rainfall floods (LRF), rain-on-snow floods (RoSF), snowmelt floods (SMF) and glacier melt floods (GMF). While the classification has been done for past measurements in other studies, this work aims to identify flood events in the future, and classify them according to a modified classification scheme (flood tree), used in Sikorska-Senoner & Seibert (2020). For this purpose, a dataset calculated with the hydrological model PREVAH is given by the WSL, with daily data from 1981 to 2099. The data is based on 39 different GCM-RCM chains that are categorised in different RCPs, which show various assumptions of future climate projections, regarding greenhouse emissions. Additionally, a control simulation between 1981 and 2017 is available. On the one hand, this control simulation is used to determine the present state and on the other hand, to evaluate the simulations of GCM-RCM chains during this period.

For the future, an increase in different most rainfall-related flood types is expected, whereas snow-related flood types are expected to decrease. These changes are expected to be more significant, when no mitigation measurements are applied.

List of abbreviations

Ac	Catchment Area (km^2)
CH2018	Swiss Climate Change Scenarios
D	Precipitation duration (d)
EURO-CORDEX	European Coordinated Downscaling Experiment
FF	Flash floods
GC	Areal Percentage Glacier cover
GCM	Global Climate Models
GCM-RCM-chain	Specific climate simulation chain of the EURO-CORDEX ensemble
GMF	Glacier melt Floods
I	Precipitation intensity
LRF	Long-rainfall floods
M_P	Min. precipitation amount (mm/d)
P	Precipitation total amount (mm/d or mm/event)
PREVAH	PREecipitation-Runoff-EVApotranspiration HRU Model
q_{max}	Maximum daily runoff (mm/event)
RCM	Regional Climate Models
RCP	Representative Concentration Pathways
RoSF	Rain-on-snow floods
SC	Snow cover (mm water equivalent)
SM	Snowmelt total amount (mm/d or mm/event)
SMF	Snowmelt floods
SRF	Short-rainfall floods
SWE	Snow water equivalent
T_d	Timing (month and day)
WSL	Swiss Federal Institute for Forest, Snow and Landscape Research
ΔP	Changes in mean annual precipitation
ΔSM	Changes in mean annual snowmelt
ΔT	Changes in mean annual temperature

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1. Background

1.1. Introduction

Floods have a significant hazard potential in Switzerland. Besides causing costly damage to the infrastructure, often running into millions of Swiss Francs, they are also a threat for humans, animals and vegetation (Aon Benfield, 2017). For this reason, a fundamental and accurate estimation of possible flood events is essential in order to mitigate or minimize damage, by creating a more appropriate land-use plan, for instance. Although excessive precipitation is the predominant source of flooding, processes such as snowmelt can influence the intensity of flood events. Occasionally, in high-mountain catchments, rain is not even needed to cause an increase in the runoff that could cause floods, whereas storm surges can threaten coastal cities such as Venice.

The topography and catchment (pre-)conditions do have an impact on flood events as well (Sikorska et al., 2015). For instance, the amount of soil moisture before a precipitation event determines how much precipitation can be stored in the ground before it gets saturated. Hence, catchments that have been prewetted prior to the flood event may be more exposed to floods. Depending on the latitude, the frequency, magnitude and characteristic of floods are different as well. For instance, tropical regions are likely to experience more thunderstorms than regions in mid-latitude (Zipser et al., 2006) and are therefore might be more exposed to flood events.

Flood events can be classified, based on their characteristics (Sikorska et al., 2015). In this work, a modified classification of Sikorska-Senoner & Seibert (2020) is used to classify flood events into six different main flood types, representing flash floods (FF), short-rainfall floods (SRF), long-rainfall floods (LRF), rain-on-snow floods (RoSF), snowmelt floods (SMF) and glacier-melt floods (GMF). The method is explained in detail in section 3. However, this method is based on past measurements and. Considering that more intensive precipitation events and increase in temperatures are projected, it must be expected that the frequency and intensity of flood events will increase as well (CH2018, 2018). Based on simulations of the PREVAH model, this work aims to determine the current spatial and seasonal patterns of these flood types and how they are expected to change in the future.

1.2. Runoff regimes in Switzerland

Runoff regimes describe how the runoff varies throughout the year and at which months average peak flow can occur in a specific region. Additionally, information on possible flood types can be retrieved as well. In Switzerland, floods occur more likely in the warmer season since excessive precipitation is usually the highest during the storm season. However, depending on the region, flood events can occur in every season. For instance, in the Swiss Plateau, flood seasonality can be centred on the winter season due to precipitation regime (Diezig & Weingartner, 2007; Sikorska et al., 2015).

The highest runoff peak of rivers and streams does not always happen during the month with the highest precipitation. The reason for this is that runoff is not only dependent on precipitation. It also depends on whether and how much precipitation occurs as snowfall, and is therefore temporarily stored, or how much of the precipitation, whether as rain or as snow, evaporates. This relationship is described in the water balance equation (Dingman, 2015):

$$P + GW_{in} - (Q_S + ET + GW_{out}) = \Delta S \tag{1}$$

Where	P	= precipitation amount (liquid and solid)
	GW_{in}, GW_{out}	= groundwater flow (in and out)
	Q_S	= stream flow of rivers
	ET	= evapotranspiration
	ΔS	= storage change

According to Dingman (2015), it can be assumed that ΔS does not change significantly over a longer period, provided that artificial intervention in the catchment is reduced to a minimum . Besides, catchments are topographically defined, so groundwater flow is only driven by gravity and hence, GW_{in} can be neglected as well. Thus, equation (1) can be reduced and rewritten to:

$$P - ET = Q_S + GW_{out} \quad \rightarrow \quad P - ET = Q_R \tag{2}$$

Where Q_R = total runoff of the watershed

The streamflow of rivers (Q_S) and groundwater flow (GW_{out}) are combined and represent the total runoff Q_R of the watershed. Therefore, in the long-term, the total runoff depends on precipitation and evapotranspiration only (Eq. 2), making them climatic boundary conditions. In contrast, hourly or daily peak discharge values additionally depend on present *catchment conditions*, such as available soil moisture.

Besides catchment conditions, *meteorological conditions*, like precipitation, have an impact on the runoff or river regimes. Due to Switzerland's marked topography, both can vary significantly between regions. For this reason, there are 16 different runoff regimes, which can be summarized in three groups (Weingartner & Aschwanden, 1992).

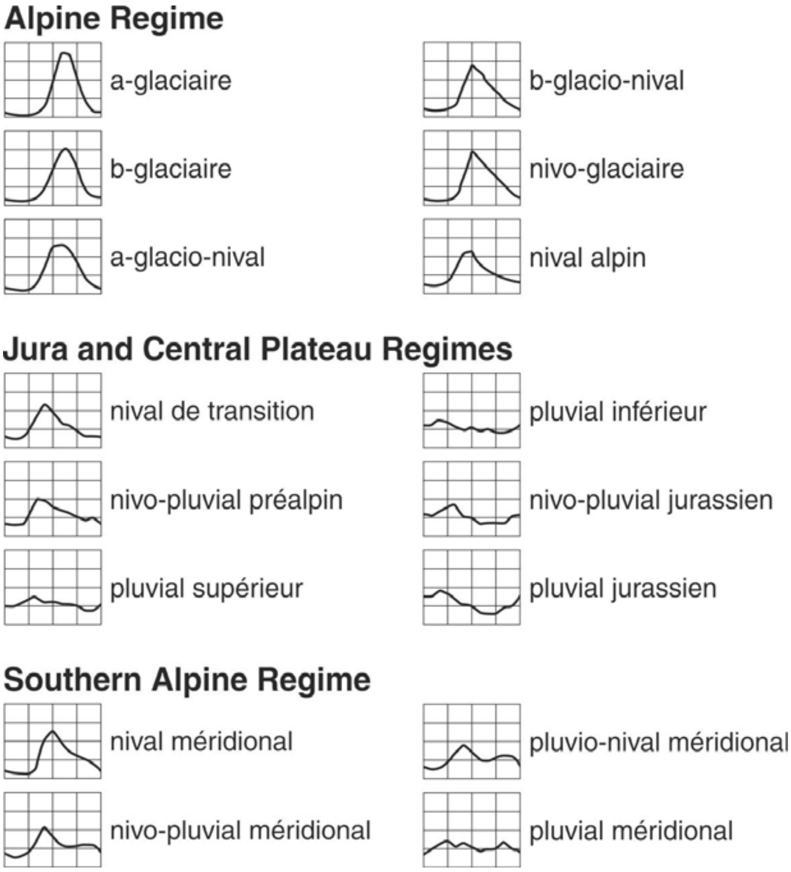

Figure 1: Runoff regimes in Switzerland (Weingartner & Aschwanden, 1992)

Researchers and experts in Switzerland distinguish regimes three different regimes: Alpine, Jura and Central Plateau and Southern Alpine Regimes. These regimes are then further subdivided according to dominant runoff generation process: glacier melt (glaciare), snowmelt (nival) or rain (pluvial), or a mix of maximum two processes (Weingartner & Aschwanden, 1992).

Alpine regimes are mostly dominated by snowmelt or glacier melt or both. The average monthly peak discharge usually occurs during the hot summer months from June to August and is much higher compared to the low discharge during the winter months. Catchments dominated by glacier melt only have a sharper peak than the ones that are partly influenced by snowmelt. Additionally, glacier melt regimes peak a little later than snowmelt regimes, because glacier melt peaks more during the end of summer, whereas snowmelt occurs more during spring and early summer. Furthermore, the runoff of snowmelt dominated regimes flattens out less quickly before it reaches the low flow during winter.

In contrast, runoff regimes in *Jura and Central Plateau* usually have a peak during the spring and partly winter months. The difference between the highest and lowest average monthly discharge is not that severe and both snowmelt and rainfall determine the runoff regime in these catchments. Rainfall-dominated regimes have a low flow during summer and high flow during winter, even though the rainiest months are during the summer period as well. However, evapotranspiration is high during these months too, and the runoff depends on this as well (Eq. 2).

Catchments in *southern alpine regimes* are similar to the northern alpine ones. The main difference is observed during the autumn months. While in the northern alpine catchments the discharge steadily decreases, in the southern alpine catchments the discharge is still reasonably high. Furthermore, rainfall-dominated regimes have two peaks during the year, one during winter or winter-spring-transition, and the other one in autumn. The reason for the autumn peak is the high and frequent precipitation events in the Southern Alps from September to November. The snowfall line is still relatively high and hence, most of the precipitation falls as rain. At the same time, evapotranspiration is significantly lower during autumn than during the summer.

However, it does not mean that one regime experiences always the same set of possible flood types. Therefore, the river regime should only be considered as a first indicator of which flood types are more likely expected in a catchment.

1.3. Available approaches to classify floods

While runoff regimes are classified by the discharge pattern during the year, floods, on the other hand, are determined by *meteorological* and *catchment conditions* before and during the flood event s(Sikorska-Senoner & Seibert, 2020; Sikorska et al., 2015). Therefore, similar meteorological and catchment conditions will result in a similar hydrological response (Sivakumar & Singh, 2012).

However, the first studies on flood type classification focussed more on one of the two mentioned conditions. Regarding meteorological conditions, Hirschboeck et al. (2000) classified floods into tropical, convective and frontal types, whereas Gupta & Dawdy (1995) distinguished between snow-related or rainfall-related flood types. Other studies focussed on catchment conditions instead and hence, were categorised into rainfall, snowmelt or glacier events, using antecedent precipitation, snow water equivalent, runoff components or catchment area (Blöschl & Sivapalan, 1997; Loukas et al., 2000; Robinson & Sivapalan, 1997; Waylen & Woo, 1982). On the other hand, the drawbacks of focussing on either meteorological or catchment condition is that it does not allow to distinguish between different events (Sikorska et al., 2015).

Later studies, particularly those in the Swiss and Austrian Alps, have combined both approaches. For instance, Merz & Blöschl (2003) focussed on catchment conditions in the Austrian Alps but used meteorological conditions as an input. They classified floods into flash, short-rainfall, long-rainfall, rain-on-snow, and snowmelt floods, using the timing of floods, storm duration, rainfall amount, snowmelt and catchment state as *flood type signatures*. Diezig & Weingartner (2007) further modified the classification of Merz & Blöschl (2003), and included glacier-melt floods as well, since they can cause floods in high-altitude catchments in summer, during the glacier melting season. Sikorska et al. (2015) further adapted the method, using the same flood types as a classification but applying slightly different signatures. Those flood type signatures were then further modified in Sikorska-Senoner & Seibert (2020) which will partly be used for this work (see section 2). This work uses similar signatures and the same flood types. However, it applies the method on projections as well, derived from the PREVAH model. A control simulation of the PREVAH model with interpolated measurements is also available and used as a benchmark.

1.4. Climate change scenarios for Switzerland

The climate in Switzerland has changed in the past decades. Between 1864 and 2017, the mean annual near-surface air temperature has increased by 2.0°C, leading to more frequent and intensive heatwaves and less cold periods. Winter precipitation has increased by 20%, whereas for summer precipitations there is no significant trend. However, extreme precipitation events resulting in flash floods have increased by 30% during the 20th century. Furthermore, the number of snow days have decreased by 20-50% and lowlands have lost more than high-mountainous regions (CH2018, 2018).

Future projections show a wide range of further possible changes, depending on the choice of the *Representative Concentration Pathways* (RCPs). RCPs are named after a range of a potential increase in radiative forcing values (in W/m^{-2}) by the year of 2100 (CH2018, 2018). RCP 2.6 is the least CO_2 emission scenario, with significant and immediate emission reductions, RCP 4.5 assumes moderate reductions, whereas in RCP 8.5 no mitigation measures are implemented. For instance, the temperature in summer is likely to increase by 0.7 to 2.4°C and 4.1 to 7.2°C for RCP 2.6 and RCP 8.5, respectively. Winter precipitation could increase by 2 to 24%, whereas summer precipitation is expected to drop by 43% or rise by 2%, for RCP 2.6 and RCP 8.5, respectively (winter and summer precipitation). Snowfall in low elevations is likely to decrease by up to 50%, while snow cover could decrease by almost 80%, if no mitigation measurements (RCP 8.5) are made (CH2018, 2018; IPCC, 2019). Besides RCP 2.6 and RCP 8.5, there are scenarios that first project an increase in emissions (RCP 6.0). However, the emission would decline in the second half of the 21st century. Hence, the changes in temperature or precipitation are projected to be somewhere between RCP 2.6 and RCP 8.5 (CH2018, 2018).

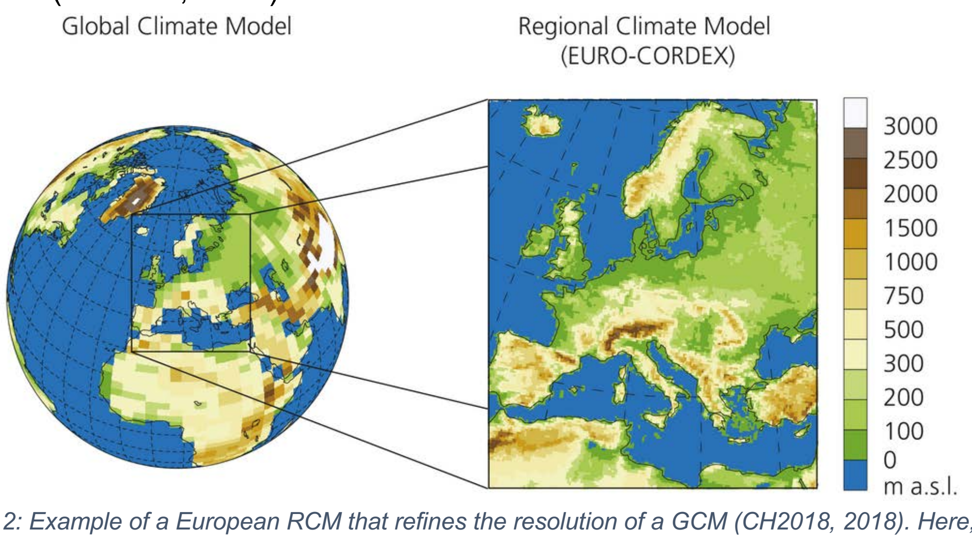

Figure 2: Example of a European RCM that refines the resolution of a GCM (CH2018, 2018). Here, the altitude is shown.

Recent changes in temperature in Alps in the past show an increase of the air temperature between 1°C and 2°C. Even though, that the climate has become somewhat drier, an increase of extreme precipitation events is observed (Beniston et al., 1997; Frei & Schär, 2001; Wilhelm et al., 2012). Hence, future climate scenarios for Switzerland make the a similar assumption (CH2018, 2018) and as a result, more flood events can be expected.

The changes for meteorological variables in CH2018 are based on the *European Coordinated Downscale Experiment* (EURO-CORDEX) ensembles of regional climate simulations with *Regional Climate Models* (RCMs) (CH2018, 2018; Jacob et al., 2014). RCMs themselves are nested in *Global Climate Models* (GCM), and the combination of one global and one regional model is commonly referred to as a nested GCM-RCM model chain. Since global GCM projections have a coarse resolution (100km), the RCMs refine it to a resolution, that represents the main topographical features of Switzerland (10-50km). This process is known as *Dynamical Downscaling* (Figure 2).

However, the resolution of 10 x 10 km is still coarse for Switzerland and the topography is still represented insufficiently, especially for inner Alpine valleys. Therefore, the RCMs are further downscaled to a 2 x 2 km, representing the *statistical downscaling*. The localised projections include the climate variables air temperature, precipitation, relative humidity, global radiation and near-surface wind speed (CH2018, 2018).

Statistical downscaling is performed by quantile mapping (Figure 3). It is a method that brings the distribution of observed and simulated climate variables in line with each other for past measurements. These corrections are therefore applied for future climate projections, leading to transient data in daily resolution (CH2018, 2018).

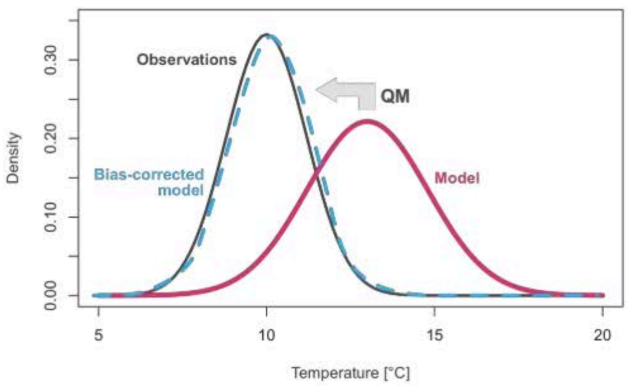

Figure 3: Example of quantile mapping for temperature. Simulated model output data of past measurements is corrected with observed datasets (CH2018, 2018).

1.5. Research questions and hypotheses

1.5.1 Research questions

Following the motivation (section 1.1), the main research question for this work is:

- How are seasonal and spatial patterns, frequency and intensity of six different flood types now, and how are they expected to change in Switzerland until 2100, under future projected climate conditions?

Following sub-questions have also been defined:

- Do the changes between the near future (2018-2058) and the remote future (2059-2099 differ, and if yes, to what extent?
- Are these changes spatial dependent?
- To what extent are the changes different between three different RCPs (2.6, 4.5 and 8.5)?
- To what extent can these changes be connected to changes in other annual meteorological and catchment variables (temperature, precipitation and snow-melt?)

1.5.2 Hypotheses

The hypotheses for the research question and the sub-questions are formulated for expected future changes.

- The frequency of some flood types will increase, and some flood types will de-crease, depending on the location in space (Swiss Plateau, Alps etc.). Due to the increase in seasonal temperatures (CH2018, 2018), an increased snowmelt as well as a seasonal shift of snow-related floods is expected.
- The differences in the changes of flood types in the remote future (2058-2099) will be more significant, compared to the near future.
- RCP 2.6 will show the least changes, whereas RCP 8.5 will show the most sig-nificant changes.
- More rainfall related and snow-related flood events are expected with increasing temperature, even though drier conditions are expected.

2. Data and methods

2.1. Study area

The study region covers (almost all of) Switzerland and consists of 307 catchments, located between 45°49’4.51’’N and 47°48’30.438’’N as well as 5°57’21.76’’E and 10°29’31.326’’E. The catchment areas range between 1 and 463 km^2, with mean elevations from 306 to 3004 meters above sea level (m.a.s.l). The spatial coverage is almost the whole area of Switzerland, with Val Poschiavo being the only region missing (Figure 4).

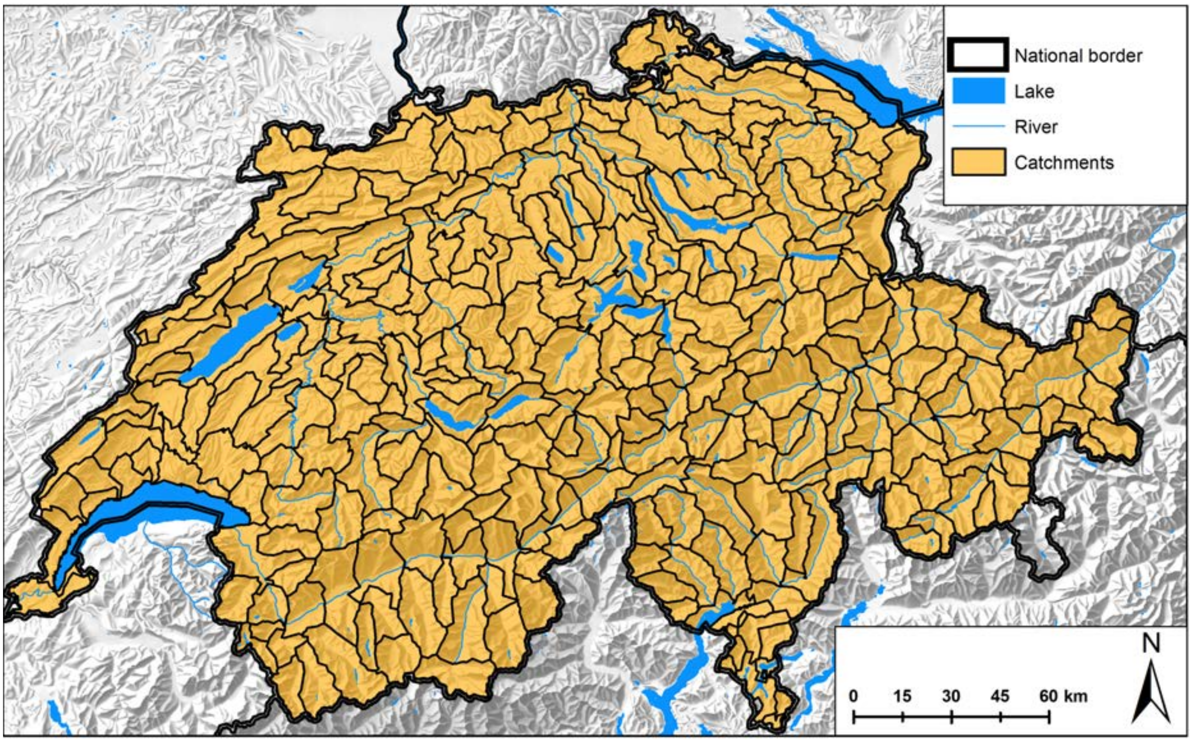

Figure 4: Study area with 307 catchments in Switzerland (Swisstopo, 2020, swisstopo.ch & WSL, 2020 , envidat.ch).

Mean annual air temperature ranges from -7.2° to 12.4° C and mean annual precipitation ranges from 575 to 2,806 mm, based on the climatological mean from 1981-2010 and point measurements (MeteoSwiss, 2020). Mean annual precipitation in most catchments, however, vary from 1,170 mm (first quartile) to 1,650 mm (third quartile). Mean annual runoff ranges from 636 mm to 1,243 mm for first and third quartile, respectively (Brunner et al., 2019). In general, higher elevated catchments are colder and wetter than lowland catchments, regarding both rain and snow.

Because of the almost full spatial coverage, these 307 catchments are representative for Switzerland in terms of climatological conditions and runoff characteristics and hence, allow to analyse spatial patterns of flood types.

2.2. Data

The *Swiss Federal Institute for Forest, Snow and Landscape Research* (WSL) performed 39 climate simulations with the *Precipitation-Runoff-Evapotranspiration HRU Model* (PREVAH), a process-based conceptual hydrological model (Viviroli et al., 2009). Some of these simulations were used in Brunner et al. (2019), which focussed on the dependence between flood peaks and flood volumes.

The PREVAH core model contains several sub-models or storage modules, representing a snow model, glacier model, interception model, a model of soil water storage and depletion by evapotranspiration, a runoff and baseflow generation model and a discharge concentration and flood routing model (Brunner et al., 2019; Viviroli et al., 2007a, 2007b, 2007c). In this work, the model uses spatial and interpolated meteorological information in daily time steps (Table 2).

Table 1: Spatial and interpolated meteorological input variables (Viviroli et al., 2007a, 2007b, 2007c)

Spatial variables	Meteorological variables	
Elevation (DEM)	Precipitation	[mm/d]
Aspect (DEM)	Air Temperature	[°C]
Slope (DEM)	Global radiation	[W/m^2]
Soil properties	Relative humidity	[%]
Land use	Sunshine duration	[%]
	Wind speed	[m/s]

The air temperature is defined into minimum, mean and maximum temperature of the day. Temperature and Global radiation are corrected for slope and aspect, using the scheme after Oke (1987) whereas precipitation is interpolated for the whole catchment using inverse variogram models (Sonderegger, 2004; Viviroli et al., 2007a, 2007b, 2007c).

Depending on the purpose of use and the time scale of the model, the calculated output variables can vary. In the dataset available for this work, 11 different variables have been stored (Table 3).

Table 2: Calculated output variables (WSL, 2020 , envidat.ch).

ETP	Potential Evapotranspiration	[mm/d]
ETR	Actual Evapotranspiration	[mm/d]
GL0	Icemelt/Snowmelt on ice	[mm/d]
GWN	Percolation into saturation zone	[mm/d]
P	Adjusted, interpolated precipitation	[mm/d]
RGS	Total Runoff	[mm/d]
SLZ	Runoff generation storage (saturated)	[mm]
SUZ	Runoff generation storage (unsaturated)	[mm]
SSM	Plant available soil moisture storage	[mm]
SSO	Snow water equivalent	[mm]
SWA	Water release from snowpack	[mm]

PREVAH additionally corrects gauging errors for the interpolated precipitation data (P), using the wind speed (Eq. 3, Viviroli et al., 2007b)

$$PR_{korr} = PR_{act} * [1 + 0.07 * \ln(v_W + 1)]$$
$$PS_{korr} = PS_{act} * [1 + 0.20 * \ln(v_W + 1)] \quad (3)$$

Where PR_{act}, PS_{act} gauged amount of rain and snow [mm/d]

PR_{korr}, PS_{korr} corrected amount of rain and snow [mm/d]

v_W wind speed [m/s]

Table 3: Considered 39 Climate Model chains in this study: RCM, GCM, Resolution and RCP. Coloured by RCPs: Green = RCP 2.6, Yellow = RCP 4.5, Blue = RCP 8.5

Chain number	GCM	RCM	Resolution	RCP
1	HADGEM	CLMCON-CCLM4	EUR44	8.5
2	ECEARTH	CLMCON-CCLM5	EUR44	8.5
3	HADGEM	CLMCON-CCLM5	EUR44	8.5
4	MIROC	CLMCON-CCLM5	EUR44	8.5
5	MPIESM	CLMCON-CCLM5	EUR44	8.5
6	ECEARTH	DMI-HIRHAM	EUR11	2.6
7	ECEARTH	DMI-HIRHAM	EUR11	4.5
8	ECEARTH	DMI-HIRHAM	EUR11	8.5
9	ECEARTH	DMI-HIRHAM	EUR44	4.5
10	ECEARTH	DMI-HIRHAM	EUR44	8.5
11	ECEARTH	KNMI-RACMO	EUR44	4.5
12	ECEARTH	KNMI-RACMO	EUR44	8.5
13	ECEARTH	KNMI-RACMO	EUR44	2.6
14	ECEARTH	KNMI-RACMO	EUR44	4.5
15	ECEARTH	KNMI-RACMO	EUR44	8.5
16	CCMA	SMHI-RCA	EUR44	4.5
17	CCMA	SMHI-RCA	EUR44	8.5
18	ECEARTH	SMHI-RCA	EUR11	2.6
19	ECEARTH	SMHI-RCA	EUR11	4.5
20	ECEARTH	SMHI-RCA	EUR11	8.5
21	ECEARTH	SMHI-RCA	EUR44	2.6
22	ECEARTH	SMHI-RCA	EUR44	4.5
23	ECEARTH	SMHI-RCA	EUR44	8.5
24	HADGEM	SMHI-RCA	EUR11	4.5
25	HADGEM	SMHI-RCA	EUR11	8.5
26	HADGEM	SMHI-RCA	EUR44	2.6
27	HADGEM	SMHI-RCA	EUR44	4.5
28	HADGEM	SMHI-RCA	EUR44	8.5
29	MIROC	SMHI-RCA	EUR44	2.6
30	MIROC	SMHI-RCA	EUR44	4.5
31	MIROC	SMHI-RCA	EUR44	8.5
32	MPIESM	SMHI-RCA	EUR11	4.5
33	MPIESM	SMHI-RCA	EUR11	8.5
34	MPIESM	SMHI-RCA	EUR44	2.6
35	MPIESM	SMHI-RCA	EUR44	4.5
36	MPIESM	SMHI-RCA	EUR44	8.5
37	NORESM	SMHI-RCA	EUR44	2.6
38	NORESM	SMHI-RCA	EUR44	4.5
39	NORESM	SMHI-RCA	EUR44	8.5

As mentioned before, simulations have been performed for 39 climate scenarios, derived from CH2018 using quantile mapping for both reference (1981-2017) and future climate scenarios (2018-2099) (Brunner et al., 2019). These scenarios are based on specific GCM-RCM-chains, which are performed for different RCPs. Table 3 shows the chains used for this work: 8 RCP 2.6 chains, 13 RCP 4.5 chains and 18 RCP 8.0 chains. None of the 39 simulations in the EURO-CORDEX framework, used in this work, takes RCP 6.0 into account. Additionally, a control simulation with data from interpolated measurements is available. This simulation is used for validation.

Meteorological input variables in the GCM-RCM-chains have a resolution of 0.44° and 0.11° (~50 x 50km and ~12.5 x 12.5 km, respectively). However, these variables are downscaled to a refined 2 x 2 km grid, using quantile mapping (CH2018, 2018). Furthermore, during the model run, this resolution is further refined to the computational grid of 500 x 500 m, using bilinear interpolation for each of the 307 catchments (Brunner et al., 2019). The calculated daily total runoff (RGS, see Table 3) is used as an input for the flood type estimation, using a flood decision tree (see section 2.3.3).

2.3. Flood type estimation method

The flood type method has 4 main steps: Flood type classification, event separation, flood type indices and signatures definition, and flood tree application.

2.3.1. Flood type classification

This work uses six different flood types, specified in Sikorska-Senoner & Seibert (2020). These flood types are the most relevant for catchments in the Alps, for both lowland and high-altitude areas:

1. Flash floods (FF): Induced by short intensive rainfalls, usually lasting less than 12 hours, and locally exceeding the infiltration capacity. Occurring mostly during the storm season (May-September) and limited to small catchments.
2. Short-rainfall floods (SRF): Occurring due to short rainfall, usually with maximum duration of one day and a high intensity, exceeding the infiltration capacity. Can happen in all seasons and in catchments of all sizes.
3. Long-rainfall floods (LRF): Caused by long lasting rainfall events of several days or weeks, usually of low to medium intensity, slowly filling the storage capacity. Usually, several regional catchments are affected and LRF can occur during the whole year.
4. Rain-on-snow floods (RoSF): Initiated by rainfall on existing snow (or ice) cover, which leads to melting. This can happen during the whole year; however, it is limited to the availability of snow cover.
5. Snowmelt floods (SMF): Caused by melting snow cover, initiated by an increase in air temperature, with insignificant rainfall amounts. It can occur during the whole year, however in lowland catchments it is common at the end of winter or beginning of spring, while in mountainous areas it is mainly during spring and summer months, due to delayed snow melting in high altitudes.

6. Glacier melt floods (GMF): Caused by glacier melting due to an increase in air temperature, with insignificant rainfall amounts. Only possible in (partly) glaciated catchments and occurring during the summer months.

2.3.2. Event separation

For each selected flood event, one of these six flood types is assigned by applying a modified flood decision tree from Sikorska-Senoner & Seibert (2020). Flood events are selected in the simulated runoff series from the PREVAH model, similar to Brunner et al. (2019), applying a peak-over-threshold approach (Lang et al., 1999)

In a first step, simulated runoff measurements higher than the 98th percentile of the discharge are selected. This threshold is selected to cover extreme flood events for each catchment. Next, the start and end of each event are defined as points where the runoff first increases above and then decreases again bellow 0.4 times of the peak runoff per event, respectively. According to Brunner et al. (2019), this factor is considered to be suitable for extreme flood events in the Alps. Froidevaux et al. (2015) found that only precipitation up to four days before the peak runoff contributes to the flood event, and after four days the runoff returns to normal conditions. Hence, start and end of each flood event is limited to 4 days before and after the peak flow, respectively.

2.3.3. Flood type indices and signatures

Each flood type has specific event characteristics, which result from the interaction of different factors. They are defined as *flood indices* and can be static or dynamic. Static indices remain constant during the entire observation period. Typical examples are catchment area, land-use or topography.

Table 4: Flood type signatures used in Sikorska-Senoner & Seibert (2020).

ID	Index (unit)	FF	SRF	LRF	RoSF	SMF	GMF
T_d	Timing (month and day)	0501-0930	0101-1231	0101-1231	0101-1231	0101-1231	0501-0930
P	Precipitation total amount (mm/d)			≥ 12	≥ 12	< 12	< 12
I	Precipitation intensity(mm/h)	≥ 7.6					
D	Precipitation duration (days)	<0.5	<1	> 1			
SM	Snowmelt total amount (mm/d)				≥ 1	≥ 1	≥ 1
SC	Areal Percentage Snow cover (%)				≥ 5	≥ 5	
GC	Areal Percentage Glacier cover (%)						≥ 5
Ac	Catchment area (km^2)	< 200					

Dynamic indices may change for each flood event but are assumed to be similar for one particular flood type. These include meteorological conditions, such as precipitation amount or precipitation duration, the timing of the year or present snow cover. However, it is unlikely that only one index determines one specific flood type (Merz & Blöschl, 2003; Merz et al., 2006). To identify a certain flood type, a combination of flood indices is used. Therefore, each flood type has a unique combination of flood indices, called *flood type signature*. Table 4 shows flood type signatures used in Sikorska- Senoner & Seibert (2020). Hourly precipitation data have been derived from gauging stations, whereas snowmelt and snow cover have been computed with precipitation and temperature data in the HBV model.

Table 5: Typical flood type signatures of six major flood types and their thresholds, modified from Sikorska-Senoner & Seibert (2020); Yellow boxes represent the modification introduced in this work of the certain indices

	ID	Index	FF	SRF	LRF	RoSF	SMF	GMF
Dynamic	T_d	Timing [a] (day of year**)	0501-0930	0101-1231	0101-1231	0101-1231	0101-1231	0501-0930
	P	Precipitation total amount [a] (mm/d)			≥ 12	≥ 12	< 12	< 12
	M_P	Min. precipitation amount [b] (mm/d)	≥ 14					
	D	Precipitation duration [a] (days)	1	1	> 1			
	SM	Snowmelt total amount [a] (mm/d)				≥ 1	≥ 1	≥ 1
	SC	Snow cover [c] (mm water equivalent)				≥ 15	≥ 15	
	GC	Areal Percentage Glacier cover [a] (%)						≥ 5
Static	Ac	Catchment area [a] (km^2)	< 150					

Thresholds according to

[a] Diezig & Weingartner(2007),Geiger et al. (1991) , Sikorska et al. (2015), Sikorska & Seibert (2018), Sikorska-Senoner & Seibert (2020)

[b] Sikorska-Senoner & Seibert (2020), derived from the Intensity-threshold ("I"; 7.6mm/h, Grebner, 1990))

[c] Kirkham et al. (2019)

** Day of year is expressed in mmdd format, where 0101 is January 1st, and 1231 December 31st.

Compared to Sikorska-Senoner & Seibert (2020), not all signatures have been equally adopted. For instance, the index *precipitation intensity* (I) (see Table 1), which is solely used to distinguish between FF and SRF, has been removed and replaced with a new index *minimum precipitation amount* (M_P). The reason for this is due to the fact that given dataset has daily precipitation outputs, whereas precipitation intensity is scaled hourly (mm/h) in Sikorska-Senoner & Seibert (2020). The new index has been

calculated by reanalysing the data on flood events used in Sikorska-Senoner & Seibert (2020). For each flood type classified as FF their dataset, the total precipitation amount per FF-event has been derived and the mean of all FF-events calculated. The value of this new mean is 15mm, which corresponds to literature values for intense thunderstorms, that are used by national weather services (DWD, 2020).
The *Precipitation duration* (D) threshold is dictated by the data timescale too and hence, can only be represented daily. As a result, FF and SRF are assumed to last exactly one day, although in reality they may last only a few hours. Additionally, the duration of LRF events is at least two days, for the same reason.
The Snow cover (SC) threshold has the snow water equivalent (SWE) as a unit, instead of the areal percentage. Kirkham et al. (2019) found that discontinuous snow cover has SWE values between 15 and 50 mm w.e. (water equivalent) This work uses a 15 mm w.e. as a threshold.

In contrast to Sikorska-Senoner & Seibert (2020), *areal percentage glacier cover* (GC) is considered to be a dynamic flood type signature. The glacier inventory from *Swisstopo* of the year 1973 serves as a reference for this work. In this work, the observation period ranges from 1981-2100. Consequently, between 1973 and 2017, areal glacier loss is determined by past measurements used in different studies (Zekollari et al., 2019, Table 6). For future glacier evolutions, the relative change in area has been calculated for the years 2050 and 2100, distinguished to the respective RCPs (Table 7).

Table 6: Measured and partly modelled average glacier area loss for Switzerland from 1973 to 2017 (Zekollari et al., 2019)

	Years			
	1973	1981	1999	2017
Glacier area loss (relative to 1973)	0.0%	-6.8%	-22.1%	-30.9%

Table 7: Projected glacier area loss from 2017 to 2100 and their uncertainty, summarized by RCPs (Zekollari et al., 2019)

	Years		
	2017	2050	2100
Glacier area loss RCP 2.6 (relative to 2017)	0.0%	-43.9% (±9.7%)	-62.1% (±8.4%)
Glacier area loss RCP 4.5 (relative to 2017)	0.0%	-45.6% (±8.0%)	-74.9% (±8.3%)
Glacier area loss RCP 8.5 (relative to 2017)	0.0%	-48.8% (±9.2%)	-91.1% (±5.4%)

The limitation of this approach is that the glacier area loss rate is equal for all glaciers in Switzerland. Furthermore, the loss rate is assumed to be constant between the years listed above and hence, a linear interpolation between the years has been performed for this purpose, for both past and future periods.

2.3.4. Flood tree application

A flood tree concept is used to determine the flood types of selected flood events, using the modified signatures introduced in the previous section. Each selected flood event is taken as input and analysed for its similarity. The tree consists of branches with sequential nodes, representing the flood type signatures, and ends up in leaves, representing one of the six flood types. At each node, the branch divides into two new branches, according to the respective threshold value of the flood signature. Hence, the flood tree "selects" only one branch at each node (Sikorska-Senoner & Seibert, 2020; Sikorska et al., 2015)

This work uses two different approaches to apply the flood tree concept – crisp approach and fuzzy approach.

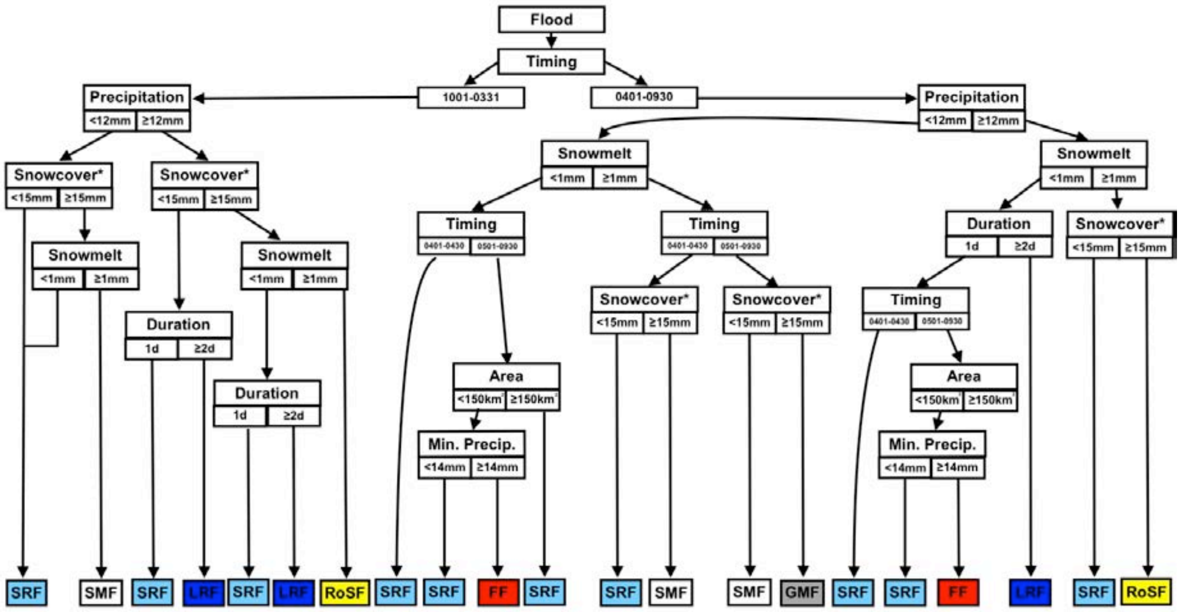

Figure 5: Modified tree from Sikorska-Senoner & Seibert (2020), as used in this work.
** Snow cover in mm water equivalent (mm w.e.)*

The *crisp approach* only allows one dominant flood type per flood event. For instance, when the value of each signature is equal or higher than the threshold, the *degree of acceptance* equals 1, and all other branches are rejected. As a result, mixed flood types are not possible in this approach. Furthermore, since the thresholds are sharp, the choice of them make it prone to errors in border cases.

On the other hand, the *fuzzy approach* tries to overcome these problems (Pradhan, 2013; Rao & Srinivas, 2006; Sikorska et al., 2015). For each threshold, at each signature (node), a likelihood of 0.5 is assigned if the simulated value is equal to the threshold value (T_H). This means that the flood tree can follow multiple branches, possibly resulting in mixed flood type events. Additionally, for each threshold value, a certain range is assigned ($T_H \pm X$), where the lower and upper boundaries for X correspond to 20% of the threshold value. Therefore, the degree of acceptance equals 0 and 1 for the lower and higher boundary, respectively. Values below and above the fuzzy range are also set to 0 and 1, respectively and for all values between these boundaries, a linear interpolation is applied. As a result, the fuzzy tree approach can include both mixed and dominant flood type events (Sikorska et al., 2015). However, the fuzzy tree approach is limited for this work, especially regarding precipitation duration. In Sikorska-Senoner & Seibert (2020), a fuzzy range of 6 hours is defined for the precipitation duration. However, since the data from WSL is scaled in 24-hour-steps, it would always assume a likelihood of 0.5, when the duration is 24 hours. This would then always give a likelihood of 0.5 between LRF and/or SRF and FF events. Hence, for the precipitation duration no fuzzy range is applied.

Detailed differences between crisp and fuzzy tree approach are not the aim of this work and the results only indicate the percentage of mixed events.

2.3.5. Spatial and seasonal pattern and intensity

The spatial pattern is shown as a map for each flood type, for the reference period. Additionally, catchments are summarised in lowland (<1000 m.a.s.l) medium-altitude (1000-1500m.a.s.l.) and high-altitude (>1500m.a.s.l.) catchments. The seasonal pattern as analysed for each altitude group.

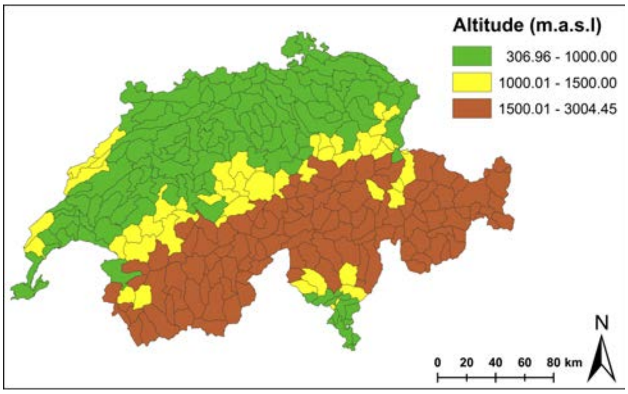

Figure 6: Altitude groups

For both future periods, differences in the spatial pattern and seasonal are shown with respect to the reference period, instead of absolute numbers.

Mean precipitation, mean snowmelt, and mean daily maximum runoff are considered event characteristics, that describe the intensity of an event (Brunner et al., 2019). These three variables are calculated for each flood-type. For the reference period, absolute numbers are used, while for both periods the differences are shown with respect to the reference period.

