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Avalanches in Switzerland 1500-1990

Martin Laternser & Christian Pfister

Summary

The most severe known situations of avalanche activity in Switzerland over the last 500 years are described and interpreted in a meteorological context. Possibilities and limitations for the reconstruction of historical avalanche events as well as methodical aspects about the severity and effects of avalanches are discussed. The well-documented situation of the last 100 years, and particularly since the 1930s, is analysed in more detail for the damage pattern. The weather conditions leading to disastrous avalanches in 1951 are described reflecting a very typical situation. This is compared with periods of high avalanche activity in previous centuries. The amount and intensity of snowfall is the main factor causing severe and disastrous avalanches. In nearly all cases a quasistationary trough connected to a strong barrage along the Alps was responsible for the heavy and continuous snowfalls. Characteristically hardly any avalanche periods affected the entire country as a whole, but often isolated valleys got struck severely whereas neighbouring areas widely escaped. This reflects the fact that heavy snowfalls within a short period most often are confined to comparatively small areas. This review presents the actual state-of-the-art, which may well be extended in the near future.

Zusammenfassung

Die größten bekannten Lawinenkatastrophen der Schweiz der letzten 500 Jahre werden in ihrem meteorologischen Zusammenhang beschrieben und interpretiert. Sowohl Möglichkeiten und Grenzen für die Rekonstruktion von Lawinenereignissen vergangener Zeit als auch methodische Aspekte über Heftigkeit und Folgen von Lawinen werden diskutiert. Die gut dokumentierte Situation der letzten 100 Jahre, insbesondere seit den dreißiger Jahren, wird ausführlich nach Schadensmustern untersucht. Die Wetterbedingungen, die die katastrophalen Lawinen von 1951 auslösten, werden als typisches Beispiel beschrieben und mit Perioden erhöhter Lawinenaktivität der letzten Jahrhunderte verglichen. Menge und Intensität des Schneefalls werden als auslösender Hauptfaktor von großen Katastrophen Lawinen angesehen. In fast allen Fällen war ein quasistationärer Trog in Zusammenhang mit einer ausgeprägten Staulage entlang der Alpen für starke und langandauernde Schneefälle verantwortlich. Typischerweise wurde nie das ganze Land gleichzeitig von ein und derselben Lawinenkatastrophe heimgesucht. Meistens wurden jeweils nur einzelne Talschaften sehr stark betroffen und angrenzende Täler blieben oftmals weitgehend verschont. Das spiegelt die Tatsache wider, daß heftige und intensive Schneefälle meist auf kleinere

Gebiete begrenzt sind. Dieser Bericht gibt einen Überblick über den heutigen Stand des Wissens, der in der näheren Zukunft weiter ausgebaut werden wird.

1. Introduction

Avalanches have always been a threat for human societies in the Alps. It seems that in previous centuries the occurrence of avalanches was very much seen as fate, particularly as a punishment sent by God, and the reaction to disasters was rather passive. People believed not being able to do anything against it and re-built their destroyed houses and sheds at the same place again, often with the result that years or even decades later the avalanches took their victims once more. The mechanics of avalanche release were not at all understood, apparently not even that forested slopes may reduce the danger considerably.

Nevertheless protective measures against avalanches in the form of deflecting constructions (splitting wedges, deflecting barriers) or shelters within known avalanche tracks are described in older writings (e.g. COLLINUS, 1569). From the second half of the nineteenth century forestry organisations began constructing defence structures within the starting zone of avalanches to prevent them from coming down at all (cf. FANKHAUSER, 1853; COAZ, 1881). These included terraces, stakes or stone walls built on steep slopes in order to stabilize the snow cover. Unfortunately, the efficiency of such measures is hard to investigate (defence structures may work well in average conditions, but a critical winter may occur only once in hundred years) which made progress in this subject rather slow.

Whereas the phenomenon of avalanches was described and tried to be understood quite early (e.g. SCHEUCHZER, 1706; FANKHAUSER, 1853; COAZ, 1881, 1910; SPRECHER, 1899, 1901; ALLIX, 1925; FANKHAUSER, 1928; HESS, 1934), snow as such began to have a value for tourism since about 1850 and scientific investigations on the physics of snow were hardly carried out before the late nineteenth century (RATZEL, 1889; HELLMANN, 1893; SELIGMAN 1936; EUGSTER, 1938; PAULCKE, 1938). The foundation of the Swiss Snow and Avalanche Research Commission in 1931, based in Davos and later moved to Weissfluhjoch, brought decisive inputs into the matter (BADER et al., 1939). Systematic studies of the snow mechanics and avalanche release factors were followed by a revolution in the avalanche defence structure development (RICHTLINIEN, 1955, 1961, 1968, 1990; see also BAVIER et al., 1972). Nowadays major snow and avalanche research centers operate in the Alpine countries of France and Switzerland, while regional monitoring and avalanche warning services are set up in Austria, France, Germany, Italy, Slovenia and Switzerland.

The importance of the knowledge of historical extreme avalanche events to planning has already been emphasized by the first engineers in this business (cf. FRUTIGER, 1970; DE QUERVAIN, 1975; FÖHN, 1975; FÖHN & MEISTER, 1982). Surprisingly no systematical database has been established in Switzerland until now, though. But the interest in this sort of events and the need for more data to apply better extreme value statistics has risen by the recent research programs on climate changes. This paper focuses upon the most severe situations of avalanche activity over the last 500 years that are documented in the sources. It contains preliminary results of a more detailed investigation which is scheduled for 1996 and 1997 (SCHNEEBELI & LATERNSER, 1996; LATERNSER & SCHNEEBELI, in prep.; PFISTER, in prep.

After a short methodical excursion about the effects and severity of avalanches typical weather situations leading to periods of high avalanche activity are discussed. A fundamental introduction about possibilities and limitations for the reconstruction of historical avalanche events follows. A statistical review of the well-documented situation of the last 100 years, and particularly since about the 1930s, together with detailed analyses of the weather situation causing the avalanche disasters in 1951, finally links up with the discussion of severe avalanche periods in previous centuries.

It must be born in mind that we are dealing with three different periods depending on the level of accuracy and resolution of the weather and avalanche data. In the first period until about 1870 only descriptive information is available, apart from isolated and unsystematical meteorological observations (see chapter 4). For the second period (1870-1940) generally systematical weather data of reasonable quality can be obtained whereas accounts of avalanche events are still descriptive and incomplete in most cases. Only for the last 50 years since about 1940 systematical data of both the weather situation and the avalanche activity together with the corresponding damage pattern are available, but often still not in digitalized form yet. The establishment of a detailed database of all recorded and reconstructable avalanches in Switzerland for about the last 100 years, therefore, is presently in progress at SFISAR[1] (LATERNSER et al., 1995).

2. Severity and effects of avalanches - methodical aspects

A key problem in classifying avalanche events is that great avalanche activity does not necessarily mean that numerous disastrous avalanches occur. The fact that makes the avalanches disastrous is very much dependent on the effect they have on human activities and infrastructure. The number of avalanches may be large in a completely unpopulated area, hence causing (for human esteem) no damage at all. But the same avalanche activity in a densely populated valley can bring about a disastrous situation. Nevertheless in our highly "civilized" alpine environment today it is likely that a great avalanche activity does cause considerable damage; just because not many spaces of some extent are left completely unused by man. Since the last few decades different interactions of protective measures such as avalanche defence structures, avalanche zoning plans, avalanche warning services and preventive release of avalanches with explosives also influence the natural avalanche activity, which further complicates the classification of severe avalanche periods.

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[1] Swiss Federal Institute for Snow and Avalanche Research (Eidgenössisches Institut für Schnee- und Lawinenforschung, SLF)

From the point of view of the effect, particularly in the last 100 years, it makes sense to distinguish - among others - between spontaneously released avalanches affecting human activities or infrastructure including forest ("disastrous avalanches") and avalanches triggered by men, particularly by tourists ("skier's avalanches"). Whereas the former, often originating from high up on the mountain sides and reaching as far down as to the valley floors, may be of great extent and can cause considerable damage, the latter are generally of smaller scale, take place in the higher mountains and are a problem for the involved people themselves only, not causing any damage to property. For this reason skier's avalanches are very much subject to individual human activity and not the effect of purely natural interactions. In this sense they are "coincidental" (had the skiers not been in this particular slope the avalanche would not have been released) and not a very good indicator for the severity of the prevailing avalanche situation.

