AVALANCHE RISK OF HIGH MOUNTAIN HUTS IN SWITZERLAND AND ITS EVOLUTION DUE TO CLIMATE CHANGE

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ABSTRACT: The Swiss Alpine Club SAC operates 153 mountain huts in the Swiss Alps. Some of these huts are located at locations exposed to avalanches. In the past, several huts were hit by avalanches and in some cases destroyed. Due to climate change, the avalanche hazard may change. At higher elevations, winter precipitation and snowfall intensity are projected to intensify, in some cases increasing the avalanche hazard. The retreat of glaciers may change the topography which can also influence the hazard. For an initial risk assessment, the SLF studied the avalanche risk for all 153 huts on behalf of the SAC. The analysis was based on existing data such as the topography, event records and hazard indication maps; neither terrain surveys nor avalanche simulations were carried out. Each hut was assigned to one of three risk categories: 57% of the huts are not at risk, 24% might be at risk, and 19% of the huts have been proven to be at risk from avalanches. Based on this overview, the hazard was evaluated in detail in a second phase, where necessary. The same safety standards as for settlement areas were applied for this assessment. Scenarios with a return period of up to 300 years were considered, including possible effects of climate change. Where the existing protective measures were not sufficient, additional measures were proposed. Based on four examples, we show different aspects of the impact of climate change on hazard assessment.

KEYWORDS: Avalanche hazard mapping, climate change, avalanche mitigation.

1. INTRODUCTION

The Swiss Alpine Club SAC owns 153 mountain huts. Some huts are located in alpine terrain and the majority of them are also operated in winter. In the last 50 years, about 6 huts have been destroyed by avalanches (Fig. 1). The history of most of the huts dates back more than 100 years. In the beginning, they were mostly small bivouac-type shelters that helped mountaineers discover the Alps (Gibello, 2014). Over time, the huts were enlarged and adapted to today's demands for comfort. In the last 25 years, 66 huts have been substantially renovated and enlarged. As the huts are located outside the settlement areas, there was no uniform assessment of the avalanche hazard. Furthermore, the SAC did not have an overview of the avalanche hazard to the individual huts. In the context of renovation projects, object-specific hazard assessments were usually carried out and, if necessary, protective measures were implemented (Fig. 2). However, there were also enlargements of huts where the SAC assumed avalanche safety solely on the basis of previous experience. In order to have an overview of the avalanche risk to its huts and in view of the fact that climate change might affect avalanche hazard over time, the SAC has commissioned the SLF in 2019 to investigate whether and to what extent the 153 SAC huts are at risk from avalanches.

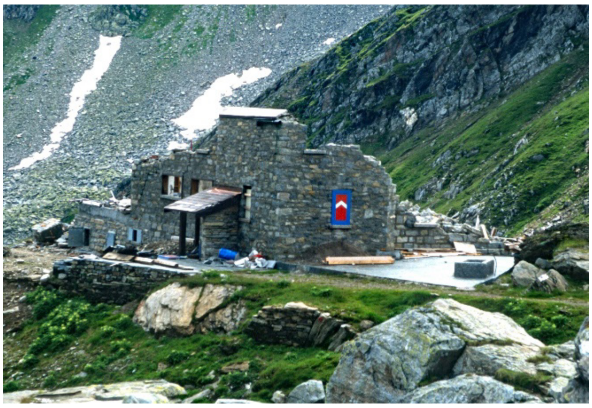

Fig. 1: In February 1999, the SAC Cristallina hut was destroyed by an avalanche from the right. The NW corner of the building (in the middle of the picture) had been designed for an avalanche pressure of 15 kPa (photo S. Margreth).

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2. OVERVIEW STUDY

The goal of the overview study (SLF, 2019) was to obtain an overview of the potential avalanche risk of the hut locations. Due to limited financial resources, the evaluation was carried out as an expert assessment based on existing documents

Fig. 2: The SAC Lämmeren hut, rebuilt in 1992 after being destroyed in 1990 by an avalanche, was relocated by 60 m and reinforced with a ramp roof designed for an impact pressure of powder snow avalanches of 3 kPa (photo S. Sauermoser).

such as hazard indication maps, previously conducted hazard assessments, terrain information, event records, photographs, and personal local knowledge. No avalanche simulations, field visits, or consultations with authorities and local experts were carried out. We considered a 300-year avalanche situation as the decisive scenario for the assessment. We classified the hazard of the huts into 3 categories A, B and C:

- **Category A, no avalanche hazard**

  Avalanche impacts on the hut can be excluded according to human judgment or the expected impacts are so small that they can hardly cause any substantial damage to a structure.