2.4. Validation and correlation analysis

The results are validated by using the control simulation, which includes interpolated data from measurements. The frequency and spatial pattern of all three simulation groups (RCP 2.6, 4.5 and 8.0) are therefore compared with the control simulations, to estimate to what extent they deviate during the reference period. In a next step, a correlation analysis of the frequency and meteorological and catchments variables is performed (mean annual temperature, mean annual precipitation and mean annual snowmelt).

For both future periods, mean frequency and mean intensity per RCP chain is compared with the mean frequency and intensity of the respective RCP chain during the reference period, instead of the control simulation. Furthermore, changes in mean frequency are compared to mean changes of mean temperature, mean precipitation and mean snowmelt.

3. Results

3.1. Reference period (1981-2017)

3.1.1. Control simulation – Frequency and spatial pattern

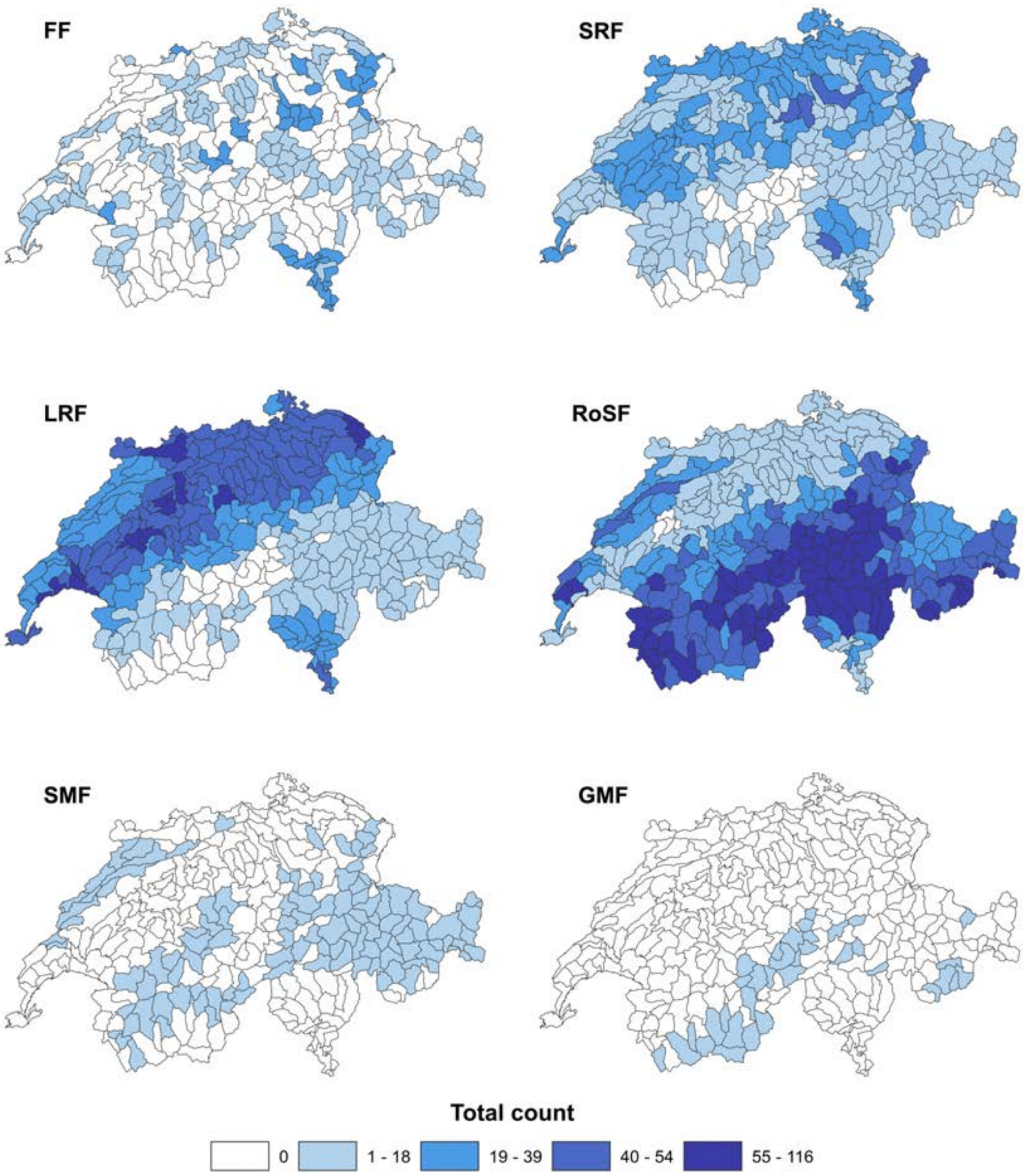

Figure 7: The maps shows the total number of each flood type in the 307 catchments for the period from 1981 to 2017. The control simulation and the crisp tree approach have been used.

In Figure 7, the total count and spatial distribution of the six different flood types of the control simulation during the control period (1981-2017), derived from the crisp tree approach, is illustrated. Since FF events are limited to smaller catchments (<150km^2), these events per definition do not occur in larger catchments at all. Consequently, in larger catchments, more events are classified as SRF events than in smaller catchments, which is visible in the maps.

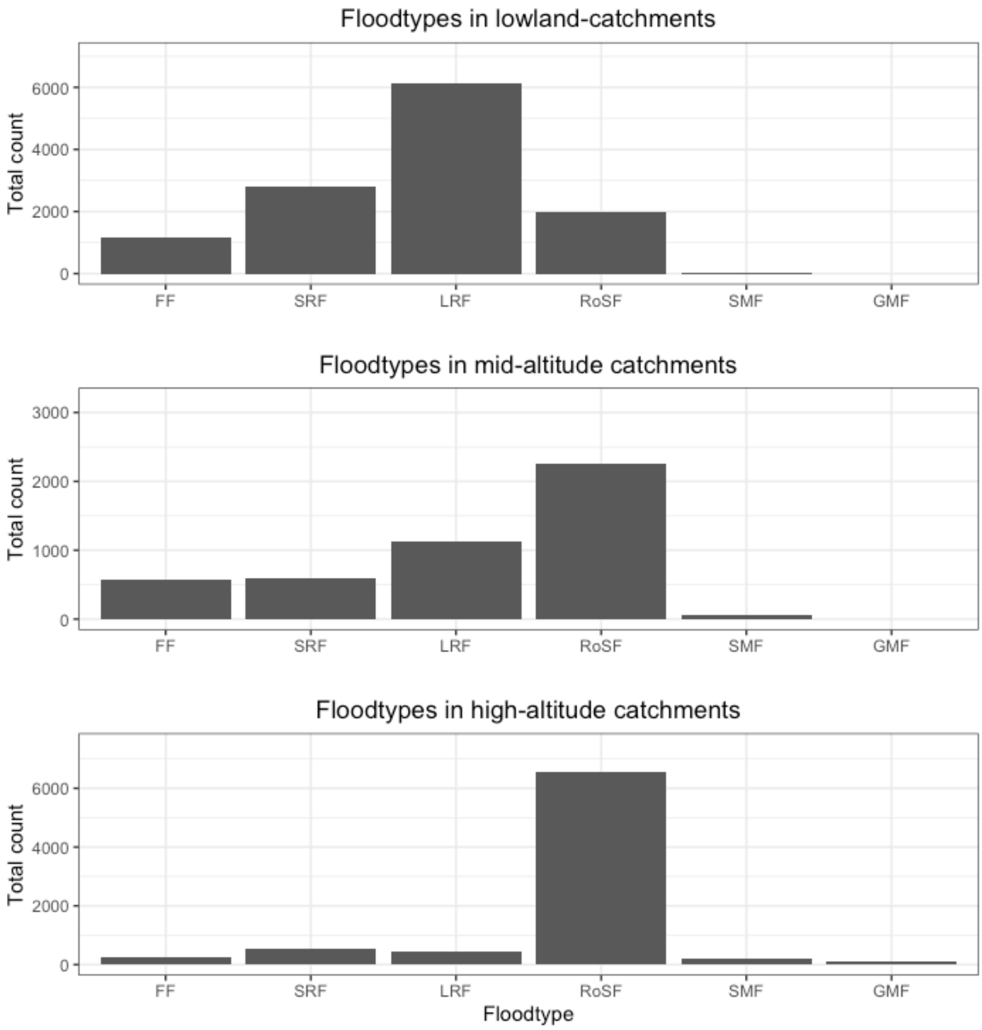

Figure 8: Total count of all flood types, summarised by catchment groups (crisp tree)

Nevertheless, the total count[1] of both FF and SRF events is higher in lowland and medium-altitude catchments, with peaks in the Central and Eastern Prealps and the Canton of Ticino. The high inner alpine catchments have a much lower total count, with some catchments not having a single FF and SRF event at all, not even in small catchments.

The lowland catchments in the Swiss Plateau have the most considerable frequency of LRF events, as well as the southernmost catchments in the Canton of Ticino. In these catchments, LRF events have the highest total frequency, compared to other flood types (Figure 8). The more the catchment is situated towards the higher-elevated alpine regions, the less LRF events are identified. Similar to FF and SRF events, some high-altitude catchments have no LRF events identified at all. Most of the flood events in high-altitude catchments are RoSF events, while in lowland catchments RoSF events are less common. Lowland catchments in the Jura region are an exception, where RoSF events are more common compared to other lowland catchments. However, these catchments are located at higher mean elevations those on the Swiss

[1] In this work, the terms "(mean) total count", "(mean) frequency" and "(mean) number of events describe the same thing

Plateau. In medium-altitude catchments, most of the flood events have been identified as RoSF. However, compared to high-altitude catchments, more events have been classified as FF, SRF or LRF events.

It is interesting that, regardless of the catchment's mean altitude, only very few SMF events have been identified. This means that floods caused exclusively by snowmelt only are rare. A combination of (heavy) rainfall and snowmelt, which leads to RoSF events, seems to occur more often. Similarly, the amount of floods caused by glacier melt only (GMF) is considerably low, in glaciated catchments

3.1.2. Control simulation – Seasonal pattern

The seasonal pattern of flood events is quite different depending on the catchment altitude (Figure 9 and appendix Table 15). This also applies to the number of mixed events when using the fuzzy approach. Here, the results of the crisp tree applications are used to describe the seasonal pattern. The results of the fuzzy tree are used as a comparison only. The spring season includes March, April and May, summer includes June, July and August, autumn includes September, October, November and the winter season December, January and February.

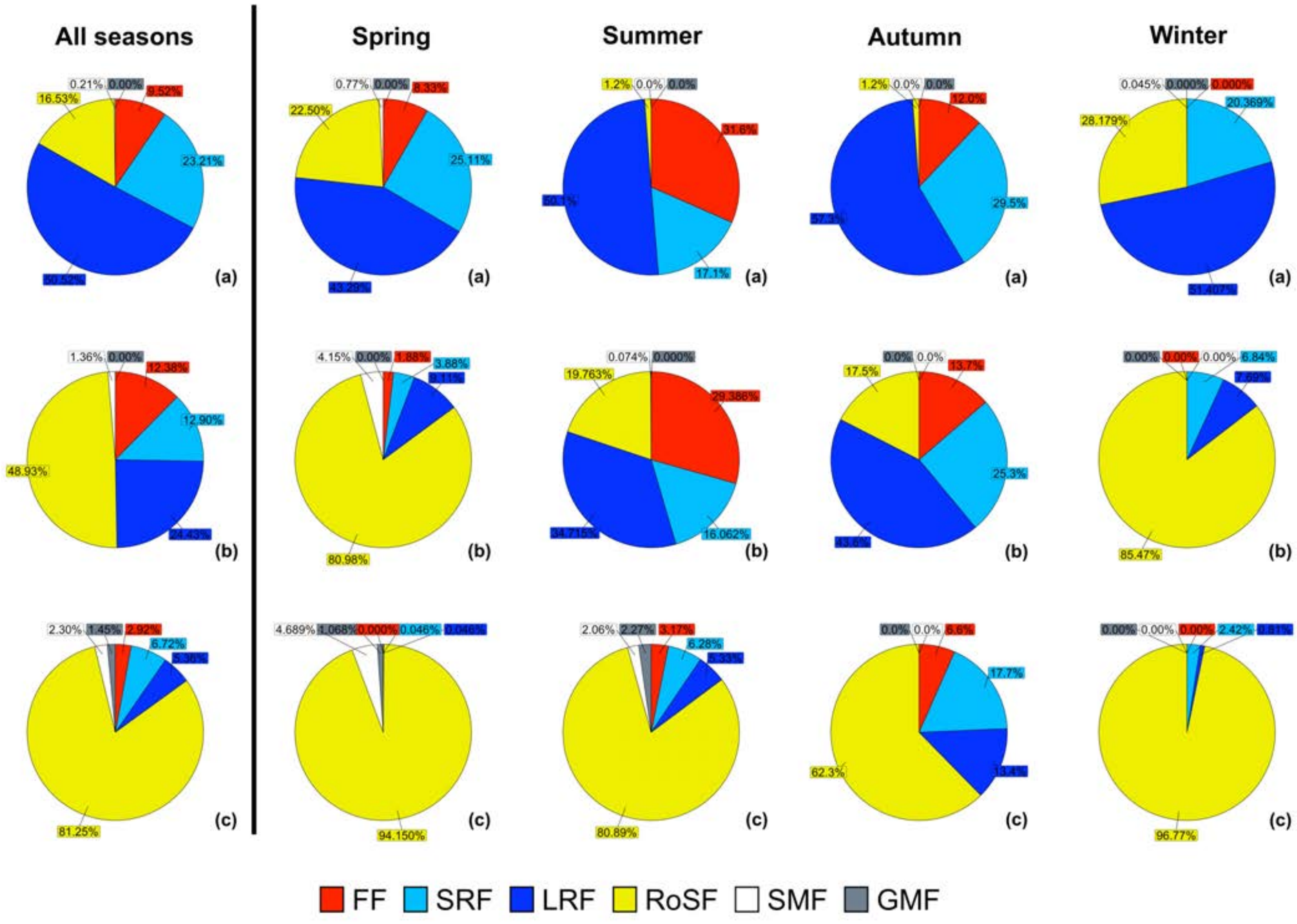

Figure 9: Seasonal distribution of the different flood types for spring, summer, autumn and winter. The numbers of the crisp tree are used

In lowland catchments, LRF events dominate during the spring months (43.3%) followed by SRF events (25.1%) and RoSF events (22.5%). During the summer months, FF and SRF events account for 48.7% of the events (31.6% and 17.1%, respectively), while most other events are identified as LRF (50.1%). In autumn the pattern again has LRF as the most identified flood type (57.3%), followed by SRF (29.5%) and FF (12%). RoSF events are almost absent during both summer and autumn seasons. It is during the winter months when RoSF events are most likely to occur in lowland catchments (28.2%). However, LRF events are also dominant during winter (51.4%). SMF events are a highly uncommon occurrence in all seasons. Only 0.2% events are identified as SMF, most of them during the spring months, using crisp tree approach. Differences between the crisp tree and fuzzy tree are small, with only 7.28% of all identified events over all catchments being mixed. In spring and winter, most mixed events are identified (8.51% and 8.26%, respectively), whereas in summer and autumn single type flood types are more common.

The pattern in the mid-altitude catchments is different. During the spring months, 1209 of 1493 (about 81%) of the identified events are classified as RoSF events. In summer and autumn, FF, SRF and LRF are the most identified flood events, whereas RoSF events are slightly less frequent. In winter, the pattern is similar to the one during spring. However, the total frequency during winter is smaller than during the spring months. SMF events have a rare occurrence in mid-altitude catchments as well (63 out of 4629 events).

In mid-altitude catchments, mixed events are more likely to occur during the autumn months, when using the fuzzy tree approach (17.08%), whereas in spring months only 5.73% of all spring events are classified as mixed. Over all seasons, 9.97% of all events are identified being mixed.

High-altitude catchments are throughout dominated by RoSF events over all seasons (81.25%). Most of the RoSF events occur during spring and summer. During this period, 5444 out of 6553 RoSF are identified, using the crisp tree, which is about 83.07% of all RoSF events in these catchments. Some FF, SRF and LRF events occur during the summer and autumn months. However, their frequency is far below compared to the ones for mid-altitude and lowland catchments. A considerable amount of snowmelt floods is identified during the spring months and summer months. In glaciated areas, GMF events most likely occur during the summer months, but some of them occur during (late) spring months as well.

Applying the fuzzy tree approach, on high-altitude catchments mixed events are most likely to occur during the autumn. 31.48% of all events during the autumn are identified as mixed events. On the other hand, during the spring months, only 2.81% are mixed events. Over all seasons, 11.48% of all flood events are of mixed origin. Most mixed events are a mixture of LRF, RoSF and SMF events. Additionally, in glaciated catchments, a mixture of GMF and SMF is typical as well.

It can be misleading to only consider the absolute number of flood events in order to see the differences between crisp tree and fuzzy tree since it might even out. A detailed evaluation of individual catchments is therefore essential to estimate the relative contribution of each flood type.

For this purpose, three example catchments are chosen, and all flood events are drawn on a graph, showing either the dominant flood type (crisp tree, Figure 11) or the degree of acceptance of each flood event (fuzzy tree, Figure 12). This example is only shown for the control simulation, to illustrate the differences between the crisp tree and fuzzy tree approach.

Figure 10: Location of the three example catchments

The lowland catchment is situated in the Canton of Aargau (Figure 10), with a mean annual temperature of 9.6°C, mean annual precipitation 1114.1mm and mean annual snowmelt 69.9mm. The mean catchment altitude is 442.8m.a.s.l and the catchment area 69.1km^2. In the western Pre-Alps near the Lake of Geneva, the is the medium altitude catchment with a mean altitude of 1031.4m.a.s.l and a catchment area of 129.7km^2. The mean annual temperature is 7.0°C, and a mean annual precipitation snowmelt of 1637.6mm and 236.1mm, respectively. The catchment in the high-altitude is situated in the inner alpine region of Canton Graubünden. Its mean altitude is 2166.0m.a.s.l with a catchment area of 86.4km^2. Mean annual temperature is considerably low with only 1.4°C and mean precipitation and snowmelt of 1908.5mm and

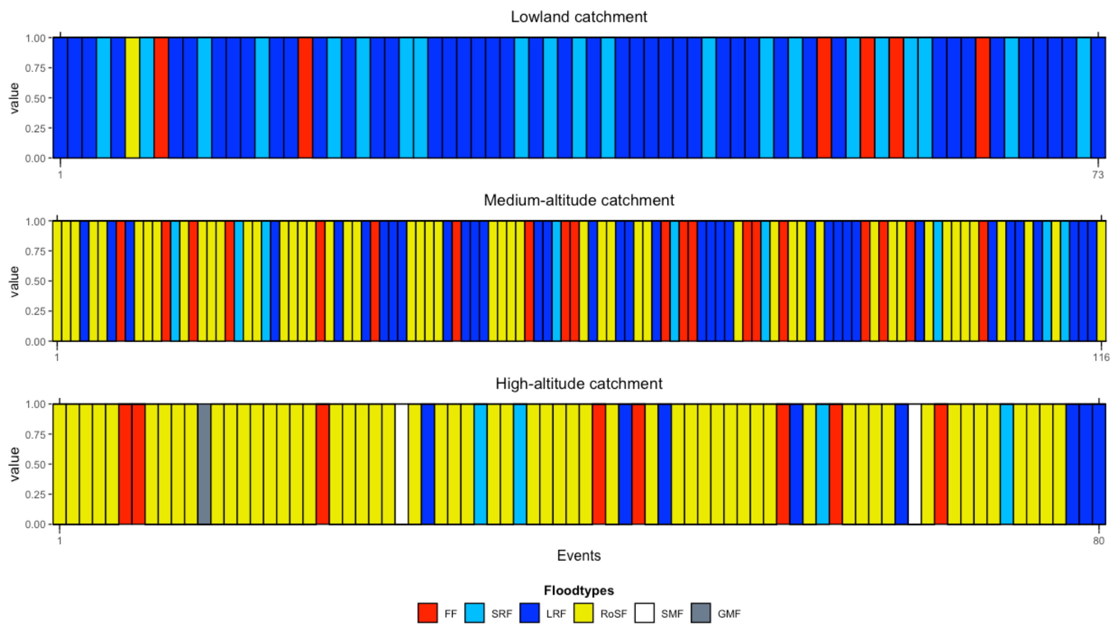

Figure 11: Distribution of flood events for three example catchments, using the crisp tree. On the x-axis the events are ordered in chronological order, while the y-axis represents the degree of acceptance of respective flood types per event (which is always 1 in the case of the crisp tree). Each bar represents one flood event. In all of the three catchments, FF events are possible, as well as GMF events in the high-altitude catchment.

760.1mm, respectively. These values already indicate that with increasing altitude, snow processes play an important role. A list for each catchment is given in the Appendix.

Figure 11 shows the distribution of flood events for three different catchments of each altitude group, using the crisp tree. It can be seen that LRF events dominate in the lowland catchments and RoSF events in the high-altitude catchments. The medium-altitude catchment shows a variety of different flood types, although RoSF events occur most frequently. The same catchments are shown in Figure 12, using the fuzzy tree approach. Only one event is identified as a mixed event for the lowland catchment, and only a few events are mixed in medium- and high-altitude catchments. Most mixed events are between rainfall-related and snow-related events (LRF and RoSF, SRF/FF and RoSF). Hence, most events are identified as one dominant flood type.

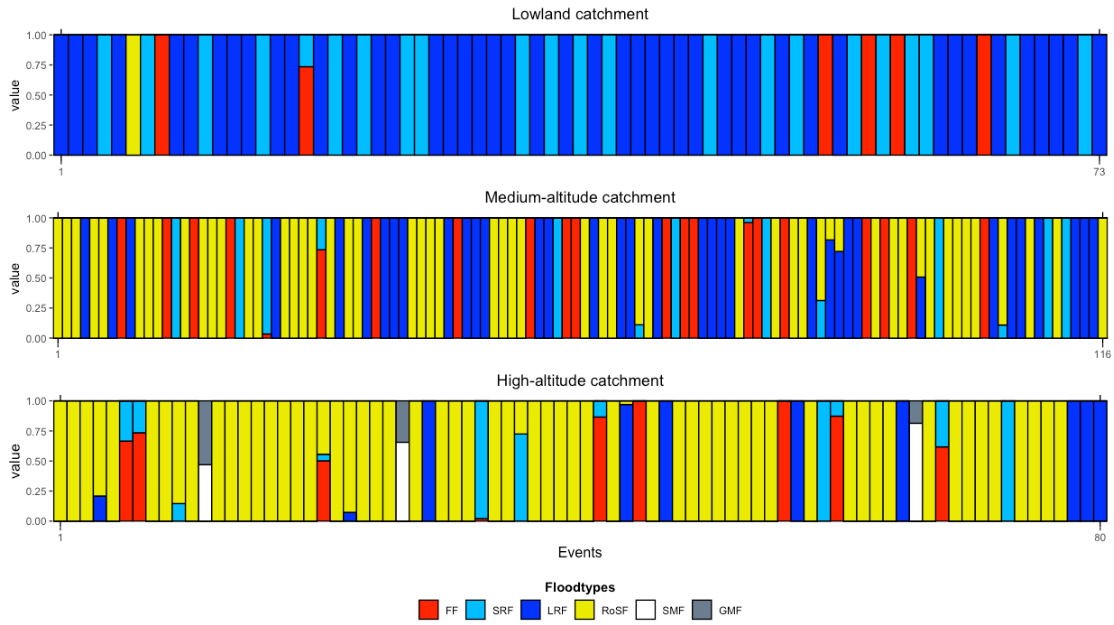

Figure 12: Distribution of flood events for three example catchments, using the fuzzy tree. On the x-axis the events are ordered in chronological order, while the y-axis represents the degree of acceptance of respective flood types per event. Each bar represents one flood event. In all of the three catchments, FF events are possible, as well as GMF events in the high-altitude catchment.

3.1.3. Control simulation – Intensity of Events

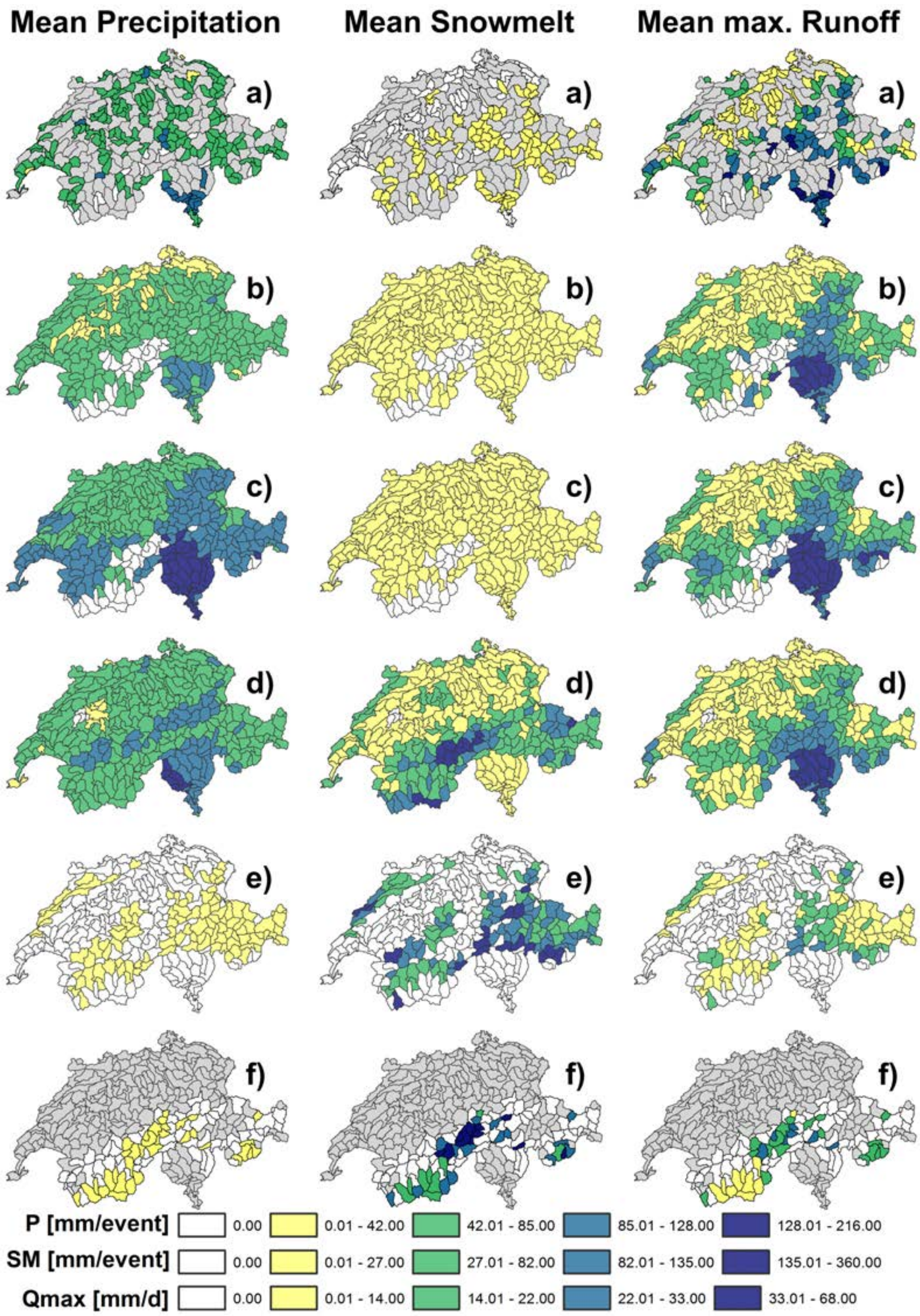

Figure 13: Mean precipitation, mean snowmelt and mean maximum daily runoff for each flood event. a = FF, b =SRF, c = LRF, d = RoSF, e = SMF, f = GMF

Mean precipitation (P), mean snowmelt (SM), and maximum daily runoff (q_{max}) of all events for each flood type have been calculated to describe the mean intensity of the respective flood types for each catchment (Figure 13). Only the crisp tree approach is used for this purpose. Mean and maximum values as well as standard deviation is given in Table 8.

The mean value for P of all events for each flood type is lowest for SMF and GMF events with 6.1mm/event and 7.1mm/event, respectively, while the highest mean value is identified for LRF and RoSF events – 86.4mm/event and 73.2mm/event, respectively. The maximum value of P shows almost a similar pattern, with SMF and GMF being in reverse order compared to the mean. Standard deviation ranges from 2.1mm/event (GMF) to 23.0mm/event (LRF).

The highest precipitation amounts of all events for each flood types are recorded in the southern alpine, the central and eastern pre-alpine catchments, regarding FF, SRF, LRF and RoSF events. SMF and GMF events consequently have low precipitation amounts, as for these events the flood tree does not allow precipitation amounts higher than 12mm.

The (almost) opposite spatial distribution can be observed by looking at SM. FF, SRF and LRF events have low mean values, whereas RoSF, SMF and GMF events have higher mean values. Generally, the higher elevated alpine catchments tend to have the highest snowmelt amounts of flood events for each flood type. Mean values for SM for all flood types range from 0.2mm/event (FF) to 147.0mm/event (GMF), while the maximum values range from 1.0mm/event (FF) to 359.7mm/event (SMF). The standard deviation is low for non-snowmelt flood types (FF, SRF and LRF), while for RoSF, SMF and GMF the standard deviation ranges between 42.3mm/event 50.7mm/event.

Over all catchments, the mean value for q_{max} of all events for each flood types is the highest for FF (19.1mm/d) and lowest for SMF events (13.5mm/d). The maximum value of q_{max} is the highest for FF (63.8mm/d) and lowest for GMF events (32.8mm). The standard deviation ranges from 5.1mm/d (SMF) to 9.6mm/d (LRF). In general, catchments on the southern side of the Alps have a higher q_{max} value than catchments on the northern side. These catchments usually also have a higher precipitation totals than others.

Table 8: Mean, maximum and standard deviation for mean precipitation, mean snowmelt and mean maximum daily runoff, divided by all flood types.

	Variable	Mean	Max	St.dev		Variable	Mean	Max	St.dev
FF	P [mm]	65.38	110.73	14.33	RoSF	P [mm]	73.02	162.75	20.71
	SM [mm]	0.15	0.99	0.22		SM [mm]	45.11	242.18	42.25
	Max Q [mm]	19.07	63.80	9.3		Max Q [mm]	17.28	46.82	7.95
SRF	P [mm]	55.92	93.45	14.28	SMF	P [mm]	6.07	11.74	2.91
	SM [mm]	2.28	13.80	2.21		SM [mm]	94.27	359.68	45.36
	Max Q [mm]	17.38	53.52	8.45		Max Q [mm]	13.51	40.62	5.06
LRF	P [mm]	86.44	170.85	22.95	GMF	P [mm]	7.06	10.64	2.06
	SM [mm]	2.62	7.78	1.58		SM [mm]	147.01	334.84	50.67
	Max Q [mm]	16.72	53.02	9.55		Max Q [mm]	17.53	32.83	5.2

3.1.4. Control simulation – Meteorological and catchment variables and their correlation with frequency

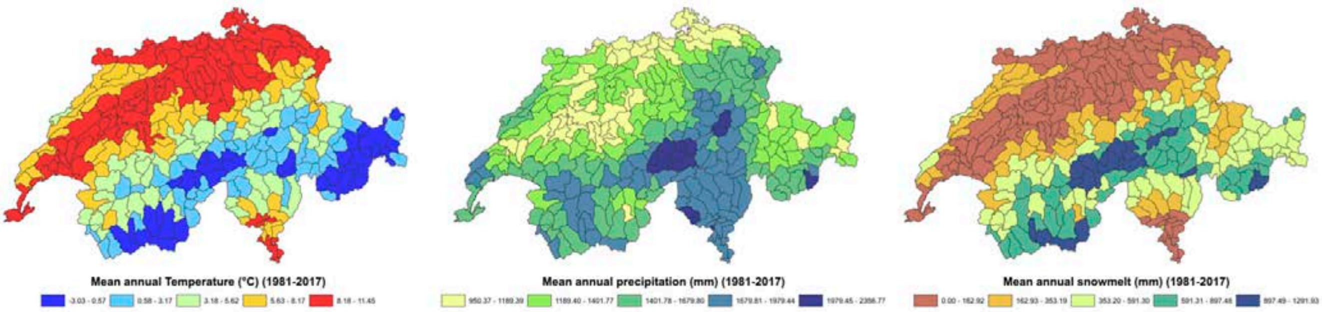

Figure 14: Mean annual temperature, mean annual precipitation and mean annual snowmelt between 1981-2017, according to the control simulation

Figure 14 illustrates the annual means of the mean temperature, precipitation and snowmelt between 1981 and 2017. The mean annual temperature ranges from -3.0°C to 11.5°C, with lowland catchments in the Swiss Plateau being the warmest, and high-altitude catchments in south-western, central and eastern Alps the coldest. Mean annual precipitation is high in the central Alps, Canton of Ticino, and in western Switzerland, and lower in the Swiss Plateau. Values range from 950.4mm/year to 2356.8mm/year. Mean annual snowmelt is distributed similar to the mean annual temperature, with the highest values in the central Alps. Snowmelt amounts range from 0.0mm/year to 1291.9mm/year.

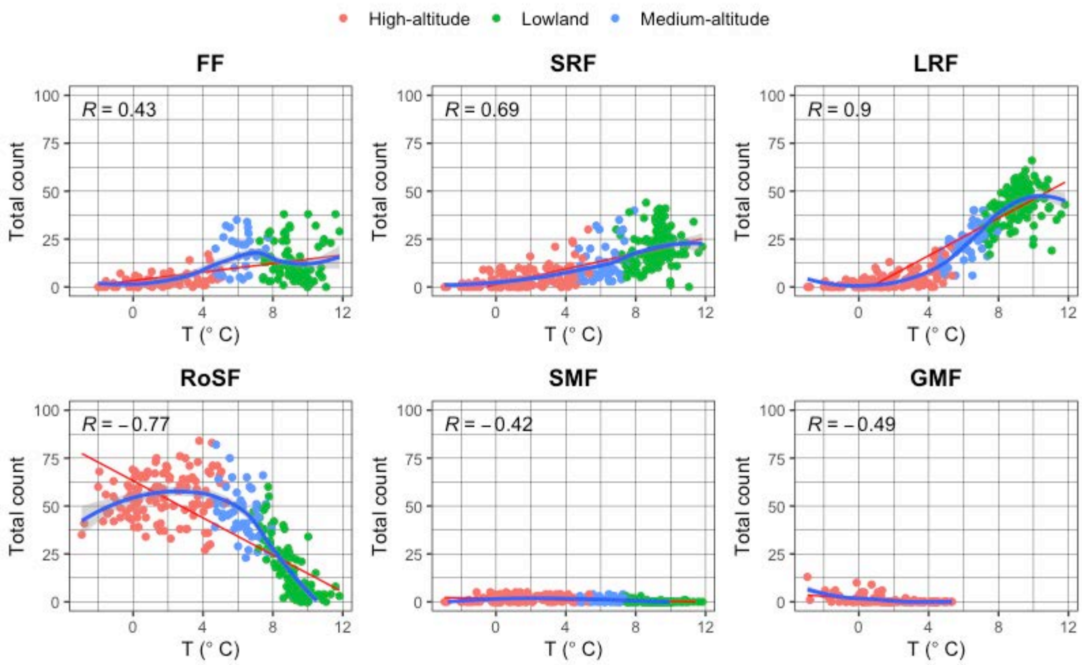

Figure 15: Mean annual temperature compared to the total count of six different flood types, coloured by altitude group. The red line represents the linear approximation, and the blue line the local regression curve. Note that catchments >150km^2 and unglaciated catchments are excluded for FF and GMF events, respectively.

In general, flood types which are not influenced by snowmelt (FF, SRF and LRF) show a partly linear correlation with the mean annual temperature (Pearson's R of 0.43, 0.69 and 0.9, respectively, see Figure 15). A higher mean temperature in average usually means a higher presence of FF, SRF and LRF events. RoSF events are negatively correlated (Pearson's R of -0.77) to the mean annual temperature. Compared to solely rainfall-related events, the local regression curve stagnates for temperature values bellow 4.0°C. This means that below this temperature, the frequency is not necessarily negatively correlated and follows a more arbitrary pattern. Although Pearson's R values for SMF and GMF events are negatively correlated (-0.42 and -0.49, respectively), in reality, their amounts are too low to speak of a significant correlation.

The distribution of the frequency of flood events seems to be less dependent on the mean annual precipitation, for all flood types except FF (Figure 16). In other words, a higher mean annual precipitation does not mean a higher total count of a specific flood type. On the other hand, it is visible that the total counts are pooled by the altitude group, which is better illustrated in Figure 18 later. Consequently, it can be assumed that annual precipitation alone can not explain the number of flood events, and it implies that antecedent catchment conditions prior to a flood event play an important role. The correlation for SMF and GMF can be neglected for the same reason as for the correlation with the mean annual temperature.

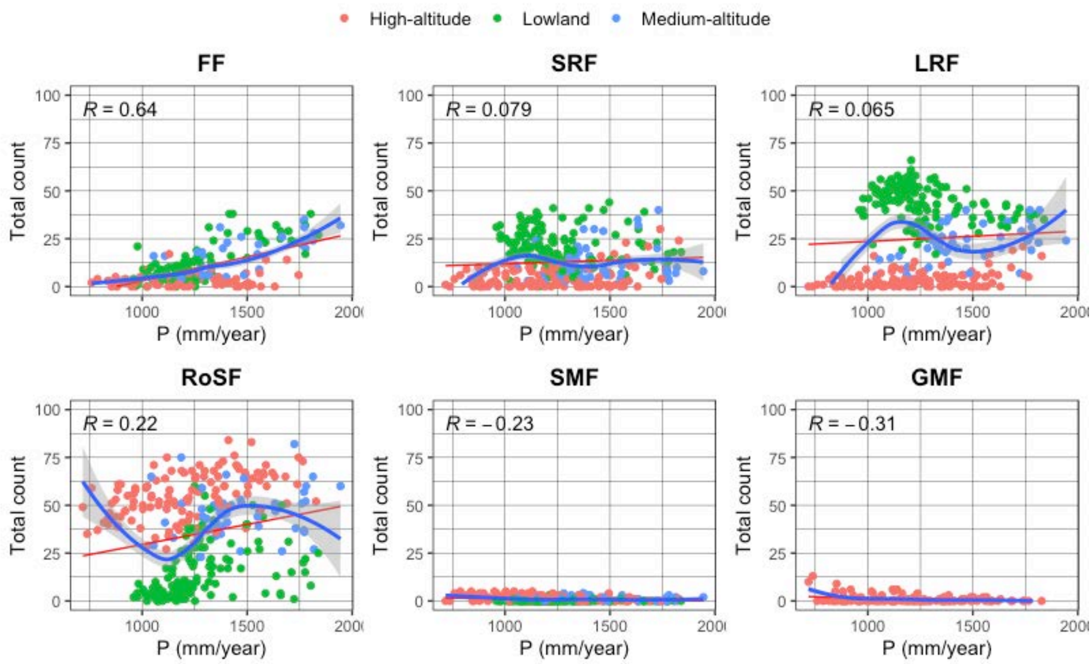

Figure 16: Mean annual precipitation compared to the total count of six different flood types, coloured by altitude group. The red line represents the linear approximation, and the blue line the local regression curve. Note that catchments >150km² and unglaciated catchments are excluded for FF and GMF events, respectively.

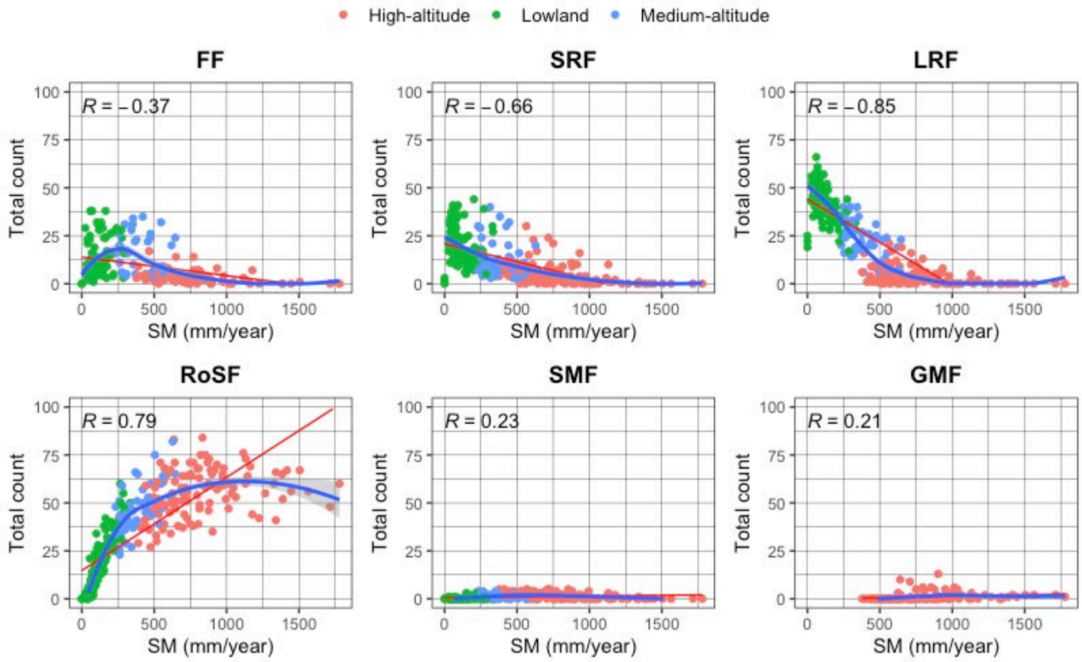

Figure 17: Mean annual snowmelt compared to the total count of six different flood types, coloured by altitude group. The red line represents the linear approximation, and the blue line the local regression curve. Note that catchments >150km² and unglaciated catchments are excluded for FF and GMF events, respectively.

The correlation of mean annual snowmelt and the total count of FF, SRF and LRF events is negative (Pearson's R of -0.37, -0.66 and -0.85, see Figure 17). Although snowmelt has only a minor influence on these flood types, the correlation is still representative. This is because low amounts of annual snowmelt mean that the snow cover is low throughout the year as well. Hence, less RoSF events can be identified, due to missing snow cover and snowmelt, and hence those events are classified as FF, SRF or LRF events. Conversely the higher the snowmelt is, presumably more RoSF events occur. The slope of the local regression curve is higher for low annual snowmelt amounts (<250mm/year), which indicates that a slight increase in annual snowmelt can increase the total count of RoSF over proportional. Similar to the mean annual temperature and mean annual precipitation, the correlation of SMF and GMF events with the mean annual snowmelt can be neglected due to their rare occurrence.

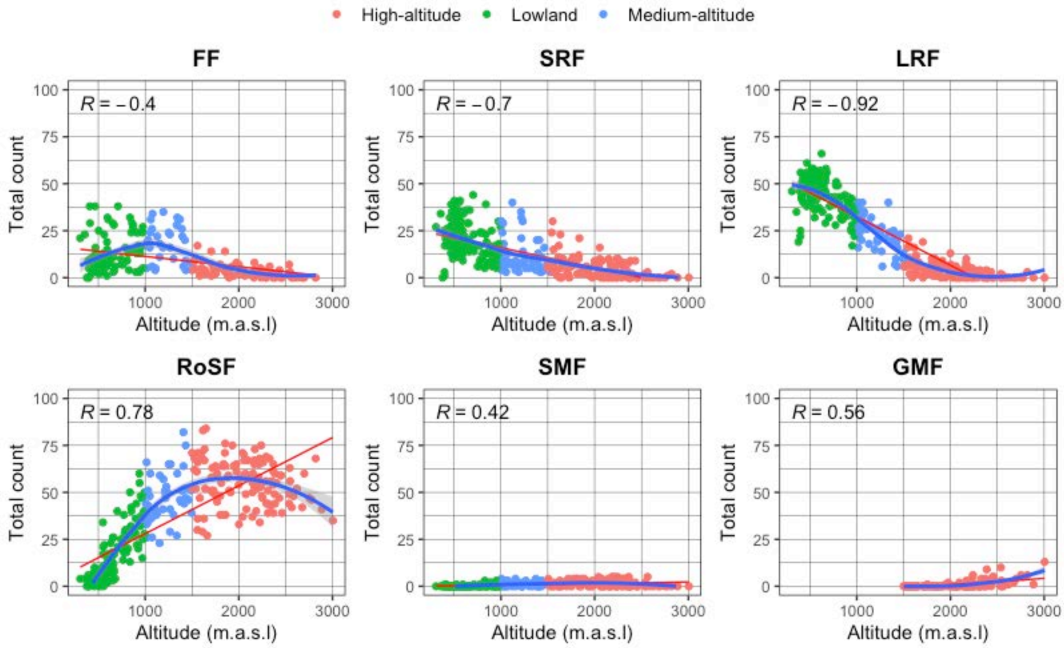

Figure 18: Catchment altitude compared to the total count of six different flood types, coloured by altitude group. The red line represents the linear approximation, and the blue line the local regression curve. Note that catchments >150km^2 and unglaciated catchments are excluded for FF and GMF events, respectively.