This leads us to the question how - in which units - the severity of an avalanche or an entire avalanche period shall be measured. The death toll is a certain indicator, but for several reasons not very satisfying. Firstly, an avalanche can destroy a fully inhabited building and kill many people. In this case everybody speaks of a disastrous avalanche. Had the same building been empty (for whatever reason) it would have been "just" an avalanche as many others and definitely not as catastrophic as in the first case. But the strength of the avalanche was exactly the same, only the effect on human activities was considerably different. Secondly, nowadays many people (tourists) go voluntarily into the mountains and - more or less conscious of the danger - trigger avalanches that would not have occurred otherwise (see above). From this point of view a relatively "safe" winter can cause a high number of victims, because the skiers and mountaineers thought to be safe and ventured into extreme slopes. On the other hand a "dangerous" winter does not necessarily have to claim many lives because it may be simply too dangerous to go skiing at all (that means nobody is in the dangerous area) or security services work well and thanks to evacuations and road closures hardly anybody gets involved personally. Finally, we have the possibility today to release avalanches artificially in an early state to prevent them from coming down spontaneously during a period when many people are present in the endangered area or after having built-up such considerable amounts of snow that the effects would be disastrous.

A less subjective approach determining the severity of avalanches can be undertaken by means of looking at the damage they cause. CALONDER (1986) defines a "large damage avalanche" as an event where either at least one house or at least two cattle-sheds or at least three barns or at least 250 m^3 of forest have to be damaged or destroyed. This criterion seems reasonable and can particularly well be applied to information from documentary sources.

An avalanche or an entire avalanche period not causing any damage or claiming victims can still be of great extent - as we have seen above, but consequently can not be called "severe", since this term inevitably implies the interference with human activities.

Another factor to consider is, that in one winter several periods of high avalanche activity may arise, whose causes possibly are absolutely independent from each other (e.g. 1888, 1951; see chapter 6 and 7). One must be aware of that when comparing the severity of different avalanche winters. In any case it is necessary to analyse with care if such periods really are independent, which may not always be easily attained.

Causes, morphology and impacts of avalanches can be very different in winter and spring. In winter the snow is usually dry causing dry-snow flow avalanches or even - depending on the height of the fall - powder snow avalanches. Although the speed of a powder snow avalanche can be considerably greater than that of a flow avalanche due to the much smaller density, the destructive force of a powder snow avalanche (per square unit) is definitely less. But because of the great vertical extent the impact can be just as severe, particularly on buildings and on forest. Spring wet-snow flow avalanches are rather slow in their movement but - due to the high density of the wet snow — can produce enormous forces destroying virtually everything standing in their usually well-known tracks.

3. Typical weather situations leading to severe avalanche events

It is generally recognised that the terrain, the weather and the condition of the snow cover are the main factors determining avalanche activity. In severe and disastrous events the amount and intensity of snowfall is clearly dominating. Virtually no large damage avalanche occurs without huge amounts of fresh snow. One important case to consider are wet-snow avalanches in spring though, which generally result from the loss of the cohesive strength of the snow pack due to warming. But these avalanches are usually confined to steep and narrow gullies and because of their regular return (every year) in their clearly defined paths people are aware of their occurrence so that these sorts of avalanches rarely cause serious damage.

After ZINGG (1969) about 80 cm of fresh snow within 24 hours or 120 cm within 48 hours are necessary to produce spontaneous and disastrous avalanches on steep enough slopes, i.e. steeper than about 30 degrees. On the other hand heavy snowfalls do not always cause large avalanches. From analyses over a period of 40 years in the Davos area FÖHN & HÄCHLER (1978) found that about 80% of all uninterrupted snowfall periods accumulating more than 1.0 m fresh snow at the test site near Weissfluhjoch (2540 m a.s.l.) did not result in severe avalanches in the valley. The better understanding of the relationship between heavy snowfalls and avalanche activity will be a major goal of further investigations (SCHNEEBELI & LATERNSER, 1996; LATERNSER & SCHNEEBELI, in prep.).

Both CALONDER (1986) and HÄCHLER (1987) carried out a detailed analysis of the weather patterns that led to about 20 severe and extraordinary avalanche situations between 1885 and 1985. It was found in nearly all cases that a quasistationary trough was responsible for such situations and that frontal developments, led by strong winds towards the Alps, intensified the snowfall rate, particularly at the windward slopes due to barrage effects. If this type of weather lasts for about four days or more, then there is a high probability of large avalanches at least in parts of Switzerland.

Since the Swiss Alps (Fig. 1) are orientated roughly east to west we can basically distinguish two different main situations: barrage from the north (by north-northwesterly winds from a trough lying over central Europe) affecting the regions north of the Alps, and barrage from the south (by south-southwesterly winds from a trough lying over the west coasts of Europe) affecting the regions south of the Alps. The areas of the central main divide of the Alps (especially the Gotthard area) usually get touched by both weather types and therefore are particularly subject to excessive avalanching. The inner alpine valleys such as the Valais and the Engadine are generally fairly sheltered from these barrage situations but still can get affected on the edges or by other circulation patterns. For these regions, and particularly for the Engadine, the actual state of the snow cover has a greater influence on avalanching than in the others.

4. Documentary sources on avalanches in the past (before the 20th century)

Some of the earliest written records of avalanche accidents can be found in Greek (Strabon) and Roman literature: Livy (Titus Livius) refers to the well known example of Hannibal whose army had to bear heavy losses when he crossed the Alps in 218 B.C.

Hardly any reports are known from the first millennium A.D. But since the high Middle Ages, parallel to an increased colonization and deforestation of the alpine valleys, occasional observations (and possibly also the events) became progressively more frequent. The following four types of documentary sources are distinguished:

1. Chronicles include a variety of narratives in the form of extended histories which provide a wealth of details. In the Middle Ages the chroniclers lived in towns or in monasteries at some distance from the Alps. Chronicles from alpine valleys or from neighbouring areas were written from the sixteenth century on by clergymen, local nobles and also by mountain farmers (e.g. ARDÜSER, 1877; STRASSER, 1890; FISCHER, 1910; BÄRTSCHI, 1916; LAELY, 1984). Disasters and extreme situations are reported inasmuch as they had affected the life in the valley. In the case of avalanches the number of casualties and houses or barns destroyed was taken as a measure of severity. The greater the magnitude of the catastrophe, the more lengthy and fully it was described. Large accidents (Leukerbad 1719, Obergesteln 1720) became known in the entire country and money was raised in favour of the victims. This was noted by local chroniclers far away from the place of the accident (BÜNTI, 1973). From the late eighteenth century the occurrence of severe avalanche impacts was also reported in the press (e.g. MONATHLICHE NACHRICHTEN, MONATHSCHRONIK).