- **Category B, possible avalanche hazard**

  Without a detailed assessment of the avalanche situation with simulations, it is not possible to determine whether there is an avalanche risk or how great the avalanche impacts are. Sites were also classified as Category B, if there is an avalanche hazard that clearly does not exceed a small to moderate level with impact pressures less than 5 kPa.

- **Category C, avalanche hazard confirmed**

  It is unquestionable that the avalanche hazard is at least moderate (avalanche pressure < 30 kPa) or severe (avalanche pressure > 30 kPa). Huts must be protected by structural measures such as a splitting wedge.

Our study showed that of the 153 huts surveyed, 24 (16%) were proven to be at risk (category C) and 42 (27%) were possibly at risk (category B) from avalanches. For 87 SAC huts, i.e. 57% of the investigated sites, according to human judgement, there is no avalanche hazard (category A).

3. AVALANCHE STRATEGY OF THE SAC

With the overview study (SLF, 2019), the SAC had an instrument at hand to decide if the avalanche risk should be considered in construction projects at the huts. The SAC adopted an avalanche strategy (Delang, 2021) with the goal to assess the avalanche risk in detail by 2030 for all category C huts and for the category B huts operated in winter. If there is a protection deficit, the necessary mitigation measures must be implemented. Typical building mitigation measures are reinforced walls and sheltered windows, avalanche splitters or ramp roofs (Fig. 2). The costs for these measures have been estimated to amount to about CHF 10 million. The detailed assessments will be carried out by engineering companies and the SLF. For the sites under investigation, hazard maps are drawn up according to the same criteria as for settlement areas, describing the hazard with the 4 levels red, blue, yellow and white (Fig. 3).

The SAC requests that hazard assessments also consider possible aspects of climate change. Due to their exposed locations in the alpine environment, the huts of the SAC are particularly exposed to the effects of climate change. In the following, we discuss the impacts of climate change on the avalanche risk of SAC huts based on four case studies.

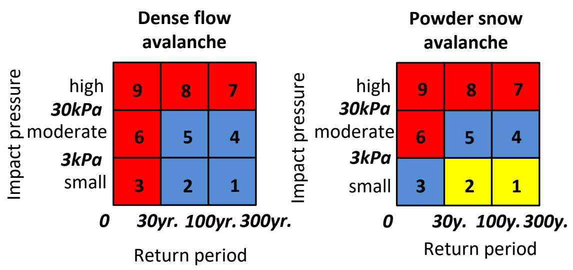

Fig. 3: Hazard matrices for dense flow and powder snow avalanches. The hazard level is defined as a function of return period and intensity (BFF and SLF, 1984).

4. CASE STUDIES

4.1 SAC Trift hut

The Trift hut is located at 2521 m a.s.l. in the western Uri Alps at the base of a small glacier. On 28 January 2021, the hut was severely damaged by an avalanche (Fig. 4). The upper floor of the extension (built in 2007) was ripped away and half of the hut's roof was removed. The old hut built in 1906 (located 40 meters below the current hut) was completely destroyed and its debris was widely scattered. The damages observed at the huts indicate a mixed dense flow and powder

Fig. 4: The avalanche of 28 January 2021 destroyed the upper floor of the uphill extension of the Trift hut and tore away parts of the hut roof. Only little snow was deposited on the side of the hut. The snow plastering on the valley side indicates a powder component of the avalanche (photo SAC Bern).

snow avalanche. A remarkable aspect of the 2021 avalanche was that it carried away several large boulders with volumes of a few cubic meters. Photos from a helicopter survey flight show that the release area was located in the partially glaciated terrain depression about 400 meters above the hut (Fig. 5). The slope of this west-facing depression is between 15 and 35 degrees. Prior to the avalanche, new snow sums of around 3.5 m were measured. On 28 January 2021, the SLF avalanche warning service forecasted a danger level 5 "very high". The large amount of new snow in combination with an unfavorable old snowpack as well as strong winds may have contributed to the numerous large damaging avalanches, which were reported during this time period in the western Uri Alps.