Overall, the amount of FF events presumably decreases with increasing altitude (Pearson's R = -0.4), even though in the lowest 1000m.a.s.l, a slight increase with altitude is visible (Figure 18). For SRF and LRF events, the overall frequency is entirely decreasing with increasing altitude (Pearson's R = -0.7 and -0.92, respectively), whereas the frequency of RoSF events increases with altitude (Pearson's R = 0.78). However, for above 2000m.a.s.l. level the correlation is inversed, and the amount of RoSF tends to decrease with increasing altitude.

3.1.5. Frequency differences by altitude group

The distribution of the flood types per catchment altitude (lowland, medium- and high-altitude) is similar to the control simulation (Figure 19). In lowland catchments, for each flood type, mean frequency values of each GCM-RCM-simulations are both, slightly above and below the frequency of the control simulation, while the overall mean of each GCM-RCM chain is close to the mean of the control simulation. The relative mean deviation from the mean is roughly between -25.0% and +24.0% for FF events, between -10.0 to + 15.0% for SRF and LRF events and about ± 30.0% for RoSF events. For GMF and SMF events, the mean deviation is high due to the fact that only a few events are identified.

Mean values of the frequency are close to the values of the control simulation for medium-altitude catchments as well, for all flood types. While GCM-RCM simulations show both, higher and lower total count values for FF, SRF, RoSF and SMF events, with respect to the control simulation, all GCM-RCM simulations, for each RCP, have a higher mean total count than the control simulation for LRF events. In these catchments, the relative mean deviations of each GCM-RCM simulation from the mean of all simulations are similar to the ones in the lowland catchments.

For high-altitude catchments, the mean of all RCP 2.6 simulations is close to the value of the control simulation, for all flood types except RoSF events, where it is higher.

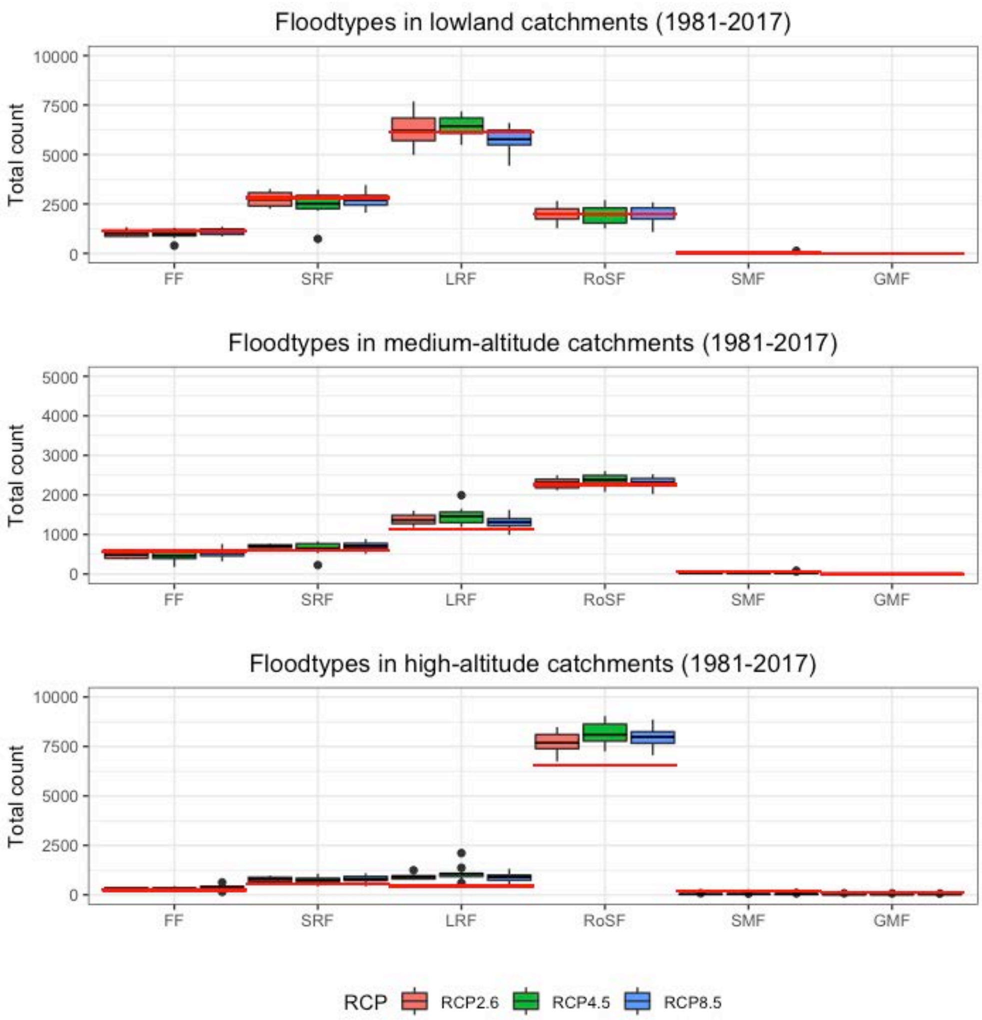

Figure 19: The boxplots show the mean and the range of the total count for the six different flood types, for all GCM-RCM chains, summarized by altitude, for the 1981-2017 period. The red line shows the respective total count of the control simulation.

3.1.6. Seasonal pattern differences by altitude group

Table 9: Seasonal distribution of all flood types in the respective altitude groups, for both crisp tree and fuzzy tree, using the mean of all RCP 2.6 simulations.

	All Seasons		Spring		Summer		Autumn		Winter	
Lowland (139)	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**
FF (%)	8.42	8.19	7.39	7.12	31.52	31.28	8.33	7.84	0.00	0.00
SRF (%)	22.79	23.00	19.19	19.46	14.65	14.88	32.43	32.94	21.87	21.82
LRF (%)	51.92	51.85	48.57	48.54	53.36	53.35	56.58	56.57	50.48	50.33
RoSF (%)	16.60	16.67	24.18	24.20	0.47	0.48	2.65	2.66	27.36	27.54
SMF (%)	0.27	0.28	0.66	0.68	0.00	0.00	0.00	0.00	0.29	0.30
GMF (%)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mixed Events (%)		6.43		7.33		3.19		6.33		7.15
Mid-altitude (49)	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**
FF (%)	9.84	9.77	2.88	2.77	26.09	26.32	10.58	10.23	0.00	0.00
SRF (%)	14.38	14.47	4.55	4.71	13.45	13.16	32.20	32.49	6.37	6.50
LRF (%)	28.02	28.01	11.57	11.57	43.17	43.16	45.02	44.96	12.18	12.22
RoSF (%)	47.45	47.43	80.15	80.06	17.29	17.36	12.18	12.30	81.31	81.11
SMF (%)	0.31	0.33	0.85	0.89	0.00	0.00	0.02	0.02	0.14	0.17
GMF (%)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mixed Events (%)		8.05		5.81		7.55		12.11		6.62
High altitude (119)	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**
FF (%)	3.14	3.04	0.01	0.01	3.99	3.96	5.30	4.96	0.00	0.00
SRF (%)	8.12	8.21	0.20	0.20	4.65	4.68	21.79	22.09	2.13	2.08
LRF (%)	9.37	9.38	0.41	0.43	8.16	8.15	20.97	20.99	0.78	0.74
RoSF (%)	78.90	78.90	98.52	98.53	82.65	82.64	51.95	51.96	97.09	97.18
SMF (%)	0.28	0.28	0.74	0.70	0.20	0.19	0.00	0.00	0.00	0.00
GMF (%)	0.19	0.19	0.12	0.13	0.36	0.37	0.00	0.00	0.00	0.00
Mixed Events (%)		7.38		0.88		5.89		16.42		3.53

Table 9 above as well as Table 17 and 18 in the appendix show seasonal distribution of each flood type, for GCM-RCM-simulations of RCP2.6, 4.5 and 8.5, respectively. All the numbers in this section represent all catchments of the specific altitude group. The relative percentage of the mixed events in the fuzzy approach slightly is similar for all RCPs, but for medium-altitude and high-altitude catchments it is considerably lower during the autumn season. For instance, for high-altitude catchments it is lower by -15.1%, -14.8% and -13.1% for RCP2.6, RCP 4.5 and RCP 8.5 GCM-RCM chains, respectively. Hence, the GCM-RCM-chains presumably identify more single-flood-types.

The subsequent numbers correspond to those of the crisp tree and are listed in Table 19, 20 and 21 in the appendix. In lowland catchments, the proportion of LRF events of all RCP2.6 GCM-RCMs is higher by 5.3% and 3.2% during spring and summer, respectively, whereas SRF events show a decrease by -5.9 and 5.8%, respectively. In autumn, a higher relative percentage of SRF (+3.0%) and lower percentage of FF events (-3.7%) are identified, whereas in winter the changes are marginal. The RCP 4.5 and RCP 8.5 chains show a similar pattern compared to the control simulation. For LRF events, the values are different by +7.9% (spring) and +5.8% (summer) as well as +3.1% (spring) and +1.0% (summer), for RCP 4.5 and RCP 8.5, respectively. However, the latter (RCP 8.6 chains) is not a major change, and rather more FF events (+1.9%) are identified. Additionally, more SRF (+2.3%) events are simulated during the winter, mostly at the cost of LRF events (-3.7%).

Differences in relative distribution of each season do not allow to describe differences between the seasons. The differences of absolute numbers are shown in Table 22, 23 and 24 in the appendix. One example would be that in RCP2.6 and 8.5 chains more SRF events are identified during the autumn and winter months, whereas in spring and winter, less SRF events are identified. Very high-percentage differences of absolute number of events of flood types indicate that only a few events of a certain flood type are identified.

In medium-altitude catchments, seasonal differences are considerably higher. During the spring months, RCP 2.6 chains identify a higher percentage of FF, SRF and LRF events (change by +1.0%, +0.7% and +2.5%, respectively), whereas RoSF and SMF events are lower by -0.8% and 3.3%. In RCP 4.5 and RCP 8.5 chains, similar differences are found. The highest differences can be observer during the summer months. Here, the mean frequency of LRF events is higher by 8.5%, 12.4% and 6.7%, for GCM-RCM chains of RCP 2.6, 4.5 and 8.5, respectively. On the other hand, the relative percentage of FF, SRF and RoSF events is lower during that season. Simultaneously, the in absolute number of FF, SRF and RoSF is generally lower as well compared to the control simulation, whereas LRF events almost remain unchanged or are considerably higher (Appendix: Table 22, 23, 24).

Seasonal differences in high-altitude catchments are mostly low during winter for all flood types, with a maximum difference of +1.2%. During the spring months, the relative percentage is higher for RoSF events (+4.4%, +4.6% and +4.4% for RCP 2.6, 4.5 and 8.5 chains) but lower for SMF events (-4.0, -4.1% and -3.9%, RCP 2.6, 4.5 and 8.5 chains, respectively). During the autumn months, the relative percentage of RoSF is lower (-10.4%, 12.2% and -10.6%, RCP 2.6, 4.5 and 8.5, respectively). This is due to the fact that the absolute numbers of LRF and SRF events are doubled or tripled, whereas RoSF events only increase by 41.8%, 33.9% and 36.2%, for each RCP 2.6, 4.5 and 8.5, respectively, which leads to a decrease in the relative percentage.

Generally, the absolute numbers of SMF events are considerably lower compared to the control simulation (up to -82.1% as in RCP 4.5 chains), in reality this is due to the fact that not all GCM-RCM simulations actually simulate SMF events. This is due to the fact that for each catchment only a few SMF events are identified in general, and hence, the mean value is lower. Consequently, cumulating over all catchments of the altitude group results in a lower mean value as well.

3.1.7. Significance of differences in frequency and intensity with respect to control simulation

A two-tailed one-sample t-test is performed, to test if the difference between control simulation and all RCP GCM-RCM-chains is significant. This is not only done for the difference in the total count, but also for the difference in mean precipitation, mean snowmelt and mean maximum daily runoff per flood event.

The test is performed for each catchment separately, since using the overall total counts for all catchments could distort the result. Furthermore, individual analysis allows to describe the difference in space.

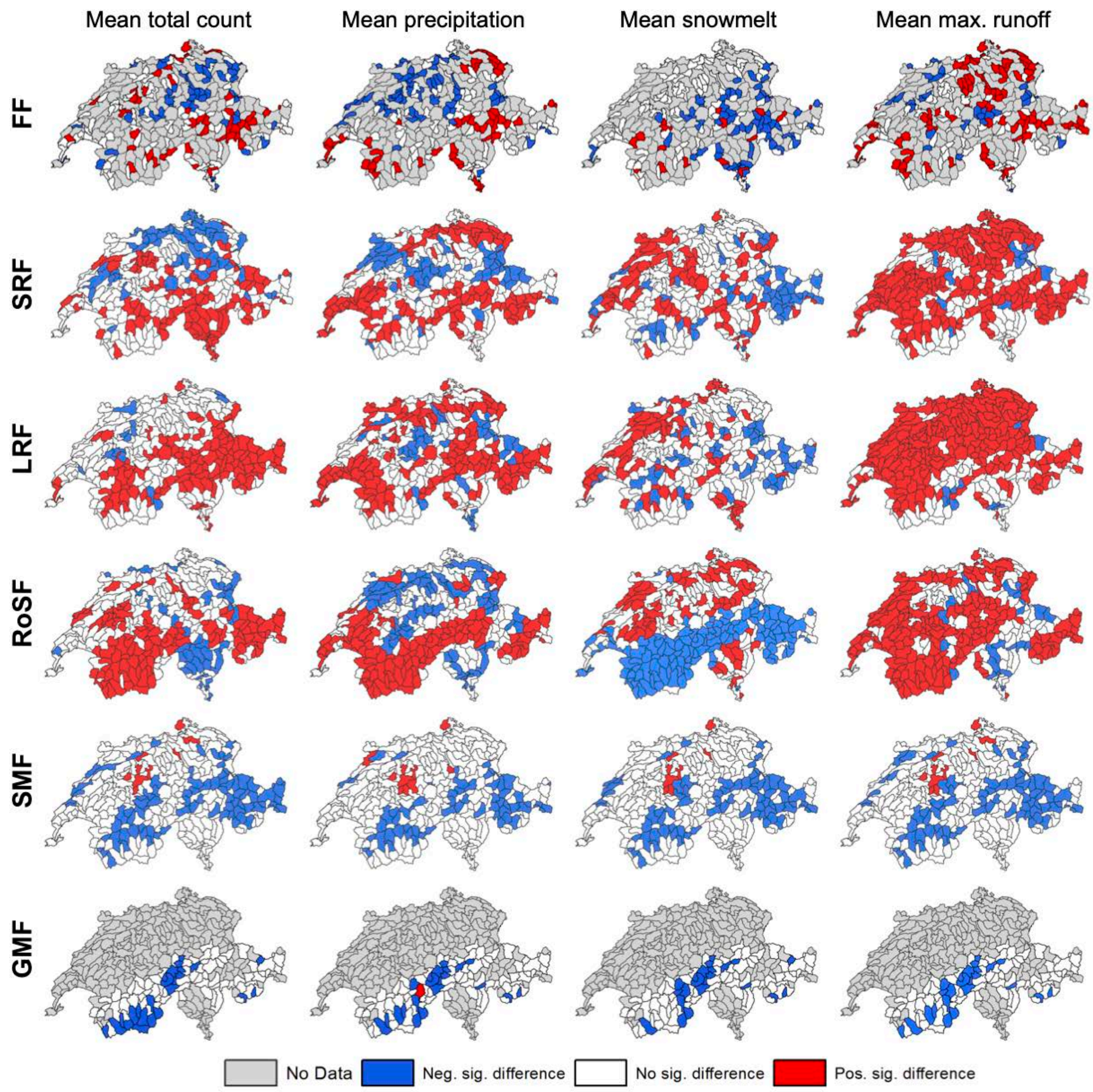

Figure 20: The maps show, if the difference of mean total count, mean precipitation per event, mean snowmelt per event, mean max. daily runoff per flood type event between the control simulation and the mean of all RCP2.6 simulations is significant. Gray catchments in FF and GMF indicate catchments, where FF and GMF can not occur at all (>150km^2 and unglaciated, respectively)

Figure 20 shows the differences for the RCP 2.6 GCM-RCM-chains, while the ones for RCP 4.5 and 8.5 can be found in the appendix (Figure 35 and 36). Table 10 illustrates the numbers of catchments according to Figures 20, 35 and 36 For FF, catchment areas larger than 150km^2 are excluded, due to the fact that in these catchments FF events can by definition never occur. Depending on the RCP, between 93 and 113 catchments, show no significant difference in the mean total count; RCP 2.6 simulations roughly have the equal number of catchments identified, where the significance is either positive or negative. The chains for RCP 4.5 and RCP 8.5 show more negative and more positive significant catchments. The majority of the positive differences are identified in alpine catchments, whereas negative ones tend to be in the Swiss Plateau and Pre-Alpes. Next, the majority of the catchments have both a positively and negatively significant difference in precipitation amount per event. It is significantly negative

Table 10: Number of catchments of positive, negative and non-significant differences for mean precipitation, mean snowmelt and mean maximum daily runoff for each flood type, comparing the mean of GCM-RCM chains to the reference period

RCP2.6	Count			P/Event [mm]			SM/Event [mm]			Max Q/Event [mm]		
Significance	N	0	P	N	0	P	N	0	P	N	0	P
FF	49	103	45	57	85	55	58	123	16	30	75	92
SRF	51	115	97	48	151	108	57	170	80	13	100	194
LRF	15	167	125	35	124	148	54	184	69	10	74	223
RoSF	42	148	117	66	121	120	123	120	64	22	99	186
SMF	87	211	9	61	236	10	74	225	8	80	217	10
GMF	25	71	0	22	73	1	23	73	0	25	71	0
RCP4.5	Count			P/Event [mm]			SM/Event [mm]			Max Q/Event [mm]		
Significance	N	0	P	N	0	P	N	0	P	N	0	P
FF	51	113	33	55	72	70	59	116	22	24	72	101
SRF	73	151	83	60	122	124	64	150	92	20	91	105
LRF	40	77	189	51	96	159	75	160	71	14	57	236
RoSF	52	104	150	76	97	133	134	99	74	25	78	203
SMF	40	267	0	19	213	74	86	202	18	96	190	20
GMF	15	81	0	1	69	26	28	67	1	31	64	1
RCP8.5	Count			P/Event [mm]			SM/Event [mm]			Max Q/Event [mm]		
Significance	N	0	P	N	0	P	N	0	P	N	0	P
FF	39	93	65	69	65	63	67	100	30	33	67	97
SRF	65	137	105	58	97	151	69	129	108	29	83	194
LRF	83	91	132	51	102	153	70	136	100	21	59	226
RoSF	60	84	162	91	76	139	103	101	103	39	77	190
SMF	39	268	0	87	176	43	90	179	37	103	159	44
GMF	16	80	0	27	67	2	29	61	5	30	61	5

in lowland and positive in high-altitude catchments. In contrast, the difference in snowmelt per event tends to be not significant in most catchments, although there is a negative difference in most alpine and some pre-alpine catchments. On the other hand, snowmelt is not necessarily relevant for FF events. Lastly, the difference in the maximum daily runoff per event is mostly positive significant, in most regions. However, some catchments show a negative difference, as well.

Depending on the RCP, between 115 and 151 catchments show no significant difference in total count for SRF events. However, it is positively significant in southern alpine catchments, and negative in catchments of northern Switzerland. Differences in mean precipitation per event are more diverse: They are not significant in 151 of the 307 catchments according to RCP 2.6 chains, 122 in the RCP 4.5 chains and only 97 in the RCP 8.5 chains. Clusters of positive anomalies can be found in alpine catchments, western and northern Switzerland, while negative anomalies are present in prealpine and Jura-catchments. While differences in snowmelt per event are mostly insignificant for most catchments (between 129 and 170), some catchments in north-western Switzerland show positive differences, while most catchments in Canton of Graubünden have negative differences. The difference in mean daily maximum runoff per event is positive significant in most of the catchments in all regions of all GCM-RCM-chains, with only some having negative significant or insignificant differences.

The total count of LRF events is significantly higher in most catchments (125, 189 and 132, for RCP 2.6, 4.5 and 8.5 chains), while most other catchments show no significant differences, and only a few are having negative differences. Values for mean precipitation per event are significantly higher for most catchments. Those can be found in alpine catchments, as well as in catchment around the Lake Geneva. Most other catchments show no significant differences. Differences in mean snowmelt per event are generally not significant for all chains. Some positive differences are concentrated in catchments around the Jura region, while few negative differences are scattered around the rest of Switzerland. The mean maximum daily runoff for LRF show over 200 catchments for all RCP chains, which are positively significant.

According to RCP2.6 chains, floods identified as RoSF show no significant differences in total count in most catchments of the Swiss Plateau, whereas in many alpine catchments this difference is significant. On the other hand, catchments in Canton of Ticino show a negative difference. For RCP 4.5 and 8.5 chains, most catchments show a significant positive difference (150 and 162). However, the spatial pattern of the changes is still similar. The mean precipitation per event shows an interesting spatial pattern, where most catchments in the Central and Western Alps show a positive difference, whereas catchments in the Swiss Plateau and Pre-Alps have either negative significant or no significant differences. The spatial pattern is almost perfectly inverted for mean snowmelt per event. Here, the high-altitude catchments in Central and Western Alps show negative differences, whereas for other regions the difference is either positive significant or not significant. Both patterns are identified in the mean of all the GCM-RCM-chains. The difference in mean maximum daily runoff per event is generally positive significant for most regions, although some clusters of non-significant differences are found in lowland catchments of the Swiss Plateau.

Given that SMF events are relatively rare in any catchment, the differences in both the frequency and intensity are generally not significant. Similarly, in glaciated catchments, almost all differences for GMF are not significant in terms of frequency. The negative differences in the total count are caused by the fact that the average of all simulations is used. It is possible that SMF may occur in one region in one simulation but not in other simulations. This then also affects mean precipitation, mean snowmelt and mean maximum daily runoff per event, that also become negative.

3.2. First future period (2018-2058)

The range of the reference period and the future period is different (37 years and 41 years, respectively). It is possible that in the case of an increase, the number of events may be too high. However, some simulations model certain events with gaps up to some years and hence, the error should be relatively small. Another possibility would have been to reduce the first future period by 4 years. This approach could cut off possible flood types and the analyse data would have missing years.

3.2.1. Frequency trends by altitude group

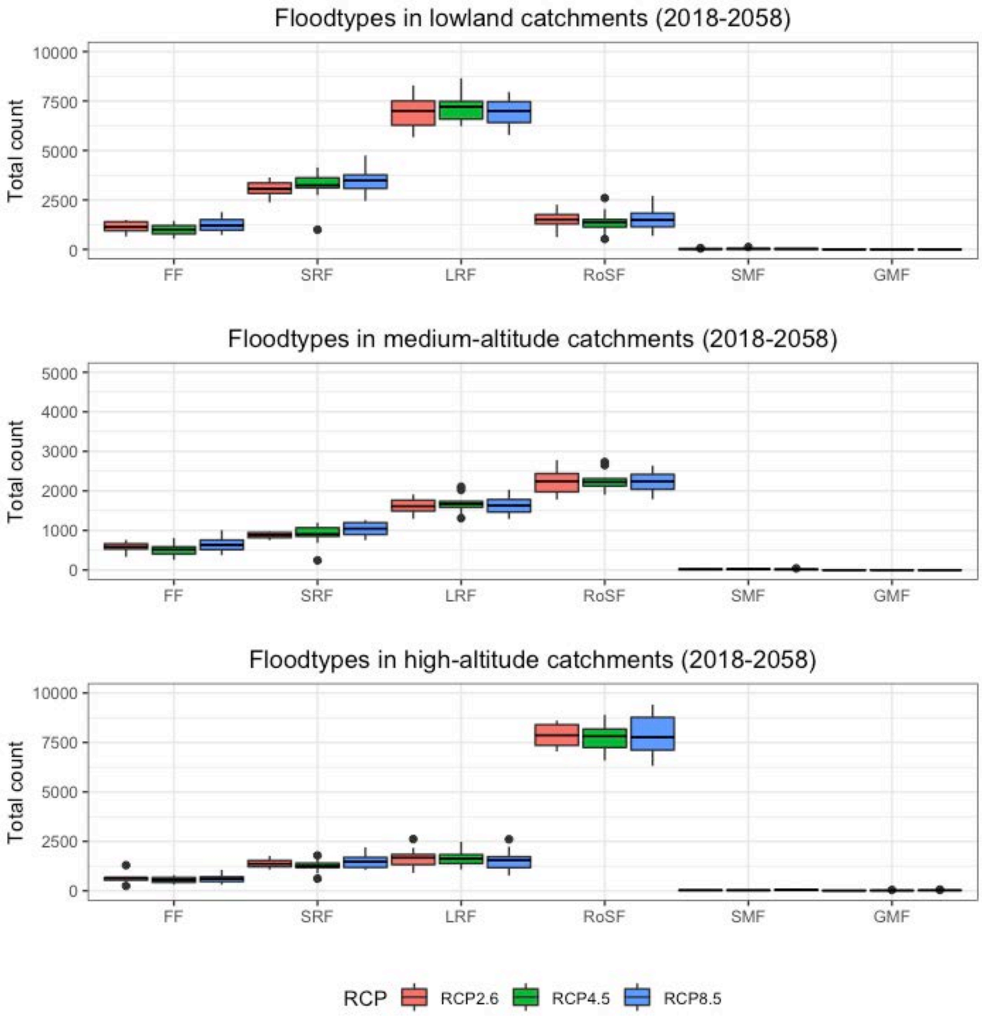

Figure 21: The boxplots show the range of the total count for the six different flood types, for RCP2.6 simulation, summarized by altitude, for the 2018-2058 period. The red line shows the respective total count of the control simulation from the reference period as comparison

Comparing the total count of all GCM-RCM simulations per catchment altitude shows a similar distribution of flood types (Figure 21 and Tables 25, 26, 27, 28, 29, 30 in the appendix). However, the mean, as well as the range per flood type, is different.

In lowland catchments, the mean of all flood types is higher for all flood types except for RoSF, where it is lower, with respect to the reference period. Hence, fewer RoSF events are expected in the first future period. FF events are highest for RCP 8.5 and lowest for RCP4.5 chains, whereas SRF floods increase with increasing RCP level.

LRF, RoSF and SMF events show similar a mean total count. The relative deviation of each RCP chain from its mean can be high, but usually it is roughly the same as for the reference period. The pattern is similar for medium-altitude catchments, where the mean frequency of RoSF events is lower compared to the reference period, but with slightly lower deviations from the mean.

All flood types in high-altitude catchments show a higher mean frequency in the first future period, compared to the reference period. This means that in high-altitude catchments, more flood events can be expected during the first future period in general. For instance, the mean of the total count for LRF events is almost doubled (911 in the reference period, compared to 1667 in the first future period). Differences between RCP chains (2.6, 4.5 and 8.5) are low, although for RoSF events a slight decrease can be identified, with increasing RCP level.

SMF and GMF events show a large deviation from the mean. This is because each GCM-RCM chain identifies only a few SMF and GMF events, and each chain identifies a different number of catchments that actually have these two events.

A detailed analysis regarding the differences in frequency for each catchment is given in section 3.2.3.

3.2.2. Seasonal pattern trends by altitude group

Table 11: Seasonal trends (in %) of all flood types in the respective altitude groups, for both crisp tree and fuzzy tree, using mean RCP 2.6 chains of the 2018-2058 period. The number in brackets next to the altitude group represents the number of catchments.

	All Seasons		Spring		Summer		Autumn		Winter	
Lowland (139)	Crisp	Fuzzy	Crisp	Fuzzy	Crisp	Fuzzy	Crisp	Fuzzy	Crisp	Fuzzy
FF (% change)	12.78	11.37	42.98	38.85	-2.57	-2.62	18.57	17.79	0.00	0.00
SRF (% change)	12.15	12.67	-2.42	-0.28	-2.91	-2.75	-3.12	-2.67	41.10	41.26
LRF (% chagne)	12.75	12.84	5.05	4.97	3.88	3.89	-5.48	-5.48	36.06	36.43
RoSF (% change)	-23.73	-23.84	-40.71	-40.54	-62.50	-63.79	-40.89	-40.31	-11.59	-11.99
SMF (% change)	-35.63	-36.05	-49.69	-47.51	0.00	0.00	-100.00	-100.00	-12.12	-76.16
GMF (% change)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mixed (% change)		-0.24		1.42		-0.28		0.18		-1.47
Mid-altitude (49)	Crisp	Fuzzy	Crisp	Fuzzy	Crisp	Fuzzy	Crisp	Fuzzy	Crisp	Fuzzy
FF (% change)	21.83	21.47	66.12	66.72	13.43	13.23	24.91	24.69	0.00	0.00
SRF (% change)	26.54	26.69	64.73	63.38	8.90	9.39	17.05	17.28	100.24	97.84
LRF (% chagne)	18.28	18.12	47.71	46.91	16.26	16.14	-0.68	-0.66	85.43	84.80
RoSF (% change)	-2.92	-2.78	-14.37	-14.22	-35.38	-35.05	-34.06	-33.94	35.93	36.18
SMF (% change)	-4.13	-7.63	-4.59	-6.89	0.00	0.00	-100.00	-100.00	33.33	0.00
GMF (% change)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mixed (% change)		0.05		1.81		-1.19		-1.06		0.47
High altitude (119)	Crisp	Fuzzy	Crisp	Fuzzy	Crisp	Fuzzy	Crisp	Fuzzy	Crisp	Fuzzy
FF (% change)	112.79	114.60	933.33	1020.00	94.23	94.89	131.73	135.88	0.00	0.00
SRF (% change)	72.74	72.43	324.10	326.36	74.27	72.88	70.08	69.94	60.00	77.35
LRF (% chagne)	82.89	82.87	197.67	187.15	86.05	86.16	78.19	78.15	230.00	253.68
RoSF (% change)	2.50	2.51	32.93	32.88	-16.01	-15.96	-29.37	-29.27	92.85	92.33
SMF (% change)	-14.61	-11.47	0.00	8.05	-50.00	-47.35	0.00	0.00	0.00	0.00
GMF (% change)	-47.26	-51.02	19.23	6.61	-61.02	-63.93	0.00	-100.00	0.00	0.00
Mixed (% change)		0.15		0.45		1.22		-1.14		0.31

While changes over all seasons might indicate an increase of certain flood types, these changes become different when performing a seasonal analysis (Table 11 for RCP 2.6 and Table 31 and 32 for RCP 4.5 and 8.5 in the appendix). Furthermore, it allows estimating which season contributes the most to overall changes. For lowland catchments, the frequency increase of FF events is most evident during the spring season

(+43.0%, +37.9% and +26.8% for RCP 2.6, 4.5 and 8.5 chains, respectively. Likewise, an increase is observed during the autumn months, whereas during the summer months less FF events occur for all RCP 2.6 and 4.5 chains (-2.6% and -13.8%, respectively). RCP 8.5 chains identify more FF events during summer as well (+10.0%). In winter, per definition, no FF events can occur. Hence, it is likely that the season of FF events is slightly extended into the spring (April and May) and autumn season (September). A reason for the slight decrease during summer in RCP 2.6 and 4.5 chains could be the increase in evapotranspiration, which is high in lowland catchments. The average amount of SRF events is somewhat lower during spring, summer and autumn (-2.4%, -2.9% and -3.1%, respectively), but considerably higher during winter (+41.1%) according to RCP 2.6 chains. However, according to the RCP 4.5 and 8.5 chains, an increase is expected for all seasons, but the highest during the winter. Hence, the winter months are most responsible for the increase of SRF events in lowland catchments, which is also the case for LRF events. This implies that the mean temperature increase is likely to be higher during the winter months.

LRF events show an increase during spring summer and winter, while during autumn, less LRF events are identified in the first future period compared to the reference period, in RCP 2.6 chains. RCP4.5 chains show a decrease during the summer (-17.6%), but an increase in all other seasons, while RCP 8.5 chains show an increase of LRF events in all seasons. RoSF events are likely to decrease in all seasons for all GCM-RCM-chains (up to -60.0%). However, it is most evident during the spring. This is probably due to the fact that the snow cover becomes smaller during the winter months, and therefore, less snowmelt is available during spring, which could cause RoSF (see section 3.2.4). This would explain the simultaneous increase of only rainfall-related flood events.

Seasonal changes for FF and SRF events are distributed more evenly in medium-altitude catchments. All seasons indicate an average increase, except winter for FF events, which are per definition not possible. The RCP 8.5 chains changes show the most considerable increase, especially during the spring (+113.0% for both flood types) and winter (+222.5%). However, during winter this increase in the first period is explained by low values during the reference period (see Table 32 appendix). The pattern is similar for LRF events that also show an increase during spring and winter, with RCP 8.5 chains having the highest increase as well.
A net decrease of RoSF events is simulated over all seasons, but during the winter months, these events are predicted to increase considerably, according to RCP 2.6 and 4.5 chains. For RCP 8.5, all seasons show a decrease in RoSF events. In spring months, the drop in RoSF is most evident. As a result, a considerable shift of RoSF events from spring to winter is likely to be expected.

The mean frequency of flood events in high altitude catchments, which are not influenced by snowmelt, is likely to increase in every season – except for FF events during the winter. It is most evident during the spring, summer and especially the autumn season, for all GCM-RCM chains. The difference generally shows a high percentage, generally more than +200%, and up to 966.7% during spring, for FF events. This means that the season of FF events starts earlier, driven by a likely higher temperature increase in those catchments as well. A high decrease of RoSF events is simulated during the summer and autumn season for all GCM-RCM chains, with RCP8.5 chains having the most severe negative trends. However, during the spring months, the difference is clearly positive. Additionally, a less sharp increase is simulated in winter. This finding suggests a clear shift of RoSF events from summer and autumn towards spring and to a certain extent towards winter. Since mean annual temperatures are still relatively low during winter, an increase of it can lead during a higher snow accumulation during winter. Furthermore, a simultaneous increase in the mean temperature in the spring means an earlier start of snowmelt. Both processes likely cause a high increase of RoSF events during the spring.

SMF and (for high-altitude catchments) GMF events show a marginal decrease overall in all catchments. However, only a few events of these flood types are identified.

3.2.3. Significance of differences in frequency and intensity with respect to reference period

To compare different means between the first future period and the reference period, two types of statistical tests are used for all GCM-RCM simulations to estimate the whether the trend is significant or not. An unpaired two-tailed t-test is performed to analyse the differences for FF, SRF, LRF and RoSF events, and a Mann-Whitney-U test for mean total counts of SMF and GMF events because they are not normally distributed. A p-value of 0.05 is applied for both tests.

Similar to section 3.1.6, both tests are performed for the mean total count, as well as for the mean precipitation, mean snowmelt and mean maximum daily runoff per event, for each catchment (Figure 20). In the first future period, most catchments experience an increase in FF events, compared to the reference period (Figure 21 for RCP 2.6 chains and Figures 37 and 38 in the appendix, for RCP 4.5 and 8.5 chains, respectively). However, the vast majority of this increase is not significant for either GCM-RCM-chain group. Most catchments that show a significant positive trend (RCP2.6: 64 catchments, RCP 4.5: 60, RCP 8.5: 79) are in high-altitude catchments. This is represented in Figure 21 very well. In some catchments, FF events are identified in the first future period, but not in the reference period, which statistically leads to a significant increase. In contrast, most of these significant positive catchments show no significant increase in mean precipitation. The GCM-RCM chains belonging to RCP 2.6 identified 17 potential catchments, which could have a positive significant trend, whereas chains belonging to RCP 4.5 and 8.5 identified 26 and 45 catchments, respectively, having a positive significant trend as well. However, it is possible that that one or more specific

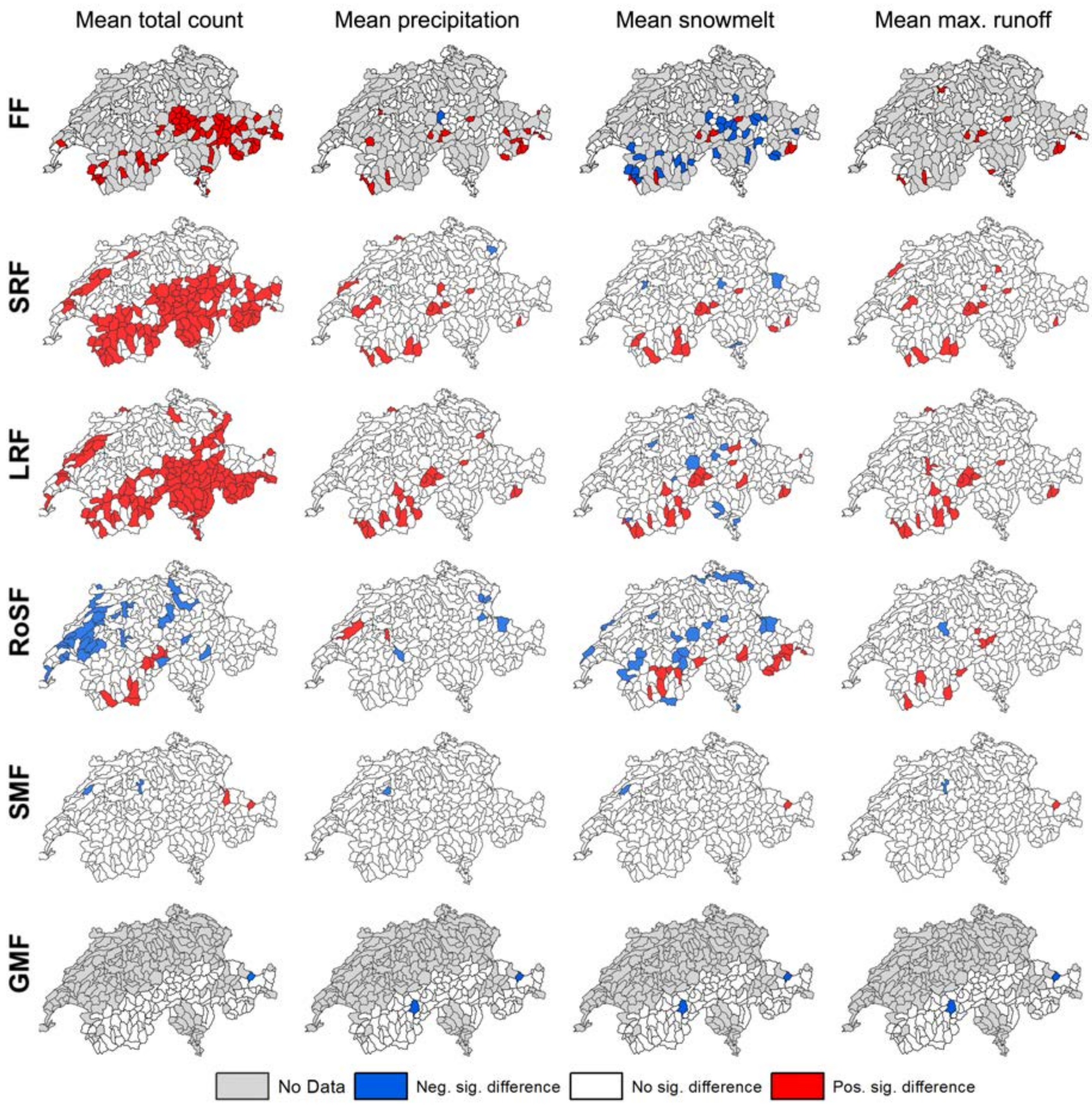

Figure 22: The maps show, if the trend of mean total count, mean precipitation per event, mean snowmelt per event, mean max. daily runoff per flood type event during the 2018-2058 period is significant, compared to the reference period for RCP 2.6 chains. Gray catchments in FF and GMF indicate catchments, where FF and GMF can not occur at all (>150km^2 and unglaciated, respectively).

GCM-RCM chains of each RCP group identify FF events during the reference period for a certain catchment, while other chains do not. As a consequence, in the latter case, mean precipitation, mean snowmelt and mean maximum daily runoff will be zero for those chains, which lowers their mean value of all chains (or becomes zero if all chains do not identify FF events). If during the first future period, the same GCM-RCM chains identify FF events, the other variables will therefore have values higher than zero, which results in statistically significant higher values. It would not be entirely correct to say that these variables (mean precipitation, mean snowmelt and mean maximum daily runoff) are higher, since it is unknown how high they would have been, if all GCM-RCM would have identified FF events. This phenomenon is commonly described as false positive, or false negative, if the situation above is inversed for both periods. Thus, false positives are excluded for the analysis (Table 12) and are not mentioned. However, they are attached in the Appendix (Table 33).

Table 12: Corrected number of catchments of positive, negative and non-significant trends for mean precipitation, mean snowmelt and mean maximum daily runoff for each flood type, during the first future period

RCP2.6	Count			P/Event [mm]			SM/Event [mm]			Max Q/Event [mm]		
Significance	N	0	P	N	0	P	N	0	P	N	0	P
FF	0	133	64	1	179	5	26	161	8	0	185	0
SRF	0	198	109	1	290	5	4	290	3	0	293	0
LRF	0	186	121	0	285	4	11	276	2	0	287	2
RoSF	29	268	10	1	300	2	18	266	18	7	299	1
SMF	2	303	2	0	306	0	0	305	0	0	305	0
GMF	1	95	0	0	94	0	0	94	0	0	94	0
RCP4.5	Count			P/Event [mm]			SM/Event [mm]			Max Q/Event [mm]		
Significance	N	0	P	N	0	P	N	0	P	N	0	P
FF	0	137	60	1	170	9	30	134	0	7	170	5
SRF	0	115	192	0	278	6	30	245	0	9	272	5
LRF	0	145	162	0	278	7	42	215	19	0	280	2
RoSF	115	186	4	4	286	0	49	224	24	8	273	3
SMF	1	304	1	0	302	0	0	300	0	0	299	0
GMF	0	96	1	1	95	0	1	95	0	2	94	0
RCP8.5	Count			P/Event [mm]			SM/Event [mm]			Max Q/Event [mm]		
Significance	N	0	P	N	0	P	N	0	P	N	0	P
FF	0	118	79	0	152	20	22	153	0	0	176	4
SRF	0	30	277	0	238	39	80	179	12	1	274	4
LRF	0	27	280	0	261	17	79	192	8	0	259	20
RoSF	129	165	11	1	290	7	59	226	4	0	289	10
SMF	4	297	5	0	297	0	0	288	0	0	286	0
GMF	1	95	0	0	95	0	0	94	0	0	94	0

Regarding the mean precipitation, this reduces the number of positive significant catchments to five (RCP 2.6), nine (RCP 4.5) and 20 (RCP 8.5). As a result, it can be said that a significant increase of FF events, does not necessarily lead to an increase in mean precipitation as well. Mean snowmelt for FF events is mostly not statistically significant. About 26, 30 and 22 catchments statistically show a negative significant trend, for the GCM-RCM-chain groups belonging to RCP 2.6, 4.5 and 8.5, respectively. However, snowmelt is not relevant for FF events in either case, since it is limited to 1mm/event and it can consequently be neglected. In RCP 2.6 chains no catchment shows a significant trend in mean maximum daily runoff whereas RCP 4.5 chains identify 7 negative and 5 positive trends, and RCP8.5 chains 4 positive trends. Similar to mean precipitation, mean maximum daily runoff mostly does not significantly increase either, if more significant FF events are identified.

For SRF events, most catchments show an increase in the mean total count. However, the situation looks quite different regarding the significance. RCP 2.6 chains have 198 catchments showing no significant trend, which are located mostly in high-altitude catchments, as well as some catchments around the Jura region. 192 and 277 catchments show a significant positive increase, for chains belonging to RCP 4.5 and 8.5, respectively. Most catchments do not indicate a significant increase in mean precipitation for SRF events, although RCP8.5, identified 39 catchments, which show a significant increase. Similar to FF events, trends in mean snowmelt can be neglected. A significant increase in the mean daily maximum runoff is not identified in most catchments, with only a few catchments in RCP4.5- and 8.5 chains indicating one as such.

The pattern is similar for LRF events: RCP 2.6 chains mostly show no significant increase for LRF events and those being identified as significant are limited to medium- and high-altitude catchments of the Alps, Pre-Alps and some lowland-catchments in the Jura-Region. On the other hand, RCP 4.5 chains show 162 positively significant and RCP 8.5 chains 280. However, all GCM-RCM chain groups mostly show no significant trend regarding mean precipitation and mean maximum daily runoff. Mean snowmelt can be neglected for the same reason as for FF and SRF events. RoSF events show an inversed pattern compared to LRF events. The RCP 2.6 chain group mostly shows no significant trend regarding the frequency, with only 29 of 307 catchments in the western Swiss Plateau having significantly less RoSF events and 10 catchments scattered around in the high-altitude catchments in the Alps having significantly more. RCP 4.5 and 8.5 chains identify 115 and 129 catchments having a significant negative trend, the majority of them in the lowland. However, hardly any catchment shows a trend regarding mean precipitation, mean snowmelt and mean maximum daily runoff, regardless of the GCM-RCM-chain group.
For SMF and GMF events, the analysis is more challenging, since both flood types have low values in mean total-count, even though almost all catchments show no significant increase or decrease, according to the Mann-Whitney-U test.