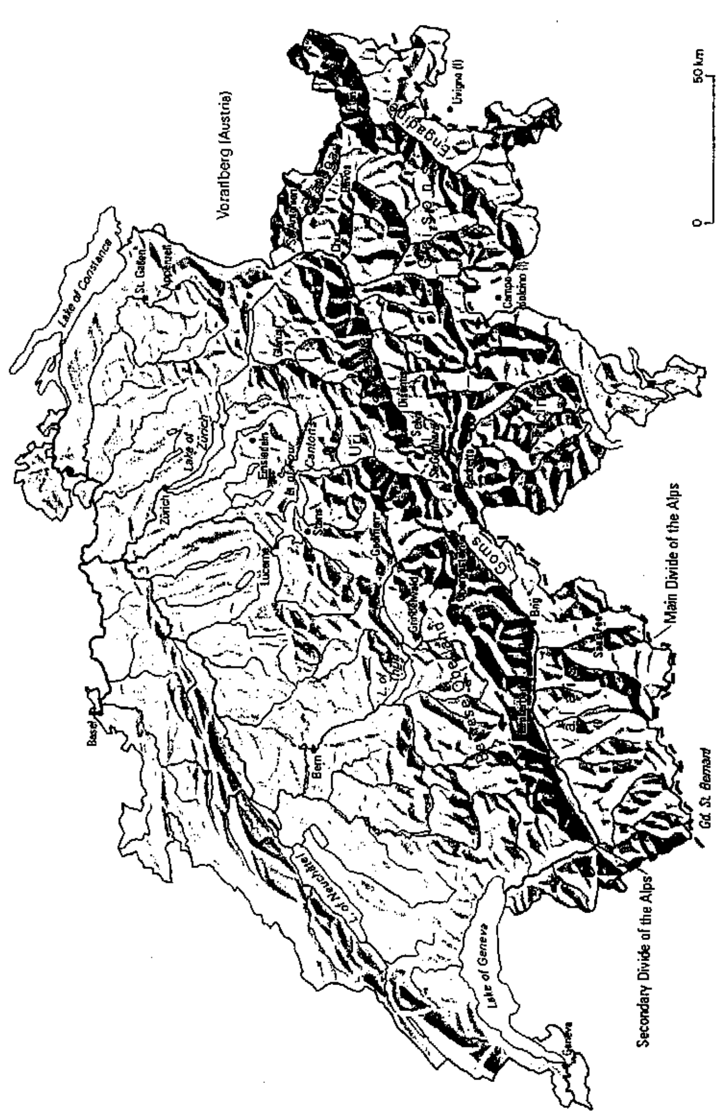

Fig. 1 Map of Switzerland showing locations and regions mentioned in the text (reproduced with permission of the Federal Office of Topography from 12 December 1994)

2. Regional or local histories often contain chronological lists of disasters that were compiled from chronicles and other types of original material by assiduous clergymen or school-teachers from the eighteenth century.
3. The history of natural hazards in the Alps was mostly drawn from compilations of reported weather extremes and natural disasters (BRÜGGER, 1882; AMBERG, 1892; SCHALLER, 1937) hitherto.
4. Weather diaries and other types of quasi regular observations carried out in alpine valleys often do not only describe avalanche accidents and the underlying meteorological situation. Some observers also kept track of avalanches that went down without doing any harm just from the thundering noise they produced (DESCHWANDEN, 1865). This noise was not particularly frightening for people living in the mountains; it was just part of their everyday experience.

On a whole it is thought that a fair picture of the most severe periods of high avalanche activity might be obtained from the early eighteenth century, if this kind of historical disaster research is intensified. But we need to bear in mind that disastrous events usually affect rather small areas (see chapter 7.3 and 8) and therefore may only be mentioned - if at all - in local reports which can be easily missed in the source research.

Observations carried out at some distance from the Alps often allow the reconstruction of the meteorological situations that are related to periods of high avalanche activity: Renward Cysat (1545-1613), chancellor in Lucerne, kept track of a broad variety of meteorological and environmental data, just to mention snowfalls in summer on the summits surrounding the city. Joseph Dietrich (1645-1704) and Sebastian Reding (1667-1704), who were monks at the convent at Einsiedeln, included a wealth of detailed lengthy weather reports in their diaries. Heinrich Fries (1639-1718), who was a professor at Zurich, kept a non instrumental diary in which he noted quite regularly the formation and the melting of snowcover. The physician Johann Jakob Scheuchzer (1672-1733) was the first to measure atmospheric pressure, temperature and precipitation in Switzerland (PFISTER, 1992).

5. Critical evaluation of sources

The scholar who attempts to reconstruct a history of natural hazards from documentary sources should be familiar with certain properties of this type of data. It has become commonplace over the last two decades or so to emphasize the importance of dealing with contemporary observations, which were laid down shortly after the event or at least within the lifetime of the author (INGRAM et al., 1981; PFISTER, 1984; ALEXANDRE, 1987; PFISTER et al., 1994). However, in hazard research we are often left with non-contemporary reports copied from original sources which have disappeared. In some cases we may even have to deal with a secondary copy drawn from a primary one without knowing it. In this situation it must be born in mind that most errors in copying texts are made by attributing an event to

the wrong year. This may be due to reading mistakes - figures in old handwritings are easily misread - or just to carelessness. The confusion is even greater in the case of older compilations which contain a mishmash of contemporary and non-contemporary reports; some do not even quote their sources. In order to assess the reliability of a disaster report with regard to the event it purports to describe, it needs to be corroborated with evidence from different independent local sources (excluding compilations) and it must be consistent with the picture of the overall meteorological situation which is obtained from reconstructions of weather and climate. For Switzerland temperature and precipitation patterns in terms of monthly indices have been rated for the period back to 1525 (PFISTER, 1992). The indices are available from the NOAA paleoclimatic data center in Boulder, Colorado (USA).

The procedure of assessing the reliability of reports is highlighted by the example of a severe hazard which took 55 lives in Leukerbad (Canton of Valais) (cf. appendix). In the known compilations it is dated January 17, 1719 (COAZ, 1881, BRÜGGER, 1882), but a local chronicle yields January 17, 1718 (LORETAN, 1935). The check of reliability involved consultation of a contemporary observer (BÜNTI, 1973), who mentions the event in 1719. This is consistent with the reconstruction of the meteorological situation (see chapter 7).

In the Swiss case particular attention must be paid to the style of dating which was used, since this depended on the decisions of the individual cantons (which at that time were still independent republics) or - in the case of the canton of Grisons - even from the quasi sovereign juridical communities ("Gerichtsgemeinden") in the different valleys. Most of the catholic cantons accepted the Gregorian style by leaping 10 days in 1583, the catholic communities in Grisons followed in 1623/24, the canton of Valais in 1656. Most protestant cantons changed in 1700, but some latecomers (e.g. the protestant valleys of Grisons and the protestant part of Appenzell) took even more time. However, many enlightened men in those cantons already adopted the new style for their personal use after 1700, i.e. prior to the official change in their canton, so that dating of private sources in the eighteenth century from these regions often is equivalent to gambling (PFISTER, 1984). The difference of ten days between the reports from protestant valleys in the canton of Grisons (Saas im Prättigau, St. Antönien, Davos) and catholic territories stands out clearly for the situations of high avalanche activity in 1689. The situation in 1689 must be dated February 2-4 (new style) according to the reports from the Habsburg territory of Vorarlberg. For 1720 dating is ambiguous. The sources mention two periods of avalanche activity - a first one on February 7 (Davos) and 8 (Ftan, Engadine), a second one on February 18 (Obergesteln in the Goms). At first the difference of ten days points to the use of different styles which would then lead to the conclusion that there was just one single period of high avalanche activity on February 17 and 18. On the other hand the meteorological record points to two potential situations of high avalanche activity (see chapter 7) so that it cannot be excluded that the reports on the earlier period already followed the Gregorian style.

6. Catastrophic avalanche events during the last 100 years and their causes

6.1 Statistical review

Since systematical statistics began in Switzerland in 1940/41 every year about 26 people are killed by avalanches and the average annual number of avalanches claiming victims or causing damage is 143 (source: SLF, 1994). The year-to-year variability is considerable. During the winter 1950/51 (the most severe avalanche winter of this century) 1301 avalanches causing damage and 98 fatalities were counted. On the other hand in 1948/49 only 8 avalanches causing damage and one single fatality were registered. In the last hundred years the following winters were outstanding for their high avalanche activity: 1887/88, 1916/17, 1934/35, 1944/45, 1950/51, 1953/54, 1967/68, 1974/75 and 1983/84 (EDI 1951; COURVOISIER & FÖHN, 1975; CALONDER, 1986).

According to the definition of a "large damage avalanche" (see chapter 2) CALONDER (1986) draws a diagram comparing the severity of selected disastrous winters for the last 100 years (Fig. 2). It is clearly seen that winter 1950/51 was by far the most severe avalanche winter, whereas all the others were at least one magnitude lesser. But we need to bear in mind that in 1951 two disastrous avalanche periods in different areas arose from two probably independent meteorological situations (see chapter 2 and 6.2), what virtually doubled the severity of this avalanche winter.

