1.3. Extreme events in Switzerland

1.3.1. Classification of extreme climatological events

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The principal extreme events in Switzerland may be classified based on their relationship to characteristic weather conditions. The horizontal transport of air masses, and with these the large-scale wind currents, are responsible for the occurrence of extreme values of temperature, humidity and precipitation. In winter, large-scale pressure differences are responsible for storms and thunderstorms, and in summer, more local effects such as soil moisture and atmospheric stability are important. Floods result from the interaction between the atmosphere, surface characteristics and the topography.

A possible approach to the classification of extreme events is to analyse the weather conditions accompanying them, together with the way an event is manifested and its effects in a particular area. The extreme climatological events occurring in Switzerland may be classified as summarised in Tab. 1. As the extreme events affect areas of varying size, their geographical extent is also given. Events consequent on these such as avalanches and landslides have not been included. Needless to say, a schematic representation of this kind has its limitations, since in the case of extreme events, quite different processes are often involved that may reinforce one another, or, when following one another at short intervals, have a cumulative effect. Although this enables specific cases to be grouped, a more precise analysis very often reveals individual differences.

The climate in any particular region is determined by the interaction of large-scale air currents (i.e. atmospheric circulation), local topography and surface characteristics. The climate in Switzerland is determined to a large extent by the westerly airflow over the Atlantic and Europe. The state of the ocean surface (e.g. regarding currents, surface temperature and distribution of floating ice) also plays an important role through its influence on the principal migration paths of the low-pressure areas (storm tracks). Also of great significance is the land-sea distribution (Atlantic Ocean, Mediterranean Sea and Eurasian Continent) and the topography of the Alps. The altitude and form ('crescent') of the latter modify the direction and characteristics of the air masses. In this way, extreme events such as intensive downhill winds (e.g., föhn), inner Alpine droughts (in Valais) and cyclone formation on the lee side of the Alps (lee or Genoa cyclones) are generated.

For the arising of extreme temperatures and precipitation (Tab. 1, upper part), the horizontal displacement of the air masses (advection), which is driven by the large-scale circulation, is decisive. In this, it is important to know where the air masses originate from, how their temperature and humidity change on their journey to Switzerland, and how fast they traverse Swiss territory. The long-term influence of natural factors (sun, volcanoes), anthropogenic influences (greenhouse and aerosol effects, and surface changes) and incidental fluctuations in the climate system on continental and regional circulation patterns and on the frequency of extreme temperatures and precipitation is still unclear.[1,2]

Depending on the time of year, either the large-scale pressure differences (particularly in winter) or more local effects such as atmospheric instability and ground humidity (particularly in summer) are important in the development of storms and thunderstorms (Tab. 1, middle part). Air masses can store energy either directly in the form of sensible heat or indirectly in the form of humidity. The energy stored in water vapour is released again on condensation. This so-called latent heat of condensation is an important source of energy for hurricanes, and these can only occur above warm surface water at a sufficiently high rate of evaporation. In Switzerland, direct and indirect heat flows are significant both on the large scale (in particular for storms arising over the West Atlantic) and regionally (in the case of summer thunderstorms).[3] Winter storms such as the Lothar hurricane result from very complex phenomena.[4]

The situation is particularly diverse in the case of floods (Tab. 1, lower part). These result from the interaction between the atmosphere, sur-

Table 1: Classification of the most marked climatological extreme events in Switzerland based on characteristic weather constellations.

Extreme event	Winter	Summer
Weather elements: **Temperature**	**(a) Cold and dry** Persistent cold air current as a result of the continental Siberian surface anticyclone. *frost and drought damage* ***Scale: semi-continental***	**(b) Hot and dry** Influence of heat and drought in the subsidence zone over the Azores high-pressure area impinging on the continent. *heat and drought damage* ***Scale: semi-continental***
Precipitation	**(c) Cold and humid** Persistent north-westerly current *heavy snowfall, avalanches* ***Scale: regional***	**(d) Cold and humid** Low-pressure areas drifting from the North-West to the South-East *damage to vegetation* ***Scale: regional to semi-continental***
Storms/ thunderstorms	**Strong pressure gradients, partly containing secondary vortices** *storm wind, gusts, hurricanes* ***Scale: regional to semi-continental***	**Weak pressure gradients, heat lows, thunderstorms** *heavy rain, hail, gusts* ***Scale: local to regional***
Floods	**Northern Alps:** Tendency towards persistent south-westerly, westerly and north-westerly flow situations with tracks of the low pressure systems lying to the South. Advection of warm and very humid air that rises under extreme convection conditions leading to heavy and persistent precipitation. May be combined with temperature increase, melting snow, and in rare cases with blockage effects at the Alps. (Occurrence: hot months, spring and autumn, predominately in spring to early summer) *massive flooding of valley and lake country* ***Scale: regional to semi-continental*** **Southern Alps and inner Alpine region** Combination of inflow of air masses, extreme upward airflow (induced both by air mass movement and Alpine topography) and subsequent rainfall. Southern Alps: predominant southerly Alpine inflow (particularly for low-pressure areas passing to the South), often in conjunction with the phenomenon of high-tropospheric 'streamers'. Inner Alpine region: also in conjunction with stationary low-pressure troughs. (Occurrence: cooler months, spring and autumn, predominately in autumn) *massive flooding of valley and lake areas* *Inner Alpine: triggering of extreme hydro and geomorphologic events causing damage such as mass movements and debris flows.* ***Scale: local to large-scale regional***	