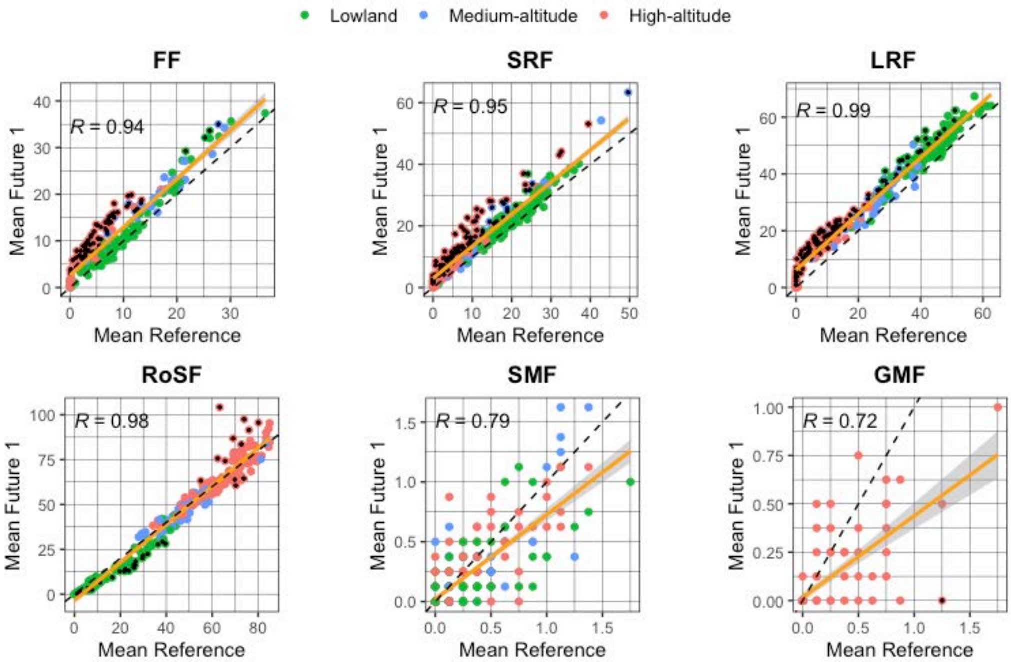

Figure 23: Frequency comparison between the reference period and first future period, coloured by catchment groups (RCP2.6). The dashed line represents equal values in both periods (reference period = future period) and the orange line represents the linear approximation between both periods). Values that significantly differ are highlighted black. The R-value stands for the Pearson’s R-coefficient.

The main challenge is that for each catchment, there is no consistency in the amount of SMF and GMF events between all GCM-RCM chains in both periods if SMF and GMF events are identified. There is no catchment, where all of the eight simulations identify SMF events as such and hence, this then gives too low values for mean precipitation, mean snowmelt and mean maximum daily runoff for SMF and GMF events, respectively.

Pearson’s R coefficients for the mean total count are above between 0.94 and 0.98 for all GCM-RCM chains and for FF, SRF, LRF and RoSF events, which indicates a good linear correlation (Figure 23 for RCP 2.6 + Figures 39 and 40 for RCP 4.5 and 8.5, respectively in the appendix). The resulting smoothing line (orange) is positively offset with a similar slope compared to the dashed line for FF, SRF and LRF events, implying a roughly equal increase in average. For RoSF events the linear approximation is partly bellow and partly above the dashed line, presumably resulting in less RoSF events, where their frequency was already low and more events, where it was high, respectively.

3.2.4. Comparison to changes in meteorological and catchment conditions

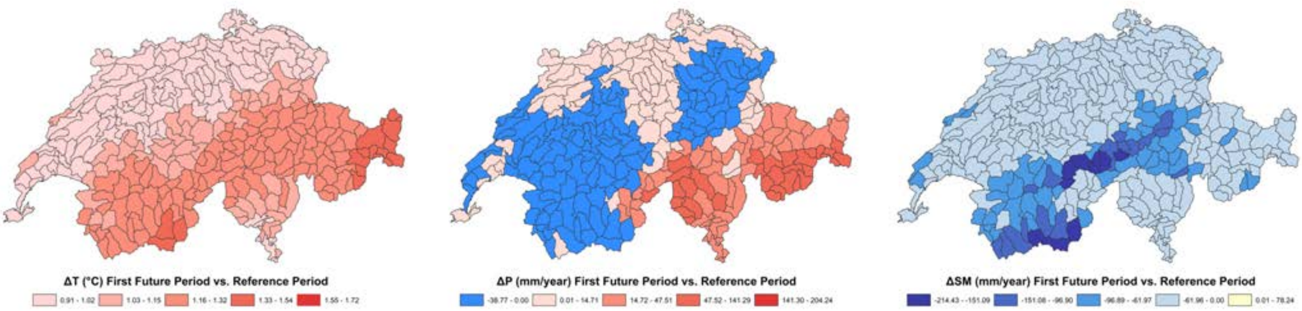

Figure 24: Changes of mean annual temperature (ΔT), mean annual precipitation (ΔP) and mean annual snowmelt (ΔSM) during the 2018-2058 period, for RCP 2.6 chains

Figure 24 shows changes of mean annual temperature ΔT, precipitation ΔP and snowmelt ΔSM for RCP 2.6 chains; RCP 4.5 and 8.5 chains are in the appendix (Figures 41 and 42). During the first future period, the average of all GCM-RCM chains of mean annual temperature is higher in all catchments and range from 0.9°C and 1.5°C for RCP 2.6 chains, 1.1°C and 1.6°C for RCP 4.5 chains as well as 1.4°C and 1.9°C for RCP 8.5°C. Catchments in the Swiss Plateau experience the lowest increase, while catchments in the eastern Alps are likely to have the highest increase.

ΔP ranges from -75.3mm/year to 141.3mm/year, for all GCM-RCM chains, with relative changes ranging from -2.4% and 5.6%. The distribution of positive and negative changes is different depending on the chosen mean of GCM-RCM chains. According to RCP 2.6 chains, western and eastern Pre-Alps show a slight decrease compared to the reference period, while catchments in the southern and eastern Alps show a massive absolute increase. The pattern changes for RCP 4.5 and 8.5. Both chains mostly show a decrease of annual precipitation. Here catchments over the whole Alps would experience less precipitation, whereas catchments in in northern Switzerland would experience more precipitation. ΔSM is negative in all catchments but one, for all GCM-

RCM chains, and can go down to -230mm/year. In central and western Alps, the change is the highest whereas catchments in other regions experience a slighter decrease of snowmelt. One catchment shows an increase in mean annual snowmelt. However, it is a possible outlier since this catchment is very small (ID=239, area=2.25km^2). Judging from its location, it is likely a single mountain in east Valais, near Simplon.

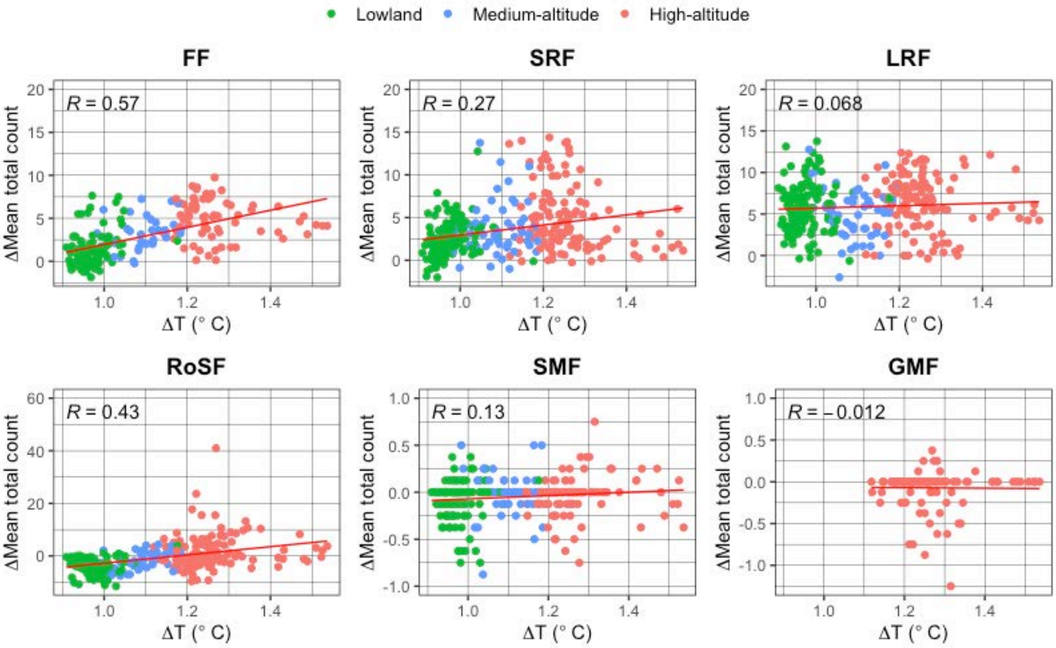

Figure 25: Correlation analysis between mean annual temperature changes (ΔT) and changes of mean total count, coloured by catchment groups, during the 2018-2058 period, for RCP 2.6. The red line represents the linear approximation. The R value represents the Pearson's R coefficient.

Figure 25 shows the correlation between the mean change in annual temperature and the mean total count, for RCP 2.6 chains, sorted by flood types. Figures for RCP 4.5 and 8.5 chains can be found in appendix (Figure 44 and 45).

For FF events, the calculated Pearson's R coefficient is 0.57, 0.57 and 0.51 for RCP 2.6, 4.5 and 8.5 chains, respectively, indicating a slight positive correlation, when looking individually. However, the change in absolute frequency does not differ too much, when comparing these three plots (Figures 25, 44 and 45). In lowland catchments, where the temperature difference is the lowest in all GCM-RCM chains, the difference in FF events is lower compared to high-altitude and medium-altitude catchments. As a result, it can be said that a higher temperature in each altitude group does not necessarily result in higher frequency of FF events. A change in ΔT is presumably coupled on the mean catchment altitude.

SRF events have Pearson's R coefficient of 0.27, -0.19 and -0.08, for RCP 2.6, 4.5 and 8.5, respectively. This does not imply a good linear correlation and a higher change in ΔT likely does not result in a higher increase of SRF events. Furthermore, there is no real increase in the number of events, when comparing all three chains. The distribution is more arbitrary for all GCM-RCM-chain groups and lowland, medium-altitude and high-altitude catchments can all have different changes in the number of events, regardless of the change in ΔT.

The Pearson's R is 0.07, -0.04 and -0.51 for LRF events according to RCP 2.6, 4.5 and 8.5 chains, which indicates that a higher ΔT does not necessarily lead to a higher increase in the mean total counts, over all catchment groups. The increase in LRF events is arbitrarily for all ΔT ranges. Although that the RCP 8.5 chains statistically show a slight linear correlation, looking at the graphs (Figures 25, 44 and 45), the distribution of the points looks more arbitrarily .

Looking at RoSF events, the overall Pearson's coefficient is 0.43, 0.22 and 0.17, for RCP 2.6, 4.5 and 8.5 change, respectively. This implies that a higher change in ΔT does not lead to a higher change in RoSF events. For the RCP 2.6 chains, a slight clustering by altitude group can be identified; most lowland catchments show a decrease in RoSF events, whereas medium- and high-altitude catchments show a slight decrease. However, the clustering is more constant, meaning that an increase in ΔT, on average results in an equal reduction or increase of RoSF events, depending on the altitude. For SMF and GMF events, a higher ΔT does not lead to more events. This is due to the fact that only a few events of those two flood types are identified, regardless of the GCM-RCM chain.

In Figure 26 and 27, the mean annual precipitation values ΔP, as well as mean annual snowmelt ΔSM are compared to the changes in the mean total count, for RCP2.6 chains. Comparisons for RCP 4.5 and 8.5 chains are in appendix (Figures 45, 46, 47 and 48) Changes in ΔSM can be neglected for FF, SRF and LRF events, since it is not a decisive variable regarding their occurrence.

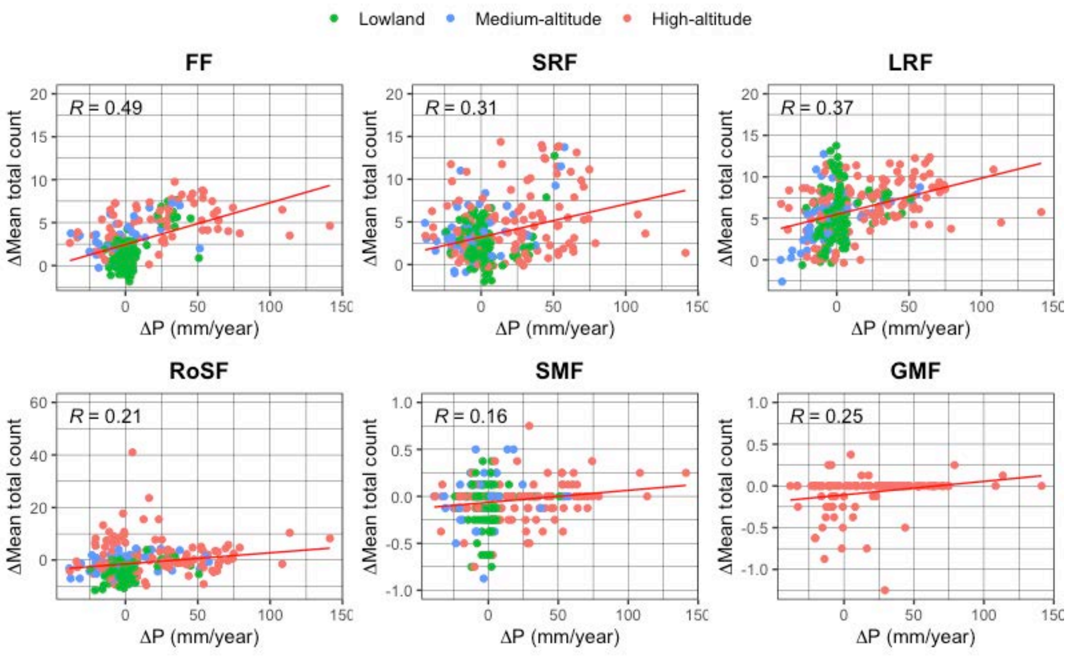

Figure 26: Correlation analysis between mean annual precipitation changes (ΔP) and changes of mean total count, coloured by catchment groups, during the 2018-2058 period, for RCP 2.6. The red line represents the linear approximation. The R value represents the Pearson's R coefficient.

Generally, it can be observed that a change in ΔP has a minor effect on the change in the mean frequency of FF, SRF, LRF and RoSF events, since the Pearson's R is often around zero, regardless of the GCM-RCM chain group. Some catchments have a lower mean annual precipitation compared to the reference period, while others have a slightly (RCP 4.5 and 8.5 chains) or massive increase (RCP 2.6 chains). Even though that the change in ΔP is sometimes positive or negative, an increase is mostly identified in all catchments, regardless of their altitude group. Consequently, no clear trend can be determined. The same can be applied for ΔSM for snowmelt events, which has a Pearson's R of -0.24, 0.08 and 0.04, for RCP 2.6, 4.5 and 8.5, respectively. Here, a reduction of snowmelt generally results in a decrease of RoSF events.

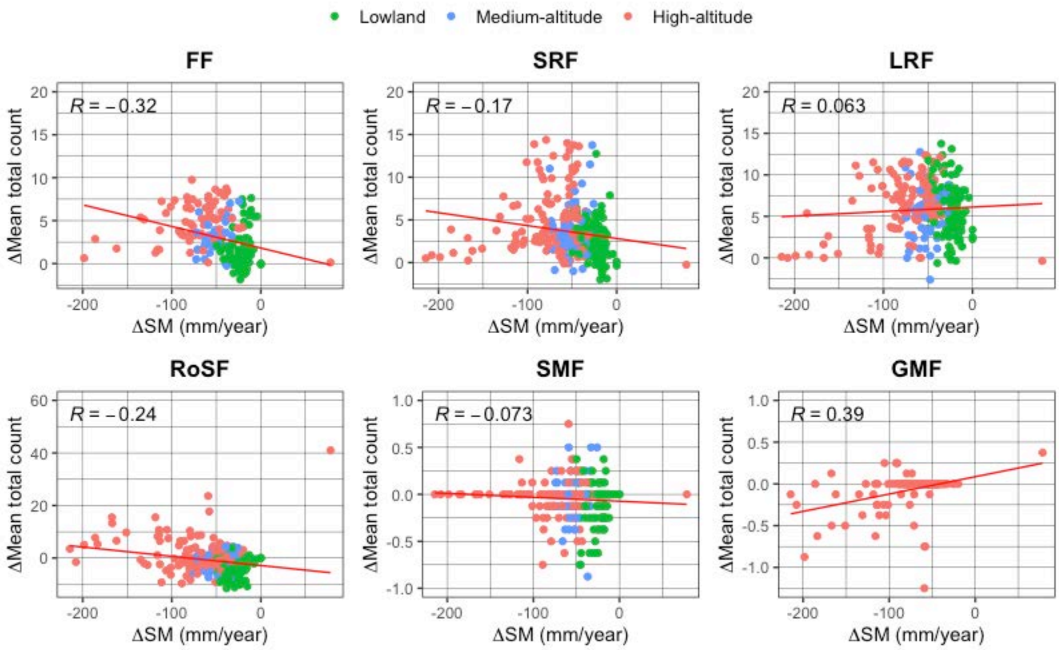

Figure 27: Correlation analysis between mean annual snowmelt changes (ΔSM) and changes of mean total count, coloured by catchment groups, during the 2018-2058 period, for RCP 2.6. The red line represents the linear approximation. The R value represents the Pearson's R coefficient.

3.3. Second future period (2059-2099)

Similar to section 3.2, the range of the reference period and the second period is different (37 years and 41 years, respectively). Hence, it is possible that some increases may be caused by this 4-year difference.

3.3.1. Frequency trends by altitude group

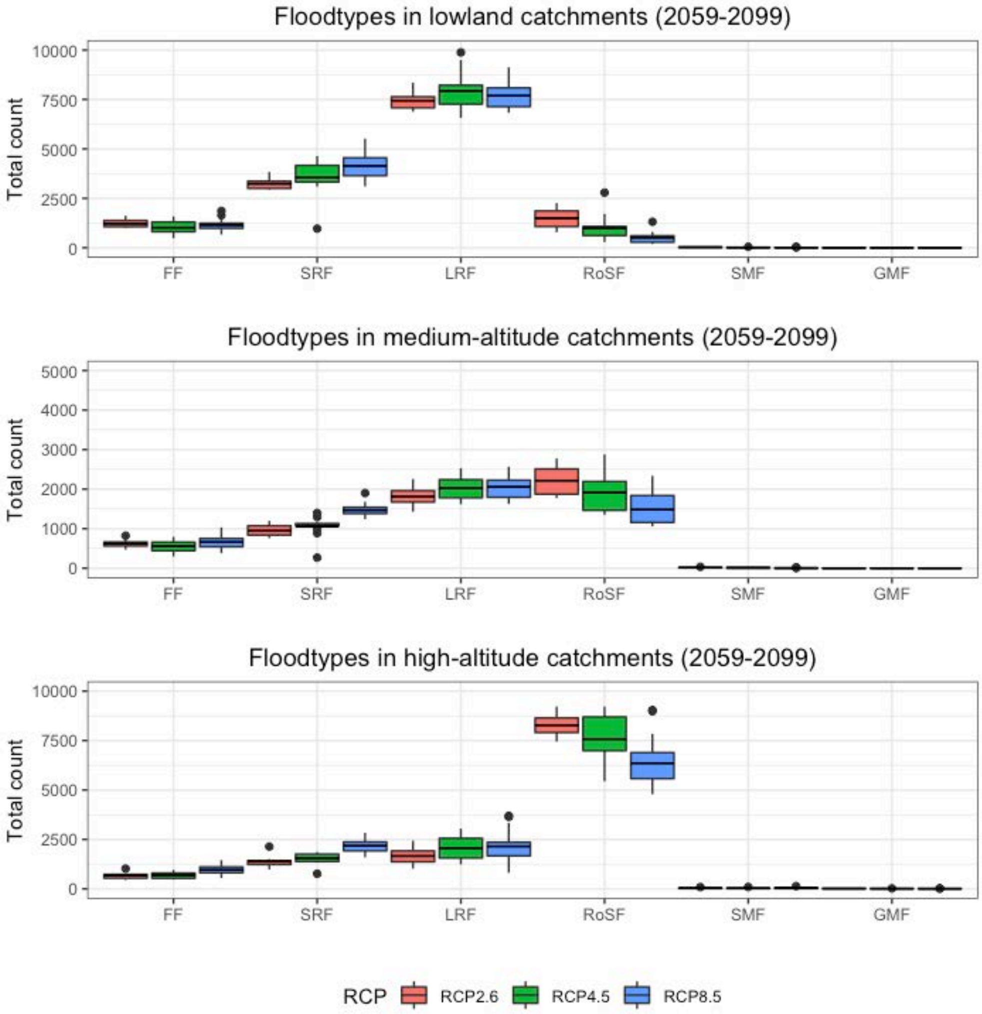

Figure 28: The boxplots show the range of the total count for the six different flood types, for RCP2.6 simulation, summarized by altitude, for the 2059-2099 period. The red line shows the respective total count of the control simulation from the reference period as comparison

During the second period, changes in the total count are enhanced for some flood types, compared to the first future period (Figure 28).

Lowland catchments show a slightly higher mean frequency of all simulations regarding FF and SRF events, with respect to the first future period. The mean of LRF events is considerably higher compared to the first future period, whereas RoSF events are expected to slowly dissipate, with increasing level of RCP. The mean frequency of RoSF events in medium-altitude catchments is slightly lower compared to the first future period, for RCP 2.6 chains, whereas for RCP 4.5 and 8.5, the mean frequency is considerably lower. All flood types except LRF events in high-altitude catchments show a slightly higher or a similar mean frequency with respect to the first future period, for

RCP 2.6 chains. Mean values of RCP 4.5 and 8.5 chains for RoSF events are considerably lower.

3.3.2. Seasonal pattern trends by altitude group

Table 13: Seasonal trends of all flood types in the respective altitude groups, for both crisp tree and fuzzy tree, using RCP 2.6 simulations of the 2059-2099 period. Note that these changes represent mean trends per altitude group. Changes in individual catchments may deviate. The number in brackets next to the altitude group represents the number of catchments.

	All Seasons		Spring		Summer		Autumn		Winter	
Lowland (139)	Crisp	Fuzzy	Crisp	Fuzzy	Crisp	Fuzzy	Crisp	Fuzzy	Crisp	Fuzzy
FF (diff %)	21.02	21.47	41.70	45.28	15.04	15.05	15.19	14.03	0.00	0.00
SRF (diff %)	18.69	18.59	19.90	18.79	11.75	11.81	8.65	8.97	30.19	30.46
LRF (diff %)	19.81	19.88	18.46	18.45	25.22	25.25	9.96	10.03	26.16	26.32
RoSF (diff %)	-24.60	-24.64	-36.17	-35.99	-57.81	-59.43	-29.00	-29.84	-16.78	-16.93
SMF (diff %)	-26.05	-27.89	-40.99	-41.39	0.00	0.00	-100.00	-100.00	-1.01	-5.76
GMF (diff %)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mixed (% change)		-0.21		0.99		-0.15		0.84		-1.63
Mid-altitude (49)	Crisp	Fuzzy	Crisp	Fuzzy	Crisp	Fuzzy	Crisp	Fuzzy	Crisp	Fuzzy
FF (diff %)	29.42	29.65	68.83	74.87	27.28	27.22	20.86	20.08	0.00	0.00
SRF (diff %)	35.27	34.90	101.88	95.87	25.23	25.88	15.16	15.59	133.10	127.87
LRF (diff %)	33.02	33.13	74.53	74.97	30.23	30.04	11.83	11.97	94.77	95.12
RoSF (diff %)	-4.02	-4.01	-11.66	-11.68	-35.58	-35.31	-11.33	-11.91	21.58	21.80
SMF (diff %)	-4.96	-7.40	-13.76	-14.89	0.00	0.00	-100.00	76.10	88.89	53.19
GMF (diff %)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mixed (% change)		0.22		1.89		-1.48		-0.85		1.65
High altitude (119)	Crisp	Fuzzy	Crisp	Fuzzy	Crisp	Fuzzy	Crisp	Fuzzy	Crisp	Fuzzy
FF (diff %)	120.31	122.44	833.33	920.64	117.62	117.96	121.50	125.64	0.00	0.00
SRF (diff %)	74.81	74.66	326.19	317.97	96.44	96.62	64.94	64.69	130.91	141.52
LRF (diff %)	82.10	82.11	217.44	210.18	106.28	105.96	63.39	63.49	520.00	578.32
RoSF (diff %)	7.86	7.84	43.04	42.98	-31.81	-31.82	-32.29	-32.22	122.50	122.00
SMF (diff %)	33.79	36.05	47.10	56.19	0.00	2.87	0.00	0.00	0.00	0.00
GMF (diff %)	-28.77	-29.57	19.23	14.02	-38.14	-38.98	0.00	-100.00	0.00	0.00
Mixed (% change)		0.14		0.48		1.42		-0.70		-0.47

During the second future period, depending on the GCM-RCM-chain group, changes either remain similar compared to the first future period, or are intensified in both directions. Table 13 shows the average percentage changes for the chains belonging to RCP 2.6, between the second future period and the reference period. Tables for other chains, as well as Tables for absolute values for all chains can be found in the appendix (Tables 34, 35, 36, 37 and 38), as well as absolute and relative numbers for all chains, and differences between the first and second period.

Lowland catchments show an increase of FF, SRF and LRF events of +41.7%, 19.9 % and 18.5%, respectively, for RCP 2.6 chains compared to the reference period. For RCP 4.5 and 8.5 chains, these changes are +36.0%, +37.9%, +37.7% and +41.2, +72.3%, +51.4%, respectively. These trends are considerably increased for these three flood types with respect to the first future period, except for FF events in RCP 2.6 and 4.5 chains, where it almost remains the same (Table X, Y). During summer, RCP 2.6 and 4.5 chains on average identify more rainfall-related events (FF, SRF and LRF), compared to the reference period, while RCP 8.5 chains identify minor changes. During autumn, FF events increase by 15.2% for RCP 2.6 chains, whereas RCP 4.5 and 8.5 show an average decrease (-4.3% and -28.2%, respectively). However, these chains show an increase of SRF events instead (+37.7% and +22.1%, respectively). LRF events show a slight increase, with respect to the reference period, for RCP 2.6 and 4.5 chains, while RCP 8.5 chains identify a slight decrease. However, the absolute average number of LRF events over all lowland catchments still remains considerably high. During winter, SRF events increase by 30.2% (RCP 2.6), 56.7% (RCP 4.5) and 89.5% (RCP 8.5), and LRF events by 26.2%, 32.9% and 79.9%, respectively. The average frequency of RoSF events during spring remains similar for RCP 2.6 chains, whereas for RCP 4.5 and 8.5 chains, this average is further decreased (-51.9% and -66.0%). During the summer months, changes RoSF events are not so relevant, where less than 10 events are identified in all periods for all GCM-RCM chains, while in autumn and winter, all GCM-RCM chains identify a decrease compared to the reference period.

All GCM-RCM-chains simulate an increase in the mean number of events of almost every single rainfall-related flood type in every season for medium-altitude catchments. During the spring months, FF events increase by 68.8%, 98.6% and 197.4%, SRF events by 101.9%, 92.5% and 271.2% and LRF events by 74.5%, 113.1% and 178.2%, all belonging to RCP 2.6, 4.5 and 8.5 chains, respectively. The high percentages indicate, that during the reference period there were considerably less rainfall-related events in medium-altitude catchments in spring, which is likely caused by a higher temperature during spring months. During the summer, RCP 2.6 chains identify the highest increase in FF and SRF events, whereas RCP 4.5 have the lowest increase. The mean frequency of LRF events increases for RCP 2.6 and 4.5 chains (+30.2% and +6.6%, which is in contrast to RCP 8.5 chains that show a decrease of LRF events (-16.7%). Similarly, the same chains calculate a decrease of FF events during autumn, and RCP 2.6 and 4.5 chains an increase. SRF events increase by 15.2%, 43.8% and 48.1%, and LRF events by 11.8%, 20.2% and 13.2% (RCP 2.6, 4.5 and 8.5 chains, respectively). During the winter months SRF and LRF events show the highest relative differences. For SRF events, this increase is 113.1%, 254.6% and 612.1% and for LRF events 94.8%, 164.2% and 517.3%. Similar to the spring months, the mean frequency was considerably low during the first period for (mostly under 100 over all catchments). RoSF events are likely to decrease in all seasons, except during winter. The highest relative decrease is expected during the spring and summer for all GCM-RCM chains with RCP 8.5 showing the most significant decrease. In autumn, this decrease is less severe. During winter months, an increase is expected for all GCM-RCM chains. Hence, the seasonality of RoSF events mostly shifts from spring, summer and autumn towards the winter.

Regardless of the GCM-RCM chain group, the frequency of rainfall-related events is higher in high-altitude catchments. Compared to medium-altitude catchments, the relative increase is considerably higher for all of these three flood types. The most noticeable changes are identified during the spring and winter. In spring, FF events increase by 833.3%, 2532.5% and 9036.4%, SRF events by 326.2%, 1013.4% and 3383.0% and LRF events by 217.4%, 854.0% and 2848.5%, all for RCP 2.6, 4.5 and 8.5 chains, respectively. The high percentage changes imply that hardly any of these three events is identified during the reference period, but a lot more during the second future period. This is in accordance to the absolute numbers (see Figures 25, 27, 29 versus 34, 35 and 36 in the appendix) and means, that a lot more rainfall-related events can be expected in high-altitude catchments during spring. In other seasons, the relative frequency increase is less severe compared to the one during spring, whereas the increase in absolute numbers may be higher. RoSF events decrease during summer and autumn months, for all GCM-RCM-chains, with RCP 8.5 showing the most severe decrease. However, during the spring and winter months, all GCM-RCM-chains expect an increase, with RCP 8.5 again showing the most severe ones in both seasons. Hence, a shift from summer and autumn towards spring and winter is likely to occur. Over all seasons, RCP 4.5 and 8.5 expect a decrease of RoSF events, as already described in section 3.2.1.

SMF and GMF events have too low values in general, and hence their changes have a rather arbitrary pattern, depending on the GCM-RCM chain. More events would be needed, to compare these changes

3.3.3. Significance of differences in frequency and intensity with respect to reference period

Similar to the first period (section 3.2.3) an unpaired two-tailed t-test is performed for FF, SRF, LRF and RoSF events, and a Mann-Whitney-U test for mean total counts of SMF and GMF events since they are not normally distributed. Additionally, a t-test is performed for mean precipitation, mean snowmelt and mean maximum daily runoff as well. For all tests, a p-value of 0.05 is selected.

All GCM-RCM-chains show more catchments with significant trends the mean frequency in both ways, for each flood type (Table 14), compared to the first future period (Table 12). Figure 29 shows the trends of the RCP 8.5 chains, whereas Figures 49 and 50 in the appendix show changes of RCP 2.6 and 4.5 chains). Similar to section 3.2.3, possible false positives and false negatives are excluded for changes in mean precipitation, mean snowmelt and mean maximum daily runoff. Most catchments experience an increase of FF events, compared to the reference period. They are significant in every GCM-RCM chain, with RCP 2.6 chains having 91 positively significant catchments, RCP 4.5 having 76 and RCP 8.5 having 102. Mean precipitation is mostly not significant for RCP 2.6 and 4.5 chains, whereas the in mean of RCP 8.5 chains, 64 catchments are identified having a higher mean precipitation during FF events. Thus, for RCP 8.5 simulations, FF events are expected to have a higher mean precipitation, to a certain degree. Mean maximum daily runoff is mostly not significant for all GCM-RCM simulations.

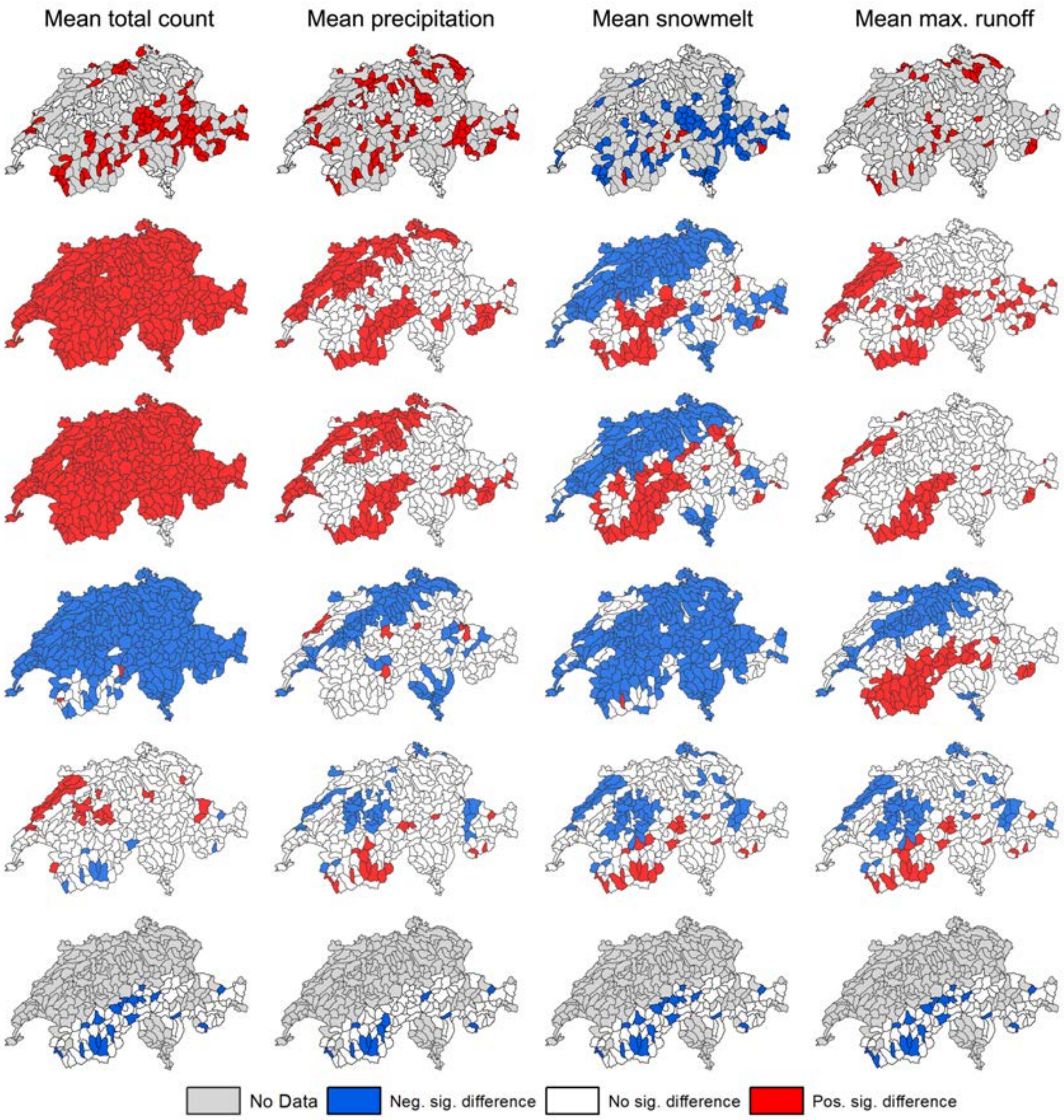

Figure 29: The maps show, if the trend during the 2059-2099 period of mean total count, mean precipitation per event, mean snowmelt per event, mean max. daily runoff per flood type event is significant, compared to the reference period, for RCP 8.5 chains. Gray catchments in FF and GMF indicate catchments, where FF and GMF can not occur at all (>150km² and unglaciated, respectively)

SRF events mostly have a higher frequency as well in the majority of the catchments. 142 of them are positively significant for RCP 2.6 chains, while RCP 4.5 and RCP 8.5 chains identify 274 and 301 catchments (which is almost the whole of Switzerland, see Figure 29), respectively, being positively significant. The mean precipitation of SRF events is mostly not significant for RCP 2.6 and RCP 4.5 chains, while for RCP 8.5 simulations the number of catchments having a significant positive increase is 93. Similar to FF events, for RCP 8.5 chains SRF events will partly produce more precipitation, most of them in the high altitudes. Mean maximum daily runoff during SRF events is likely to have no significant trend, whereas RCP 8.5 chains model 47 catchments having a statistically significant increased runoff.

Table 14: Corrected number of catchments of positive, negative and non-significant trends for mean precipitation, mean snowmelt and mean maximum daily runoff for each flood type, during the second future period

RCP2.6	Count			P/Event [mm]			SM/Event [mm]			Max Q/Event [mm]		
Significance	N	0	P	N	0	P	N	0	P	N	0	P
FF	0	106	91	0	171	6	26	156	7	0	159	27
SRF	0	165	142	0	280	10	13	274	8	0	285	12
LRF	0	100	207	0	285	4	21	262	7	1	288	2
RoSF	25	249	33	2	302	2	26	274	7	0	283	23
SMF	2	302	3	0	298	0	0	299	0	0	300	0
GMF	2	304	1	0	93	0	0	93	0	0	92	0
RCP4.5	Count			P/Event [mm]			SM/Event [mm]			Max Q/Event [mm]		
Significance	N	0	P	N	0	P	N	0	P	N	0	P
FF	0	121	76	0	168	8	26	112	0	0	172	5
SRF	0	33	274	0	271	6	72	197	1	0	271	8
LRF	0	31	276	0	263	12	91	172	7	0	274	6
RoSF	186	116	3	0	263	8	90	171	43	0	247	19
SMF	6	296	4	0	288	0	0	286	0	0	287	0
GMF	0	93	3	0	90	0	0	88	0	0	89	0
RCP8.5	Count			P/Event [mm]			SM/Event [mm]			Max Q/Event [mm]		
Significance	N	0	P	N	0	P	N	0	P	N	0	P
FF	0	95	102	0	108	64	15	100	0	0	161	19
SRF	0	6	301	0	179	93	116	117	14	0	221	47
LRF	0	15	292	0	183	85	123	116	27	0	254	17
RoSF	278	24	3	17	193	10	144	61	2	0	158	62
SMF	11	266	29	0	248	0	0	223	0	0	224	0
GMF	1	91	5	0	83	0	0	78	0	0	77	0

The mean number of LRF events is higher for most catchments. While RCP 2.6 chains only have 142 catchments with a significant positive trend, RCP 4.5 and 8.5 chains have 276 and 292 catchments, out of 307. Similar to FF and SRF events, the mean precipitation is not significant in most catchments in RCM 2.6 and 4.5 chains, whereas for RCP 8.5 chains, 85 catchments show a positive trend. This means that in some catchments, LRF events will produce more rainfall, possibly indicating that their duration is longer. The mean maximum daily runoff is not significantly different in most catchments, regardless of the GCM-RCM-chain group. Differences in mean snowmelt are not relevant for neither FF, SRF or LRF events.

RoSF events are not significantly different regarding their frequency, for RCP 2.6 chains, with only 25 and 33 catchments showing either a significant negative or positive decrease or increase, respectively. RCP 4.5 and 8.5 chains identified 186 and 278 catchments, respectively, having a significant negative trend. Thus, most catchments in Switzerland are likely to expect a decrease in RoSF events, with a higher RCP simulation. On the other hand, most of the catchments show no significant increase or decrease in mean precipitation, whereas mean snowmelt during RoSF events is likely to significantly decrease in 26, 90 and 144 catchments (RCP 2.6, 4.5 and 8.5, respectively). It is interesting, that some catchments show a significant increase in the mean maximum daily runoff, for RCP 8.5 simulations.

The number of SMF and GMF events is mostly low and inconsistent in every catchment. Although the Mann-Whitney-U test shows mostly no significant changes for most catchments, this is not necessarily true. More events would therefore be needed

For the mean total count, Pearson's R coefficients range from 0.95 to 0.99 for FF, SRF, LRF and RoSF events, implying a good linear correlation (Figure 30, for RCP 8.5, Figures 51 and 52 for RCP 2.6 and 4.5, respectively). The correlation (orange) is either positive (FF, SRF, LRF) or partly negative and positive offset (RoSF), compared to the dashed line, which would indicate no increase or decrease.

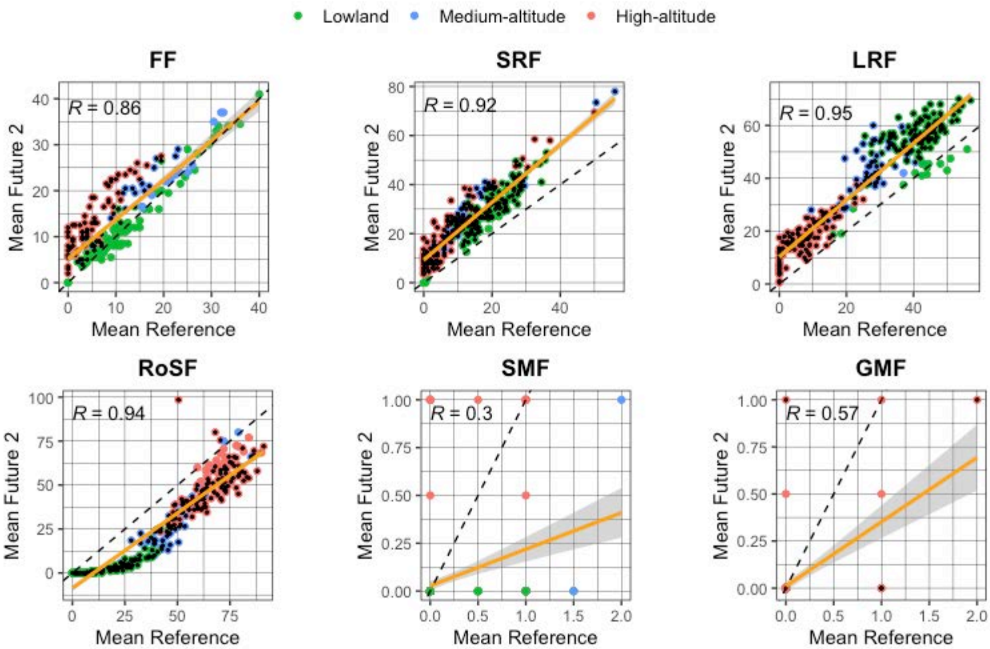

Figure 30: Frequency comparison between the reference period and second future period, coloured by catchment groups, for RCP 8.5 chains. The dashed line represents equal values in both periods (reference period = future period) and the orange line represents the linear approximation between both periods). Significant values are highlighted black. The R-value stands for the Pearson's R-coefficient.

Overall, more catchments indicate a significant positive increase in rainfall-related flood events, compared to the first future period. However, a further increase in intensity is mostly not significant in most cases. For RoSF events, there is a significant decrease in mean snowmelt in some catchments, which does not affect the mean maximum runoff. In other catchments mean maximum daily runoff is higher, mostly induced by a significant increase in mean precipitation.

3.3.4. Comparison to changes in meteorological and catchment conditions

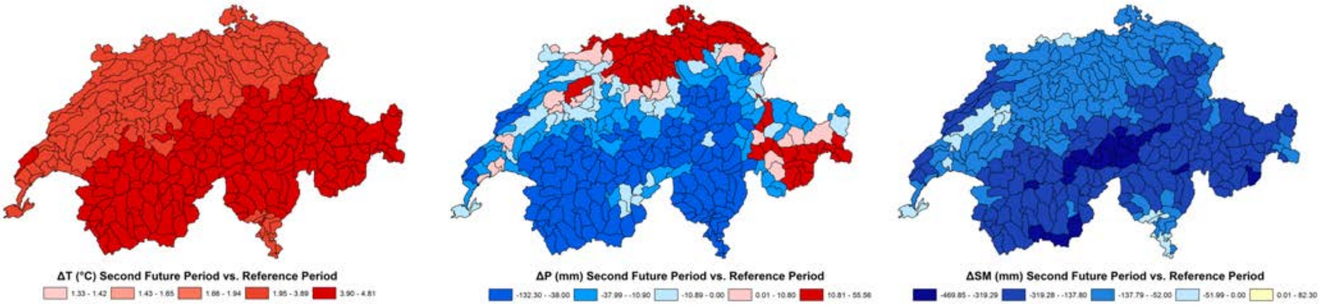

Figure 31: Changes of mean annual temperature (ΔT), mean annual precipitation (ΔP) and mean annual snowmelt (ΔSM) during the 2059-2099 period, for RCP 8.5 chains.