From SFISAR data (SLF, 1936/37-1992/93; MEISTER, 1987) similar diagrams regarding the deaths and the total amount of avalanches causing any reported (that often means insured) damage including human casualties over the period 1936/37 to 1992/93 can be drawn (Fig. 3). The fatal avalanche accidents are split into disaster fatalities (victims of the mainly

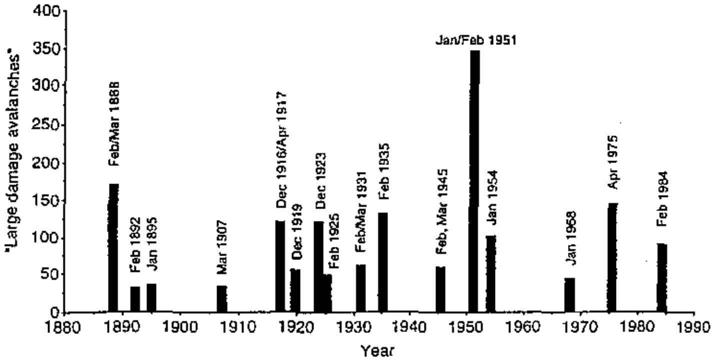

Fig. 2 Number of "large damage avalanches" in Switzerland for selected periods of high avalanche activity since 1880 (redrawn from CALONDER, 1986)

native population caught by naturally released avalanches inside their houses, sheds, at work or on traffic routes) and tourist fatalities (victims amongst skiers and mountaineers in the open country, who usually trigger "their" avalanche themselves). Looking at Figure 3b it can be seen that since about 1970 the tourist fatalities clearly increased to reach a constantly high level whereas the disaster fatalities rather decreased. This decrease probably reflects the resolute forcing of the (federally subsidized) construction of avalanche defence structures, increased efforts on the planning level and well-organised avalanche warning services particularly since the catastrophe in the winter 1950/51 (DE QUERVAIN & MEISTER, 1987). The increase of tourist fatalities coincides with increased recreational activities within the wintry mountain environment.

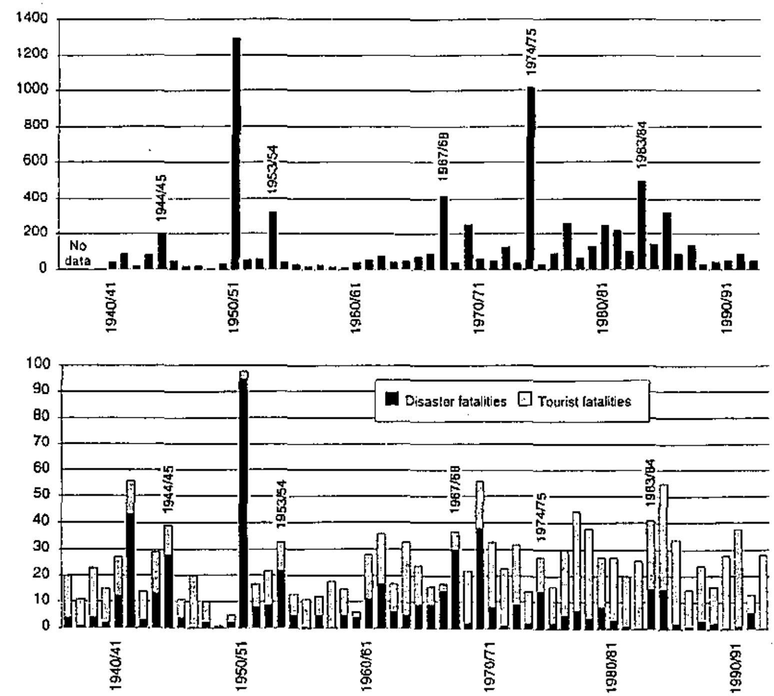

Fig. 3 Number of damage avalanches and the corresponding fatalities in Switzerland since 1936/37: (a) shows the total number of recorded avalanches causing damage or claiming victims (from SLF, 1994). The "peak years" are easily recognised as well as a general trend to rather more damage avalanches. (b) shows the number of avalanche fatalities split into disaster fatalities (deaths in houses, at work and on traffic routes) and tourist fatalities (skiers and mountaineers outside of the controlled skiing area) (after MEISTER, 1987)

Figure 3 further demonstrates that years with a high number of damage avalanches do not necessarily have to cause many (disaster) deaths, particularly the closer we come to present times. The winter of 1974/75 stands for an instructive example. Also 1983/84, with a high number of damage avalanches, shows clearly less fatalities than the following winter with hardly any damage avalanches. In 1969/70 the many disaster fatalities are made up by virtually one event - one huge avalanche claiming 30 victims at a time - and in 1941/42 only a few, but severe locally concentrated avalanches caused enormous damage and killed many people.

Compared to Figure 2 it can be seen that the catastrophic winters mentioned there since 1944/45 well coincide with the peaks in Figure 3a. Having a return period of roughly 10 years some single years are obviously outstanding for their clearly above-average number of damage avalanches. It is interesting to notice that according to Figure 3a the general trend for "damage avalanches" (i.e. avalanches causing damage and claiming victims) seems to be rather rising. This may be due to increased human activities mainly in the recreational sector, since the numbers of tourist fatalities are rising too. With the establishment of a detailed database of all recorded and reconstructable avalanches in Switzerland of this century (Laternser et al., 1995) further analyses will show if the number of "large damage avalanches" (e.g. after CALONDER, 1986) remains on a constant level or also points to a certain trend (SCHNEEBELI & LATERNSER, 1996; LATERNSER & SCHNEEBELI, in prep.).

6.2 Causes of the disastrous avalanches in the winter of 1950/51

The winter of 1950/51 was by far the most severe avalanche winter of this century in Switzerland and is well documented in SLF (1952). The avalanche activity was confined to two distinct periods: the first period lasted from January 19-21 with a clear peak on the 20th and the second period was from February 11-14 with dominating activity on the 11/12th. According to the two completely different weather situations the avalanches affected two quite different areas. The January disaster was caused by a classical NW-storm and affected mainly the Swiss cantons of Grisons, Uri and parts of the Valais (all areas on the northern side of the main divide of the Alps). In contrast to that the February catastrophe was initiated by a long-lasting period of foehn intensified by a strong southerly barrage, which caused excessive avalanching mainly in the canton of Ticino (south of the Alps) and in neighbouring areas of Grisons, Uri and Valais across the main divide.

Figure 4 shows the synoptical weather map of January 20, 1951. The situation before this date was characterized by a changeable period of westerly winds since January 12 after a very wet November and a rather dry and cold December. On January 18 heavy and continuous snowfalls began, caused by the rising of warm air masses over a wedge of cold air lying north of the Alps. The same evening an active cold front reached the Alps and initiated a furious NW-storm which lasted till the 21st. During this 3-day-period 150-250 cm of fresh snow were dropped in the central and eastern areas north of the Alps. In the northeastern parts of Grisons the snowfalls even exceeded 250 cm (Fig. 5). Peak snowfall intensities were up to 10-15 cm per hour. Although the snow cover up to this date was reasonably mighty and well solidified the enormous amount of fresh snow was just too much at a time and collapsed spontaneously under its own weight, producing innumerable extraordinary and destructive avalanches. The area severely affected by avalanches is virtually identical with the area enclosed by the 150 cm isoline in Figure 5.

From February 4 a strong cyclone situated over the British Isles initiated a pronounced foehn period with intensive precipitation south of the Alps (Fig. 6a). In some of the uppermost valleys of Ticino more than 100 cm of fresh snow fell within 24 hours, which already caused isolated avalanches. Due to rather warm temperatures during the snowfalls and the following weather improvement connected with a cooler spell the snow cover could stabilize considerably. Renewed heavy snowfalls from February 9 onwards, caused by strong southern barrage put the tin lid on it (Fig. 6b). During this four-day period until the 12th again more than 200 cm of snow fell above 1500 m a.s.l. The precipitation records of Mosogno (780 m a.s.l., Valle Onsernone) showed more than 158 mm within 24 hours, which is about 600% of the average value for the entire month of February for this station!