The damaged hut was built in 1947 on a shallow ridge without avalanche protection measures. In 1998, as an extension of the hut was planned, we assessed the avalanche risk. We assumed the possible release of smaller avalanches, which are partially deflected above the hut by a moraine ridge (Fig. 5). We classified the hazard as medium (blue area, Fig. 3) and we recommended to protect the hut with a ramp roof like extension reinforced to 10 kPa. In February 1999, an avalanche which caused only minor damage to the chimney, supported this assessment. However, in 2021, the hut would probably have been completely destroyed without the reinforced extension built in 2007. Over the past 35 years, the thickness of the glacier above the Trift hut has decreased by about 25 m. Consequently, the release area relevant for 300-year avalanches has increased from about 17'000 m^2 to at least 33'000 m^2 (Fig. 5). In 2016, the average ice thickness was about 20 m and the maximum thickness was about 30 m (Grab et al., 2020). It seems certain that in the near future, only individual patches of firn snow will cover the otherwise ice-free former glacier basin. We assume that the avalanche hazard will increase even further in the future.

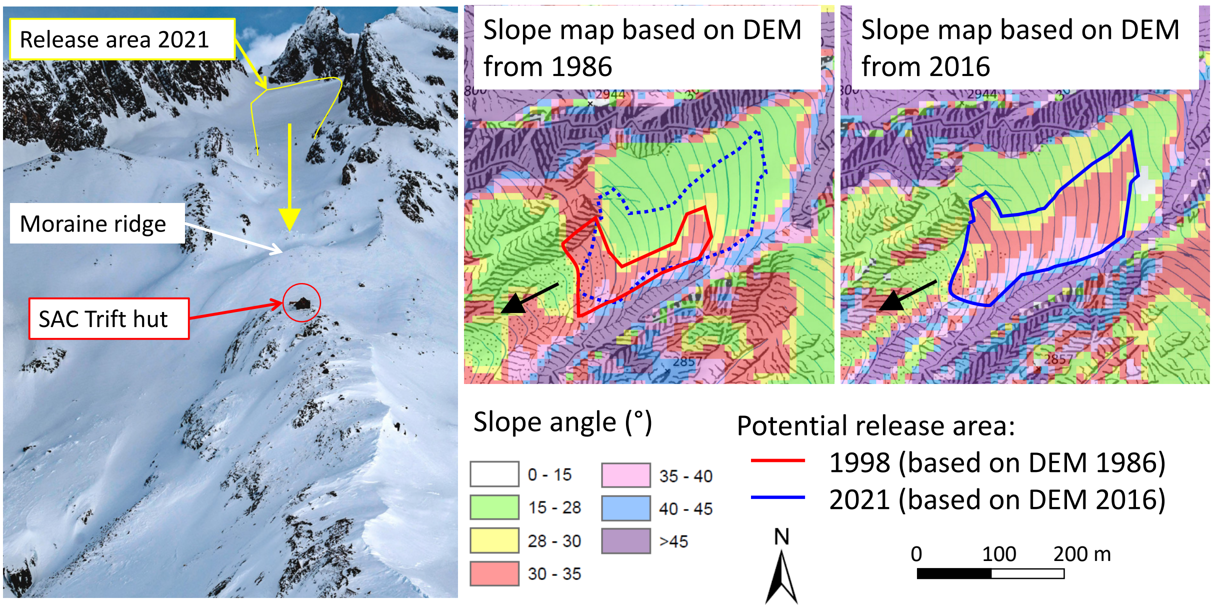

Fig. 5: Overview of the location of the Trift hut with the release area of 2021. The effect of the strong winds is clearly visible along the ridge below the hut (left, photo D. Bürki). The two map sections show slope maps based on different digital elevation models from 1986 and 2016. The release area that was delineated in 1998 was significantly smaller compared to the 2021 release area (data © swisstopo).

In our 2019 study, we classified the hut in category C. Today, the location of the hut is heavily exposed to avalanches (red area, Fig. 3). A 300-year dense flow avalanche has a maximum avalanche pressure of about 270 kPa and a maximum flow height of 2.5 m. Since structural avalanche protection is very difficult to realize at the present location, we proposed to rebuild the hut at a safer site. We evaluated 4 alternative sites around the Trift glacier. Since several release areas are located on glaciers, we also investigated an extreme scenario without glaciers. One would need to know the exact future topography without glaciers to reliably delineate the future extent of release areas and to be able to perform two-dimensional avalanche simulations. However, these data were not available. We estimated the future size of the release areas based on present-day topography, ice thickness (Grab et al., 2020), and the orientation of rock formations, among other factors. We then ran avalanche simulations with the RAMMS::Avalanche (Christen et al., 2010) and RAMMS::RKE (Bartelt et al., 2016) avalanche dynamics programs with the same input parameters as for the 300-year avalanche scenario. The investigations showed that the main effects of climate change have already occurred at the site of the destroyed Trift hut. In the case of dense flow avalanches, we did not expect any further relevant increase of the avalanche pressure, but in the case of powder snow avalanches, an increase from 5 to 10 kPa might be possible. Glacier melt due to climate change has increased the avalanche hazard in the case of the Trift hut considerably.