Figure 31 shows the changes in mean annual temperature, mean annual precipitation and mean annual snowmelt for RCP 8.5 chains (for RCP 2.6 and 4.5, see appendix Figures 53 and 54, respectively). The average mean annual temperatures of all are higher in all three GCM-RCM-chain groups during the second future period, compared to the first. ΔT ranges from 1.0°C to 1.7°C for RCP 2.6, 2.0°C. and 2.8° for RCP 4.5 and 3.7°C and 4.8°C. The spatial pattern of temperature changes is similar compared to the first future period, with the (eastern) Alps having the highest positive trend. Mean annual precipitation (ΔP) shows fewer catchments with negative deviations compared to the first future period, for RCP 2.6 chains. Only some catchments in the western and eastern Pre-Alpes have slightly lower absolute precipitation values (up to -21.0mm/y), whereas catchments in southern and eastern Alps have up to 204.2mm/y more precipitation. Catchments in the central Swiss Plateau show minor differences. Relative changes with respect to the reference period lie between -1.17% and 8.44%. RCP 4.5 chains show a decrease in precipitation in most catchments of the western Alps, Pre-Alps and Jura Region, whereas catchments in the Swiss Plateau and eastern Alps mostly show an increase. For RCP 8.5 chains, most catchments show a decrease in mean annual precipitation, and an increase is only identified in north-eastern Swiss Plateau and in some catchments of Canton of Graubünden. Similar to the first period, during the second period the same catchment (ID=239) presumably is an outlier regarding mean annual snowmelt (ΔSM), since it is the only catchment where more snowmelt is modelled. All other catchments show negative snowmelt trends. The catchments in the Central Alps show the most considerable decrease in snowmelt: RCP 2.6 chains identify a maximum decrease of -230.5mm/y, RCP 4.5 chains -330.6mm and RCP 8.5 chains -469.9mm/y. The higher the catchment's mean altitude is, the more likely the mean annual snowmelt will be decreased.

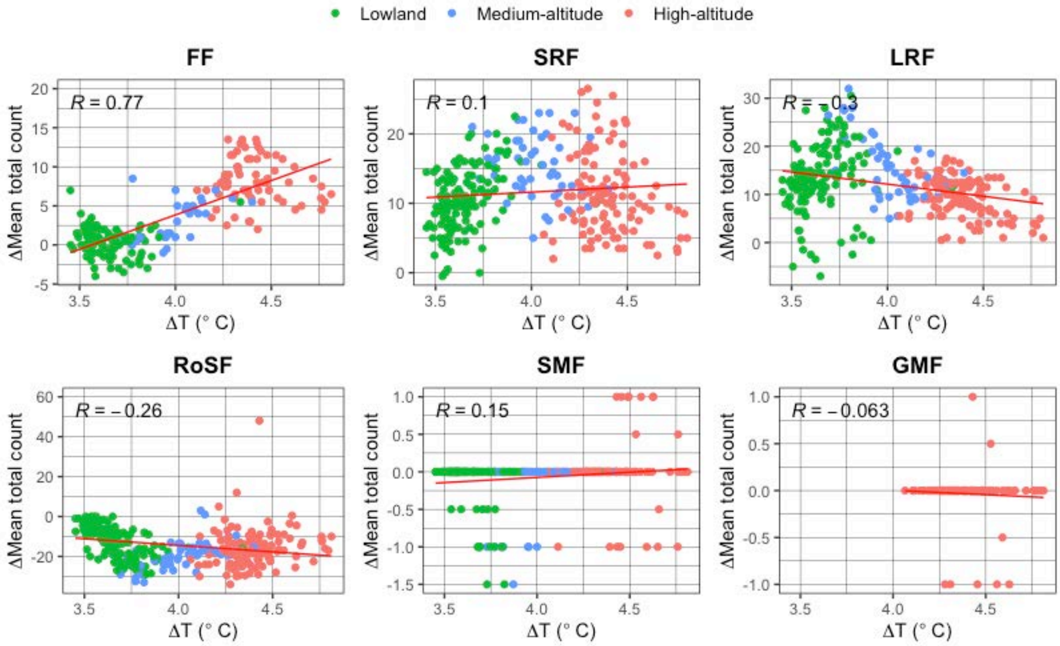

Figure 32: Correlation analysis between mean annual temperature changes (ΔT) and changes of mean total count, coloured by catchment groups, during the 2059-2099 period, for RCP 8.5 chains The red line represents the linear. The R value represents the Pearson's R coefficient.

Figure 32 shows the comparison of the changes in mean annual temperature and mean total count for the RCP 8.5 chains. Comparisons of RCP 2.6 and 8.5 chains are attached in the appendix (Figures 55 and 56). For FF events, Pearson' R coefficient is 0.39, 0.7 and 0.77, for RCP 2.6, 4.5 and 8.5 chains, respectively. This is clearly visible in the Figures mentioned above, where a higher increase in ΔT likely increase the mean number of FF events. However, it is highly dependent on the altitude, since most catchments with a higher increase in ΔT are high-altitude catchments. This also applies, when comparing the three GCM-RCM chain groups. For instance, high-altitude catchments RCP 8.5 chains show a higher increase of the mean ΔT, because the temperature there increases the highest. Hence, it is better to say that higher elevated catchments likely experience a higher increase in FF events with increasing temperature, whereas for lowland catchments there is almost no change, regardless of the GCM-RCM chains.

Frequency changes of other flood types (SRF, LRF and RoSF) show no significant linear correlation with increasing temperature. The changes have more of an arbitrary pattern, meaning that an increase in ΔT does not necessarily lead to an increase in the mean number of events. However, when including the altitude, and comparing all GCM-RCM chains, LRF events in lowland catchments show a higher mean frequency with increasing RCP level.

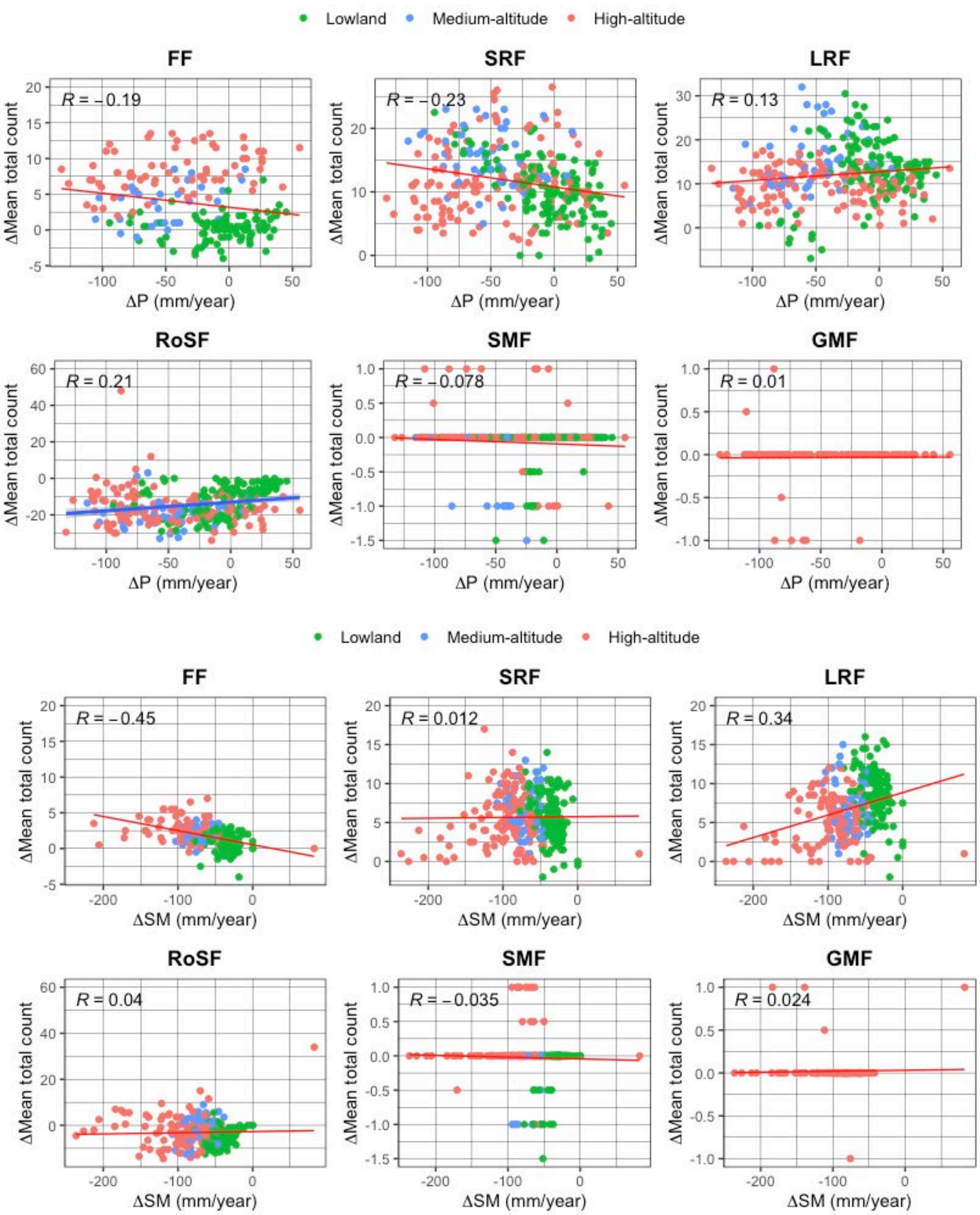

Figure 33: Correlation analysis between mean annual precipitation changes (ΔP) and changes of mean total count, and between mean annual snowmelt (ΔSM) and changes of mean total count, respectively, coloured by catchment groups, during the 2059- 2099 period, for RCP 8.5. The red line represents the linear approximation and the blue line the local regression curve. The R value represents the Pearson's R coefficient.

Figure 33 shows the correlation between ΔP and frequency change, as well as between ΔSM and frequency change, for RCP 8.5. Changes for RCP 2.6 and 8.5 are in the appendix (Figures 57 and 58). Similar to the first period, differences and correlations of ΔSM can be neglected for FF, SRF and LRF events.

Overall, Pearson's R coefficients are mostly low for all flood types and for all GCM-RCM chains. This means that the differences in ΔP alone can not explain the increase or decrease of a certain flood type. The same applies to the ΔSM for RoSF events. The increase in the number of events of follows an arbitrary pattern.

SMF and GMF events have too low and inconsistent average numbers of events. Thus, no clear conclusions can be made, and further research is needed to analyse it.

Comparing the total number of events between both periods, shows a good correlation for FF, SRF, LRF and RoSF events (Figure 34 for RCP 2.6 and Figures 59 and 60 for RCP 4.5 and 8.5, respectively). Pearson's R coefficients are over 0.9 for all three GCM-RCM chains, for FF, SRF, LRF and RoSF events. The linear approximation is parallel to the dashed line (which would indicate that the number of events remains the same in both periods). Thus, it can be said that most catchments have roughly an equal level of increase or decrease in the number of events, depending on the flood type. Furthermore, the changes in the second period are most severe in RCP 8.5 chains and least in RCP 2.6, compared to the first period.

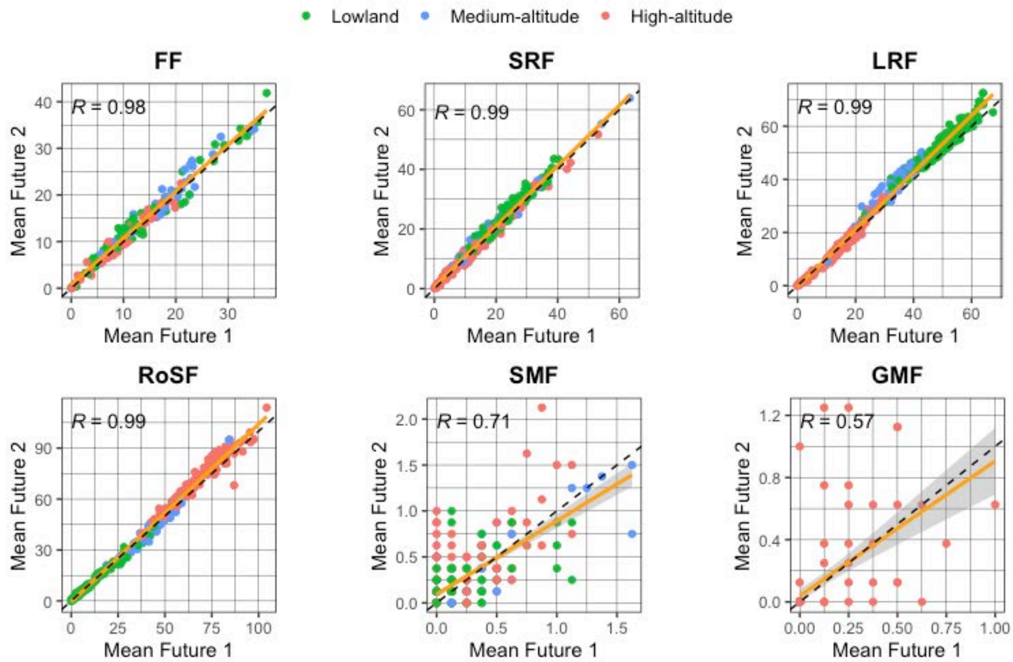

Figure 34: Comparison of the mean frequency between the first future and second future period.

4. Discussion

4.1. Present state

The results during the reference period show that the total count of the different flood types is spatially heterogeneous, using the control simulation with interpolated measurement data.

Generally, three main processes influence the flood events in the analysed catchments: short rainfall, long rainfall and rainfall on snow floods. While lowland catchments mostly experience LRF and SRF events, the proportion of snow-related floods, in particular RoSF events, increases with altitude. Both findings are in accordance with Sikorska et al. (2015) that came to a similar result.
Floods like SMF and GMF, which are induced by snowmelt only, with almost no rainfall (P <12mm), are sparse. This implies that most snow-related floods occur in combination with rainfall events (RoSF), which is in agreement with Sikorska-Senoner & Seibert (2020). The vast majority of RoSF events is observed during spring and summer season.

The difference between the selected approach (crisp or fuzzy tree) is marginal. Depending on the altitude group, between 7.3% and 11.1% of all flood events are categorised as mixed flood type over all seasons. However, during autumn months this ratio can be 31.4% in high-altitude catchments. The values are lower than in previous studies (Merz & Blöschl, 2003; Sikorska-Senoner & Seibert, 2020; Sikorska et al., 2015), but the fuzzy approach used in this work is not the same as used in Sikorska-Senoner & Seibert (2020). Hence, some possible mixed events are lost due to the daily scaling of the data (see section 2.3.3).

Most of the classified mixed events have one major flood generation process and one or more minor processes, i.e. one flood event with 80% LRF and 20% RoSF as classified with the fuzzy approach. The same flood event would be classified as 100% LRF when using the crisp tree approach. This makes sense, due to the functioning of both trees (see section 2.3.3) and is in coherence with previous findings (Sikorska-Senoner & Seibert, 2020; Sikorska et al., 2015).

The frequency of each flood type is highly dependent by a combination of the mean annual temperature, mean annual precipitation, mean annual snowmelt and on the catchment altitude (see section 3.1.4, Figure 13, 14 15, 16). For instance, catchments with a high frequency in RoSF events tend to have a low mean annual temperature, high annual snowmelt and are almost likely to be above 1500m.a.s.l. However, the frequency of RoSF events seems not to be too dependent on the mean annual precipitation (Figure 14).

4.2. Changes in future periods

The GCM-RCM chains with the highest mitigation of greenhouse gases (RCP 2.6) show mean temperature changes between 0.9°C and 1.5°C until the 2058 and between 1.0°C and 1.7°C until 2099, depending on the region. GCM-RCM chains with moderate mitigation of greenhouse gases (RCP 4.5) have changes in mean temperature between 1.1°C and 1.6°C until 2058 and between 2.0°C and 2.8°C until the end of the century. If no mitigation of greenhouse gases is applied (RCP 8.5), temperature will change by 1.4°C to 1.9°C until 2058 and by 3.7°C to 4.8°C. All these values are roughly in the range of the CH2018 (2018) scenarios.

Mean annual precipitation changes between -2.4% and +5.7%, -2.7% and +4.7% as well as -7.6% and +4.0% from the current annual mean, for RCP 2.6, 4.5 and 8.5, respectively, until 2058. Changes until the end of the century are between -1.2% and +8.4%, -2.4% and +1.3% as well as -2.6% and +2.0%, for RCP 2.6, 4.5 and 8.5, respectively. According to the CH2018 (2018), a net median decrease of precipitation values -4% until the end of the century is expected over all seasons, for RCP 2.6. In contrast, for RCP 8.5 a decrease of 23% is expected for southern Switzerland, which is considerably lower than what is calculated with the given dataset of the PREVAH output. However, the uncertainty regarding precipitation changes is high. Hence, the calculated mean values are within the range of CH2018 simulations.

These changes in temperature and precipitation have an influence on flood types. A change in mean annual temperature presumably can be associated with changes in mean annual precipitation and mean annual snowmelt. Both are linked to the maximum available moisture content and wind patterns (Lawrence, 2005). Furthermore, it also depends on how much of the available moisture actually generates precipitation and where the prevailing winds will transport it (Liu et al., 2020). Additionally, evapotranspiration also influences precipitation and is expected to increase with increasing temperatures (CH2018, 2018).

During the first period, a temperature change leads to an increase of FF, SRF and LRF events between two and ten events per catchment, with respect to the reference period, for all GCM-RCM chains. For FF events changes in frequency are dependent on the change in mean temperature but at the same time, it also depends on the altitude. For instance, in high-altitude catchments, an increase of temperature likely leads to a further increase FF events. This is in accordance to CH2018 (2018), which notes that short precipitation events are likely to increase especially in the Alps, due to a reduction of snowfall and snow cover. The number of SRF and LRF events is less dependent on temperature changes and rather follows an arbitrary pattern, while the change of RoSF events is two-sided. On the one hand, a slight increase in temperature, as it is projected for RCP 2.6, can lead to an increase of RoSF events. This is due to the fact that the effect of the above-mentioned reduction in snowfall and snow cover is not too high. On the other hand, a further increase in the mean annual temperature, as in RCP 4.5 and 8.5 chains presumably leads to a decrease of RoSF events in all catchments. This does not mean that the number of events of all flood types decreases; it is more likely that events being identified as RoSF in the reference period, are instead identified as FF, SRF or LRF events.

Regarding the significance of events, it is interesting that although the number of catchments with a significant trend increases with increasing RCP level, the mean intensity of events – derived from mean precipitation, mean snowmelt and mean maximum daily runoff – mostly does not increase. RCP 8.5 chains show a significant increase of the mean intensity of certain flood events, especially during the second future period. On the other hand, not all catchments experience a significant increase regarding the mean intensity. These results confirm the assumption that extreme precipitation events will increase in intensity if greenhouse emissions are not reduced as in RCP 8.5 (CH2018, 2018; IPCC, 2019). It has to be noted that even though some catchments show non-significant trends, especially for RCP 2.6 chains during the first future period, this does not mean that there is no trend at all. It is better to stay that the trend is marginal in those catchments.
It is interesting that even though most catchments show a decrease in mean annual precipitation, especially in the second future period for RCP 4.5 and 8.5 chains, significantly more rainfall-related flood events occur. However, some studies show that a trend is already observed that extreme precipitation events will increase, even though the overall climate becomes drier, when comparing past and today's present measurements (Beniston et al., 1997; Frei & Schär, 2001; Wilhelm et al., 2012).

Seasonal pattern changes show a shift of RoSF events in medium and high-altitude catchments during both future periods. While in medium-altitude catchments more RoSF events tend to occur during winter and less during spring and summer, in high-altitude catchments a shift is expected to occur from summer and autumn towards spring. This effect is more severe for RCP 8.5 chains. These changes can be connected to changes in mean seasonal temperatures. A higher temperature during winter, leads to more liquid precipitation during at the start and end of winter, resulting in delayed snow accumulation at the beginning. Since snowmelt in high-altitude catchments is mostly during the spring and summer period, an earlier beginning of snowmelt leads to this shift of RoSF events, due to an earlier onset of rain events instead of snowfall events. This is in accordance with the CH2018 (2018) scenarios, which simulate a reduction in both snowfall and snow cover. Furthermore, in these scenarios the reduction of snowfall is most severe in the lowland catchments. Here, by the end of the century a snow cover could be a rare occurrence. A reduction of RoSF events presumably leads to an increase in rainfall related events, as already mentioned. In medium- and high-altitude catchments, FF and SRF events are likely to increase in all GCM-RCM chains. For RCP 8.5 chains, the increase is most evident during the second future period. Compared to the reference period, where many medium and high-altitude catchments have a few FF or SRF events, during the second future period considerably more events are identified. This implies that in these catchments the season of extreme short rainfall events starts earlier.

Lowland catchments are likely to experience more SRF and LRF are identified during the winter, with respect to the reference period, whereas in other seasons there is a smaller difference. The difference of LRF events over all seasons is high, compared to the reference period. FF and SRF events are likely to increase during the spring, while a marginal during the summer, the difference is not that high, regardless of the GCM-RCM chains. The reason for this is that a higher temperature in spring generally causes higher precipitation (CH2018, 2018), whereas during the summer months, a decrease in mean precipitation is expected, which could be linked to an increase in evapotranspiration (CH2018, 2018). RoSF events are likely to decrease, especially during spring and winter months. Here, a snow cover is likely to be more absent during winter and hence, less snowmelt can occur that could trigger RoSF events (CH2018, 2018; IPCC, 2019). LRF and SRF events are identified to increase during winter. This is could be due to the fact that during the winter an increase in precipitation is expected in general (CH2018, 2018).

4.3. Limitations

A modified flood tree concept from Sikorska-Senoner & Seibert (2020) is applied in this work. However, as already indicated in the methods (section 2), some modifications are due to the fact that the low temporal resolution of the given dataset. For instance, this limits the possible number of mixed events, when applying the fuzzy tree approach mainly between FF/SRF and LRF events. This could be a reason why less mixed events are identified in the results.

The choice which flood events are analysed (>0.98 percentile of the runoff) has a major influence on the presence of SMF and GMF events. Most catchments only have few events identified as SMF or GMF (in glaciated catchments) and in some catchments they are completely absent. Furthermore, not all single GCM-RCM simulations of RCP groups have identified SMF and GMF events for the same catchment. As seen in section 3.1.3, most SMF and GMF events have a considerably lower peak daily runoff. Hence, it is possible that SMF and GMF have been cut off by the choice how to identify events. A lower threshold could possibly identify more consistent number of SMF and GMF events in each catchment. However, according to Sikorska-Senoner & Seibert (2020), which used another approach in identifying flood events, generally only a few SMF and GMF events are identified anyway.

The different length between the reference period and both future periods might have an influence on possible trends (37 years and each 41 years, respectively). As already indicated in section 3, it is possible that positive trends may be somewhat overestimated. The flood events are chosen based on the length of the whole period, from 1981 to 2099, which is 119 years and only the most extreme flood events (>0.98 percentile) are chosen. Thus, not in every year extreme flood events are necessarily identified.

5. Conclusion

For a better flow in the text, the research questions and sub-questions are answered at once.

It can be said that the frequency of flood events generally increases for FF, SRF and LRF events, whereas RoSF are expected to decrease, compared to the present state. While in RCP 2.6 chains most catchments show no significant increase or decrease, for RCP 4.5 and RCP 8.5 most catchments show positively significant trends for FF events (in the Alps), and SRF and LRF events (in most parts of Switzerland). The significance is more severe during the second future period. For RoSF events, a significant decrease is expected in some lowland catchments for RCP 2.6 but for almost all catchments in RCP 8.5, especially for the second future period.

The intensity, which is estimated by the mean precipitation, mean snowmelt and mean maximum runoff, does not change significantly for RCP 2.6 and RCP 4.5 chains. However, in RCP 8.5 chains in some catchments a significant increase of mean precipitation and mean maximum runoff is identified in the second future period, although most catchments still show nonsignificant differences. Overall it can be said that changes in the second future period are more severe for all GCM-RCM chains. Furthermore, the changes also depend on where the catchment is located. High-altitude catchments show the most severe changes. Here, the seasonal pattern is expected to be most sever, where, a large decrease in RoSF during summer is expected, but also a large increase during spring, which implies a shift in RoSF events. Furthermore, FF and SRF events are expected to increase in spring. In general, an increase of rainfall related event is expected. Lowland catchments on the other hand expect a considerable increase of SRF and LRF events during winter. All seasonal changes are presumably more severe with increasing level of RCP.

A correlation with the change of mean annual temperature is dependent on the altitude of the catchment. With increasing temperature, in high-altitude catchments more FF events are identified. For all other flood types, an increase in temperature results in more events, but it is more arbitrary, meaning that a higher temperature increase does not necessarily lead to an increase of those events. The same applies, when making correlation of all flood types with changes in mean annual precipitation and (for RoSF events) mean snowmelt. No clear conclusions could be made for SMF and GMF events, due to the fact that only a few events are identified. In order to observe changes, a change in the approach of selecting flood events is needed, to identify more SMF and GMF events.

Most hypotheses have been proven right, except that with increasing temperature, an increase in snow-related flood events is not expected.

Lastly, it can be said that if no mitigation measures are applied (RCP 8.5) a more severe increase in flood events can be expected in all catchments. The most dominant flood type is likely to remain the same in lowland catchments, where LRF and SRF events will predominate. In medium-altitude catchments, LRF events will become dominant, “overtaking” the RoSF events. In high-altitude catchments, RoSF events are still dominant at the end of the century under no mitigation measures (RCP 8.5), but rainfall-related events (FF, SRF and LRF) will play a more important role as well. In contrast, if the greenhouse gas emissions can be reduced and limited to a minimum in the foreseen future, the changes in dominant flood types are likely to remain similar.

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Appendix

I: Reference period

Table 15: Seasonal distribution of flood events, with the absolute number, summarized by catchment groups during the reference period, using the control simulation.

	All Seasons		Spring		Summer		Autumn		Winter	
Lowland (139)	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**
FF (count)	1154	1104.629	258	250.888	559	553.135	337	300.606	0	0
SRF (count)	2812	2854.939	778	782.001	302	308.086	827	863.913	905	900.939
LRF (count)	6121	6116.051	1341	1341.911	887	887.052	1609	1606.498	2284	2280.59
RoSF (count)	2003	2014.16	697	698.774	21	20.727	33	34.983	1252	1259.676
SMF (count)	26	26.221	24	24.426	0	0	0	0	2	1.795
GMF (count)	0	0	0	0	0	0	0	0	0	0
Mixed Events (%)	–	7.28	–	8.51	–	3.99	–	6.57	–	8.26
Mid-altitude (49)	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**
FF (count)	573	570.366	28	27.196	397	399.982	148	143.188	0	0
SRF (count)	597	601.576	58	60.997	217	215.366	274	276.545	48	48.668
LRF (count)	1131	1133.404	136	134.191	469	469.276	472	474.441	54	55.496
RoSF (count)	2265	2261.457	1209	1209.419	267	265.376	189	188.826	600	597.836
SMF (count)	63	62.197	62	61.197	1	1	0	0	0	0
GMF (count)	0	0	0	0	0	0	0	0	0	0
Mixed Events (%)	–	9.97	–	5.73	–	9.57	–	17.08	–	9.85
High altitude (119)	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**
FF (count)	239	233.097	0	0.286	134	135.256	105	97.555	0	0
SRF (count)	550	557.919	1	0.719	265	264.019	281	289.686	3	3.495
LRF (count)	439	441.148	1	1.058	225	221.462	212	217.222	1	1.406
RoSF (count)	6553	6546.349	2028	2025.105	3416	3419.608	989	982.537	120	119.099
SMF (count)	188	185.24	101	102.327	87	82.913	0	0	0	0
GMF (count)	119	124.247	23	24.505	96	99.742	0	0	0	0
Mixed Events (%)	–	11.14	–	2.81	–	9.23	–	31.48	–	13.76

Table 16: Relative seasonal distribution of flood events, summarized by catchment groups during the reference period, using the control simulation.

	All Seasons		Spring		Summer		Autumn		Winter	
Lowland (139)	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**
FF (%)	9.52	9.12	8.33	8.10	31.60	31.27	12.01	10.71	0.00	0.00
SRF (%)	23.21	23.56	25.11	25.24	17.07	17.42	29.47	30.79	20.37	20.28
LRF (%)	50.52	50.48	43.29	43.32	50.14	50.14	57.34	57.25	51.41	51.33
RoSF (%)	16.53	16.62	22.50	22.56	1.19	1.17	1.18	1.25	28.18	28.35
SMF (%)	0.21	0.22	0.77	0.79	0.00	0.00	0.00	0.00	0.05	0.04
GMF (%)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mixed Events (%)	–	7.28	–	8.51	–	3.99	–	6.57	–	8.26
Mid-altitude (49)	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**
FF (%)	12.38	12.32	1.88	1.82	29.39	29.61	13.67	13.22	0.00	0.00
SRF (%)	12.90	13.00	3.88	4.09	16.06	15.94	25.30	25.54	6.84	6.93
LRF (%)	24.43	24.48	9.11	8.99	34.72	34.74	43.58	43.81	7.69	7.91
RoSF (%)	48.93	48.85	80.98	81.01	19.76	19.64	17.45	17.44	85.47	85.16
SMF (%)	1.36	1.34	4.15	4.10	0.07	0.07	0.00	0.00	0.00	0.00
GMF (%)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mixed Events (%)	–	9.97	–	5.73	–	9.57	–	17.08	–	9.85
High altitude (119)	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**
FF (%)	2.95	2.88	0.00	0.01	3.17	3.20	6.62	6.15	0.00	0.00
SRF (%)	6.80	6.90	0.05	0.03	6.28	6.25	17.71	18.25	2.42	2.82
LRF (%)	5.43	5.45	0.05	0.05	5.33	5.24	13.36	13.69	0.81	1.13
RoSF (%)	81.02	80.94	94.15	94.02	80.89	80.98	62.32	61.91	96.77	96.05
SMF (%)	2.32	2.29	4.69	4.75	2.06	1.96	0.00	0.00	0.00	0.00
GMF (%)	1.47	1.54	1.07	1.14	2.27	2.36	0.00	0.00	0.00	0.00
Mixed Events (%)	–	11.14	–	2.81	–	9.23	–	31.48	–	13.76

*Table 17: Relative seasonal distribution of flood events, summarized by catchment groups during the reference period, using the mean of all **RCP 4.5** chains.*

	All Seasons		Spring		Summer		Autumn		Winter	
Lowland (139)	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**
FF (%)	8.19	7.97	7.01	6.88	30.22	29.95	8.35	7.75	0.00	0.00
SRF (%)	21.13	21.30	18.23	18.31	13.33	13.60	29.88	30.47	20.65	20.59
LRF (%)	54.04	54.00	51.16	51.15	55.98	55.97	59.07	59.04	51.99	51.92
RoSF (%)	16.45	16.52	23.17	23.23	0.46	0.48	2.70	2.73	27.11	27.23
SMF (%)	0.20	0.20	0.42	0.44	0.00	0.00	0.00	0.00	0.25	0.26
GMF (%)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mixed Events (%)		6.13		7.15		3.06		5.75		6.93
Mid-altitude (49)	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**
FF (%)	9.32	9.25	2.69	2.69	23.60	23.80	10.79	10.32	0.00	0.00
SRF (%)	13.04	13.13	5.13	5.19	12.04	11.87	28.98	29.36	7.09	7.17
LRF (%)	29.37	29.38	12.57	12.57	47.11	47.17	46.66	46.64	12.33	12.34
RoSF (%)	47.97	47.94	78.75	78.71	17.25	17.16	13.56	13.66	80.51	80.41
SMF (%)	0.30	0.30	0.86	0.85	0.00	0.00	0.02	0.02	0.07	0.08
GMF (%)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mixed Events (%)		7.71		6.01		7.11		11.52		6.39
High altitude (119)	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**
FF (%)	3.01	2.89	0.02	0.02	3.37	3.35	6.07	5.64	0.00	0.00
SRF (%)	7.17	7.30	0.16	0.17	4.38	4.40	20.16	20.61	1.52	1.55
LRF (%)	10.47	10.49	0.34	0.35	9.79	9.81	23.72	23.78	2.05	2.04
RoSF (%)	78.91	78.87	98.75	98.72	81.89	81.87	50.05	49.97	96.44	96.41
SMF (%)	0.27	0.27	0.64	0.64	0.22	0.22	0.00	0.00	0.00	0.00
GMF (%)	0.17	0.18	0.10	0.11	0.34	0.35	0.00	0.00	0.00	0.00
Mixed Events (%)		7.14		0.71		5.83		16.73		3.56

*Table 18: Relative seasonal distribution of flood events, summarized by catchment groups during the reference period, using the mean of all **RCP 8.5** chains.*

	All Seasons		Spring		Summer		Autumn		Winter	
Lowland (139)	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**
FF (count)	9.49	9.21	9.04	8.68	33.46	33.20	9.37	8.78	0.00	0.00
SRF (count)	23.26	23.53	19.38	19.76	15.04	15.31	32.62	33.20	22.62	22.61
LRF (count)	49.85	49.82	46.38	46.39	51.12	51.12	55.54	55.55	47.66	47.55
RoSF (count)	17.07	17.10	24.54	24.51	0.37	0.37	2.47	2.46	29.23	29.34
SMF (count)	0.33	0.34	0.66	0.67	0.00	0.00	0.00	0.00	0.49	0.49
GMF (count)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mixed Events (%)		6.77		7.98		3.24		6.40		7.66
Mid-altitude (49)	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**
FF (count)	10.93	10.85	2.89	2.83	27.79	28.06	12.38	11.93	0.00	0.00
SRF (count)	14.47	14.56	4.94	5.05	14.01	13.71	32.00	32.40	6.64	6.69
LRF (count)	26.69	26.68	11.46	11.42	41.40	41.41	42.81	42.81	10.19	10.23
RoSF (count)	47.43	47.43	79.50	79.48	16.78	16.81	12.78	12.85	82.80	82.68
SMF (count)	0.47	0.48	1.21	1.22	0.02	0.02	0.02	0.02	0.37	0.39
GMF (count)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mixed Events (%)		8.21		6.06		7.46		12.71		8.21
High altitude (119)	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**
FF (count)	3.70	3.55	0.02	0.02	4.15	4.11	7.18	6.69	0.00	0.00
SRF (count)	7.91	8.06	0.18	0.18	5.02	5.06	21.60	22.14	1.93	1.95
LRF (count)	8.91	8.93	0.33	0.34	8.48	8.49	19.47	19.53	1.38	1.40
RoSF (count)	78.95	78.92	98.50	98.49	81.70	81.69	51.74	51.64	96.69	96.65
SMF (count)	0.33	0.32	0.82	0.81	0.25	0.25	0.00	0.00	0.00	0.00
GMF (count)	0.21	0.22	0.15	0.16	0.39	0.40	0.00	0.00	0.00	0.00
Mixed Events (%)		9.67		0.87		10.31		18.38		3.55

*Table 19: Changes in the relative seasonal distribution of all flood types with respect to the reference period in the respective altitude groups, using the mean of all **RCP 2.6** chains*

	All Seasons		Spring		Summer		Autumn		Winter	
Lowland (139)	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**
FF (% change)	0.50	0.38	3.74	3.29	-0.97	-0.98	1.92	1.74	0.00	0.00
SRF (% change)	1.22	1.35	0.52	0.97	-0.50	-0.49	0.18	0.34	3.02	3.08
LRF (% chagne)	3.08	3.12	5.14	5.10	1.77	1.78	-1.07	-1.07	4.92	5.13
RoSF (% change)	-4.70	-4.74	-9.09	-9.05	-0.30	-0.31	-1.03	-1.01	-7.85	-7.96
SMF (% change)	-0.11	-0.11	-0.31	-0.30	0.00	0.00	0.00	0.00	-0.08	-0.24
GMF (% change)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mixed (% change)		0.00		0.00		0.00		0.00		0.00
Mid-altitude (49)	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**
FF (% change)	1.09	1.05	1.96	1.91	1.93	1.90	2.17	2.08	0.00	0.00
SRF (% change)	2.21	2.24	3.04	3.08	0.42	0.47	4.16	4.27	2.36	2.31
LRF (% chagne)	2.19	2.15	5.73	5.63	4.36	4.31	-1.88	-1.87	3.28	3.24
RoSF (% change)	-5.45	-5.39	-10.69	-10.56	-6.71	-6.68	-4.43	-4.46	-5.64	-5.49
SMF (% change)	-0.04	-0.05	-0.03	-0.05	0.00	0.00	-0.02	-0.02	-0.01	-0.05
GMF (% change)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mixed (% change)		0.00		0.00		0.00		0.00		0.00
High altitude (119)	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**
FF (% change)	2.48	2.44	0.10	0.10	3.70	3.71	4.65	4.52	0.00	0.00
SRF (% change)	3.66	3.68	0.43	0.44	3.40	3.36	8.25	8.34	-0.37	-0.17
LRF (% chagne)	5.02	5.03	0.50	0.49	6.92	6.92	9.31	9.32	0.55	0.61
RoSF (% change)	-10.97	-10.96	-0.83	-0.87	-13.70	-13.66	-22.21	-22.17	-0.18	-0.44
SMF (% change)	-0.08	-0.07	-0.19	-0.13	-0.10	-0.09	0.00	0.00	0.00	0.00
GMF (% change)	-0.10	-0.11	-0.01	-0.03	-0.22	-0.24	0.00	0.00	0.00	0.00
Mixed (% change)		0.00		0.00		0.00		0.00		0.00

*Table 20: Changes in the relative seasonal distribution of all flood types with respect to the reference period in the respective altitude groups, using the mean of all **RCP 4.5** chains*

	All Seasons		Spring		Summer		Autumn		Winter	
Lowland (139)	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**
FF (% change)	-1.34	-1.15	-1.31	-1.22	-1.38	-1.32	-3.66	-2.96	0.00	0.00
SRF (% change)	-2.08	-2.26	-6.88	-6.93	-3.74	-3.81	0.41	-0.31	0.29	0.31
LRF (% chagne)	3.52	3.52	7.88	7.83	5.84	5.83	1.73	1.78	0.59	0.59
RoSF (% change)	-0.08	-0.10	0.67	0.67	-0.72	-0.69	1.52	1.49	-1.07	-1.12
SMF (% change)	-0.02	-0.01	-0.35	-0.35	0.00	0.00	0.00	0.00	0.20	0.22
GMF (% change)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mixed (% change)		-1.15		-1.36		-0.93		-0.82		-1.33
Mid-altitude (49)	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**
FF (% change)	-3.06	-3.07	0.82	0.86	-5.79	-5.81	-2.88	-2.90	0.00	0.00
SRF (% change)	0.14	0.13	1.25	1.10	-4.03	-4.07	3.68	3.83	0.26	0.23
LRF (% chagne)	4.94	4.90	3.46	3.58	12.40	12.44	3.08	2.83	4.64	4.44
RoSF (% change)	-0.96	-0.91	-2.23	-2.29	-2.51	-2.49	-3.89	-3.77	-4.96	-4.75
SMF (% change)	-1.06	-1.05	-3.30	-3.25	-0.07	-0.07	0.02	0.02	0.07	0.08
GMF (% change)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mixed (% change)		-2.26		0.28		-2.46		-5.56		-3.46
High altitude (119)	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**
FF (% change)	0.05	0.01	0.02	0.01	0.20	0.15	-0.54	-0.51	0.00	0.00
SRF (% change)	0.37	0.40	0.11	0.13	-1.90	-1.85	2.46	2.36	-0.90	-1.27
LRF (% chagne)	5.04	5.04	0.29	0.30	4.46	4.56	10.36	10.10	1.24	0.91
RoSF (% change)	-2.11	-2.07	4.60	4.70	1.00	0.90	-12.27	-11.94	-0.34	0.36
SMF (% change)	-2.05	-2.02	-4.05	-4.11	-1.84	-1.75	0.00	0.00	0.00	0.00
GMF (% change)	-1.30	-1.36	-0.96	-1.03	-1.93	-2.01	0.00	0.00	0.00	0.00
Mixed (% change)		-4.00		-2.10		-3.40		-14.75		-10.20

Table 21: Changes in the relative seasonal distribution of all flood types with respect to the reference period in the respective altitude groups, using the mean of all ***RCP 8.5*** *chains*

	All Seasons		Spring		Summer		Autumn		Winter	
Lowland (139)	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**
FF (% change)	-0.04	0.09	0.71	0.58	1.86	1.93	-2.64	-1.94	0.00	0.00
SRF (% change)	0.05	-0.03	-5.73	-5.49	-2.03	-2.11	3.15	2.42	2.25	2.34
LRF (% chagne)	-0.67	-0.66	3.09	3.07	0.98	0.98	-1.80	-1.70	-3.74	-3.78
RoSF (% change)	0.54	0.48	2.04	1.95	-0.82	-0.80	1.29	1.22	1.05	0.99
SMF (% change)	0.12	0.12	-0.12	-0.12	0.00	0.00	0.00	0.00	0.44	0.45
GMF (% change)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mixed (% change)		-0.51		-0.53		-0.75		-0.17		-0.60
Mid-altitude (49)	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**
FF (% change)	-1.45	-1.47	1.01	1.01	-1.60	-1.55	-1.28	-1.30	0.00	0.00
SRF (% change)	1.58	1.56	1.06	0.96	-2.05	-2.23	6.70	6.86	-0.20	-0.24
LRF (% chagne)	2.26	2.20	2.35	2.43	6.68	6.67	-0.78	-1.00	2.50	2.33
RoSF (% change)	-1.50	-1.43	-1.48	-1.53	-2.98	-2.84	-4.67	-4.58	-2.67	-2.48
SMF (% change)	-0.89	-0.87	-2.94	-2.88	-0.06	-0.05	0.02	0.02	0.37	0.39
GMF (% change)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mixed (% change)		-1.76		0.33		-2.11		-4.37		-1.64
High altitude (119)	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**
FF (% change)	0.74	0.67	0.02	0.01	0.98	0.91	0.57	0.54	0.00	0.00
SRF (% change)	1.11	1.16	0.14	0.15	-1.25	-1.19	3.90	3.88	-0.48	-0.87
LRF (% chagne)	3.48	3.48	0.29	0.29	3.15	3.25	6.11	5.84	0.57	0.27
RoSF (% change)	-2.07	-2.02	4.35	4.47	0.81	0.72	-10.58	-10.27	-0.09	0.61
SMF (% change)	-2.00	-1.97	-3.87	-3.94	-1.81	-1.72	0.00	0.00	0.00	0.00
GMF (% change)	-1.26	-1.32	-0.92	-0.98	-1.89	-1.96	0.00	0.00	0.00	0.00
Mixed (% change)		-1.47		-1.94		1.08		-13.10		-10.21

Table 22: Changes of the absolute numbers in % of all flood types with respect to the reference period in the respective altitude groups, using the mean of all ***RCP 2.6*** *chains*

	All Seasons		Spring		Summer		Autumn		Winter	
Lowland (139)	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**
FF (% change)	-12.69	-11.24	-12.98	-13.85	-4.25	-3.95	-26.48	-22.48	0.00	0.00
SRF (% change)	-3.01	-3.59	-25.08	-24.43	-17.59	-17.96	16.60	13.37	2.90	3.14
LRF (% chagne)	1.50	1.45	9.97	9.85	2.16	2.14	4.58	4.70	-5.91	-6.04
RoSF (% change)	-0.84	-0.97	5.36	5.15	-61.90	-60.39	139.02	125.91	-6.96	-6.90
SMF (% change)	25.48	28.18	-16.15	-15.30	0.00	0.00	0.00	0.00	518.75	615.88
GMF (% change)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mixed (% change)		-0.85		-1.18		-0.80		-0.24		-1.11
Mid-altitude (49)	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**
FF (% change)	-16.36	-16.60	64.73	63.47	-25.91	-25.80	-6.08	-6.10	0.00	0.00
SRF (% change)	17.25	17.09	25.86	23.72	-30.13	-31.12	54.43	54.39	9.38	10.13
LRF (% chagne)	20.62	20.30	36.40	38.23	3.78	3.70	25.34	24.51	85.88	81.42
RoSF (% change)	1.99	2.11	6.28	6.13	-26.97	-26.25	-15.34	-14.41	11.69	11.79
SMF (% change)	-75.99	-74.52	-78.02	-76.82	-100.00	-100.00	0.00	0.00	0.00	0.00
GMF (% change)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mixed (% change)		-1.92		0.08		-2.02		-4.97		-3.23
High altitude (119)	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**
FF (% change)	27.98	26.87	0.00	30.24	21.27	19.44	36.19	37.15	0.00	0.00
SRF (% change)	43.55	43.22	425.00	644.73	-28.49	-27.72	109.21	105.79	129.17	91.59
LRF (% chagne)	107.63	106.81	975.00	958.60	47.78	50.11	166.86	160.72	150.00	68.92
RoSF (% change)	17.12	17.24	27.72	27.91	-1.35	-1.47	41.75	42.72	160.63	162.85
SMF (% change)	-85.44	-85.45	-80.82	-82.14	-90.80	-90.63	0.00	0.00	0.00	0.00
GMF (% change)	-84.66	-84.80	-85.87	-85.68	-84.64	-84.71	0.00	0.00	0.00	0.00
Mixed (% change)				-1.93		-3.34		-15.06		-10.23

Table 23: Changes of the absolute numbers in % of all flood types with respect to the reference period in the respective altitude groups, using the mean of all ***RCP 4.5*** *chains*