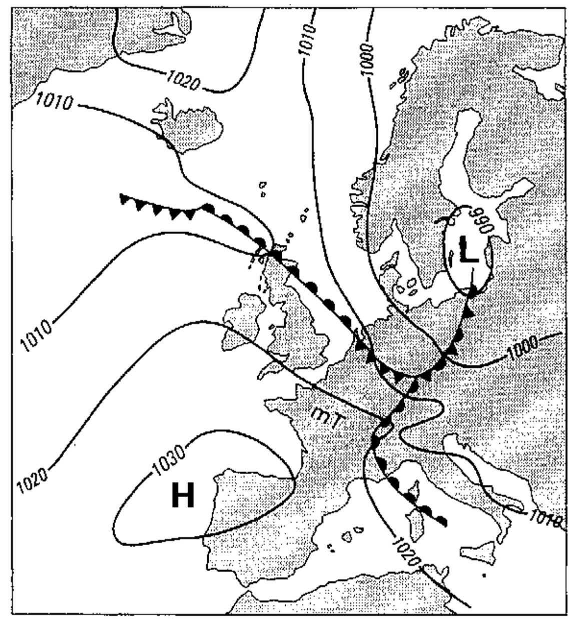

Fig. 4 Weather situation on January 20, 1951: The inflow of maritime, tropical air (mT) from NW caused very intensive snowfalls connected to a strong barrage north of the Alps (after SLF, 1952).

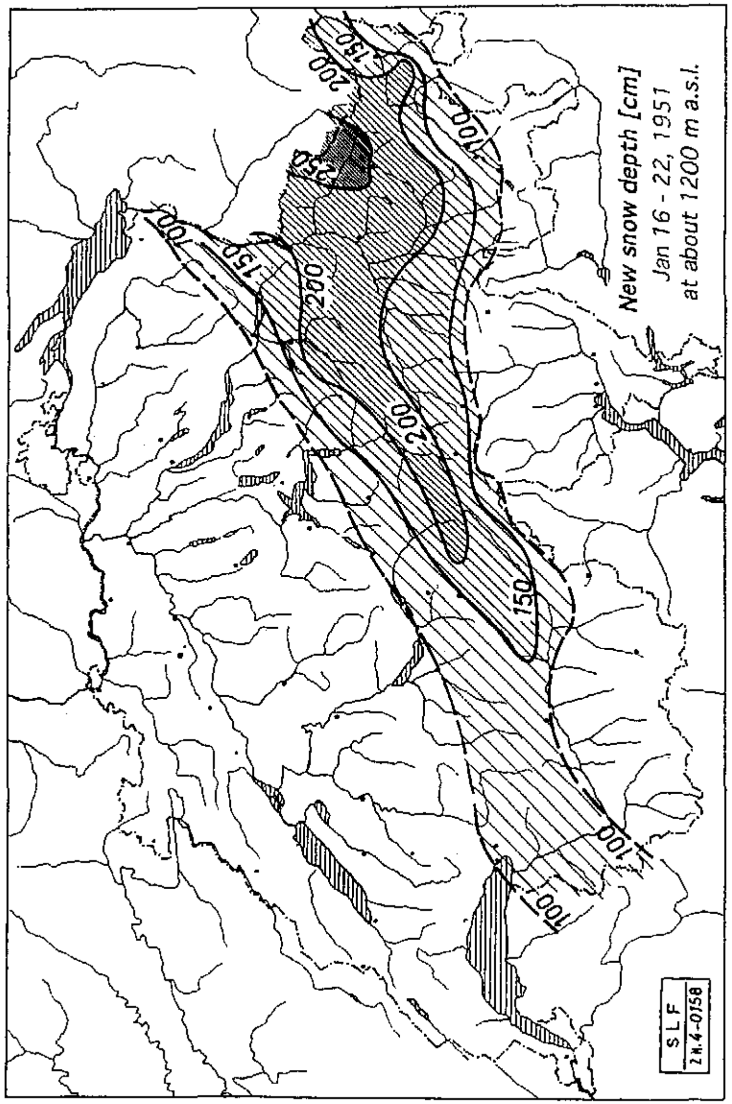

Fig. 5 Distribution of new snow depth (sum values) fallen in the period of January 16-22, 1951. The area severely affected by avalanches is virtually identical with the area enclosed by the 150 cm isoline (from SLF, 1952).

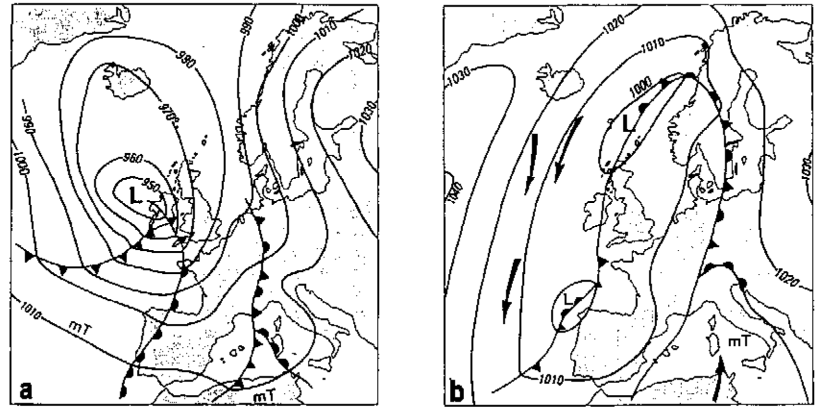

Fig. 6 Weather situations on February 4, 1951 and February 10, 1951: (a) shows the pronounced foehn period during February 4 to 5 dropping more than 1 m of fresh snow in parts of the upper Ticino; (b) shows, after a short respite, the renewed and continual inflow of maritime, tropical air (mT) from S lasting from February 8 to 12. Due to a strong barrage effect the snow falls along the southern slope of the Alps were tremendous (up to 3 m) and partly spread further to the northern side (after SLF, 1952)

In the Val Bedretto and the upper Valle Maggia the total amount of fresh snow fallen during the period from February 4-14 (at an altitude of 1200 m a.s.l.) exceeded 400 cm! The remaining areas of northern Ticino and neighbouring parts of Valais, Uri and Grisons still received 200 cm and more (Fig. 7). These enormous amounts of snow arising from an extraordinary meteorological situation caused disastrous avalanches as hardly ever registered in living memory. Only thanks to the rather high temperatures most of the precipitation in the lower reaches fell in the form of rain, otherwise there would have been even more snow to avalanche. Even up to 1800 m a.s.l. the snow was very wet and partly mixed with rain, which allowed the snow cover to settle very fast. But the sheer amount of snow proved to be just too much in the end.

This example demonstrates the "problem" of a mighty and well-solidified snow cover. If the snow pack had been more fragile in January, many slopes would probably have offloaded their weight at that time already or at least earlier in February, hence causing avalanches of less destructive power. But the well-solidified snow cover allowed to accumulate more and more snow multiplying the destructive force of the avalanches.

Each severe avalanche period has its own characteristics depending on the spatial and temporal distribution, the causes and effects. It simply exceeds the scope of this paper to describe all the other disaster periods of this century in the same detail as the 1951 event.