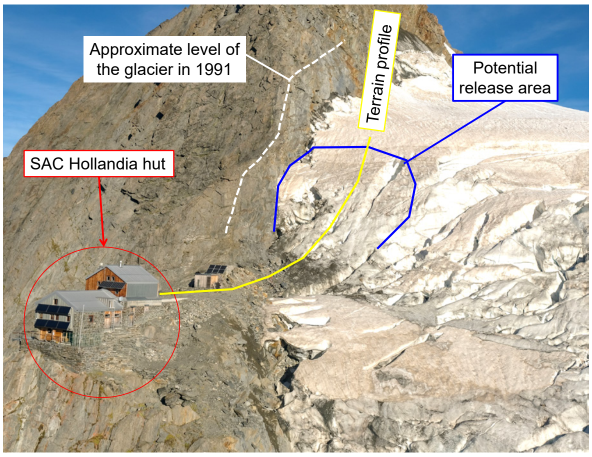

Fig. 6: Location of the SAC Hollandia hut on a rocky ridge in the upper basin of the Aletsch Glacier (photo S. Margreth).

4.2 *SAC Hollandia hut*

The Hollandia hut (built in 1907) is located at 3245 m a.s.l. in the Bernese Alps in the upper basin of the Aletsch Glacier (Fig. 6). The main threat comes from small avalanches that start on the steep and about 50 m high glacier hump

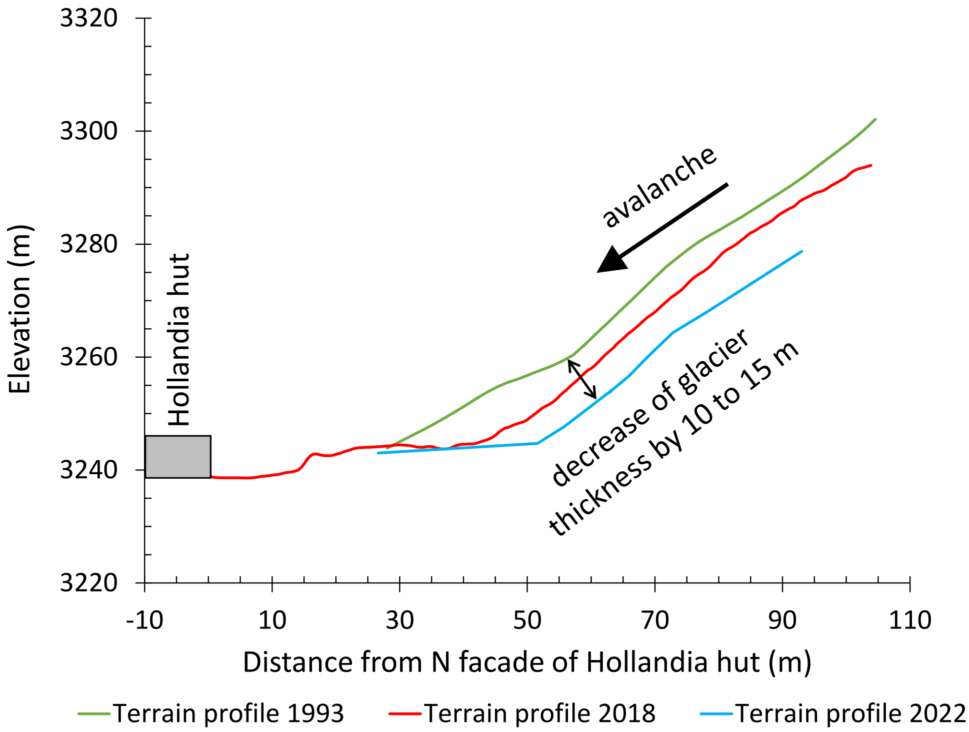

Fig. 7: Terrain profiles north of Hollandia Hut for 1993, 2018 and 2022 glacier levels (Fig. 6). The glacier has retreated by about 20 m. The runout distance for avalanches became correspondingly longer.

directly above the hut. In February 1983, a small avalanche broke off on the glacier hump, stopping just in front of the hut. In 1991, the hazard was classified as medium (blue area, Fig. 3). We assumed that the hut can be hit by small avalanches with a pressure of 7 kPa. In our 2019 study, we classified the hut in category B.