	All Seasons		Spring		Summer		Autumn		Winter	
Lowland (139)	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**
FF (% change)	-15.45	-13.98	-20.39	-19.75	-3.87	-3.72	-30.88	-28.05	0.00	0.00
SRF (% change)	-10.45	-11.06	-31.39	-31.44	-21.50	-21.50	0.80	-1.59	0.96	1.11
LRF (% chagne)	5.24	5.24	11.71	11.60	12.22	12.19	2.42	2.52	0.70	0.71
RoSF (% change)	-2.10	-2.22	-2.66	-2.68	-60.81	-59.05	127.97	117.97	-4.23	-4.37
SMF (% change)	-10.36	-7.33	-48.42	-47.19	0.00	0.00	0.00	0.00	442.30	529.53
GMF (% change)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mixed (% change)					0.00	0.00				
Mid-altitude (49)	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**
FF (% change)	-19.16	-19.39	56.59	60.74	-27.55	-27.49	-10.97	-11.97	0.00	0.00
SRF (% change)	8.57	8.45	44.03	38.40	-32.40	-32.81	29.17	29.68	33.33	32.82
LRF (% chagne)	29.08	28.86	50.45	52.45	22.42	22.51	20.75	20.06	105.98	100.66
RoSF (% change)	5.26	5.36	6.04	5.95	-21.26	-21.21	-12.37	-11.62	21.05	21.35
SMF (% change)	-76.56	-76.20	-77.55	-77.38	-100.00	-100.00	0.00	0.00	0.00	0.00
GMF (% change)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mixed (% change)						0.00				
High altitude (119)	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**
FF (% change)	29.06	26.99	0.00	92.80	9.87	8.13	53.11	52.95	0.00	0.00
SRF (% change)	33.72	34.17	353.84	563.37	-27.90	-27.29	89.93	88.33	105.13	79.63
LRF (% chagne)	144.40	143.82	853.84	827.04	89.95	93.27	196.08	189.79	730.76	489.86
RoSF (% change)	23.45	23.52	38.04	38.21	4.64	4.51	33.93	34.60	226.03	228.40
SMF (% change)	-85.19	-85.14	-82.10	-82.36	-88.77	-88.57	0.00	0.00	0.00	0.00
GMF (% change)	-85.07	-85.10	-87.29	-87.40	-84.54	-84.53	0.00	0.00	0.00	0.00
Mixed (% change)				-55.13						-0.01

Table 24: Changes of the absolute numbers in % of all flood types with respect to the reference period in the respective altitude groups, using the mean of all ***RCP 8.5*** *chains*

	All Seasons		Spring		Summer		Autumn		Winter	
Lowland (139)	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**
FF (% change)	-5.05	-3.73	-0.67	-1.94	1.04	1.30	-18.53	-14.48	0.00	0.00
SRF (% change)	-4.48	-4.81	-29.38	-28.38	-15.91	-16.12	15.55	12.59	2.42	2.84
LRF (% chagne)	-5.93	-5.92	-1.96	-2.01	-2.71	-2.72	1.13	1.31	-14.49	-14.56
RoSF (% change)	-1.56	-1.94	-0.19	-0.59	-70.37	-69.91	118.86	106.34	-4.34	-4.57
SMF (% change)	48.50	50.11	-22.45	-22.13	0.00	0.00	0.00	0.00	897.22	1028.86
GMF (% change)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mixed (% change)					0.00	0.00				
Mid-altitude (49)	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**
FF (% change)	-6.60	-6.81	66.47	68.10	-16.76	-16.61	6.83	6.34	0.00	0.00
SRF (% change)	18.72	18.48	37.55	33.58	-23.20	-24.34	49.13	49.57	12.96	12.38
LRF (% chagne)	15.57	15.29	35.99	37.36	4.98	4.89	15.80	15.20	54.22	50.68
RoSF (% change)	2.54	2.70	6.14	6.08	-25.26	-24.72	-13.64	-13.10	12.76	13.01
SMF (% change)	-63.23	-62.36	-68.37	-67.73	-77.78	-74.99	0.00	0.00	0.00	0.00
GMF (% change)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mixed (% change)						0.00				
High altitude (119)	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**
FF (% change)	56.30	53.94	0.00	101.44	38.72	36.05	78.15	78.60	0.00	0.00
SRF (% change)	45.30	46.02	388.89	580.57	-15.09	-14.19	100.18	98.98	125.90	95.05
LRF (% chagne)	105.13	104.63	794.44	749.29	68.79	71.76	139.12	134.08	383.33	248.79
RoSF (% change)	21.80	21.87	30.00	30.17	7.11	6.98	36.23	36.86	182.22	184.26
SMF (% change)	-82.33	-82.30	-78.33	-78.75	-87.04	-86.75	0.00	0.00	0.00	0.00
GMF (% change)	-82.17	-82.21	-83.09	-82.43	-81.94	-82.15	0.00	0.00	0.00	0.00
Mixed (% change)				-104.74						-0.29

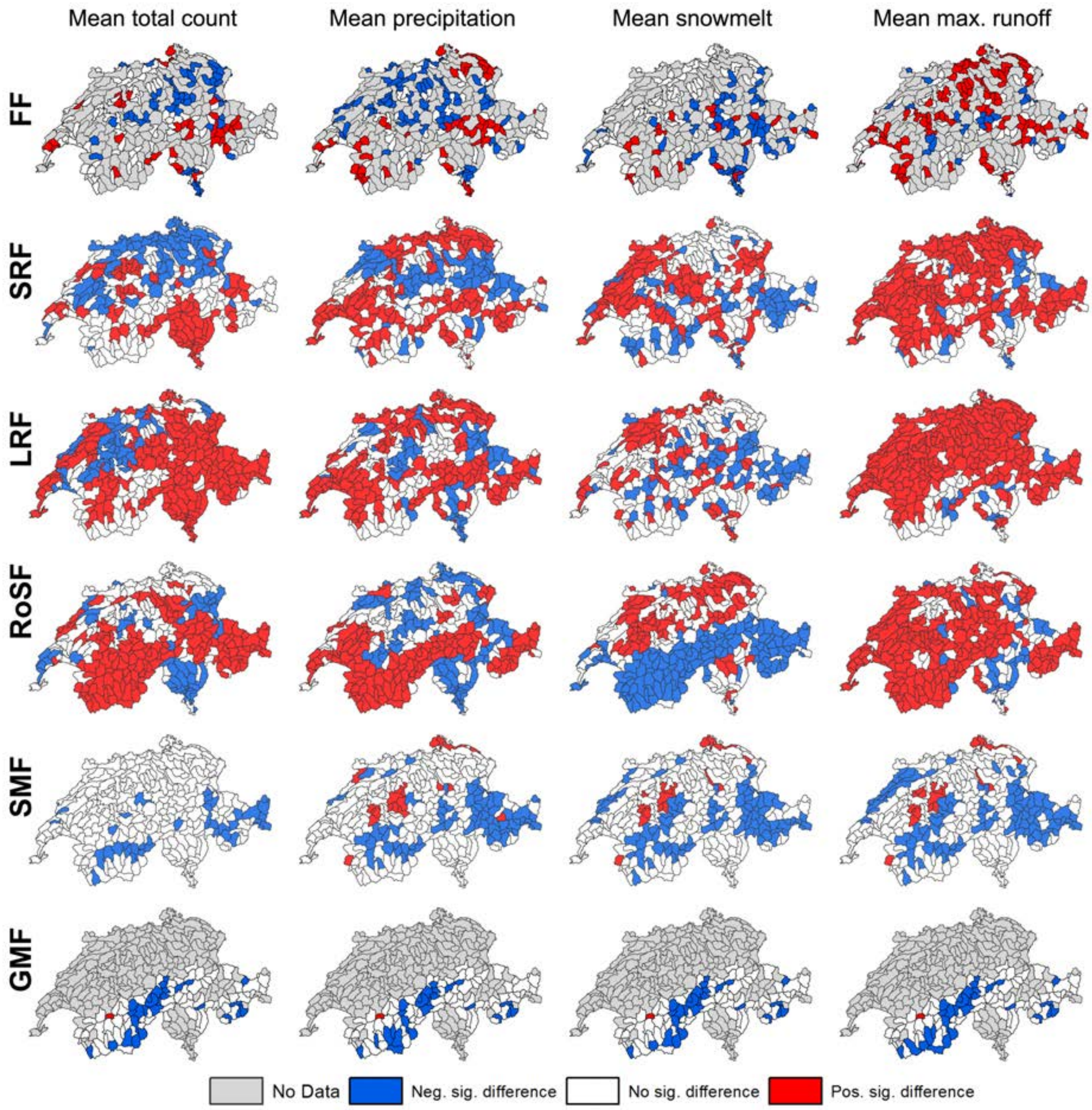

Figure 35: The maps show, if the difference of mean total count, mean precipitation per event, mean snowmelt per event, mean max. daily runoff per flood type event between the control simulation and the mean of all ***RCP 4.5*** *simulations is significant. Gray catchments in FF and GMF indicate catchments, where FF and GMF can not occur at all (>150km^2 and unglaciated, respectively)*

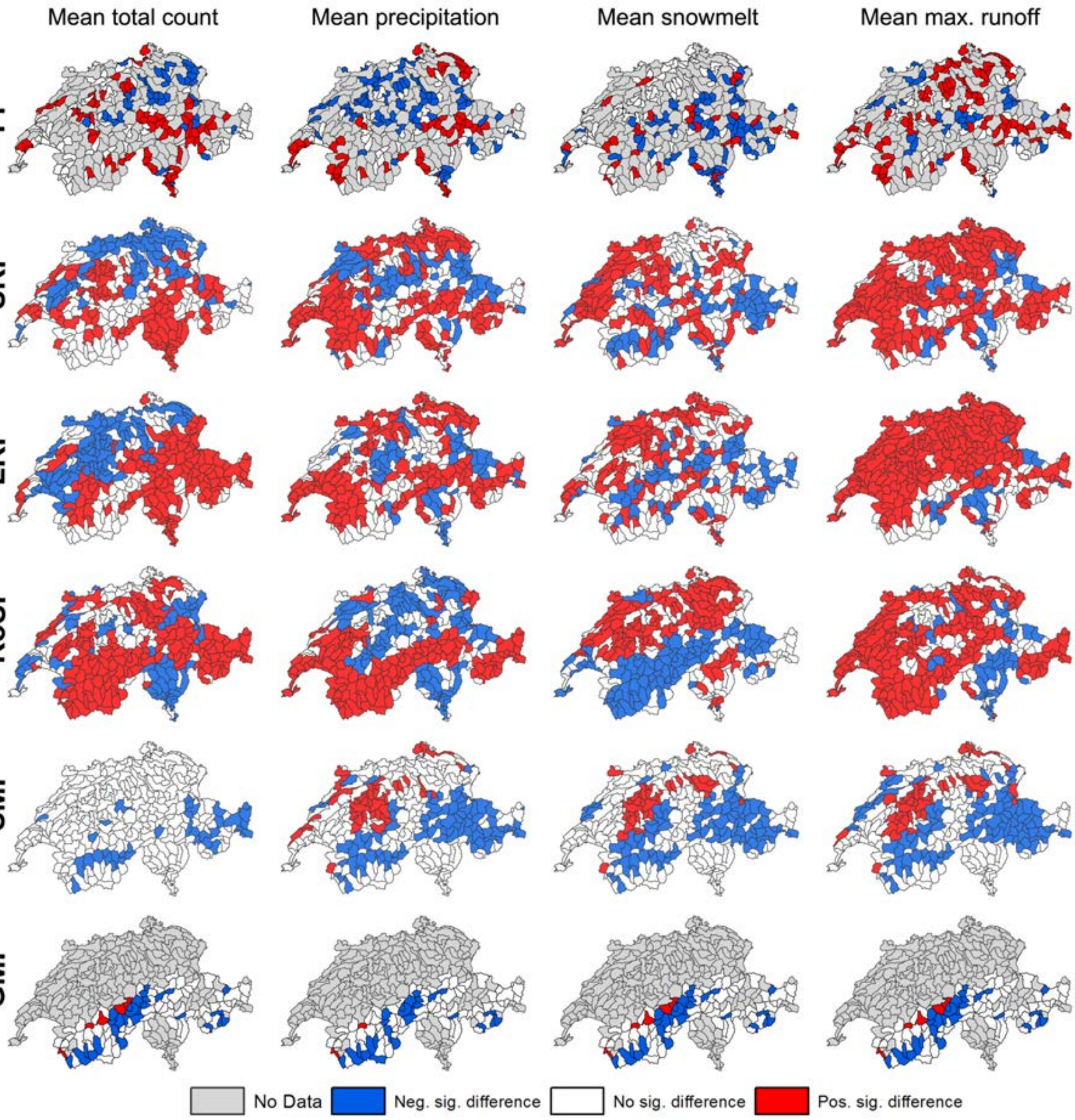

*Figure 36: The maps show, if the difference of mean total count, mean precipitation per event, mean snowmelt per event, mean max. daily runoff per flood type event between the control simulation and the mean of all **RCP 8.5** simulations is significant. Gray catchments in FF and GMF indicate catchments, where FF and GMF can not occur at all (>150km^2 and unglaciated, respectively)*

II: First future period

*Table 25: Seasonal distribution of flood events, with the absolute number, summarized by catchment groups during the **reference** period, using the mean of all **RCP 2.6** chains.*

	All Seasons		Spring		Summer		Autumn		Winter	
Lowland (139)	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**
FF (count)	1007.50	980.46	224.50	216.15	535.25	531.26	247.75	233.04	0.00	0.00
SRF (count)	2727.25	2752.37	582.88	590.97	248.88	252.76	964.25	979.43	931.25	929.22
LRF (count)	6212.63	6204.95	1474.75	1474.04	906.13	906.01	1682.63	1682.06	2149.13	2142.85
RoSF (count)	1986.13	1994.72	734.38	734.76	8.00	8.21	78.88	79.03	1164.88	1172.72
SMF (count)	32.63	33.61	20.13	20.69	0.00	0.00	0.13	0.01	12.38	12.85
GMF (count)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mixed Events (%)		6.43		7.33		3.19		6.33		7.15
Mid-altitude (49)	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**
FF (count)	479.25	475.71	46.13	44.46	294.13	296.79	139.00	134.46	0.00	0.00
SRF (count)	700.00	704.37	73.00	75.47	151.63	148.33	423.13	426.96	52.50	53.60
LRF (count)	1364.25	1363.54	185.50	185.49	486.75	486.64	591.63	590.72	100.38	100.68
RoSF (count)	2310.00	2309.16	1284.88	1283.52	195.00	195.72	160.00	161.61	670.13	668.30
SMF (count)	15.13	15.85	13.63	14.19	0.00	0.00	0.25	0.25	1.13	1.41
GMF (count)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mixed Events (%)		8.05		5.81		7.55		12.11		6.62
High altitude (119)	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**
FF (count)	305.88	295.72	0.38	0.37	162.50	161.55	143.00	133.80	0.00	0.00
SRF (count)	789.50	799.03	5.25	5.35	189.50	190.84	587.88	596.14	6.88	6.70
LRF (count)	911.50	912.35	10.75	11.20	332.50	332.43	565.75	566.34	2.50	2.38
RoSF (count)	7674.63	7675.09	2590.13	2590.40	3369.88	3369.41	1401.88	1402.23	312.75	313.05
SMF (count)	27.38	26.95	19.38	18.28	8.00	7.77	0.00	0.00	0.00	0.00
GMF (count)	18.25	18.89	3.25	3.51	14.75	15.25	0.00	0.13	0.00	0.00
Mixed Events (%)		7.38		0.88		5.89		16.42		3.53

*Table 26: Seasonal distribution of flood events, with the absolute number, summarized by catchment groups during the **first future** period, using the mean of all **RCP 2.6** chains.*

	All Seasons		Spring		Summer		Autumn		Winter	
Lowland (139)	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**
FF (count)	1136.25	1091.97	321.00	300.13	521.50	517.33	293.75	274.50	0.00	0.00
SRF (count)	3058.50	3101.07	568.75	589.35	241.63	245.81	934.13	953.33	1314.00	1312.59
LRF (count)	7005.00	7001.94	1549.25	1547.29	941.25	941.26	1590.38	1589.86	2924.13	2923.52
RoSF (count)	1514.88	1519.15	435.38	436.87	3.00	2.97	46.63	47.18	1029.88	1032.13
SMF (count)	21.00	21.49	10.13	10.86	0.00	0.00	0.00	0.00	10.88	3.06
GMF (count)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mixed Events (%)		6.19		8.75		2.91		6.51		5.68
Mid-altitude (49)	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**
FF (count)	583.88	577.85	76.63	74.12	333.63	336.06	173.63	167.66	0.00	0.00
SRF (count)	885.75	892.35	120.25	123.30	165.13	162.27	495.25	500.73	105.13	106.04
LRF (count)	1613.63	1610.57	274.00	272.51	565.88	565.16	587.63	586.84	186.13	186.06
RoSF (count)	2242.63	2244.97	1100.25	1100.98	126.00	127.13	105.50	106.75	910.88	910.09
SMF (count)	14.50	14.64	13.00	13.21	0.00	0.00	0.00	0.00	1.50	1.41
GMF (count)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mixed Events (%)		8.10		7.62		6.36		11.05		7.09
High altitude (119)	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**
FF (count)	650.88	634.62	3.88	4.17	315.63	314.85	331.38	315.60	0.00	0.00
SRF (count)	1363.75	1377.73	22.27	22.83	330.25	329.92	999.88	1013.10	11.00	11.88
LRF (count)	1667.00	1668.38	32.00	32.16	618.63	618.84	1008.13	1008.96	8.25	8.40
RoSF (count)	7866.75	7867.54	3443.00	3442.08	2830.50	2831.53	990.13	991.83	603.13	602.09
SMF (count)	23.38	23.85	19.38	19.75	4.00	4.09	0.00	0.00	0.00	0.00
GMF (count)	9.63	9.25	3.88	3.74	5.75	5.50	0.00	0.00	0.00	0.00
Mixed Events (%)		7.53		1.33		7.11		15.28		3.84

*Table 27: Seasonal distribution of flood events, with the absolute number, summarized by catchment groups during the **reference** period, using the mean of all **RCP 4.5** chains.*

	All Seasons		Spring		Summer		Autumn		Winter	
Lowland (139)	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**
FF (count)	975.69	950.20	205.38	201.35	537.38	532.55	232.92	216.30	0.00	0.00
SRF (count)	2518.15	2539.12	533.77	536.16	237.08	241.84	833.62	850.18	913.69	910.93
LRF (count)	6441.46	6436.57	1498.00	1497.55	995.38	995.20	1648.00	1647.01	2300.08	2296.81
RoSF (count)	1961.00	1969.42	678.46	680.04	8.23	8.49	75.23	76.25	1199.08	1204.65
SMF (count)	23.31	24.30	12.38	12.90	0.00	0.00	0.08	0.10	10.85	11.30
GMF (count)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mixed Events (%)		6.13		7.15		3.06		5.75		6.93
Mid-altitude (49)	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**
FF (count)	463.23	459.78	43.85	43.71	287.62	290.01	131.77	126.05	0.00	0.00
SRF (count)	648.15	652.39	83.54	84.42	146.69	144.71	353.92	358.62	64.00	64.64
LRF (count)	1459.92	1460.48	204.61	204.57	574.15	574.90	569.92	569.63	111.23	111.36
RoSF (count)	2384.15	2382.78	1282.00	1281.37	210.23	209.08	165.62	166.88	726.31	725.45
SMF (count)	14.77	14.80	13.92	13.84	0.00	0.00	0.23	0.27	0.62	0.69
GMF (count)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mixed Events (%)		7.71		6.01		7.11		11.52		6.39
High altitude (119)	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**
FF (count)	308.46	296.01	0.46	0.55	147.23	146.25	160.77	149.21	0.00	0.00
SRF (count)	735.46	748.56	4.54	4.77	191.08	191.96	533.69	545.55	6.15	6.28
LRF (count)	1072.92	1075.62	9.54	9.81	427.38	428.03	627.69	629.49	8.31	8.29
RoSF (count)	8090.00	8086.23	2799.54	2798.81	3574.62	3573.77	1324.62	1322.52	391.23	391.12
SMF (count)	27.85	27.53	18.08	18.05	9.77	9.48	0.00	0.00	0.00	0.00
GMF (count)	17.77	18.52	2.92	3.09	14.85	15.43	0.00	0.00	0.00	0.00
Mixed Events (%)		7.14		0.71		5.83		16.73		3.56

*Table 28: Seasonal distribution of flood events, with the absolute number, summarized by catchment groups during the **first future** period, using the mean of all **RCP 4.5** chains.*

	All Seasons		Spring		Summer		Autumn		Winter	
Lowland (139)	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**
FF (count)	1006.12	980.54	283.23	276.90	446.62	443.88	276.31	259.77	0.00	0.00
SRF (count)	3240.69	3265.41	661.77	667.90	187.92	190.59	1145.92	1161.97	1245.08	1244.96
LRF (count)	7206.46	7202.24	1908.77	1907.15	820.69	820.77	1785.15	1784.77	2691.85	2689.56
RoSF (count)	1373.92	1379.20	446.54	448.70	3.23	3.22	40.53	41.47	883.62	885.81
SMF (count)	28.38	28.20	12.31	11.97	0.00	0.00	0.46	0.41	15.62	15.82
GMF (count)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mixed Events (%)		5.74		7.22		2.75		5.84		5.57
Mid-altitude (49)	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**
FF (count)	513.31	510.42	69.85	68.93	285.15	287.87	158.31	153.63	0.00	0.00
SRF (count)	903.54	906.57	124.00	124.81	136.00	133.01	488.62	493.08	154.92	155.66
LRF (count)	1673.00	1671.99	323.00	322.64	491.46	491.08	661.46	660.65	197.07	197.63
RoSF (count)	2225.23	2225.74	1150.77	1150.95	97.08	97.75	143.23	144.15	834.15	832.89
SMF (count)	17.69	18.04	15.00	15.29	0.23	0.22	0.15	0.25	2.31	2.29
GMF (count)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mixed Events (%)		8.09		7.41		6.20		10.89		7.25
High altitude (119)	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**
FF (count)	552.92	543.69	4.92	4.99	285.08	284.84	262.93	253.86	0.00	0.00
SRF (count)	1250.92	1261.97	23.31	23.57	276.15	276.40	931.38	940.88	20.08	21.11
LRF (count)	1633.00	1634.60	46.62	46.82	577.08	577.25	990.08	991.15	19.23	19.08
RoSF (count)	7809.62	7805.80	3530.15	3529.30	2540.15	2539.57	1037.38	1035.89	701.92	701.04
SMF (count)	22.77	23.54	15.15	15.68	7.62	7.86	0.00	0.00	0.00	0.00
GMF (count)	14.38	14.02	2.85	2.64	11.54	11.39	0.00	0.00	0.00	0.00
Mixed Events (%)		7.43		1.31		6.64		16.03		3.88

*Table 29: Seasonal distribution of flood events, with the absolute number, summarized by catchment groups during the **reference** period, using the mean of all **RCP 8.5** chains.*

	All Seasons		Spring		Summer		Autumn		Winter	
Lowland (139)	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**
FF (count)	1095.67	1063.46	256.28	246.03	564.83	560.34	274.56	257.09	0.00	0.00
SRF (count)	2685.89	2717.72	549.44	560.05	253.94	258.41	955.61	972.71	926.89	926.55
LRF (count)	5757.72	5753.91	1314.72	1314.96	862.94	862.95	1627.11	1627.49	1952.94	1948.51
RoSF (count)	1971.72	1975.15	695.67	694.67	6.22	6.24	72.22	72.18	1197.61	1202.06
SMF (count)	38.61	39.36	18.61	19.02	0.00	0.00	0.06	0.08	19.94	20.26
GMF (count)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mixed Events (%)										
Mid-altitude (49)	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**
FF (count)	535.17	531.54	46.61	45.72	330.44	333.56	158.11	152.26	0.00	0.00
SRF (count)	708.78	712.74	79.78	81.48	166.67	162.94	408.61	413.63	54.22	54.69
LRF (count)	1307.11	1306.69	184.94	184.32	492.33	492.20	546.56	546.56	83.28	83.62
RoSF (count)	2322.62	2322.47	1283.28	1282.96	199.56	199.77	163.22	164.08	676.56	675.63
SMF (count)	23.17	23.41	19.61	19.75	0.22	0.25	0.28	0.25	3.06	3.17
GMF (count)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mixed Events (%)										
High altitude (119)	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**
FF (count)	373.56	358.83	0.61	0.58	185.89	184.02	187.06	174.24	0.00	0.00
SRF (count)	799.17	814.68	4.89	4.89	225.00	226.56	562.50	576.41	6.78	6.82
LRF (count)	900.50	902.74	8.94	8.99	379.78	380.38	506.94	508.47	4.83	4.90
RoSF (count)	7981.28	7977.80	2636.44	2636.16	3658.83	3658.36	1347.33	1344.72	338.67	338.56
SMF (count)	33.22	32.79	21.89	21.74	11.28	10.99	0.06	0.06	0.00	0.00
GMF (count)	21.22	22.11	3.89	4.31	17.33	17.80	0.00	0.00	0.00	0.00
Mixed Events (%)										

*Table 30: Seasonal distribution of flood events, with the absolute number, summarized by catchment groups during the **first future** period, using the mean of all **RCP 8.5** chains.*

	All Seasons		Spring		Summer		Autumn		Winter	
Lowland (139)	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**
FF (count)	1210.22	1177.60	323.89	313.61	621.39	617.06	264.94	246.92	0.00	0.00
SRF (count)	3478.28	3509.17	805.06	815.40	287.11	291.45	1038.17	1056.21	1347.94	1346.11
LRF (count)	6997.83	6992.29	1651.33	1649.77	900.22	900.23	1627.39	1626.90	2818.89	2815.39
RoSF (count)	1486.94	1493.86	461.22	462.54	1.94	1.92	32.56	33.02	991.22	996.39
SMF (count)	22.56	22.91	16.67	16.35	0.00	0.00	0.00	0.00	6.39	6.56
GMF (count)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mixed Events (%)										
Mid-altitude (49)	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**
FF (count)	634.78	626.84	99.61	96.50	376.67	380.61	158.50	149.73	0.00	0.00
SRF (count)	1043.44	1051.53	170.17	173.94	188.56	184.79	509.83	518.05	174.89	174.75
LRF (count)	1627.89	1626.60	313.50	313.31	529.11	528.66	584.28	583.77	201.00	200.86
RoSF (count)	2238.11	2239.06	1122.50	1121.82	103.22	103.50	118.22	119.24	894.17	894.50
SMF (count)	13.00	13.19	11.00	11.20	0.06	0.06	0.00	0.04	1.94	1.90
GMF (count)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mixed Events (%)										
High altitude (119)	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**
FF (count)	602.72	587.06	6.39	6.22	346.72	346.39	249.61	234.45	0.00	0.00
SRF (count)	1464.50	1481.39	30.67	31.41	366.78	367.89	1038.33	1052.59	28.72	29.50
LRF (count)	1543.94	1544.73	52.00	51.93	618.72	618.24	860.33	861.02	12.89	13.55
RoSF (count)	7763.78	7761.96	3596.17	3595.57	2651.44	2651.50	809.94	810.11	706.22	704.78
SMF (count)	41.56	42.03	28.67	29.10	12.67	12.64	0.11	0.17	0.11	0.12
GMF (count)	21.67	20.99	8.00	7.66	13.67	13.33	0.00	0.00	0.00	0.00
Mixed Events (%)										

*Table 31: Seasonal trends (in %) of all flood types in the respective altitude groups, for both crisp tree and fuzzy tree, using mean **RCP 4.5** chains of the 2018-2058 period. The number in brackets next to the altitude group represents the number of catchments.*

	All Seasons		Spring		Summer		Autumn		Winter	
Lowland (139)	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**
FF (% change)	3.12	3.19	37.90	37.52	-16.89	-16.65	18.63	20.10	0.00	0.00
SRF (% change)	28.69	28.60	23.98	24.57	-20.73	-21.19	37.46	36.67	36.27	36.67
LRF (% chagne)	11.88	11.90	27.42	27.35	-17.55	-17.53	8.32	8.36	17.03	17.10
RoSF (% change)	-29.94	-29.97	-34.18	-34.02	-60.75	-62.06	-46.13	-45.62	-26.31	-26.47
SMF (% change)	21.78	16.06	-0.59	-7.24	0.00	0.00	506.58	325.77	43.97	40.03
GMF (% change)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mixed (% change)		-0.39		0.07		-0.31		0.09		-1.36
Mid-altitude (49)	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**
FF (% change)	10.81	11.02	59.30	57.67	-0.86	-0.74	20.14	21.88	0.00	0.00
SRF (% change)	39.40	38.96	48.44	47.84	-7.29	-8.08	38.06	37.49	142.07	140.80
LRF (% chagne)	14.60	14.48	57.86	57.71	-14.40	-14.58	16.06	15.98	77.17	77.47
RoSF (% change)	-6.67	-6.59	-10.24	-10.18	-53.82	-53.25	-13.52	-13.62	14.85	14.81
SMF (% change)	19.79	21.89	7.76	10.43	0.00	0.00	-33.68	-5.62	275.12	231.45
GMF (% change)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mixed (% change)		0.38		1.40		-0.91		-0.63		0.86
High altitude (119)	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**
FF (% change)	79.25	83.67	966.65	805.51	93.63	94.76	63.55	70.14	0.00	0.00
SRF (% change)	70.09	68.59	413.56	394.21	44.53	43.99	74.52	72.46	226.25	236.25
LRF (% chagne)	52.20	51.97	388.71	377.36	35.03	34.86	57.73	57.45	131.48	130.01
RoSF (% change)	-3.47	-3.47	26.10	26.10	-28.94	-28.94	-21.68	-21.67	79.41	79.24
SMF (% change)	-18.23	-14.48	-16.17	-13.14	-22.05	-17.03	0.00	0.00	0.00	0.00
GMF (% change)	-19.05	-24.27	-2.63	-14.57	-22.28	-26.22	0.00	0.00	0.00	0.00
Mixed (% change)		0.29		0.60		0.81		-0.70		0.32

*Table 32: Seasonal trends (in %) of all flood types in the respective altitude groups, for both crisp tree and fuzzy tree, using mean **RCP 8.5** chains of the 2018-2058 period. The number in brackets next to the altitude group represents the number of catchments.*

	All Seasons		Spring		Summer		Autumn		Winter	
Lowland (139)	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**
FF (% change)	10.46	10.73	26.38	27.47	10.01	10.12	-3.50	-3.95	0.00	0.00
SRF (% change)	29.50	29.12	46.52	45.60	13.06	12.79	8.64	8.58	45.43	45.28
LRF (% chagne)	21.54	21.52	25.60	25.46	4.32	4.32	0.02	-0.04	44.34	44.49
RoSF (% change)	-24.59	-24.37	-33.70	-33.42	-68.75	-69.25	-54.92	-54.26	-17.23	-17.11
SMF (% change)	-41.58	-41.79	-10.45	-14.06	0.00	0.00	-100.00	-100.00	-67.97	-67.61
GMF (% change)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mixed (% change)		0.00		0.00		0.00		0.00		0.00
Mid-altitude (49)	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**
FF (% change)	18.61	17.93	113.71	111.08	13.99	14.11	0.25	-1.66	0.00	0.00
SRF (% change)	47.22	47.53	113.30	113.49	13.13	13.41	24.77	25.25	222.54	219.50
LRF (% chagne)	24.54	24.48	69.51	69.98	7.47	7.41	6.90	6.81	141.36	140.21
RoSF (% change)	-3.64	-3.59	-12.53	-12.56	-48.27	-48.19	-27.57	-27.33	32.16	32.40
SMF (% change)	-43.88	-43.66	-43.91	-43.28	-75.00	-77.81	-100.00	-85.18	-36.36	-40.23
GMF (% change)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mixed (% change)		0.00		0.00		0.00		0.00		0.00
High altitude (119)	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**
FF (% change)	61.35	63.60	945.45	979.27	86.52	88.24	33.44	34.56	0.00	0.00
SRF (% change)	83.25	81.84	527.27	541.84	63.01	62.38	84.59	82.61	323.82	332.74
LRF (% chagne)	71.45	71.12	481.37	477.90	62.92	62.53	69.71	69.33	166.65	176.27
RoSF (% change)	-2.73	-2.71	36.40	36.39	-27.53	-27.52	-39.89	-39.76	108.53	108.17
SMF (% change)	25.08	28.18	30.96	33.85	12.32	15.04	100.20	190.35	0.00	0.00
GMF (% change)	2.09	-5.05	105.72	77.80	-21.15	-25.10	0.00	0.00	0.00	0.00
Mixed (% change)		0.00		0.00		0.00		0.00		0.00

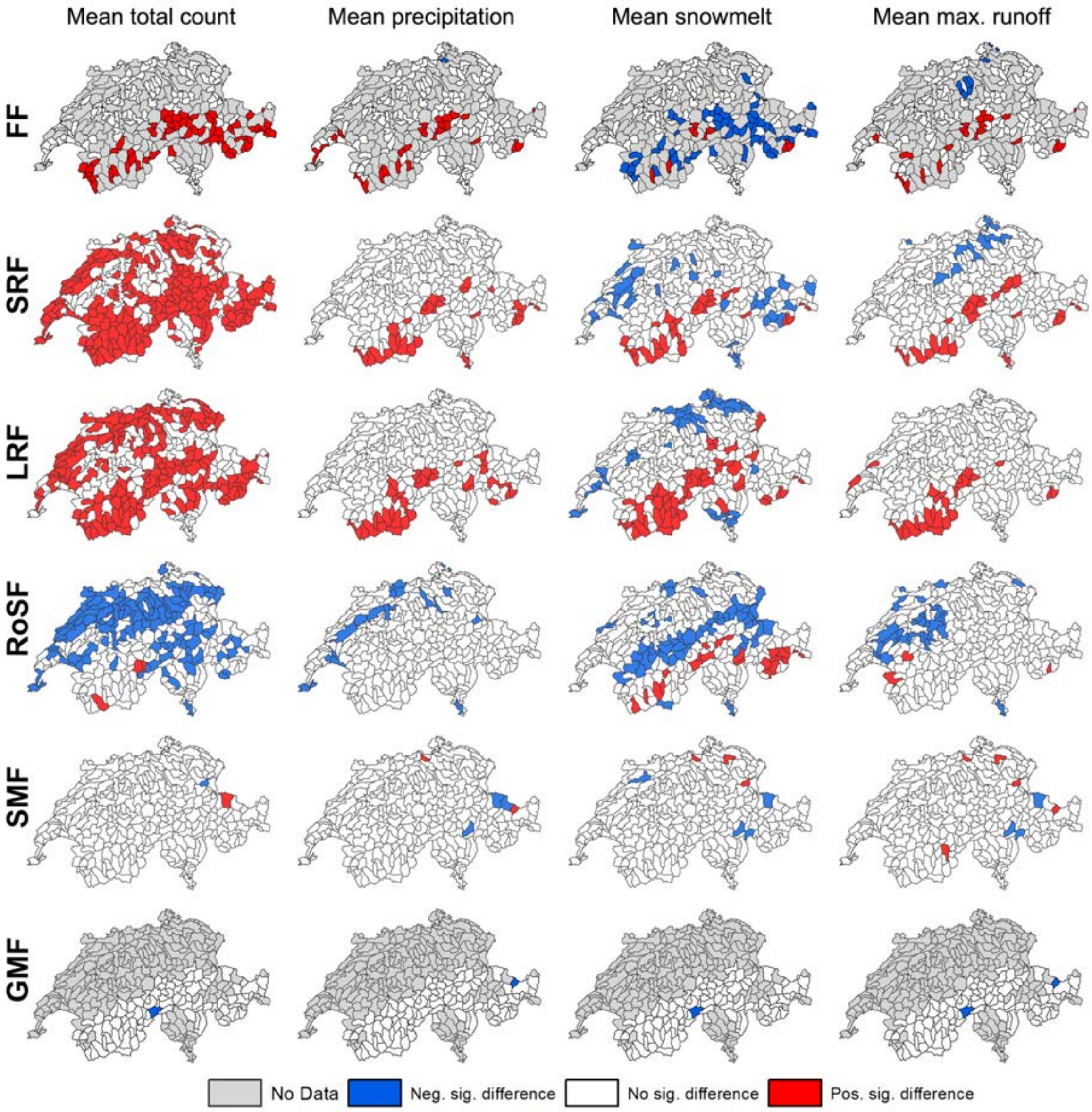

*Figure 37: The maps show, if the trend of mean total count, mean precipitation per event, mean snowmelt per event, mean max. daily runoff per flood type event during the 2018-2058 period is significant, compared to the reference period for **RCP 4.5** chains. Gray catchments in FF and GMF indicate catchments, where FF and GMF can not occur at all (>150km^2 and unglaciated, respectively).*

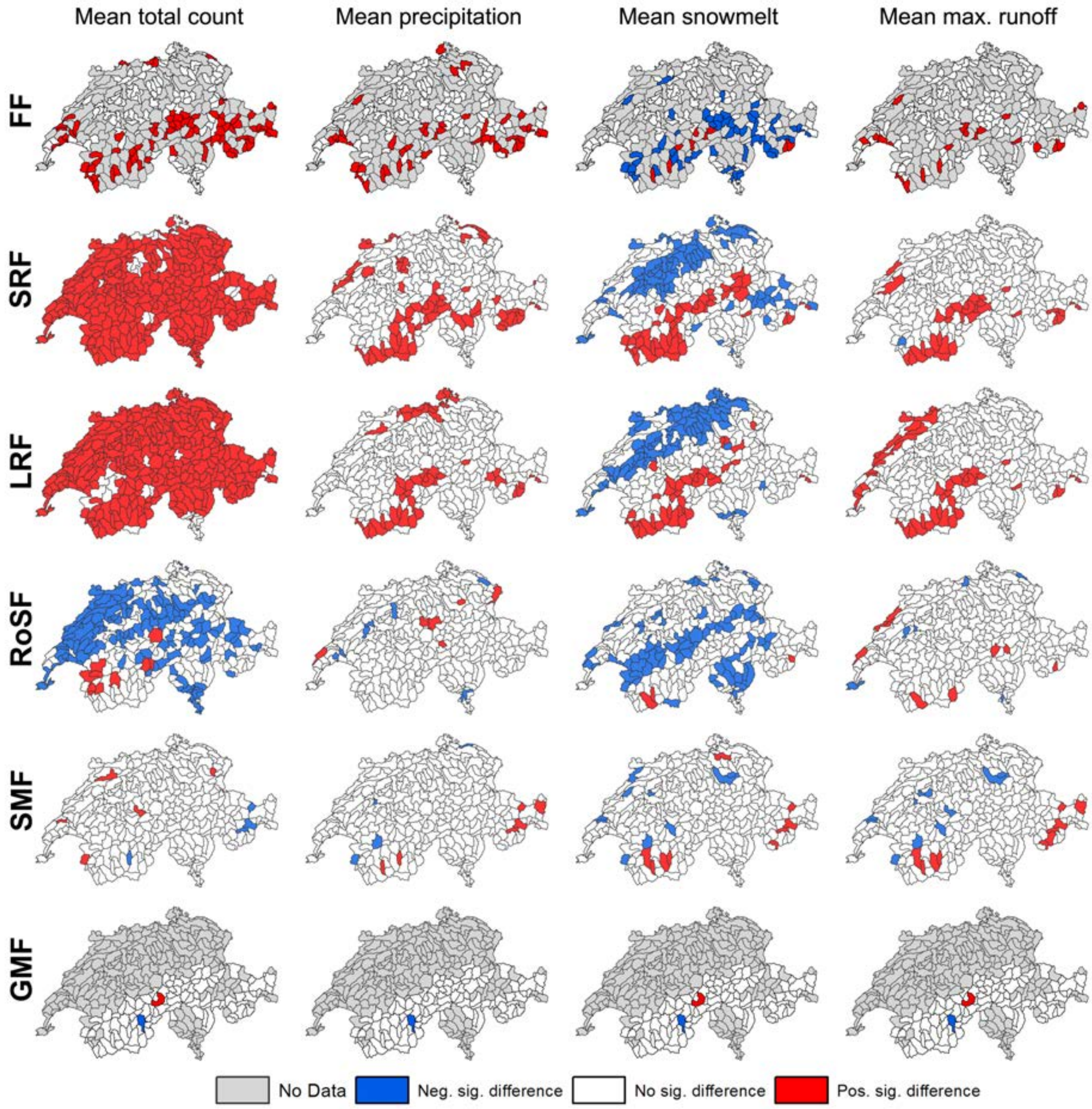

Figure 38: The maps show, if the trend of mean total count, mean precipitation per event, mean snowmelt per event, mean max. daily runoff per flood type event during the 2018-2058 period is significant, compared to the reference period for ***RCP 4.5*** *chains. Gray catchments in FF and GMF indicate catchments, where FF and GMF can not occur at all (>150km^2 and unglaciated, respectively).*

Table 33: Uncorrected number of catchments of positive, negative and non-significant trends for mean precipitation, mean snowmelt and mean maximum daily runoff for each flood type, during the first future period

RCP2.6	Count			P/Event [mm]			SM/Event [mm]			Max Q/Event [mm]		
Significance	N	0	P	N	0	P	N	0	P	N	0	P
FF	0	133	64	1	179	17	28	161	8	0	185	12
SRF	0	198	109	1	290	16	4	290	13	0	293	14
LRF	0	186	121	0	285	22	11	276	20	0	287	20
RoSF	29	268	10	5	300	2	23	266	18	7	299	1
SMF	2	303	2	1	306	0	1	305	1	1	305	1
GMF	1	95	0	2	94	0	2	94	0	2	94	0

RCP2.6	Count			P/Event [mm]			SM/Event [mm]			Max Q/Event [mm]		
Significance	N	0	P	N	0	P	N	0	P	N	0	P
FF	0	133	64	1	179	17	28	161	8	0	185	12
SRF	0	198	109	1	290	16	4	290	13	0	293	14
LRF	0	186	121	0	285	22	11	276	20	0	287	20
RoSF	29	268	10	5	300	2	23	266	18	7	299	1
SMF	2	303	2	1	306	0	1	305	1	1	305	1
GMF	1	95	0	2	94	0	2	94	0	2	94	0

RCP2.6	Count			P/Event [mm]			SM/Event [mm]			Max Q/Event [mm]		
Significance	N	0	P	N	0	P	N	0	P	N	0	P
FF	0	133	64	1	179	17	28	161	8	0	185	12
SRF	0	198	109	1	290	16	4	290	13	0	293	14
LRF	0	186	121	0	285	22	11	276	20	0	287	20
RoSF	29	268	10	5	300	2	23	266	18	7	299	1
SMF	2	303	2	1	306	0	1	305	1	1	305	1
GMF	1	95	0	2	94	0	2	94	0	2	94	0

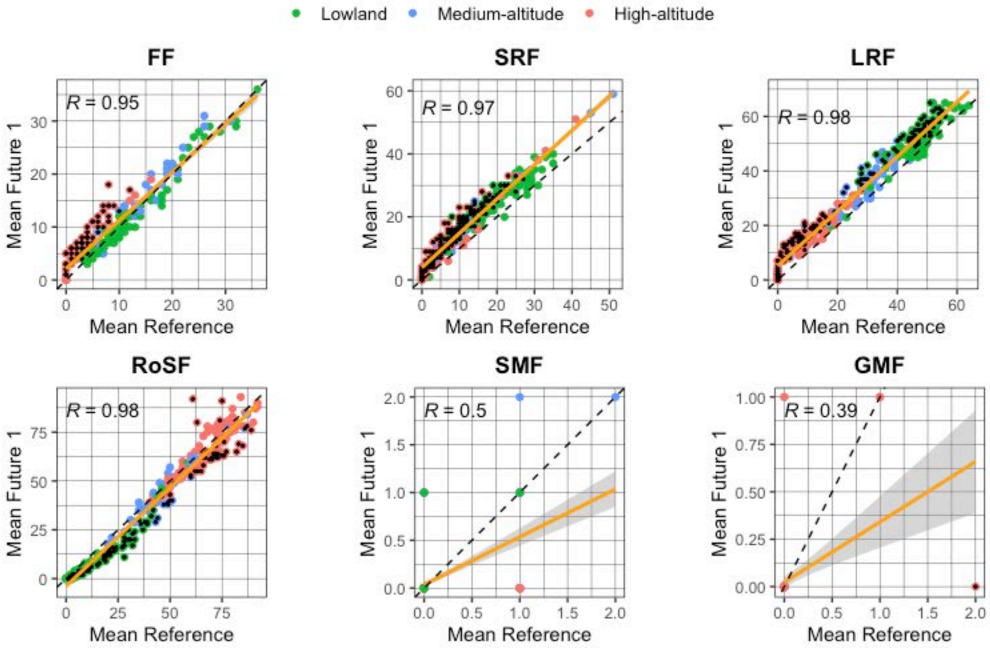

Figure 39: Frequency comparison between the reference period and first future period, coloured by catchment groups, for ***RCP 4.5*** *chains. The dashed line represents equal values in both periods (reference period = future period) and the orange line represents the linear approximation between both periods). Values that significantly differ are highlighted black. The R-value stands for the Pearson's R-coefficient.*