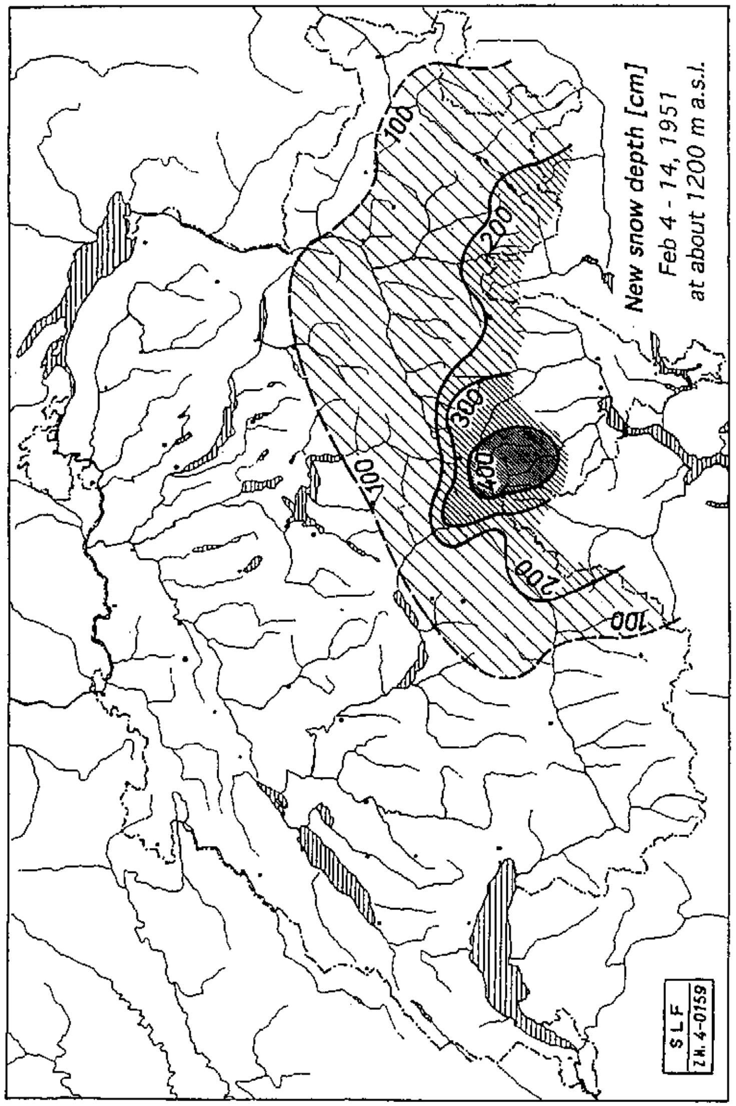

Fig. 7 Distribution of new snow depth (sum values) fallen in the period of February 4-14, 1951. The areas affected by avalanches were mainly in the Ticino (Valle Maggia, Leventina/Val Bedretto) and in parts of Valais (Simplon) and Grisons (Valle Mesolcina, Val Bregaglia), all areas lying on the southern slope of the Alps (from SLF, 1952)

7. Extraordinary climatic conditions leading to disastrous avalanches during earlier centuries

In the following paragraphs some earlier situations of extreme avalanche activity over the last centuries are described and interpreted in a meteorological context. We begin with the period of 1888 and then move back in time, considering more remote cases which are not so well documented (a selection of the most important events and the corresponding sources is given in the appendix).

7.1 The situation in February and March 1888

The situation in the winter of 1887/88 was recently reinterpreted by Zysset (1989). He distinguishes three avalanche periods: February 15-20, February 26-28 and March 27-30 (Fig. 8). The first displays the typical picture of a northerly barrage situation mainly affecting the central and eastern Swiss Alps. The catalogue of weather situations by HESS & BREZOWSKI (1977) indicates a high-reaching, quasistationary cyclone over Central Europe for the critical period. Most stations north of the Alps observed northwesterly winds, but the amounts of measured precipitation at lower altitudes were not so significant. Local records from alpine stations indicate considerable amounts of snowfall though (COAZ, 1889). Temperatures were below average and atmospheric pressure was low on both sides of the Alps over the entire month. During the second period (February 26-28) the focus of precipitation was south of the Alps which was connected to a cyclonary south-southeasterly current affecting

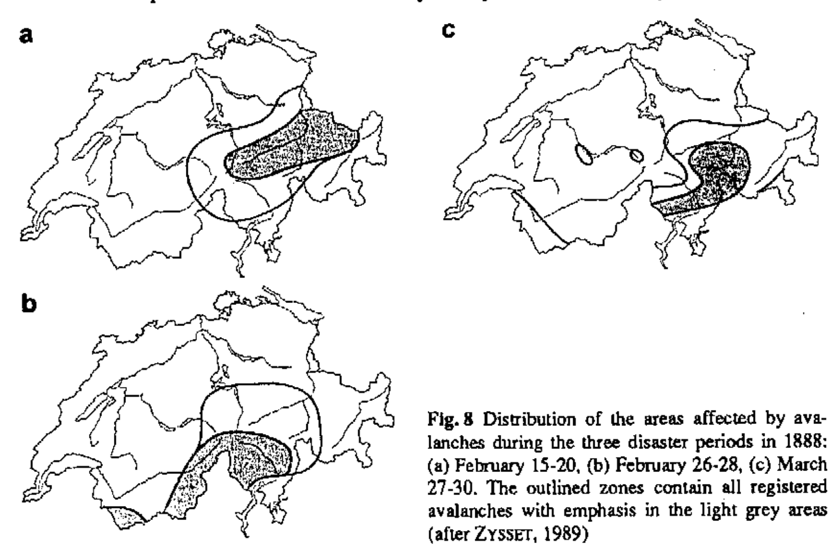

Fig. 8 Distribution of the areas affected by avalanches during the three disaster periods in 1888: (a) February 15-20, (b) February 26-28, (c) March 27-30. The outlined zones contain all registered avalanches with emphasis in the light grey areas (after ZYSSET, 1989)

the southern areas of the Valais unusually strongly. The third situation at the end of March was initiated by the passage of a strong occlusion causing heavy precipitation - up to 2000 m a.s.l. as rain - brought in by southerly winds. This mainly affected the areas south of the Alps but also spread over large parts of Grisons. Avalanches were caused by the heavy snowfalls in the higher reaches as well as by the destabilizing effect of the continuous rain on the mighty snow cover at lower altitudes (CALONDER, 1986). Huge avalanches occurred also in some parts of the Bernese Oberland, possibly due to strong warming.

7.2 The situation from December 11 to 13, 1808

From December 11 to 13, 1808 another northerly barrage situation developed, but this time it extended farther to the west and the airflow came perhaps more from the north: According to the instrumental diary of Samuel Studer in Bern it snowed more or less continuously from December 11 to 13 and temperatures were substantially below zero (SCHWEIZ. METEOROLOG. BEOBACHTUNGEN, 1885). In Chur 60 cm of fresh snow fell from December 11 to 12 accompanied by stormy winds. In the mountain areas snow accumulated to an estimated depth of 1.8 m during these days. The highest accumulations of snow were observed in the Central and Eastern part of the Bernese Oberland, in the region around the Gotthard and in the Grisons. Most of the avalanches broke off during the night from December 12th to 13th damaging a substantial number of houses and barns and killing cattle and dozens of people. For the Grisons Salis reports the destruction of 81 stables and barns and of 9 houses; 355 head of cattle and 24 people were killed (SALIS, 1809:158). In the Bernese Oberland 42 victims were counted (MONATHLICHE NACHRICHTEN, 1750-1798).

7.3 The situation from February 6 to 7, 1749

During the first days of February snow and rain fell in the Lowlands together with high windspeeds and rivers flooding their banks. At the same time heaps of snow were accumulated in the mountains (PFISTER, 1985). Missing details about the precise meteorological situation, particularly the wind directions, as well as the fact that avalanches are reported from both sides of the Alps (see appendix) unfortunately make it difficult to get a clear picture about this severe period. Nevertheless, it seems to have been a rather exceptional situation, since usually only a few single regions get severely affected by disastrous avalanches at a time, but in 1749 wide areas of the Swiss Alps got struck simultaneously.

7.4 The situation in February 1720

For this month two periods of high avalanche activity, February 7 to 8 and February 17 to 18, are reported. It is not clear whether the date given in the first source already follows the Gregorian style (see chapter 5). Therefore, the meteorological situation of both periods is described in the following paragraph.