Our assessment in 2022 showed that the glacier margin had retreated by about 20 m over the past 30 years in the area of the hut. The thickness of the glacier has decreased by 10 to 15 m and the glacier is now heavily crevassed. The approximately 40° steep release area has a surface area of 2600 m^2. The existing run-out distance upslope of the hut became longer (Fig. 7). Simulations with RAMMS::Avalanche (Christen et al., 2010) and our assessment showed, that a 300-year avalanche does not reach the hut anymore. The snow masses are flowing to the left and right of the rocky ridge the hut is situated on (Fig. 6). Today, the site is no longer endangered by avalanches (white area, Fig. 3). We assume that the hazard around the hut will further decrease in the near future as the glacier will continue to retreat. In the case of the Hollandia hut, climate change led to a decrease in avalanche hazard.

4.3 *SAC Cavardiras hut*

The Cavardiras hut is located at 2640 m a.s.l. on a small rocky hump in the eastern Uri Alps (Fig. 8). The hut was built in 1928. In our 2019 study (SLF, 2019), the site was assessed as not at risk (category A). Nevertheless, since a major rebuilding project is scheduled, a detailed assessment of the avalanche hazard of the site was requested, including the aspect of climate change. An approximately 39° steep release area is located east of a rocky ridge. The potential release area covered by boulders is not glaciated. The surface area is 14'600 m^2 and the height difference from the crown line to the hut is about 150 m. The avalanche track is not canalized and slightly stepped. About 100 m before the hut, the terrain becomes rather flat (Fig. 8).

Climate change is affecting snow cover with increasing air temperatures and changes in precipitation. For release areas above 2300 m, the number of dry-snow avalanches is expected to decrease and the number of wet-snow avalanches to increase (Mayer at al., 2023). The latest climate scenarios show that extreme precipitation could increase at high elevations in winter (CH2018, 2018). However, these scenarios are of limited use in predicting the future activity in extreme avalanches (Strapazzon et al., 2021). Due to the large uncertainties at the process level, the current state of knowledge does not allow to make quantitative statements on the expected changes

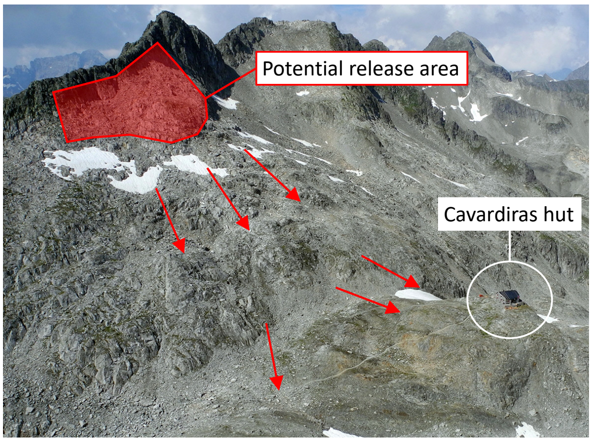

Fig. 8: Overview SAC Cavardiras hut with the potential release area. The hut is located on a terrain ridge. In front of the hut the terrain is flat.

with respect to hazard assessments of extreme avalanches. In the case of the Cavardiras hut, with an avalanche release area at 2800 m and a runout at 2650 m, climate change might increase the avalanche risk most likely as a result of possible higher avalanche fracture depths due to higher snowfall intensities or increased snow drift accumulations.

Tab. 1: Distance between the end of the runout and the Cavardiras hut simulated for 4 scenarios with RAMMS::Avalanche (Christen et al., 2010).