face characteristics and the topography. In mountainous areas, an important role is also played by rising air masses and subsequent precipitation from these, resulting both from large-scale movements and from air currents in the entire troposphere. Of somewhat lesser importance is the triggering of precipitation through air rising on collision with the Alpine topography.[5] Long-enduring and heavy precipitation can saturate the ground with water, and in some cases lead to regional or large-scale floods when combined with melting snow in the Alpine region. In central European areas to the north of the Alps, the migration paths of the low-pressure areas must be considered. Deviations of these to the south occur especially with negative North-Atlantic Oscillation (i.e. when the North Atlantic is warm and the South Atlantic cold), leading to long-enduring south-west to north-west flow situations.[2] In some cases, cold cut-off lows occur that remain for days above a region, leading to extensive precipitation periods. In addition to the lee-side formation of low-pressure areas already mentioned, particular attention must be paid to low-pressure areas south of the Alps that migrate slowly from the Atlantic via the Mediterranean towards the eastern fringe of the Alps and then on to Poland.

1.3.2. A calendar of the last 500 years

Christian Pfister

Our capacity to identify trends in extreme anomalies from instrumental measurements is limited owing to the short periods over which data have been recorded and also to the rareness of these events. To extend the available data base, recourse may be had to historical documents.[6] The most conclusive information on extreme events is available for the period from approx. 1100 to 1800. In fact, for this period, natural disasters can only be identified through reports in historical documents: the more extraordinary and the more extreme an event, the more numerous and exhaustive the available reports.

Contrary to 'natural archives' such as the tree rings, which only permit conclusions on anomalies for certain parts of the year, documents from 'human archives cover all seasons and calendar months. The documents cite the date, and often the hour, of the events. To express the magnitude of an anomaly, observers often made use of easily identifiable natural indicators, and today these may be quantified and calibrated on the basis of analogous events. Following a very cold March and April, cherries, for example, blossom three weeks too late. On current knowledge, this corresponds to a general temperature deficit of 5°C.[7]

Single documents only cover a limited period of time, are heterogeneous, and mostly contain gaps. Alone, they are usually not quantifiable and cannot therefore be statistically evaluated. To obtain conclusive results, as many reliable sources as possible must be brought together. In this way, the data may be checked and complemented. In Switzerland, approximately 40 000 individual observations from some 350 sources were brought together for the period 1500 - 1864.[6,8] In the period following 1550, reports on the weather and/or observations of natural indicators are available for 99% of all months.

Monthly temperature and precipitation data are assigned to a seven-part intensity index. The resulting index series are then compared with those of neighbouring regions. These carefully prepared index series correlate almost as well as instrumental measurement series.[9]

Based on the classification of extreme events given in Chapter 1.3.1, a selection of extreme anomalies in Switzerland is shown below for the last 500 years.[6] In this chapter, the time series are characterised based simply on periods with frequent or less frequent reports of extreme events. Whether the fluctuations shown are incidental, or whether they indicate real changes in the probability of occurrence, cannot be decided owing to the rareness of the events (cf. Chapter 1.4).