February 1720 was cold and very snowy. Huge amounts of snow accumulated in the eastern part of the Swiss Alps (Canton of Appenzell). The meteorological situation was reconstructed from the instrumental diary kept by Scheuchzer in Zürich: The amount of precipitation measured over the entire month was 152 mm (250% of the 1901-60 average). Two potential situations of high avalanche activity may be drawn from the record. The first developed on February 7 and 8 with rain and snow and violent winds at first from south to southwest, then from northwest. This reflects the classic situation of the passage of a warm front followed by an active cold front. The maximum daily intensity of precipitation was recorded on Feb 8 (38 mm), but it may well be that part of the water was blown away from the raingauge, so that the actual precipitation was greater. A similar situation arose on February 17 to 18: Warm weather, storm from southwest and west, much rain, snowmelt (Scheuchzer, in: SAMMLUNG, 1720:150-151). This suggests that particularly the first period was related to a northerly barrage situation, affecting - according to experience - mainly the northeastern areas of the Swiss Alps. And the records mention destructive avalanches in the Canton of Grisons (Davos, Ftan). During the second period, however, the most active weather (with winds from W/SW) seems to have moved right up the Valais, which is completely open to this direction, and caused disastrous conditions mainly in this part of the Alps (e.g. Obergesteln).

7.5 The situation from January 15 to 18, 1719

The meteorological situation was again reconstructed from the instrumental diary kept by Scheuchzer in Zürich: Over the entire month barometric pressure was low, temperatures were near the twentieth century average - the fresh snow layers were soon melted - and 109 mm of precipitation (160% of the 1901-60 average) were measured in Zürich. Great amounts of rain and snow fell from January 15 to 18 with strong southwesterly winds, then the winds turned to northwest (SAMMLUNG, 1719:20). This reflects again a typical northerly barrage situation with a quasistationary trough. On January 17 a huge avalanche broke off that buried a part of the village of Leukerbad (Valais). The occurrence of disastrous avalanches from other parts of the Alps is not known.

7.6 The situation from February 2 to 4, 1689

The main witness for this period of high avalanche activity is Johann Heinrich Fries in Zürich (see chapter 4). We know from his diary that it snowed and rained at the beginning of the month, but he gives no wind direction. The accumulation of huge snow masses is reported from the Valais (DUFOUR, 1870). More is known on the meteorological situation of these days from evidence collected in the context of a European project which aimed at reconstructing weather situations in the late Maunder Minimum period, i.e. the period from 1675 to 1715 (FRENZEL et al., 1994). Louis Morin, who was a physician in Paris, kept track of the direction and speed of clouds in his instrumental diary, which is a very valuable indicator for the main atmospheric current (PFISTER & BAREISS, 1994: 151). During the first ten days of February the clouds in Paris came mainly from northwest, which again points to a situation of northwesterly barrage. Considering the number of victims (see appendix), it was perhaps the worst situation prior to 1951.

7.7 The situation in February, 1598

R. CYSAT (1969) describes this winter as follows: From Christmas 1597 until March 1598 it snowed almost every day and night in the Lowlands, it rarely rained in between, so that the snow accumulated more and more (this holds even for places such as Geneva, where a long lasting snow cover is rather rare nowadays). In some locations the snow was 8 to 10 feet deep. In the mountains people had to dig tunnels through the snow to move the cattle from one stable to another. Considering this situation it is striking that the sources hardly mention an increased avalanche activity north of the Alps. However, disastrous avalanches broke off in the southeastern parts of the Swiss Alps and in neighbouring areas of Italy around February 17.

7.8 The period from 1566 to 1579

For the period between 1566 and 1576 several sources mention a series of winters with unusually large amounts of snow without, however, providing a full report of avalanche activity. In 1565/66 snow was so deep in the eastern part of the Swiss Alps, that cattle could not be moved from one stable to another any more and starved as a consequence (PFISTER, 1985). This suggests the frequent occurrence of long lasting northwesterly situations during that winter. This interpretation would be in agreement with a reported extreme drought in Catalonia during the same period (BARRIENDOS, pers. comm.). In the valley of Grindelwald (Bernese Oberland) a huge amount of snow fell on Dec 28, 1572 which crushed several houses under its weight; in spring 1573 avalanches broke off everywhere in the valley and caused many victims. It is the worst avalanche period which is documented for this valley. The situation was not much better in the following winter of 1573/74. In the winter of 1575/76 again the snow blocked people in their houses for a prolonged time (HUGI 1842: 86; KAUFMANN, 1905). Such descriptions give the impression that avalanche activity during the years from 1565 to 1579 might have been above the mean level of the last 500 years. On a more general level, winters were colder and somewhat wetter than those of the period 1901-60 (PFISTER, 1984). This was an important element - together with the high frequency of wet and cool summers - to promote the expansion of alpine glaciers in the second phase of the Little Ice Age.

8. Conclusions

Situations of increased avalanche activity for the preinstrumental and early instrumental period may be reconstructed from reports in historical documents, if the historians' rules of

source verification are observed. Since the sixteenth century extraordinary climatic conditions leading to disastrous avalanches were in most cases connected to quasistationary troughs over Central Europe producing a northwesterly air-flow and a barrage situation over the Alps. This coincides with PROHASKA (1943), who points out that northwesterly currents are particularly notorious for heavy snowfalls in the Alps.

It seems that the central and eastern parts of the Swiss Alps get affected more frequently than the western part. For the areas south of the Alps not many events prior to the last century are known. That does not necessarily mean that disaster avalanches were less frequent - maybe they are just not recorded - but by means of statistical analyses CALONDER (1986) comes to the conclusion that the probability of high avalanche activity is far less than the probability of excessive snowfalls for the southern slope of the Swiss Alps. That means not many great snowfalls (which occur more frequent on the southern compared to the northern slope) have destructive avalanches as a consequence. This stands in clear contrast to the situation in the central (greater Gotthard region) and "inner eastern" (Engadine, Mittelbünden) areas of the Swiss Alps, where heavy snowfalls led to disastrous avalanches much earlier (CALONDER, 1986). This makes also sense from the physical point of view, since on the southern slope of the Alps the temperatures during snowfall periods are generally higher than in the north which allows the snow to settle faster and brings about a more stable snow cover.

So far historical periods of high avalanche activity can be reasonably well explained by their corresponding meteorological conditions. But it must be emphasized that the results should not be over-interpreted. Many weather descriptions of earlier centuries are too incomplete for unambiguous identification of the meteorological situation. Possibly large scale situations can better be reconstructed, but definitely not the local wind fields and precipitation patterns (unless specific observations or measurements exist!). And that is exactly what we need in many situations. Characteristically, hardly any avalanche periods affected the entire country as a whole (as in 1749), but often isolated valleys got struck severely whereas neighbouring areas widely escaped. This reflects the fact that heavy snowfalls within a short period are most often confined to comparatively small areas (generally less than about 5000 km^2), which - for example - implies the necessity of high resolution in avalanche forecasting. The second avalanche period in 1951 stands as an impressive example.

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Appendix

Table 1 Selected examples of great disasterous avalanches or entire avalanche periods in Switzerland since the 16th century