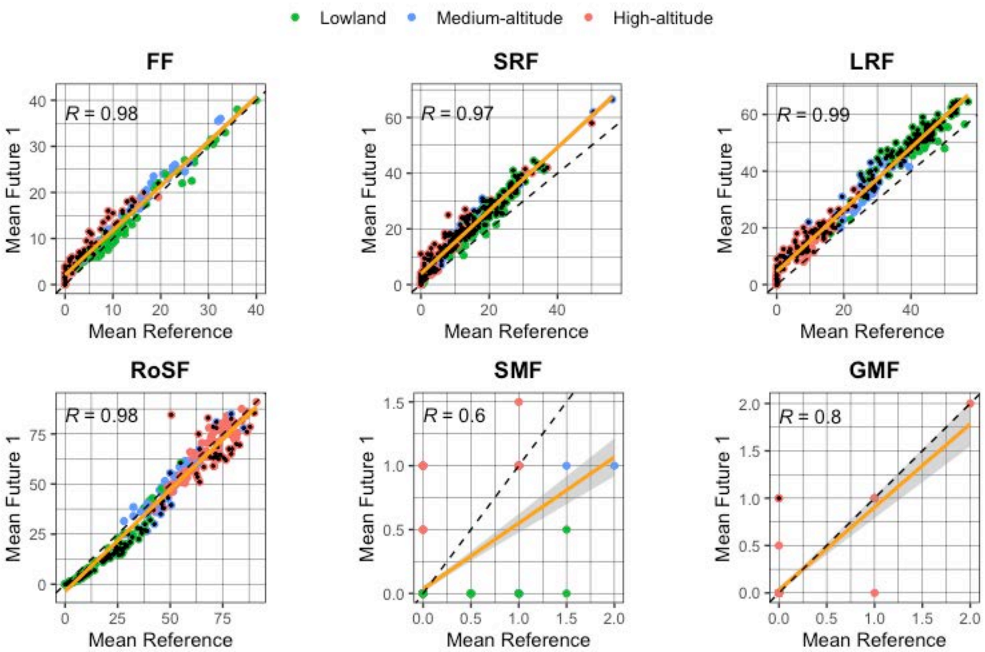

Figure 40: Frequency comparison between the reference period and first future period, coloured by catchment groups, for ***RCP 8.5*** *chains. The dashed line represents equal values in both periods (reference period = future period) and the orange line represents the linear approximation between both periods). Values that significantly differ are highlighted black. The R-value stands for the Pearson's R-coefficient.*

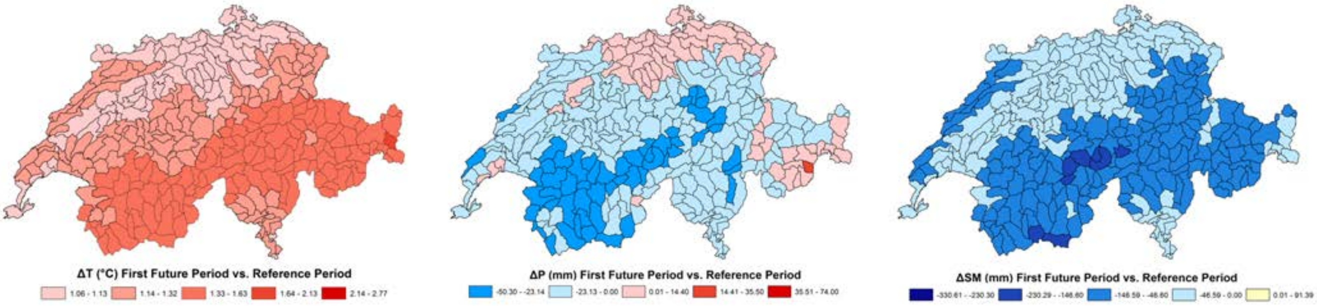

*Figure 41: Changes of mean annual temperature (ΔT), mean annual precipitation (ΔP) and mean annual snow-melt (ΔSM) during the 2018-2058 period, for **RCP 4.5** chains*

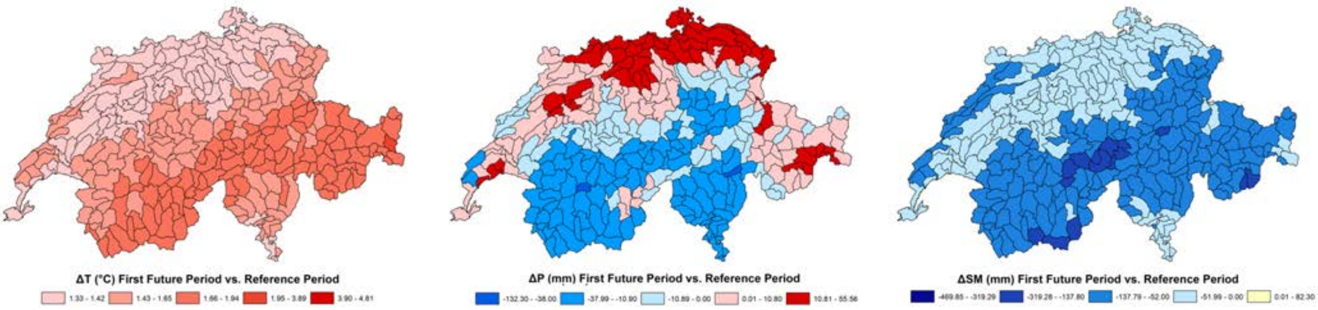

*Figure 42: Changes of mean annual temperature (ΔT), mean annual precipitation (ΔP) and mean annual snow-melt (ΔSM) during the 2018-2058 period, for **RCP 8.5** chains*

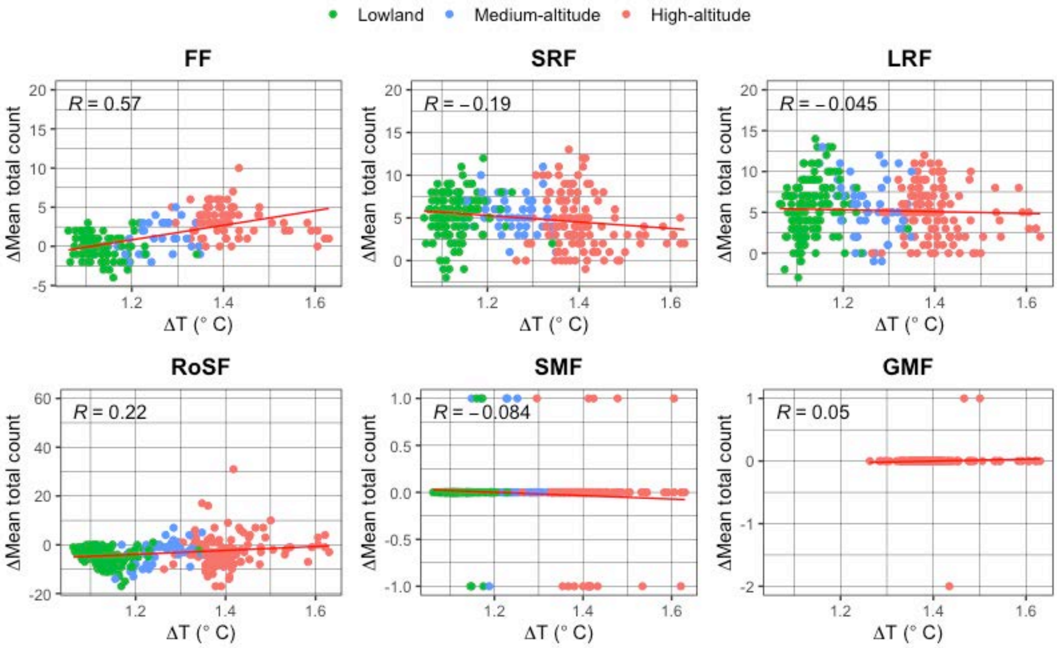

Figure 43: Correlation analysis between mean annual temperature changes (ΔT) and changes of mean total count, coloured by catchment groups, during the 2018-2058 period, for ***RCP 4.5****. The red line represents the linear approximation. The R value represents the Pearson's R coefficient.*

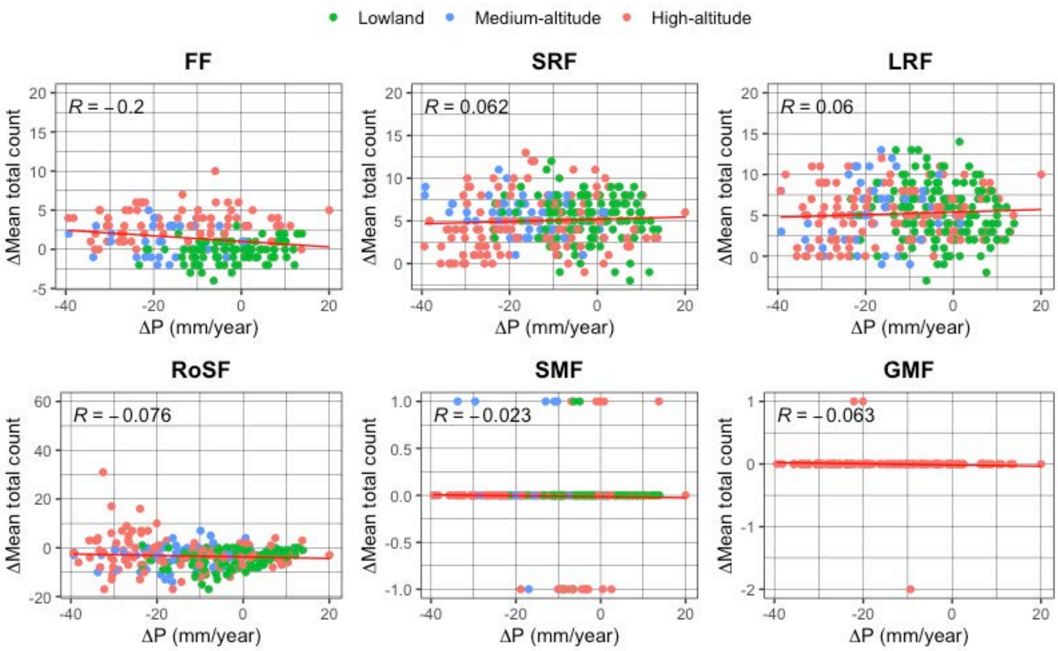

Figure 44: Correlation analysis between mean annual precipitation changes (ΔP) and changes of mean total count, coloured by catchment groups, during the 2018-2058 period, for ***RCP 4.5****. The red line represents the linear approximation. The R value represents the Pearson's R coefficient.*

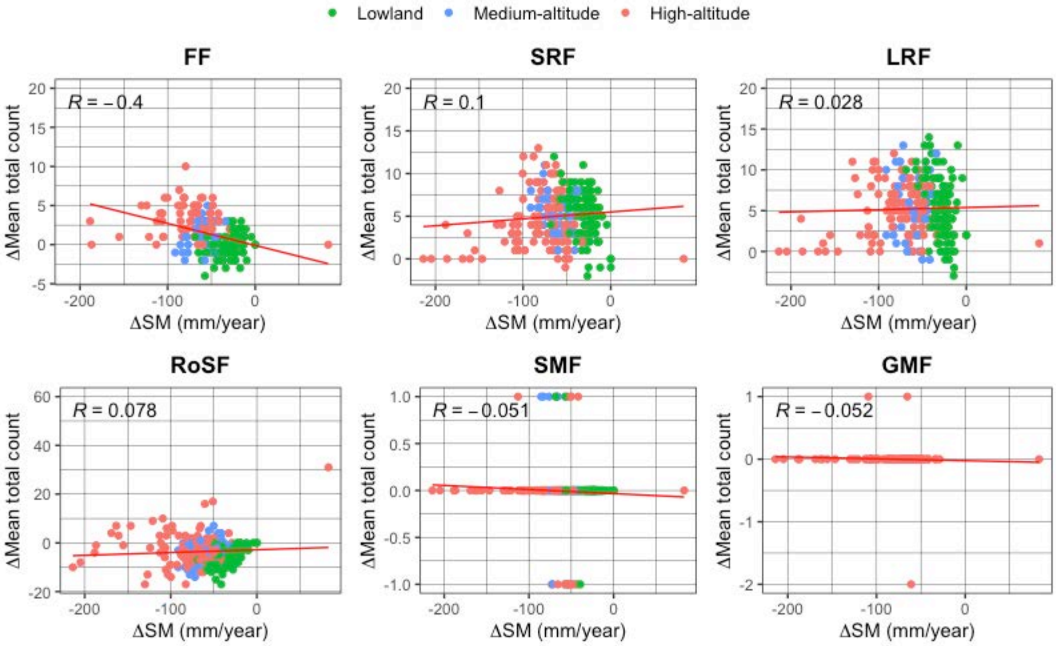

Figure 45: Correlation analysis between mean annual snowmelt changes (ΔSM) and changes of mean total count, coloured by catchment groups, during the 2018-2058 period, for ***RCP 4.5****. The red line represents the linear approximation. The R value represents the Pearson's R coefficient.*

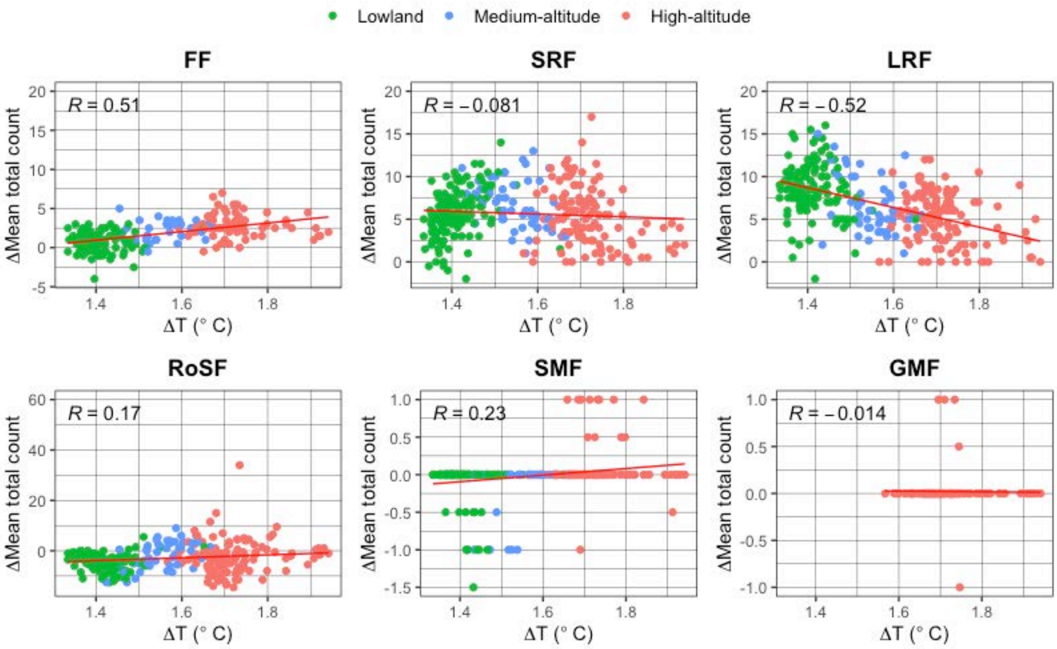

Figure 46: Correlation analysis between mean annual temperature changes (ΔT) and changes of mean total count, coloured by catchment groups, during the 2018-2058 period, for ***RCP 8.5****. The red line represents the linear approximation. The R value represents the Pearson's R coefficient.*

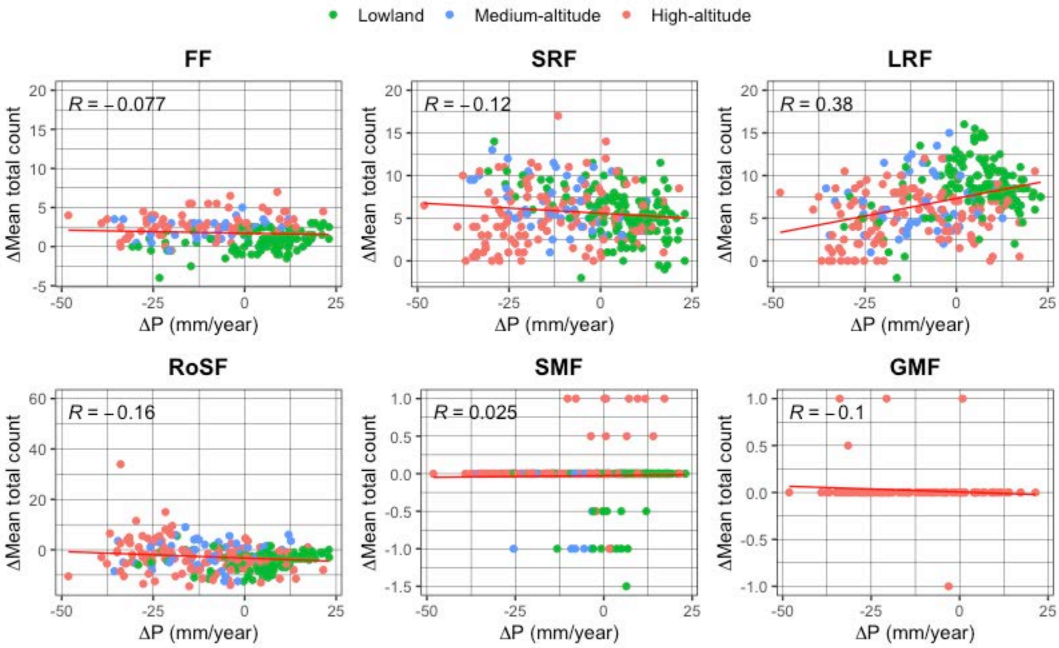

*Figure 47: Correlation analysis between mean annual precipitation changes (ΔP) and changes of mean total count, coloured by catchment groups, during the 2018-2058 period, for **RCP 8.5**. The red line represents the linear approximation. The R value represents the Pearson's R coefficient.*

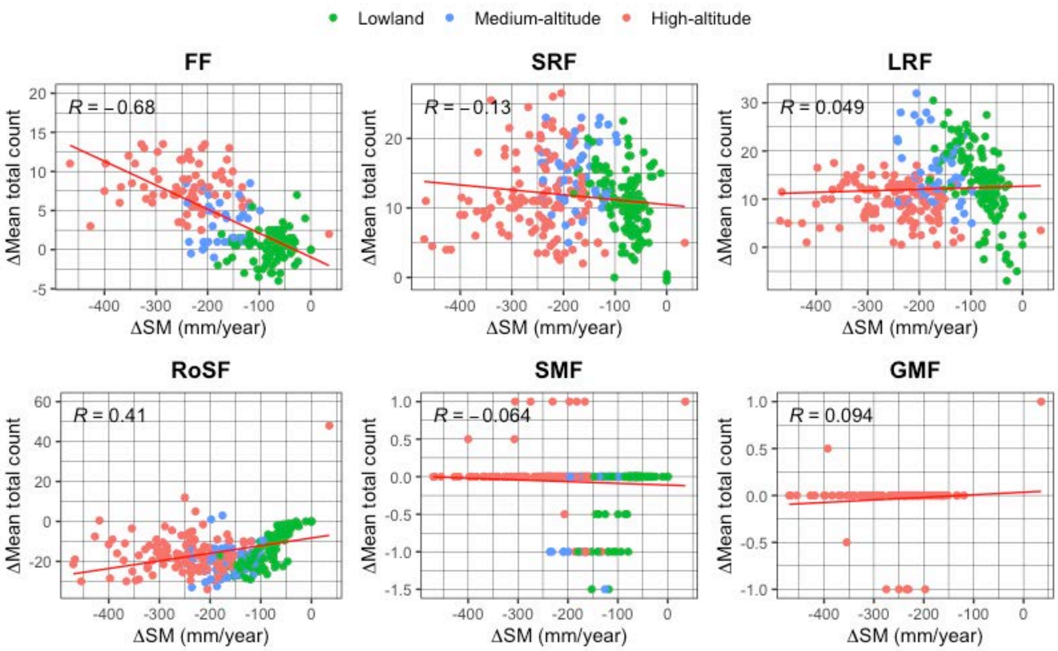

*Figure 48: Correlation analysis between mean annual snowmelt changes (ΔSM) and changes of mean total count, coloured by catchment groups, during the 2018-2058 period, for **RCP 4.5**. The red line represents the linear approximation. The R value represents the Pearson's R coefficient.*

III: Second future period

Table 34: Seasonal distribution of flood events, with the absolute number, summarized by catchment groups during the ***second future*** *period, using the mean of all* ***RCP 2.6*** *chains.*

	All Seasons		Spring		Summer		Autumn		Winter	
Lowland (139)	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**
FF (count)	1219.25	1190.94	318.13	314.02	615.75	611.20	285.38	265.73	0.00	0.00
SRF (count)	3236.88	3264.13	698.85	702.00	278.13	282.61	1047.63	1067.26	1212.38	1212.25
LRF (count)	7443.25	7438.48	1747.00	1746.05	1134.63	1134.74	1850.25	1850.80	2711.38	2706.89
RoSF (count)	1497.50	1503.21	468.75	470.30	3.38	3.33	56.00	55.45	969.38	974.12
SMF (count)	24.13	24.24	11.88	12.13	0.00	0.00	0.00	0.00	12.25	12.11
GMF (count)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mixed Events (%)		6.22		8.32		3.04		7.17		5.52
Mid-altitude (49)	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**
FF (count)	620.25	616.78	77.88	77.74	374.38	377.58	168.00	161.46	0.00	0.00
SRF (count)	946.88	950.23	147.38	147.82	189.88	186.73	487.25	493.54	122.38	122.14
LRF (count)	1814.75	1815.28	323.75	324.55	633.88	632.84	661.63	661.46	195.50	196.44
RoSF (count)	2217.25	2216.53	1135.00	1133.57	125.63	126.61	141.88	142.35	814.75	814.01
SMF (count)	14.38	14.68	11.75	12.08	0.00	0.00	0.00	0.44	2.13	2.16
GMF (count)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mixed Events (%)		8.27		7.70		6.07		11.26		8.27
High altitude (119)	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**
FF (count)	673.88	657.81	3.50	3.80	353.63	352.11	316.75	301.90	0.00	0.00
SRF (count)	1380.13	1395.58	22.38	22.38	372.25	375.23	969.63	981.79	15.88	16.17
LRF (count)	1659.88	1661.46	34.13	34.74	685.88	684.68	924.38	925.92	15.50	16.11
RoSF (count)	8277.75	8276.44	3704.88	3703.78	2297.85	2297.31	949.25	950.39	695.88	694.97
SMF (count)	36.63	36.66	28.50	28.55	8.00	7.99	0.00	0.00	0.13	0.12
GMF (count)	13.00	13.30	3.88	4.00	9.13	9.31	0.00	0.00	0.00	0.00
Mixed Events (%)		7.52		1.36		7.31		15.72		3.06

Table 35: Seasonal distribution of flood events, with the absolute number, summarized by catchment groups during the ***second future*** *period, using the mean of all* ***RCP 4.5*** *chains.*

	All Seasons		Spring		Summer		Autumn		Winter	
Lowland (139)	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**
FF (count)	1018.92	993.12	279.31	269.37	516.69	512.78	222.92	210.97	0.00	0.00
SRF (count)	3547.38	3573.19	736.00	746.19	232.15	236.10	1147.54	1159.49	1431.69	1431.41
LRF (count)	7938.62	7934.87	2062.00	2061.21	1050.92	1050.79	1769.69	1769.42	3056.00	3053.44
RoSF (count)	989.08	993.17	326.46	326.99	2.31	2.39	33.46	33.70	626.84	630.08
SMF (count)	12.92	12.55	7.07	7.08	0.00	0.00	0.08	0.10	5.76	5.38
GMF (count)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mixed Events (%)		5.17		6.52		2.77		4.98		5.25
Mid-altitude (49)	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**
FF (count)	553.92	548.25	87.07	85.02	324.46	327.95	142.38	135.27	0.00	0.00
SRF (count)	1054.77	1060.01	160.84	162.49	157.92	153.89	509.08	516.31	226.92	227.32
LRF (count)	2027.31	2027.64	436.00	436.79	612.23	612.01	685.23	684.20	293.84	294.64
RoSF (count)	1910.92	1911.10	881.00	880.75	77.23	77.98	118.31	119.22	834.38	833.14
SMF (count)	9.85	9.77	8.92	8.79	0.00	0.00	0.08	0.08	0.85	0.90
GMF (count)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mixed Events (%)		8.13		7.97		5.58		9.92		8.13
High altitude (119)	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**
FF (count)	695.23	673.36	12.15	11.82	400.69	400.66	282.38	260.87	0.00	0.00
SRF (count)	1555.69	1579.24	50.53	51.58	386.23	386.36	1049.23	1070.36	69.69	70.94
LRF (count)	2062.77	2061.49	91.00	90.87	866.62	865.78	1052.62	1051.93	52.54	52.90
RoSF (count)	7576.46	7575.65	3714.23	3713.47	2128.92	2129.45	808.85	809.89	924.46	922.83
SMF (count)	30.76	30.87	19.92	19.99	10.84	10.85	0.00	0.02	0.00	0.01
GMF (count)	10.00	10.30	1.62	1.71	8.38	8.59	0.00	0.00	0.00	0.00
Mixed Events (%)		7.63		1.93		8.07		14.74		5.53

Table 36: Seasonal distribution of flood events, with the absolute number, summarized by catchment groups during the ***second future*** *period, using the mean of all* ***RCP 8.5*** *chains.*

	All Seasons		Spring		Summer		Autumn		Winter	
Lowland (139)	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**
FF (count)	1148.22	1110.34	363.83	346.73	587.11	583.42	197.28	180.19	0.00	0.00
SRF (count)	4144.06	4180.78	946.78	963.60	274.06	277.74	1167.06	1184.14	1756.17	1755.29
LRF (count)	7688.00	7684.92	1990.28	1989.78	724.00	723.98	1460.67	1460.41	3513.06	3510.75
RoSF (count)	509.44	513.70	156.67	157.51	0.06	0.08	9.78	10.04	342.94	346.08
SMF (count)	7.39	7.38	1.50	1.44	0.00	0.00	0.00	0.00	5.89	5.94
GMF (count)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mixed Events (%)										
Mid-altitude (49)	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**
FF (count)	659.17	651.38	138.61	132.99	385.00	389.63	135.56	128.75	0.00	0.00
SRF (count)	1468.22	1476.93	296.17	301.34	180.94	176.50	605.00	612.09	386.11	387.00
LRF (count)	2055.94	2055.49	514.44	514.41	409.00	409.07	618.44	618.04	514.06	513.97
RoSF (count)	1481.33	1481.10	646.78	647.49	27.83	27.58	52.33	52.44	754.39	753.59
SMF (count)	3.94	3.71	2.94	2.71	0.00	0.00	0.11	0.11	0.89	0.89
GMF (count)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mixed Events (%)										
High altitude (119)	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**
FF (count)	957.39	936.80	55.83	54.87	567.94	569.91	333.61	312.02	0.00	0.00
SRF (count)	2174.28	2200.16	170.28	172.96	491.22	489.18	1389.11	1411.81	123.67	126.20
LRF (count)	2150.50	2150.43	263.72	264.09	711.50	711.44	1089.83	1088.46	85.44	86.44
RoSF (count)	6358.56	6353.24	3569.00	3566.98	1114.61	1114.60	537.56	537.81	1137.39	1133.84
SMF (count)	43.06	42.90	33.89	33.71	8.88	8.89	0.00	0.00	0.28	0.29
GMF (count)	7.78	8.02	2.11	2.22	5.67	5.80	0.00	0.00	0.00	0.00
Mixed Events (%)										

Table 37: Seasonal trends (in %) of all flood types in the respective altitude groups, for both crisp tree and fuzzy tree, using mean ***RCP 4.5*** *chains of the 2059-2099 period. The number in brackets next to the altitude group represents the number of catchments.*

	All Seasons		Spring		Summer		Autumn		Winter	
Lowland (139)	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**
FF (% change)	4.43	4.52	35.99	33.78	-3.85	-3.71	-4.29	-2.47	0.00	0.00
SRF (% change)	40.87	40.73	37.89	39.17	-2.08	-2.37	37.66	36.38	56.69	57.14
LRF (% chagne)	23.24	23.28	37.65	37.64	5.58	5.59	7.38	7.43	32.87	32.94
RoSF (% change)	-49.56	-49.57	-51.88	-51.92	-71.97	-71.79	-55.52	-55.81	-47.72	-47.70
SMF (% change)	-44.55	-48.35	-42.89	-45.11	0.00	0.00	0.00	3.09	-46.89	-52.43
GMF (% change)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mixed (% change)		-0.96		-0.63		-0.29		-0.77		-1.68
Mid-altitude (49)	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**
FF (% change)	19.58	19.24	98.58	94.49	12.81	13.08	8.06	7.32	0.00	0.00
SRF (% change)	62.73	62.48	92.54	92.48	7.66	6.35	43.84	43.97	254.56	251.66
LRF (% chagne)	38.86	38.83	113.09	113.52	6.63	6.46	20.23	20.11	164.17	164.58
RoSF (% change)	-19.85	-19.80	-31.28	-31.26	-63.26	-62.70	-28.56	-28.56	14.88	14.84
SMF (% change)	-33.33	-33.97	-35.92	-36.51	0.00	0.00	-67.06	-71.54	37.56	30.72
GMF (% change)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mixed (% change)		0.42		1.96		-1.53		-1.60		1.74
High altitude (119)	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**
FF (% change)	125.39	127.48	2532.50	2043.63	172.15	173.96	75.65	74.84	0.00	0.00
SRF (% change)	111.53	110.97	1013.39	981.43	102.13	101.27	96.60	96.20	1032.50	1029.96
LRF (% chagne)	92.26	91.66	854.04	826.48	102.77	102.27	67.70	67.11	532.41	537.85
RoSF (% change)	-6.35	-6.31	32.67	32.68	-40.44	-40.41	-38.94	-38.76	136.30	135.95
SMF (% change)	10.46	12.14	10.20	10.74	10.96	14.49	0.00	0.00	0.00	0.00
GMF (% change)	-43.72	-44.36	-44.75	-44.59	-43.52	-44.31	0.00	0.00	0.00	0.00
Mixed (% change)		0.49		1.22		2.24		-1.99		1.97

Table 38: Seasonal trends (in %) of all flood types in the respective altitude groups, for both crisp tree and fuzzy tree, using mean ***RCP 8.5*** *chains of the 2059-2099 period. The number in brackets next to the altitude group represents the number of catchments.*

	All Seasons		Spring		Summer		Autumn		Winter	
Lowland (139)	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**
FF (% change)	4.80	4.41	41.97	40.93	3.94	4.12	-28.15	-29.91	0.00	0.00
SRF (% change)	54.29	53.83	72.32	72.06	7.92	7.48	22.13	21.74	89.47	89.44
LRF (% chagne)	33.53	33.56	51.38	51.32	-16.10	-16.10	-10.23	-10.27	79.89	80.18
RoSF (% change)	-74.16	-73.99	-77.48	-77.33	-99.11	-98.78	-86.46	-86.09	-71.36	-71.21
SMF (% change)	-80.86	-81.24	-91.94	-92.42	0.00	0.00	-100.00	-100.00	-70.48	-70.69
GMF (% change)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mixed (% change)		0.00		0.00		0.00		0.00		0.00
Mid-altitude (49)	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**
FF (% change)	23.17	22.55	197.38	190.90	16.51	16.81	-14.27	-15.44	0.00	0.00
SRF (% change)	107.15	107.22	271.24	269.84	8.57	8.32	48.06	47.98	612.09	607.58
LRF (% chagne)	57.29	57.30	178.16	179.09	-16.93	-16.89	13.15	13.08	517.28	514.64
RoSF (% change)	-36.22	-36.23	-49.60	-49.53	-86.05	-86.20	-67.94	-68.04	11.50	11.54
SMF (% change)	-82.97	-84.13	-84.99	-86.26	-100.00	-100.00	-60.40	-55.04	-70.91	-71.96
GMF (% change)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mixed (% change)		0.00		0.00		0.00		0.00		0.00
High altitude (119)	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**	**Crisp**	**Fuzzy**
FF (% change)	156.29	161.07	9036.38	9424.92	205.53	209.70	78.35	79.08	0.00	0.00
SRF (% change)	172.07	170.06	3382.96	3434.61	118.32	115.92	146.95	144.93	1724.79	1751.25
LRF (% chagne)	138.81	138.21	2848.45	2839.03	87.35	87.04	114.98	114.07	1667.82	1662.67
RoSF (% change)	-20.33	-20.36	35.37	35.31	-69.54	-69.53	-60.10	-60.01	235.84	234.91
SMF (% change)	29.60	30.84	54.82	55.05	-21.26	-19.08	-100.00	-94.74	0.00	0.00
GMF (% change)	-63.35	-63.71	-45.72	-48.50	-67.31	-67.40	0.00	0.00	0.00	0.00
Mixed (% change)		0.00		0.00		0.00		0.00		0.00

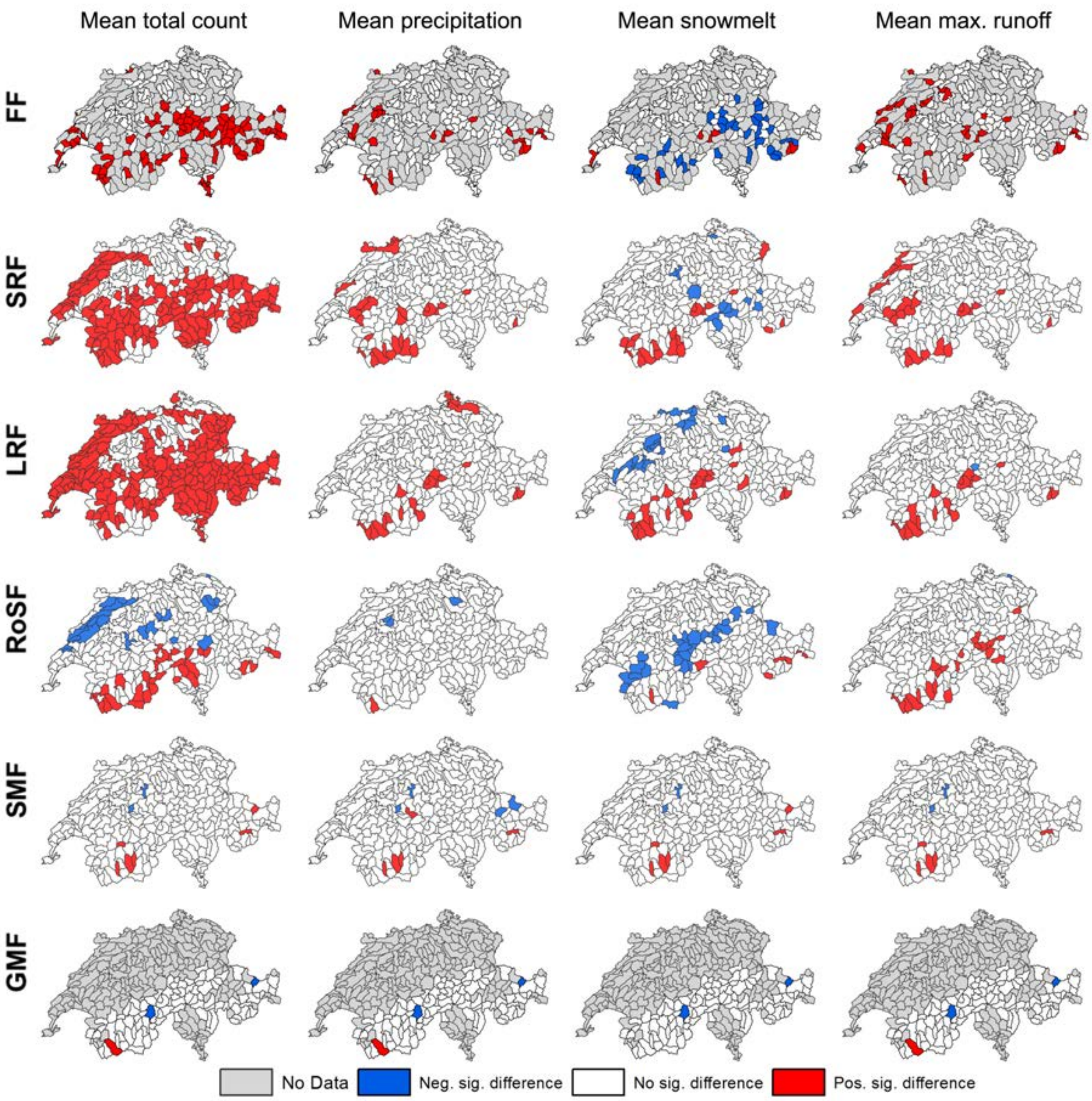

*Figure 49: The maps show, if the trend during the 2059-2099 period of mean total count, mean precipitation per event, mean snowmelt per event, mean max. daily runoff per flood type event is significant, compared to the reference period, for **RCP 2.6** chains. Gray catchments in FF and GMF indicate catchments, where FF and GMF can not occur at all (>150km^2 and unglaciated, respectively)*

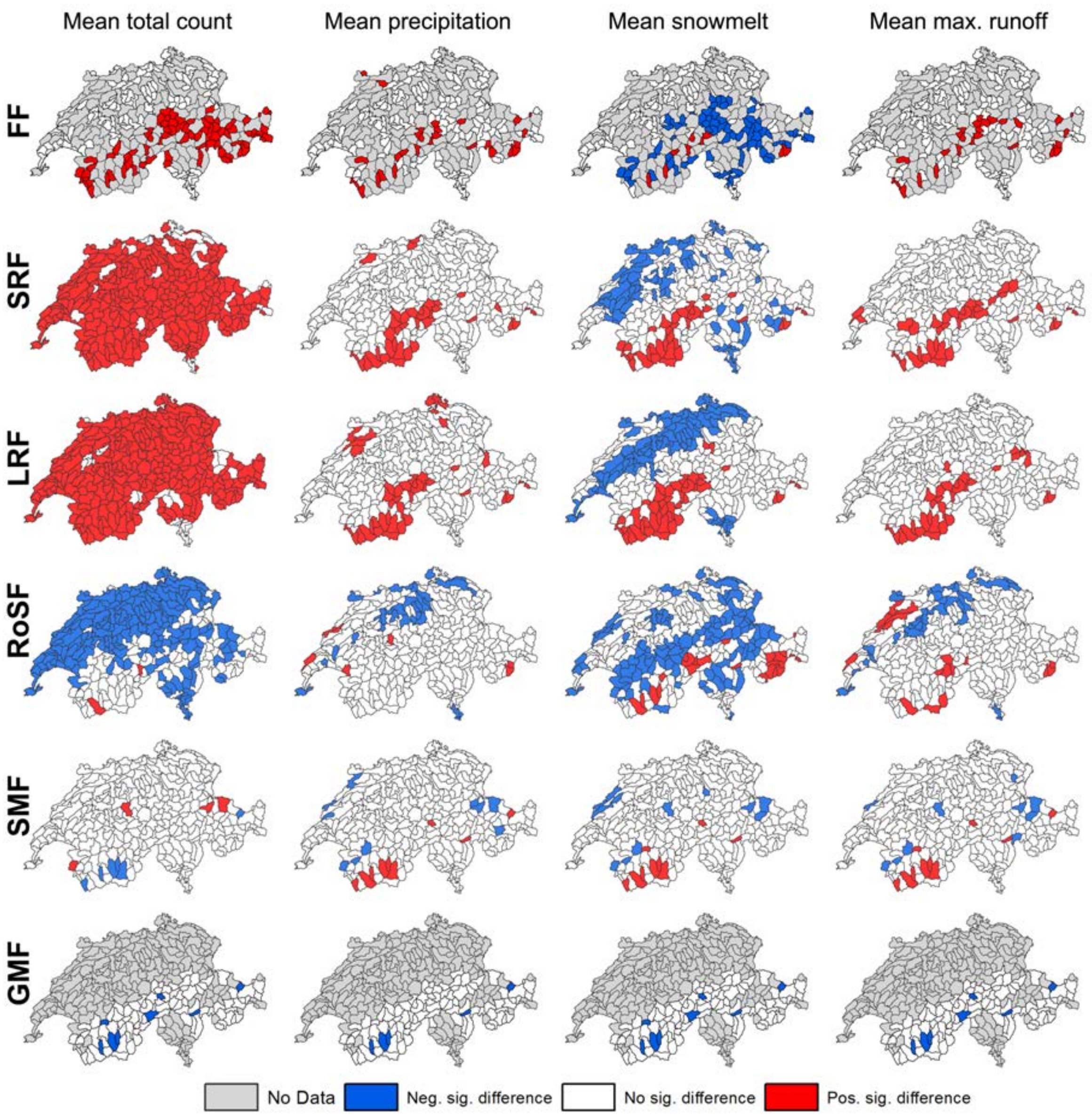

*Figure 50: The maps show, if the trend during the 2059-2099 period of mean total count, mean precipitation per event, mean snowmelt per event, mean max. daily runoff per flood type event is significant, compared to the reference period, for **RCP 4.5** chains. Gray catchments in FF and GMF indicate catchments, where FF and GMF can not occur at all (>150km^2 and unglaciated, respectively)*

Table 39: Uncorrected number of catchments of positive, negative and non-significant trends for mean precipitation, mean snowmelt and mean maximum daily runoff for each flood type, during the second future period

RCP2.6	Count			P/Event [mm]			SM/Event [mm]			Max Q/Event [mm]		
Significance	N	0	P	N	0	P	N	0	P	N	0	P
FF	0	106	91	0	171	16	34	156	7	0	159	38
SRF	0	165	142	0	280	27	13	274	20	0	285	22
LRF	0	100	207	0	285	22	21	262	24	1	288	18
RoSF	25	249	33	3	302	2	26	274	7	1	283	23
SMF	2	302	3	4	298	5	2	299	6	2	300	5
GMF	2	304	1	2	93	1	1	93	2	2	92	2
RCP4.5	Count			P/Event [mm]			SM/Event [mm]			Max Q/Event [mm]		
Significance	N	0	P	N	0	P	N	0	P	N	0	P
FF	0	121	76	0	168	29	76	112	9	0	172	25
SRF	0	33	274	0	271	36	76	197	34	0	271	36
LRF	0	31	276	0	263	44	92	172	43	0	274	33
RoSF	186	116	3	36	263	8	112	171	24	41	247	19
SMF	6	296	4	10	288	9	9	286	12	10	287	10
GMF	0	93	3	5	90	1	8	88	1	7	89	1
RCP8.5	Count			P/Event [mm]			SM/Event [mm]			Max Q/Event [mm]		
Significance	N	0	P	N	0	P	N	0	P	N	0	P
FF	0	95	102	0	108	89	90	100	7	0	161	36
SRF	0	6	301	0	179	128	147	117	43	0	221	86
LRF	0	15	292	0	183	124	127	116	64	0	254	53
RoSF	278	24	3	104	193	10	244	61	2	87	158	62
SMF	11	266	29	41	248	18	61	223	23	59	224	24
GMF	1	91	5	12	83	1	18	78	0	19	77	1

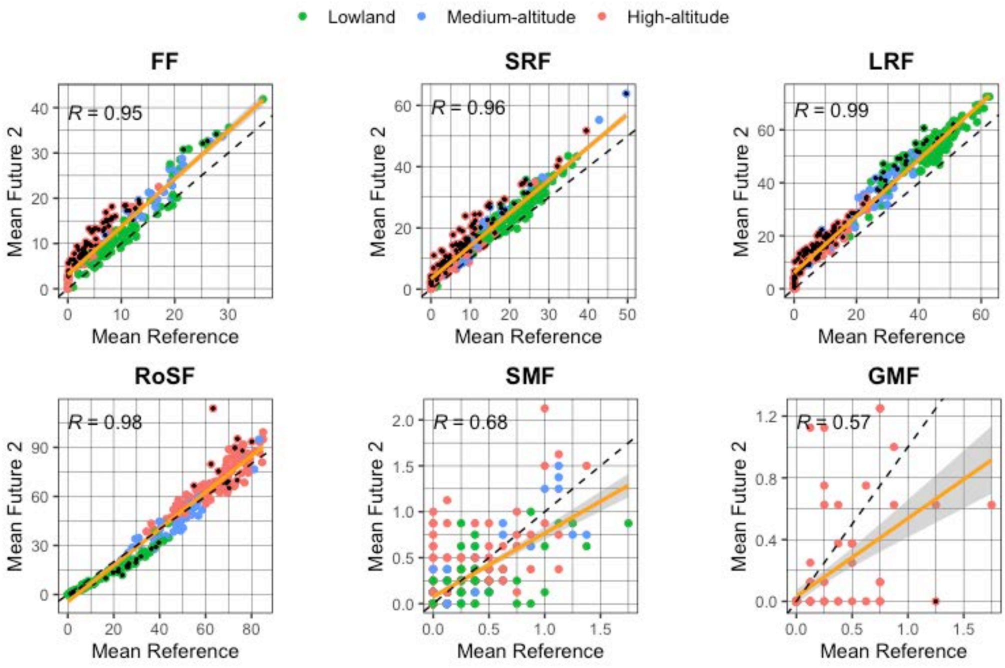

*Figure 51: Frequency comparison between the reference period and second future period, coloured by catchment groups, for **RCP 2.6** chains. The dashed line represents equal values in both periods (reference period = future period) and the orange line represents the linear approximation between both periods). Values that significantly differ are highlighted black. The R-value stands for the Pearson's R-coefficient.*