Cold and dry in winter

Between 1496 and 1566, no cold or dry anomalies occurred, and in the subsequent 110 years they were very seldom (Fig. 3). Between 1676 and 1895, their frequency rose. One to eight cold and dry months with a persistent cold air current from the Siberian ground anticyclone were identified in all decades of this period. For people living in the 18th century, full ice cover of Lake Bienne was not exceptional. Between 1895 and January 1963 (complete freezing over of Lake Zurich), the cold and dry months became much

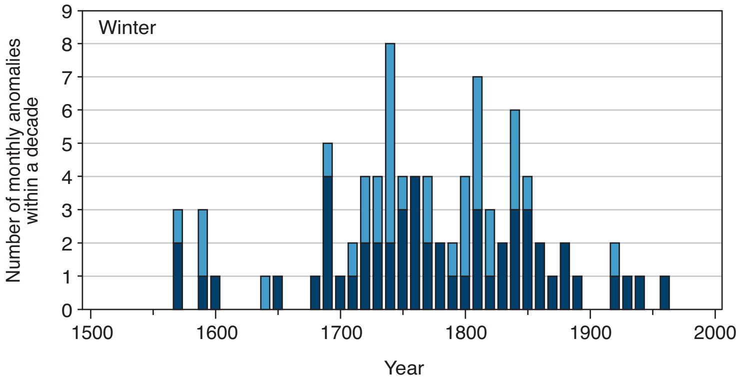

Fig. 3 Frequency of cold (dark blue) and cold-and-dry (light blue) months in winter (November-March/April) from 1496-2000 (10-yearly sums).

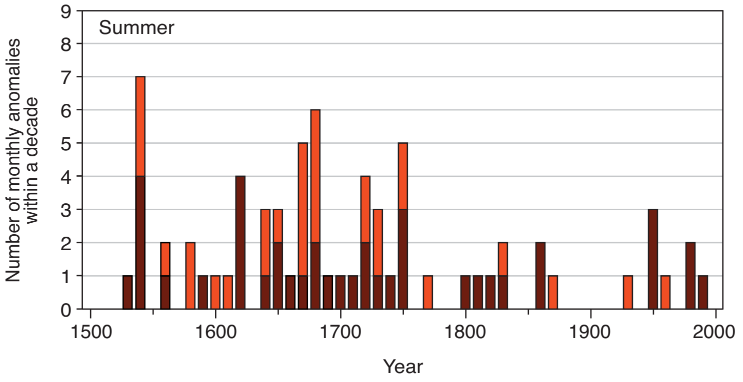

Fig. 4 Frequency of hot (dark red) and hot-and-dry (red) months in summer (April-September) from 1496-2000 (10-yearly sums).

less frequent, and since then have ceased altogether (as of March 2003).

Cold and wet in winter

It is known that several days of intensive northwesterly weather may lead to a large number of avalanches causing losses. However, such weather conditions are not apparent from the average monthly figures for temperature and precipitation. Therefore the above index series do not represent an adequate statistical tool.

The winters in which avalanche damage occurred are fairly evenly distributed over time, and do not occur more frequently in the 20th than in previous centuries.

Hot and dry in summer

Hot and dry months were significantly more frequent prior to 1730 than afterwards (Fig. 4). Between 1718 and 1728, every second summer was significantly too dry. Although there was no century-wide meteorological extreme in these years (as for example in 1540 and 1947), the cumulative effects of the events in 1718/19 and 1723/24 were equivalent to this. In these years, consecutive dry summers interspersed by a lack of rain in winter and the early part of the year occurred.

In the 20th century – with the exception of the decade 1946-1955 – hot and dry months occurred relatively infrequently during the vegetation period.

Cold and wet in summer

Prior to 1880, when the Swiss economy gained access to the international transport network, cold and wet summers and the resulting damage to vegetation led to price increases, supply shortages and occasionally to famine (e.g. 1816/17). Between 1576 and 1635, cold and wet summer months were particularly frequent, and the glaciers grew. Since then, extreme events of this kind have become rare.

Storms in winter

In the 20th century, the statistical tendency in the northern Alps shows a reduction in the number of storm days, and a diminution in the duration of wind strengths between 7 and 9, in the winter months.[10]

Between 1500 and 1960, whilst most of the storms occurred in December, the most extreme amongst them occurred in January and February. Also, there were repeated periods without heavy storms (Fig. 5). Between 1600 and 1900, the Central Lowlands were affected every century by a record storm. These storms all arose in winter from westerly directions and devastated forests, buildings and infrastructure over large expanses. In the 20th century, three record storms were recorded in the space of only 33 years: in February 1967, February 1990 (Vivian) and

December 1999 (Lothar). As events of this kind are very rare, no long-term statistical trend can be identified.