Date *	Locality (Region or Canton) *	Fatalities, Damage (Source [chronicle]) *
1518	Leukerbad (VS)	61 deaths, many buildings and spa destroyed (Loretan 1935; Coaz 1881)
1598 Feb 17	Grisons, particularly in the Engadine and Val Müstair	about 50 deaths, many farmsteads incl. cattle (>150) destroyed (Brügger 1882 [Ardüser])
	Livigno (Italy)	50 deaths (Brügger 1882 [Ardüser])
	Campodolcino (Italy)	18 deaths (Brügger 1882 [Ardüser])
1602 Jan 16	Davos (GR)	13 deaths, 70 buildings, 20 cows and numerous other cattle (Laely 1984 [Ardüser, Christ, Sprecher])
1609 Mar 3	Davos (GR)	16 (or 26?) deaths, buildings and cattle (Laely 1984 [Ardüser, Christ, Sprecher])
1689 Feb 4 (g)	Saas (Prättigau, GR)	2 avalanches claim 59 victims, destroy 22 houses and many more sheds, barns, orchards and wood (and cattle?) (Sprecher 1940 [Jost])
	St. Antönien (Prättigau, GR)	13 deaths, 8 houses, 2 mills, sheds, cattle and large areas of forest (Finze-Michaelsen 1988 [Ruosch])
1689 Feb 3 (g)	Davos (GR)	8 deaths, 6 houses and many sheds incl. cattle (Laely 1984 [Christ, "private chronicle"])
1689 Feb 2 - 4 (g)	Montafon (Vorarlberg, Austria)	120 deaths, 119 houses, nearly 700 other buildings, 740 head of cattle and 1830 trees (Sprecher 1940 ["old chronicle"], Flaig 1955)
1689	Galtür/Paznauntal (Tyrol, Austria)	29 deaths, more than 800 houses and many sheds (Brügger 1882 [Amstein])
1695 Feb 21 (g)	Bosco-Gurin (Valle Maggia, TI)	34 deaths, 11 houses and 11 sheds (Brügger 1882 [Scheuchzer], Viglezio 1977)
1695 Feb 21/22 (g)	Val Bedretto (TI)	church and several houses destroyed, priest killed (Brügger 1882 [Lavizarri])
1695 Mar	Chur area (GR)	several damage avalanches, at least 3 deaths (Brügger 1882 [church book of Churwalden])
1719 Jan 17	Leukerbad (VS)	55 deaths, chapel, spa, more than 50 houses and many other buildings destroyed (Coaz 1881; Brügger 1882 [BZZ]; Loretan 1935 [Matter])
1720 Feb 7 (g?)	Davos (GR)	damage on a church, houses and in the forest (Laely 1984 [Brüchen chronicle])
1720 Feb 8 (g?)	Ftan (Engadine, GR)	35 or 36 deaths, many buildings and wood (Coaz 1881; Brügger 1882 [Leonhardi])
1720 Feb 18 (g?)	Obergestein (Goms, VS)	many deaths (according to different sources 48, 84 or 88), up to 120 buildings destroyed and 400 head of cattle killed (Coaz 1881; Brügger 1882 [BZZ]; Hess 1936)
1720	near Brig (VS)	40 people "buried" (dead?) (Brügger 1882 [BZZ])
	Randa (VS)	12 deaths (?) (Schild 1972)
	Gd. St. Bernard (VS)	23 deaths (?) (Schild 1972)

Table 1 (continued)

1741 Mar 16 (g)	Saas Fee area (VS)	18 deaths, approx. 25 buildings destroyed (Ruppen et al. 1979; Coaz 1881; Brügger 1882 [BZZ])
1749 Feb 6	Disentis (Surselva, GR)	5 deaths, 13 buildings and more than 50 head of cattle (Brügger 1882 [monastery of Disentis])
	Rueras (Surselva, GR)	64 deaths, 23 houses, 39 sheds, 33 barns, 5 mills, 1 sawmill and 237 head of cattle (Brügger 1882 [Annals of Sedrun])
	Zarcuns (Surselva, GR)	6 deaths, 1 house, 6 sheds, 2 barns and some cattle (Brügger 1882 [Annals of Sedrun])
1749 Feb 6/7	Grindelwald (Bernese Oberland, BE)	avalanches (Kaufmann 1905)
	Mattmark, St. Niklaus, Reckingen (VS)	avalanches (Lütschg 1926; Brügger 1882 [BZZ]; Furrer 1852)
	Ossasca (Val Bedretto, TI)	13 deaths (Coaz 1881; Brügger 1882 [Lavizarri], Viglezio 1977)
1749	Bosco-Gurin (TI)	41 deaths (?) (SLF 1952; Viglezio 1977)
1808 Oct-Dec	Davos (GR)	great avalanche activity in early winter; not much damage (Laely 1984)
1808 Dec 11-13	Eastern Bernese Oberland (mainly Gadmen and Grindelwald, also Eblingen, Ringgenberg, Saxeten, Frutigen, Kandersteg, Lenk)	42 deaths, some cattle and buildings (Monathliche Nachrichten)
	Central Switzerland (Gersau, Oberrickenbach, Bürglen)	avalanches (Monathliche Nachrichten)
	Grisons (mainly Selva, also Trun, Tamins, Castiel, Avers)	24 deaths, destruction of 9 houses, 81 sheds and barns, 355 head of cattle killed (Salis 1809:158)
1812/13	Selva (Surselva, GR)	27 deaths (?) (SLF 1952)
1827	Selkingen, Biel (Goms, VS)	52 deaths (Monathliche Nachrichten; Schild 1972)
1849 Apr 3	Saas Fee area (VS)	19 deaths, 6 houses and more than 50 other buildings destroyed, numerous cattle killed (Ruppen et al. 1979; Coaz 1881)
1851 Mar 23	Ghirone-Cozzera (TI)	23 deaths, 300 head of cattle killed (?) (SLF1952)
1888 Feb 15-20 1888 Feb 26-28 1888 Mar 27-30	GR, SG, (UR, TI) TI, VS, (GR, UR) GR, TI, (UR, BE, VS)	During winter 1887/88 1094 severe damage avalanches in Switzerland claimed 49 victims, destroyed 850 buildings, killed 700 head of cattle and broke 1325 ha of forest (Coaz 1889)
1951 Jan 19-21 1951 Feb 11-14	GR, UR, (VS) TI, (VS, GR, UR)	During winter 1950/51 1301 damage avalanches in Switzerland claimed 98 victims, destroyed about 1489 buildings, killed about 800 head of cattle and broke 1945 ha of forest (SLF 1952)
* *Notes*	* *Notes*	* *Notes*
(j) refers to Julian (old) style, (g) to Gregorian (new) style	Abbrevations of Swiss cantons: Berne (BE), Grisons (GR), St. Gall (SG), Ticino (TI), Uri (UR), Valais (VS)	«Cattle» most often means cows, goats and sheep; sometimes also horses, donkeys and pigs. Entries with (?) are not confirmed by contemporary sources

Dating of rapid mass movements in Scandinavia: talus rockfalls, large rockslides, debris flows and slush avalanches

Christer Jonasson, Rolf Nyberg & Anders Rapp

Summary

The dating of rapid mass movements and the possibility of drawing climatic inferences from such datings are discussed on the basis of studies in mainly northern Scandinavia. Rockfall-produced rockwall chutes can, by indirect means, be judged as being of pre-Weichsel age and were not obliterated by ice sheet erosion. Rockfalls and other rapid mass movements occurring above permanent snow patches or small-scale glaciers may create protalus ramparts in front of these features. These ramparts are very similar to, or grade into, small-scale moraines. Dating is possible by TL-method, and the ramparts can serve as indicators of climatic periods of intense rapid mass movements, among other processes. Several large rockslides are most likely of Lateglacial age and related to a climatic amelioration and i.a. permafrost thawing, or to pressure release of glacial ice. Debris flows and slush avalanches have been tentatively dated by lichenometry covering the last few thousand years. More precision is needed in the datings to improve the use of these processes as climatic indicators. To monitor rapid mass wasting activity during the whole Postglacial period, lake sediment studies are more useful than geobotanical datings. According to these studies, the intensity of rapid mass wasting processes has varied considerably during the Holocene. Periods of increased rapid mass wasting can be roughly correlated with periods of cold climate. However, more research on the application of dating methods in this context is needed due to the complex relationships between mass movements and climate.

Zusammenfassung

Die Datierung von schnellen Massenbewegungen und die Möglichkeiten, hieraus klimatische Schlußfolgerungen abzuleiten, werden auf der Grundlage von Untersuchungen, die hauptsächlich im nördlichen Skandinavien durchgeführt wurden, diskutiert. Steinschlagrinnen können mit Hilfe indirekter Datierungsmöglichkeiten als vorweichselzeitlich eingestuft werden und wurden durch glazialerosive Prozesse nicht zerstört. Im Bereich von Schneeflecken oder Eis- und Firnfeldern können sich frontal "protalus ramparts" entwickeln, die vollständig oder zumindest teilweise auf Steinschläge oder andere Typen schneller Massenbewegungen zurückgehen. Diese "protalus ramparts" können mit der TL-Methode datiert werden und somit als Indikatoren für Klimaabschnitte, die u.a. durch häufig auftretende, schnelle Massenbewegungen gekennzeichnet sind, gelten. Mehrere große Bergstürze haben ein vermutlich spätglaziales Alter und ereigneten sich in Verbindung mit der einsetzenden