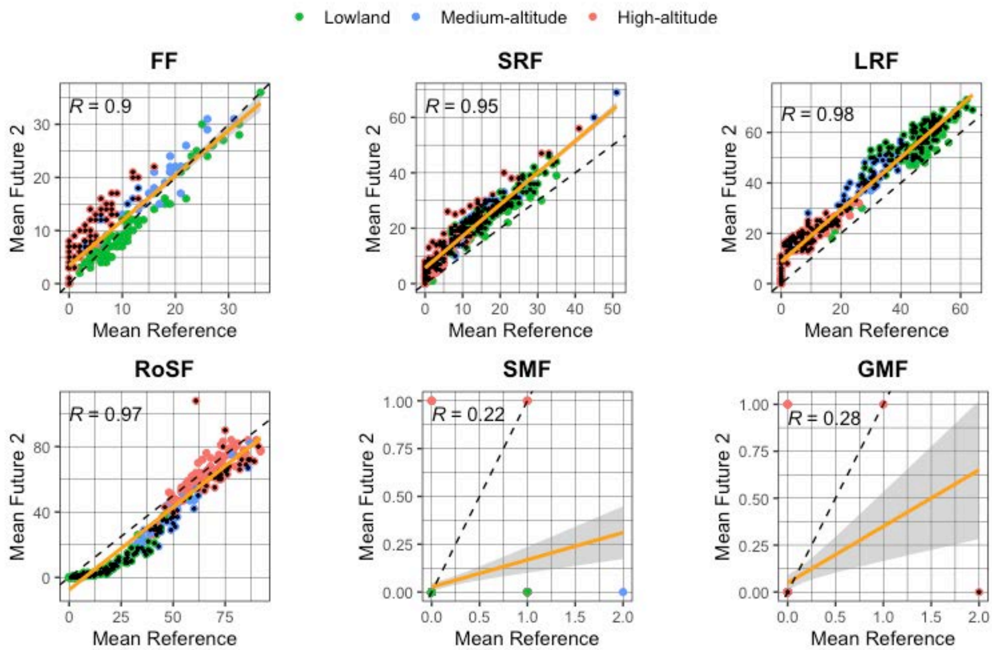

*Figure 52: Frequency comparison between the reference period and second future period, coloured by catchment groups, for **RCP 4.5** chains. The dashed line represents equal values in both periods (reference period = future period) and the orange line represents the linear approximation between both periods). Values that significantly differ are highlighted black. The R-value stands for the Pearson's R-coefficient.*

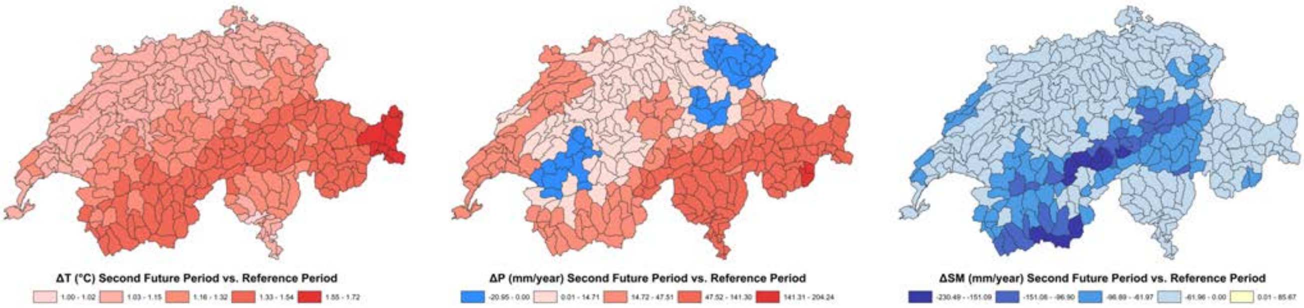

Figure 53: Changes of mean annual temperature (ΔT), mean annual precipitation (ΔP) and mean annual snowmelt (ΔSM) during the 2059-2099 period, for RCP 2.6 chains

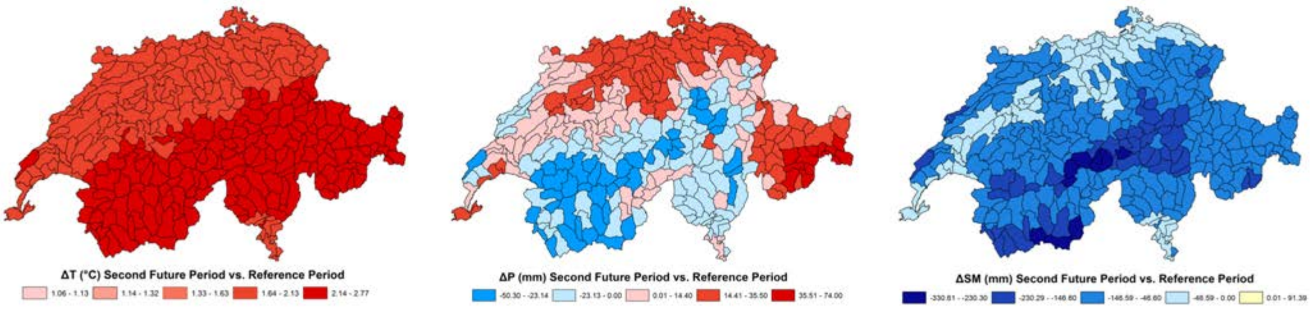

Figure 54: Changes of mean annual temperature (ΔT), mean annual precipitation (ΔP) and mean annual snowmelt (ΔSM) during the 2059-2099 period, for RCP 4.5 chains

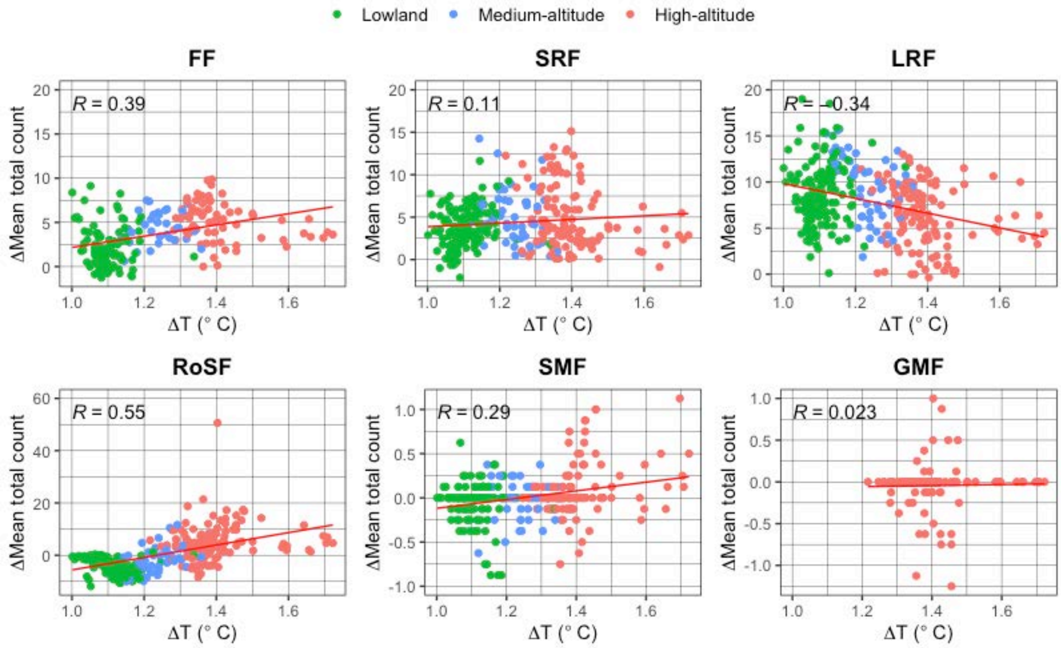

*Figure 55: Correlation analysis between mean annual temperature changes (ΔT) and changes of mean total count, coloured by catchment groups, during the 2059-2099 period, for **RCP2.6** chains. The red line represents the linear approximation*

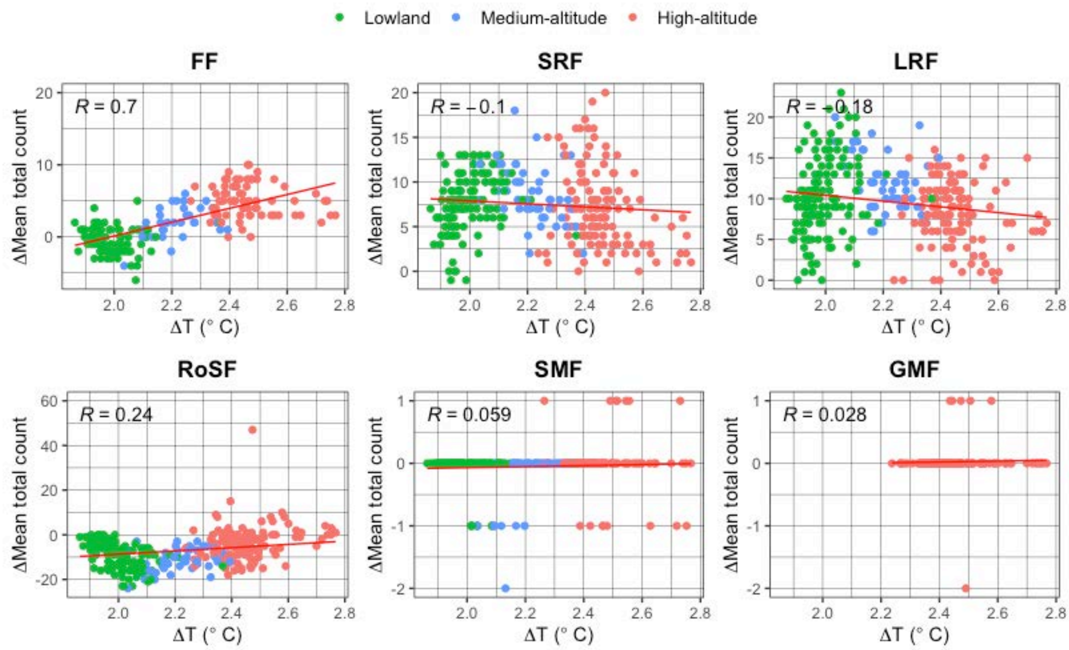

*Figure 56: Correlation analysis between mean annual temperature changes (ΔT) and changes of mean total count, coloured by catchment groups, during the 2059-2099 period, for **RCP4.5** chains. The red line represents the linear approximation. The R value represents the Pearson's R coefficient.*

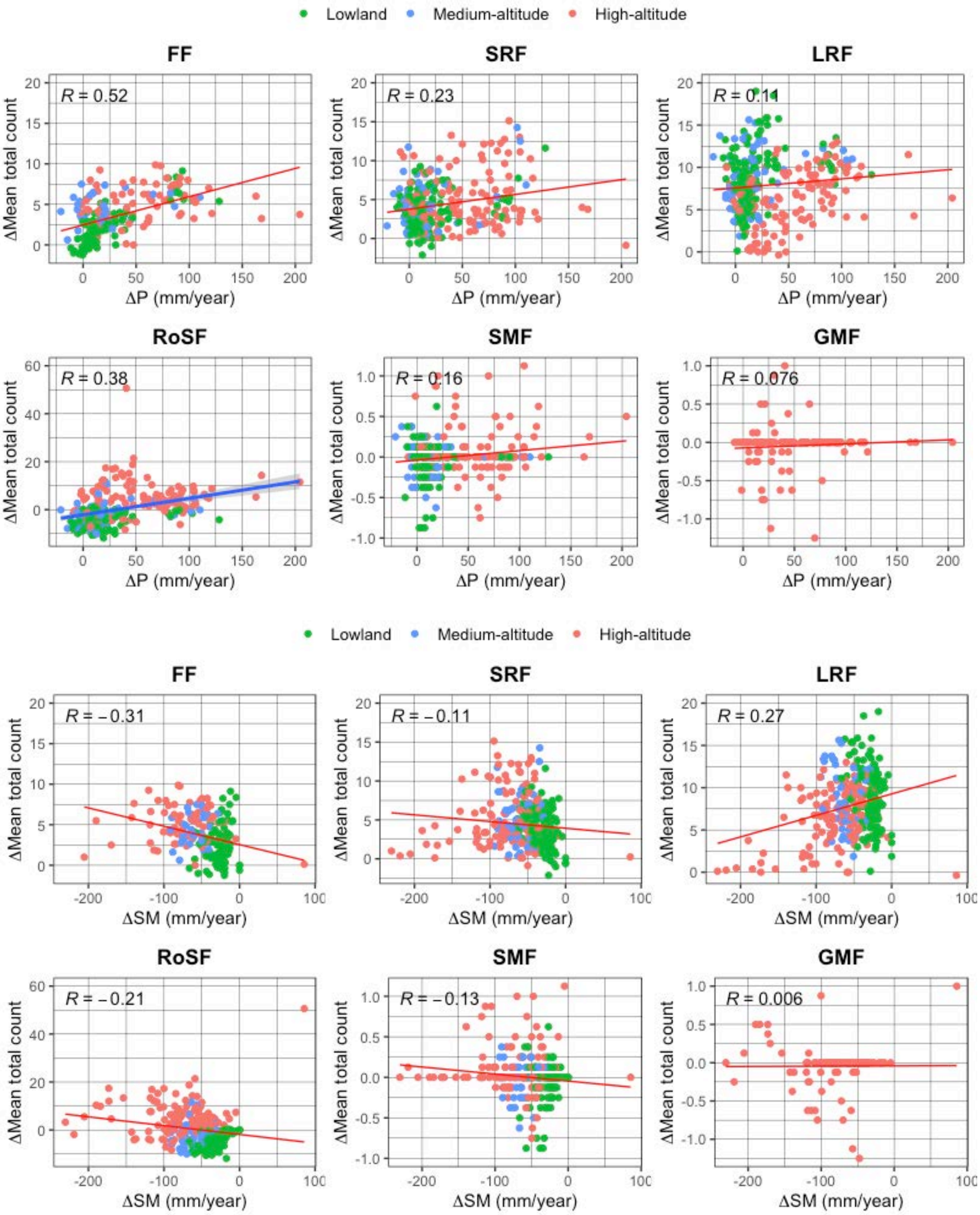

*Figure 57: Correlation analysis between mean annual precipitation changes (ΔP) and changes of mean total count, and between mean annual snowmelt (ΔSM) and changes of mean total count, respectively, coloured by catchment groups, during the 2059- 2099 period, for **RCP 2.6**. The red line represents the linear approximation. The R value represents the Pearson's R coefficient.*

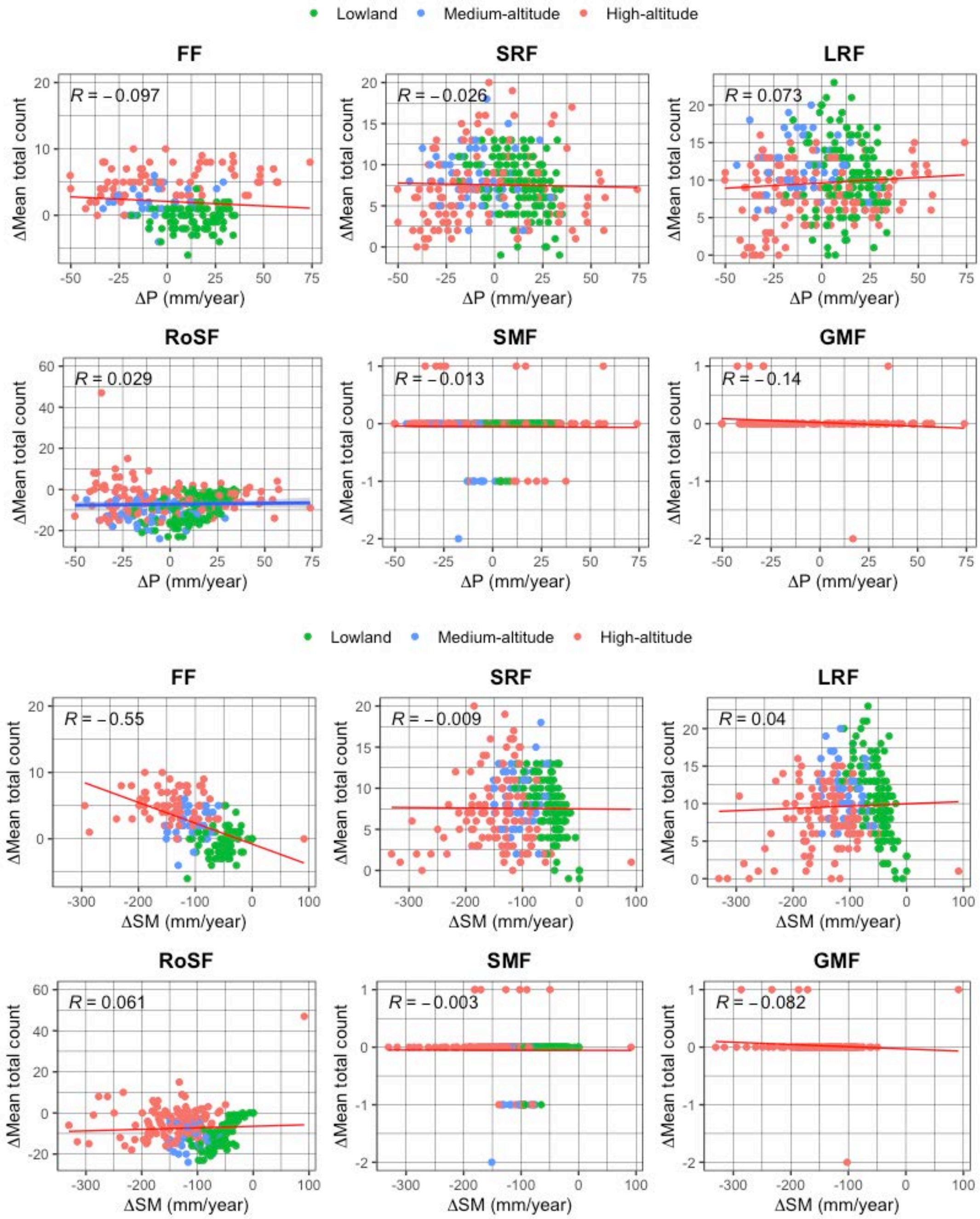

*Figure 58: Correlation analysis between mean annual precipitation changes (ΔP) and changes of mean total count, and between mean annual snowmelt (ΔSM) and changes of mean total count, respectively, coloured by catchment groups, during the 2059- 2099 period, for **RCP 4.5**. The red line represents the linear approximation. The R value represents the Pearson's R coefficient.*

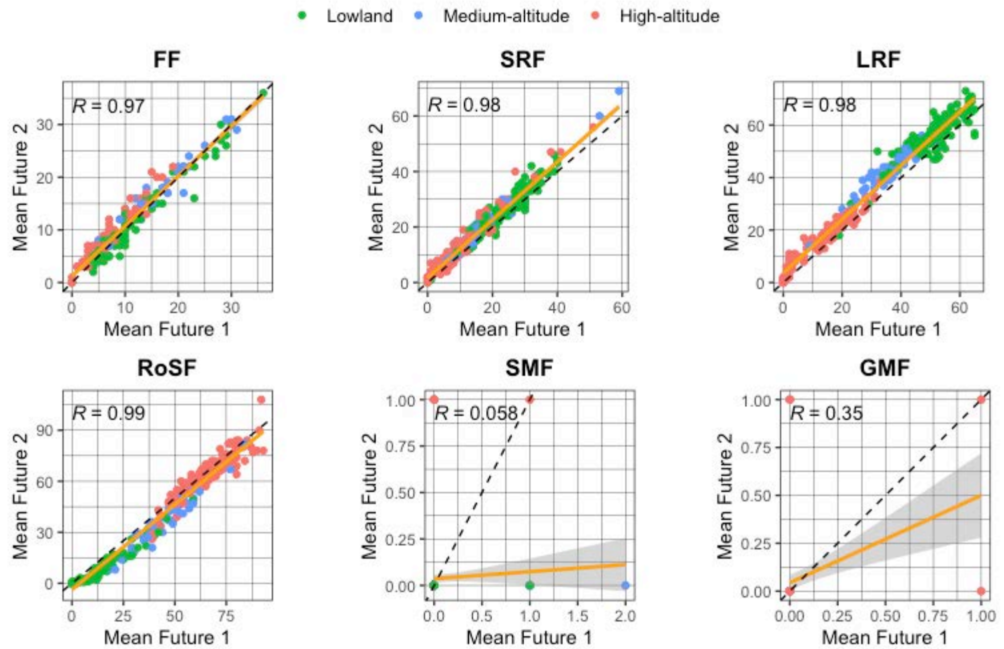

Figure 59: Comparison of the mean frequency between the first future and second future period.

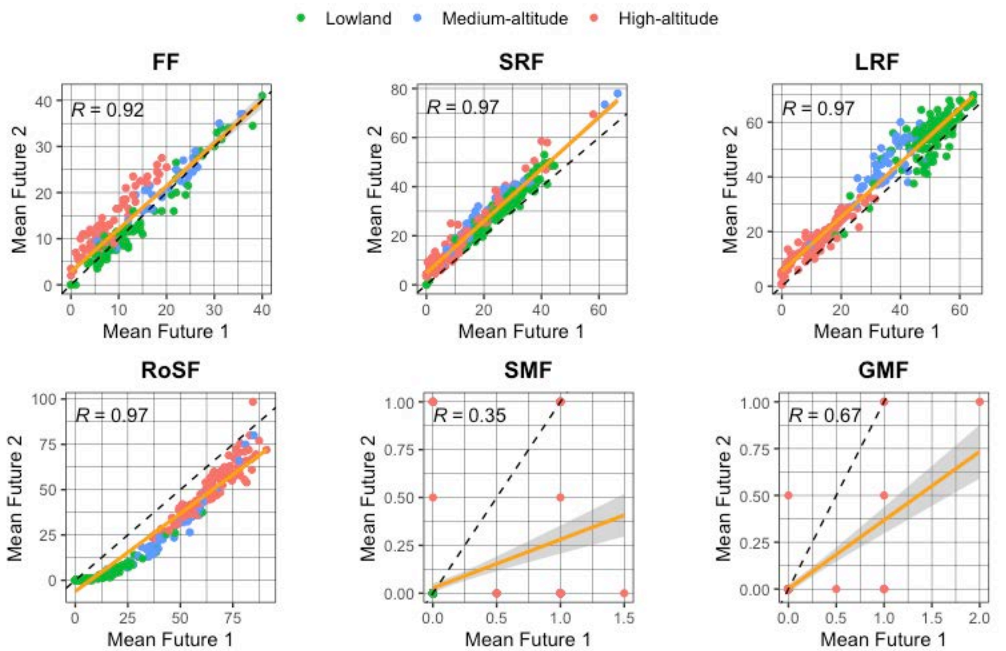

Figure 60: Comparison of the mean frequency between the first future and second future period.

Table 40: List of all catchments with mean annual temperature, mean annual precipitation, mean annual snowmelt, altitude and catchment area, according to the control simulation.

OBJECTID	Temperature	Precipitation	Snowmelt	Altitude	Altitude-Class	AREA	OBJECTID	Temperature	Precipitation	Snowmelt	Altitude	Altitude-Class	AREA
1	4.00	1856.99	452.70	1617.24	High-altitude	244.5	155	1.95	1208.30	400.35	2001.63	High-altitude	118.1
2	9.34	1217.20	87.75	518.87	Lowland	0.9	156	5.46	1560.88	402.28	1235.48	Medium-altitude	199.1
3	7.49	1782.02	252.10	940.05	Lowland	106.9	157	0.98	1472.50	747.12	2196.66	High-altitude	177.6
4	9.07	1448.18	110.19	552.17	Lowland	163.2	158	1.09	1867.13	1084.91	2066.61	High-altitude	180.2
5	7.42	1616.65	272.70	860.51	Lowland	84.9	159	0.30	1530.44	666.80	2311.36	High-altitude	81.0
6	0.13	1526.01	766.84	2460.58	High-altitude	112.3	160	10.04	1064.09	43.65	392.35	Lowland	0.2
7	0.29	1391.70	543.46	2245.72	High-altitude	159.0	161	9.10	1173.57	91.25	510.42	Lowland	178.9
8	8.14	1972.59	91.16	925.85	Lowland	34.1	162	6.78	1245.04	205.19	992.97	Lowland	221.1
9	9.54	1220.32	78.22	476.66	Lowland	223.7	163	9.14	1368.34	103.72	564.60	Lowland	214.1
10	6.11	1231.89	233.63	1190.00	Medium-altitude	55.3	164	8.37	1125.47	104.05	708.66	Lowland	182.1
11	9.37	1121.75	77.87	480.07	Lowland	23.6	165	8.64	1189.39	113.58	611.30	Lowland	88.8
12	8.12	1317.64	132.29	777.06	Lowland	192.9	166	8.82	1204.85	98.68	589.14	Lowland	127.1
13	4.09	1631.20	436.04	1559.21	High-altitude	85.4	167	3.60	1778.14	659.81	1718.54	High-altitude	299.6
14	7.97	1773.96	90.79	971.09	Lowland	75.5	168	2.78	1697.45	645.02	1898.71	High-altitude	124.3
15	9.09	1111.53	86.35	528.84	Lowland	55.6	169	0.76	1604.29	673.73	2164.52	High-altitude	143.1
16	7.62	1356.91	180.90	852.74	Lowland	119.6	170	4.56	1471.08	397.12	1432.82	Medium-altitude	98.3
17	8.36	1330.33	149.83	772.82	Lowland	160.8	171	10.85	1539.58	0.00	377.29	Lowland	5.6
18	9.59	1114.12	69.93	442.80	Lowland	69.2	172	-1.22	1888.27	1204.06	2621.34	High-altitude	77.2
19	6.90	1430.58	253.57	996.00	Lowland	186.7	173	-0.15	1491.89	819.44	2537.94	High-altitude	282.8
20	9.16	1243.44	90.57	485.78	Lowland	74.0	174	7.69	1225.24	132.43	851.31	Lowland	148.0
21	-1.13	2068.69	1014.22	2543.61	High-altitude	124.7	175	9.12	1165.37	77.81	550.47	Lowland	95.3
22	7.12	1156.85	190.98	878.50	Lowland	222.0	176	8.52	1206.41	104.58	647.78	Lowland	92.2
23	2.21	1564.72	548.51	1912.20	High-altitude	139.3	177	6.51	1425.71	270.23	1028.46	Medium-altitude	171.4
24	-0.54	1134.32	439.46	2311.97	High-altitude	57.7	178	-0.08	1583.35	670.17	2329.23	High-altitude	91.0
25	2.82	1537.01	544.19	1800.97	High-altitude	105.1	179	10.15	1492.55	68.25	408.45	Lowland	6.3
26	10.08	1209.35	0.00	398.85	Lowland	1.4	180	9.02	1257.60	88.74	579.95	Lowland	72.7
27	9.14	1237.49	80.53	506.03	Lowland	202.5	181	0.84	2228.31	1100.29	2177.73	High-altitude	71.3
28	0.79	1521.90	632.99	2210.52	High-altitude	114.6	182	8.54	1107.77	102.71	681.67	Lowland	122.0
29	-2.97	1865.07	1291.93	3004.45	High-altitude	200.9	183	3.21	1824.40	696.00	1648.75	High-altitude	107.2
30	9.50	1100.03	75.63	442.66	Lowland	54.2	184	7.09	1302.69	219.01	974.01	Lowland	115.1
31	5.32	1806.96	465.03	1251.92	Medium-altitude	74.7	185	4.21	1631.86	552.16	1562.82	High-altitude	78.3
32	3.34	1590.52	619.92	1812.63	High-altitude	235.8	186	4.40	1896.75	587.15	1409.29	Medium-altitude	160.7
33	-0.26	1652.43	897.48	2450.64	High-altitude	297.3	187	8.38	1398.71	160.53	666.99	Lowland	93.6
34	11.17	1933.19	32.98	465.23	Lowland	108.2	188	1.39	1908.48	760.07	2165.95	High-altitude	86.4
35	8.70	1152.00	89.04	651.81	Lowland	183.1	189	9.82	1518.86	69.40	535.49	Lowland	88.3
36	3.82	1615.46	583.79	1640.93	High-altitude	87.9	190	3.89	1251.88	418.05	1707.45	High-altitude	141.5
37	8.94	1269.79	82.90	634.46	Lowland	229.6	191	7.71	1229.02	183.27	773.40	Lowland	217.6
38	-0.19	1172.95	466.01	2341.53	High-altitude	109.9	192	3.87	1255.38	303.98	1612.91	High-altitude	99.9
39	5.86	1823.34	377.98	1226.64	Medium-altitude	174.0	193	5.56	2065.09	261.10	1397.88	Medium-altitude	108.2
40	3.84	1527.15	480.29	1583.77	High-altitude	3.1	194	4.49	1473.74	432.25	1417.82	Medium-altitude	38.5

Table 40: continued

41	4.39	1662.11	524.18	1527.12	High-altitude	43.3	195	9.12	1237.06	98.41	541.76	Lowland	94.9
42	6.20	2060.65	181.92	1337.38	Medium-altitude	10.9	196	0.51	1921.19	876.33	2218.04	High-altitude	186.5
43	-0.73	2356.77	1132.36	2537.70	High-altitude	0.4	197	1.13	1979.44	919.32	2170.98	High-altitude	117.1
44	0.25	1455.76	542.49	2231.27	High-altitude	64.4	198	-0.46	1534.05	630.94	2432.86	High-altitude	119.6
45	9.27	1271.99	84.85	513.36	Lowland	101.9	199	8.74	1114.79	115.74	536.34	Lowland	142.8
46	9.08	1484.51	107.55	550.71	Lowland	370.7	200	7.27	1398.54	240.11	938.42	Lowland	265.7
47	8.22	1442.18	171.43	646.00	Lowland	79.4	201	7.15	1766.84	143.06	1073.82	Medium-altitude	133.4
48	5.89	1161.15	246.64	1154.29	Medium-altitude	84.5	202	8.40	1449.08	113.01	781.46	Lowland	236.8
49	8.91	1386.72	114.70	606.96	Lowland	75.1	203	7.03	1115.57	178.97	1014.97	Medium-altitude	178.5
50	10.02	1581.09	58.39	507.41	Lowland	51.4	204	2.59	1219.43	370.56	1830.76	High-altitude	76.2
51	7.21	1554.26	249.12	869.71	Lowland	84.4	205	9.49	1166.13	77.93	468.67	Lowland	175.6
52	6.33	1541.62	303.47	973.42	Lowland	225.2	206	9.04	1204.49	68.12	587.69	Lowland	74.4
53	5.56	1534.48	375.28	1110.73	Medium-altitude	96.4	207	4.87	1842.75	493.55	1342.88	Medium-altitude	96.6
54	5.10	1462.10	360.95	1382.61	Medium-altitude	180.0	208	1.16	2088.38	1011.33	2095.54	High-altitude	168.9
55	8.89	1173.34	84.01	661.94	Lowland	138.2	209	-1.04	1560.26	768.07	2564.78	High-altitude	19.5
56	3.52	2130.99	788.58	1634.60	High-altitude	176.0	210	6.50	1487.24	230.38	1157.05	Medium-altitude	133.2
57	5.45	1711.65	390.22	1194.46	Medium-altitude	89.7	211	5.24	1267.78	241.47	1372.48	Medium-altitude	21.0
58	2.42	1200.14	492.61	1975.49	High-altitude	180.6	212	7.25	1868.05	168.77	1121.59	Medium-altitude	181.8
59	9.28	1188.24	81.84	549.22	Lowland	189.5	213	3.17	1839.00	713.25	1747.43	High-altitude	215.2
60	6.99	1637.62	236.11	1031.41	Medium-altitude	129.7	214	4.49	1531.64	452.33	1496.31	Medium-altitude	274.0
61	6.54	1169.19	206.42	1022.46	Medium-altitude	203.7	215	9.63	1440.45	63.07	624.64	Lowland	145.6
62	0.00	1926.48	945.46	2291.94	High-altitude	70.5	216	8.41	1627.75	195.44	702.55	Lowland	218.1
63	5.62	1481.09	332.67	1232.35	Medium-altitude	335.1	217	10.50	1520.40	48.04	431.93	Lowland	24.4
64	0.01	2097.46	1081.19	2369.15	High-altitude	75.6	218	5.55	1326.96	256.30	1265.16	Medium-altitude	120.7
65	4.00	1595.26	529.86	1603.52	High-altitude	140.4	219	8.75	1245.95	114.29	581.91	Lowland	86.2
66	6.16	1631.74	362.45	1055.09	Medium-altitude	80.2	220	9.10	1037.66	74.56	570.86	Lowland	57.4
67	5.50	1524.89	353.19	1218.35	Medium-altitude	187.8	221	3.01	1918.59	480.21	1851.42	High-altitude	139.8
68	4.02	1958.44	638.41	1540.47	High-altitude	231.7	222	9.03	1209.63	84.36	558.39	Lowland	91.4
69	10.65	1585.48	37.60	400.08	Lowland	2.4	223	3.12	1401.77	475.20	1768.01	High-altitude	155.7
70	8.74	1208.56	107.23	557.60	Lowland	133.5	224	-1.90	1861.40	1056.56	2675.78	High-altitude	84.8
71	10.20	1875.95	33.30	562.64	Lowland	16.5	225	6.53	1856.72	211.74	1213.73	Medium-altitude	159.7
72	5.82	1364.58	309.03	1217.72	Medium-altitude	183.8	226	4.30	1842.86	606.38	1500.40	High-altitude	129.3
73	-0.16	1785.60	940.14	2447.66	High-altitude	103.5	227	7.62	1105.61	137.68	818.01	Lowland	70.8
74	1.10	1475.87	628.71	2238.73	High-altitude	169.0	228	9.82	1660.71	88.38	549.76	Lowland	129.6
75	9.58	1184.01	70.75	460.11	Lowland	44.2	229	2.35	1598.13	622.19	1882.19	High-altitude	108.4
76	4.79	1694.83	464.49	1463.09	Medium-altitude	288.6	230	6.46	1426.04	280.31	1030.87	Medium-altitude	200.2
77	2.47	1231.03	412.59	1859.13	High-altitude	222.8	231	5.34	1278.78	320.94	1265.63	Medium-altitude	128.9
78	8.88	1236.20	92.34	641.13	Lowland	180.8	232	0.02	1779.43	787.47	2230.11	High-altitude	183.9
79	1.57	1376.21	503.42	2080.38	High-altitude	238.6	233	9.37	1091.37	74.65	479.15	Lowland	463.4
80	10.51	1568.24	48.43	427.09	Lowland	163.0	234	1.95	1793.09	847.35	2066.38	High-altitude	79.2

Table 40: continued

81	1.85	1946.57	697.37	2054.16	High-altitude	165.2	235	9.37	1201.46	73.79	513.84	Lowland	76.8
82	8.05	1156.96	122.56	750.49	Lowland	104.8	236	4.17	1239.09	346.19	1557.89	High-altitude	296.1
83	4.23	1845.43	399.98	1633.92	High-altitude	282.3	237	8.89	1209.79	85.64	586.23	Lowland	103.3
84	1.65	1739.16	809.45	2103.79	High-altitude	185.2	238	9.74	1245.75	73.92	461.66	Lowland	45.1
85	-0.60	1606.65	634.40	2382.44	High-altitude	186.3	239	-2.22	1835.41	721.85	2819.86	High-altitude	2.3
86	8.60	1159.99	100.71	663.21	Lowland	89.4	240	-0.43	1338.21	519.36	2368.98	High-altitude	60.4
87	2.23	1679.80	618.44	2039.94	High-altitude	108.3	241	2.31	1843.98	538.28	1931.73	High-altitude	120.2
88	4.34	1599.94	458.36	1490.72	Medium-altitude	107.5	242	0.46	2098.81	937.16	2260.05	High-altitude	196.5
89	8.28	1453.94	156.64	667.27	Lowland	298.2	243	0.30	1509.08	550.16	2252.85	High-altitude	65.2
90	0.94	1434.94	525.56	2168.34	High-altitude	89.0	244	-2.10	1655.04	932.73	2698.43	High-altitude	66.8
91	7.78	1158.28	149.27	743.04	Lowland	97.5	245	8.71	1364.79	118.09	592.64	Lowland	132.8
92	8.72	1243.22	110.23	561.85	Lowland	94.5	246	9.07	1236.02	76.73	671.40	Lowland	66.1
93	1.37	1953.44	792.74	2150.64	High-altitude	155.0	247	-1.74	1819.51	1159.93	2753.53	High-altitude	157.1
94	9.38	1182.52	71.95	474.49	Lowland	210.1	248	1.40	1377.88	475.51	2074.10	High-altitude	159.0
95	9.73	1085.50	67.69	428.51	Lowland	95.2	249	-1.47	1972.58	868.84	2547.27	High-altitude	73.6
96	11.45	1738.68	12.06	411.18	Lowland	32.9	250	3.80	1543.04	503.55	1730.16	High-altitude	143.3
97	4.75	1396.03	367.01	1391.44	Medium-altitude	115.2	251	6.17	1487.17	300.75	1073.97	Medium-altitude	9.7
98	5.84	1568.02	405.43	1272.93	Medium-altitude	160.7	252	9.32	1137.83	81.53	465.29	Lowland	56.8
99	10.15	1255.35	40.86	489.49	Lowland	71.2	253	-0.51	1551.23	668.92	2363.19	High-altitude	187.5
100	1.23	1794.18	816.18	2161.00	High-altitude	72.2	254	8.17	1899.26	101.38	924.96	Lowland	100.6
101	7.12	1903.13	296.59	1015.89	Medium-altitude	121.6	255	3.06	1825.92	467.54	1836.56	High-altitude	194.8
102	10.99	1744.94	40.82	356.45	Lowland	19.4	256	-1.56	1667.83	1007.76	2775.17	High-altitude	201.9
103	8.49	950.37	96.86	593.03	Lowland	0.3	257	9.45	1200.42	81.51	468.17	Lowland	254.0
104	2.13	1957.20	841.68	1946.76	High-altitude	87.0	258	2.12	1234.83	496.62	2022.41	High-altitude	77.0
105	7.06	1093.26	162.03	910.48	Lowland	107.5	259	7.89	2214.09	111.56	975.64	Lowland	50.9
106	0.23	1351.80	547.98	2294.58	High-altitude	354.3	260	-3.03	1888.76	1174.55	2886.06	High-altitude	202.4
107	9.21	1143.64	85.15	548.20	Lowland	285.3	261	9.91	1858.95	55.25	598.48	Lowland	63.4
108	6.68	1520.27	273.33	905.53	Lowland	126.5	262	8.40	1636.50	171.74	655.92	Lowland	76.3
109	8.22	1764.50	93.45	838.55	Lowland	31.2	263	9.22	1126.23	87.74	507.45	Lowland	67.5
110	7.90	1215.69	142.88	763.87	Lowland	60.2	264	9.53	1270.37	69.72	503.21	Lowland	166.0
111	8.79	1230.74	112.04	663.91	Lowland	228.3	265	7.50	1348.72	170.84	899.60	Lowland	250.5
112	3.96	1497.78	485.63	1592.36	High-altitude	170.1	266	3.65	1912.58	425.40	1704.69	High-altitude	92.8
113	1.84	1547.33	512.58	1974.46	High-altitude	95.7	267	1.70	1473.19	540.61	2041.69	High-altitude	16.9
114	1.54	1646.51	743.52	2146.45	High-altitude	84.2	268	6.05	1760.03	341.92	1059.77	Medium-altitude	70.2
115	8.76	1238.00	110.69	587.32	Lowland	340.1	269	9.51	1064.21	60.97	559.76	Lowland	162.8
116	6.74	1341.04	245.87	987.31	Lowland	215.8	270	3.27	1795.22	643.76	1717.24	High-altitude	107.4
117	9.72	1066.80	69.45	435.26	Lowland	77.3	271	-1.08	1647.14	720.37	2402.32	High-altitude	93.9
118	0.78	1696.38	867.55	2237.43	High-altitude	120.2	272	7.47	1255.50	184.80	900.92	Lowland	77.9
119	5.88	1437.21	328.26	1107.57	Medium-altitude	66.8	273	3.90	1237.44	338.67	1662.58	High-altitude	152.9
120	10.54	994.01	34.08	306.96	Lowland	59.1	274	1.72	1887.09	610.35	2055.59	High-altitude	159.5

Table 40: continued

121	6.84	1253.46	184.58	1004.95	Medium-altitude	215.4	275	9.72	1044.49	45.49	501.22	Lowland	107.3
122	9.20	1128.90	89.32	525.73	Lowland	128.3	276	8.79	1219.87	104.07	596.27	Lowland	69.5
123	8.63	1205.41	106.69	593.32	Lowland	140.4	277	-1.42	2213.89	1235.26	2584.00	High-altitude	50.2
124	4.42	1455.24	411.90	1423.85	Medium-altitude	90.9	278	2.81	1831.80	661.76	1827.32	High-altitude	297.9
125	9.42	1117.26	80.50	463.22	Lowland	94.8	279	6.85	1274.23	217.74	1019.13	Medium-altitude	11.7
126	4.95	1903.34	309.16	1551.69	High-altitude	234.0	280	7.04	1244.89	199.22	947.50	Lowland	129.6
127	9.09	1249.51	97.78	524.57	Lowland	160.7	281	0.78	1781.25	1062.02	2145.28	High-altitude	165.8
128	9.56	1208.69	78.51	468.62	Lowland	111.4	282	7.21	1300.75	206.38	952.49	Lowland	56.0
129	-0.02	2026.02	1090.88	2290.83	High-altitude	68.8	283	7.38	1624.65	249.72	838.63	Lowland	225.1
130	7.28	1309.22	200.85	950.29	Lowland	89.8	284	9.19	1274.70	103.67	552.40	Lowland	192.5
131	0.38	1670.85	847.40	2386.53	High-altitude	255.5	285	8.50	1510.01	162.92	710.64	Lowland	110.1
132	9.59	1004.86	53.74	519.95	Lowland	65.6	286	10.57	1528.37	47.66	415.80	Lowland	0.8
133	3.02	1571.35	578.94	1751.70	High-altitude	59.6	287	2.80	1851.25	724.74	1770.91	High-altitude	209.4
134	10.45	1767.56	39.90	503.78	Lowland	116.7	288	6.29	1362.58	271.68	1129.78	Medium-altitude	49.8
135	10.04	1072.99	46.92	453.19	Lowland	72.8	289	4.60	1789.87	360.81	1561.29	High-altitude	330.1
136	-0.34	2041.28	1099.35	2353.20	High-altitude	209.7	290	4.04	1474.28	445.19	1628.35	High-altitude	132.2
137	1.32	1219.38	377.98	2184.84	High-altitude	127.8	291	8.78	1140.20	94.58	656.32	Lowland	164.5
138	6.66	1295.08	216.40	1049.33	Medium-altitude	53.0	292	4.87	1584.52	479.96	1433.56	Medium-altitude	116.0
139	-0.01	1524.06	608.13	2311.71	High-altitude	166.3	293	1.87	1923.40	731.22	1999.08	High-altitude	110.0
140	6.00	1781.87	420.79	1078.83	Medium-altitude	83.5	294	7.33	1783.63	286.99	871.83	Lowland	110.6
141	7.36	1284.10	187.00	807.72	Lowland	138.8	295	2.78	1274.72	365.61	1800.30	High-altitude	144.3
142	7.94	1208.45	160.82	827.43	Lowland	56.5	296	2.48	1437.25	518.93	1856.09	High-altitude	155.5
143	3.43	985.77	341.51	1888.50	High-altitude	97.7	297	7.45	1369.08	212.64	846.69	Lowland	200.4
144	5.42	1378.00	317.24	1303.13	Medium-altitude	108.1	298	7.46	1606.21	236.82	788.61	Lowland	130.1
145	-0.29	2303.61	1284.91	2386.51	High-altitude	93.5	299	9.30	956.69	75.49	479.50	Lowland	32.3
146	2.52	2094.93	840.43	1855.12	High-altitude	117.8	300	1.44	1305.51	504.39	2145.23	High-altitude	110.2
147	9.91	1112.16	0.00	397.58	Lowland	0.9	301	9.49	1241.02	65.17	552.26	Lowland	460.3
148	1.18	1888.92	742.40	2222.88	High-altitude	126.7	302	4.77	1530.63	420.90	1408.73	Medium-altitude	140.2
149	4.32	1741.50	567.40	1526.73	High-altitude	143.7	303	4.98	1727.45	528.63	1505.71	High-altitude	255.1
150	9.73	1107.31	65.13	421.45	Lowland	150.5	304	0.57	1186.14	451.52	2224.90	High-altitude	175.4
151	8.94	1059.42	80.35	600.65	Lowland	288.6	305	9.31	1012.55	63.48	557.95	Lowland	30.6
152	7.70	1156.18	145.19	799.78	Lowland	235.2	306	9.06	1011.77	90.03	511.22	Lowland	212.1
153	-0.18	1320.10	591.30	2368.85	High-altitude	93.6	307	9.15	1147.55	87.97	552.77	Lowland	196.8
154	6.88	1441.65	260.11	1008.00	Medium-altitude	115.7							

Figure 61: Catchments and their ID numbers

Declaration of Originality

I hereby declare that the submitted thesis is the result of my own, independent work. All external sources are explicitly acknowledged in the thesis.

Mladen Marijanovic, Zurich, 30th September 2019