Floods north of the Alps

In the Central Lowlands, most of the floods occur in early and midsummer when the melting rate of snow in the mountains is large and the highest rainfall occurs over substantial parts of the catchment area.

Up to 1882, the Rhine in Basel overflowed its banks on average every 10 years (Fig. 6). This frequency dropped in the course of the next 120 years. Between 1882 and 1992, extreme floods were entirely absent. However, this development cannot be attributed solely to meteorological and hydrological factors, since the runoff conditions altered in the course of the last 120 years by virtue of structural intervention.

Floods in the central Alps and to the south of the Alps

In the four Cantons of Valais, Uri, Ticino and Grisons, two periods of low flooding frequency (1641-1706; 1927-1975) and two periods of high flooding frequency (1550-1580; 1827-1875) may be identified in the course of the last five centuries (Fig. 7). Long-term fluctuations in the frequency of flooding have also been identified in the Pyrenees and in Germany.[11] These are the result of natural climate variations and have no identifiable connection to human activity.

Contrary to the average values pertaining in the 20th century, the number of extreme floods occurring in the inner and southern Alps has increased over the last 15 years (August 1987, September 1993, October 2000), whereby, however, the frequency of these events still lies within the range of previous occurrences.

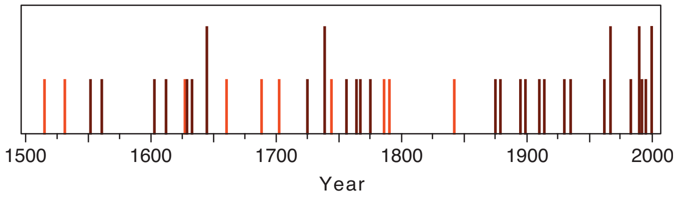

Fig. 5 Heavy (short bars) and extreme (long bars) winter storms in Switzerland over the last 500 years. In some cases (orange), the historical data are indecisive.[6]

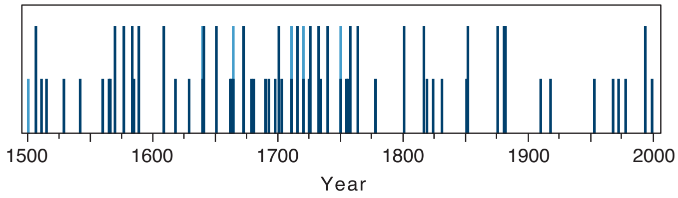

Fig. 6 Heavy (short bars) and extreme (long bars) flooding of the Rhine at Basel over the last 500 years. In some cases (light blue), the historical data are indecisive.[6]

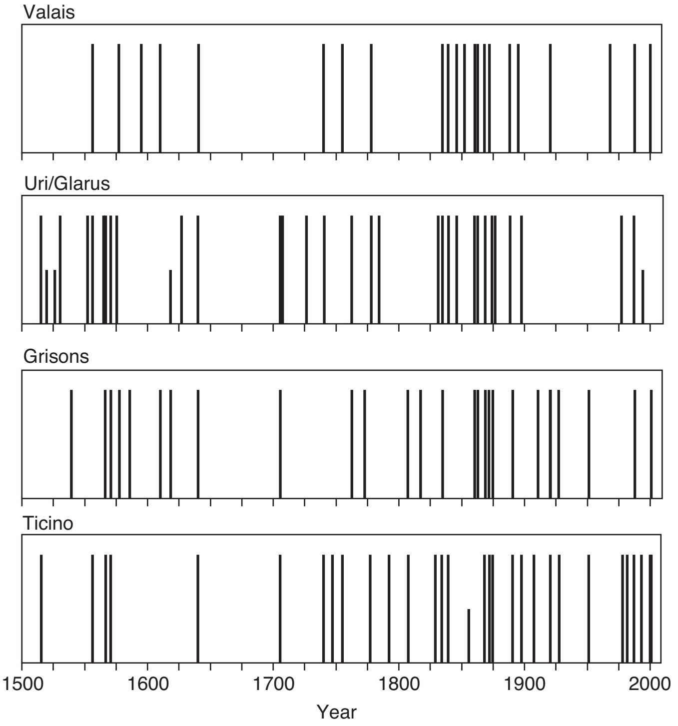

Fig. 7 Heavy (short bars) and extreme (long bars) flooding events in the four cantons in the region of the St. Gotthard Pass, i.e. Valais, Uri, Ticino and Grisons, over the last 500 years. Extreme floods are defined as those that caused damage in at least two Alpine valleys and/or in neighbouring countries.[6]

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