Scenario	Fracture depth d_0 and avalanche volume	Minimal distance end of avalanche runout to hut	
		RAMMS Friction parameter category	
		Medium 300-y	*Small 300-y*
300-year	1.45 m / 21'200 m^3	16 m	31 m
300-year with climate change	1.60 m / 23'400 m^3	11 m	25 m

To cover possible consequences of climate change, we determined the 300-year fracture depth very cautiously (Salm et al., 1990) and choose a maximum snow drift addition of 0.5 m instead of the 0.3 m typically chosen at such sites. The estimated 300-year fracture depth thus increased from 1.45 to 1.60 m. This difference is within the range of the existing uncertainties of the analysis, as it roughly corresponds to the confidence interval of the snow depth increase in 3 days, which is the initial value for determining the fracture depth. The corresponding avalanche volumes vary between 21'200 and 23'400 m^3. When

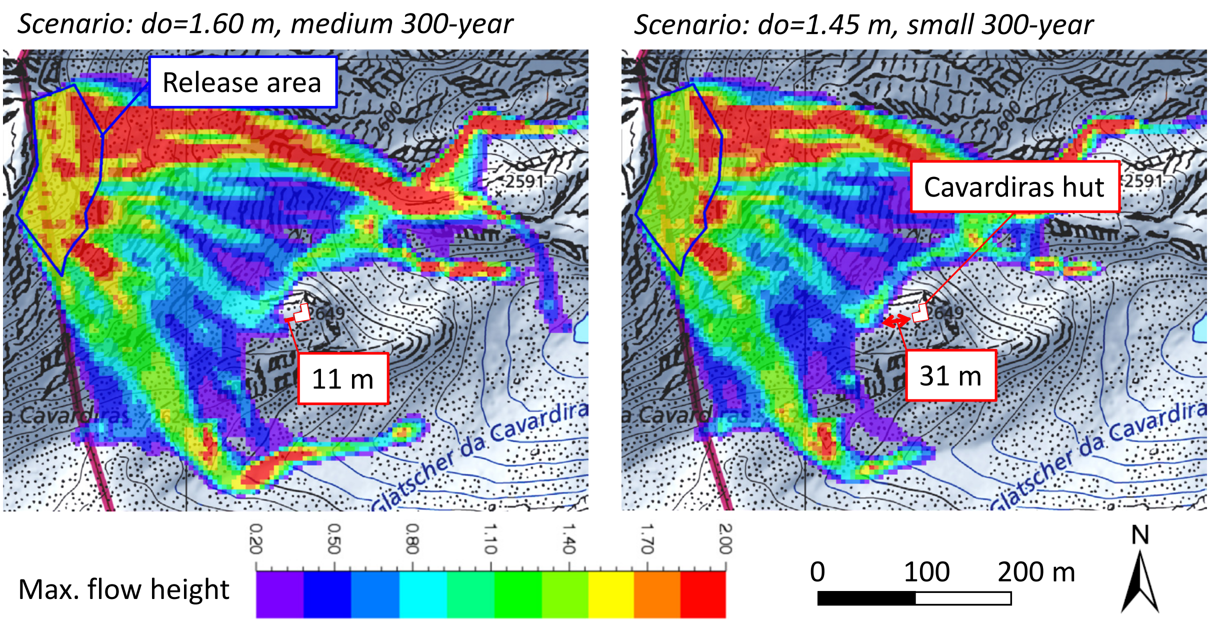

Fig. 9: Simulations with RAMMS::Avalanche of 300-year avalanches. Left: Scenario with fracture depth d_o of 1.6 m and friction parameters for a medium avalanche. The avalanche stops 11 m before the hut. Right: Scenario with fracture depth d_o of 1.45 m and friction parameters for a small avalanche. The avalanche stops 31 m before the hut. Note that south of the hut, the runout lengths of the two scenarios differ by about 110 m, because the terrain at this spot is sloping and not horizontal (data © swisstopo).

performing simulations with RAMMS::Avalanche (Christen et al., 2010), these volumes are in the transitional range where friction parameters for “small” or “medium” avalanches may be applied (the formal threshold is 25'000 m^3). To check the sensitivity of the input parameters, we performed simulations with friction parameters for “small” and “medium” avalanches (Fig. 9 and Tab. 1). The avalanche simulations showed that even with the increased fracture depth of 1.6 m and friction parameters for a “medium” avalanche, the 300-year avalanche stops about 10 m before the hut. This is a difference of only 5 m compared to the scenario with a fracture depth of 1.45 m. If the simulation is performed with friction parameters for “small” avalanches, the distance from the end of the runout to the hut is about 30 m.

For cases like the Cavardiras hut, it is difficult to quantify the influence of climate change on the avalanche hazard to the hut. We assume that the influence is in the range of the uncertainties that exist anyway in an avalanche hazard assessment. For this particular situation, the simulations show that the choice of the friction parameter category has a significantly greater influence on the length of the runout than the choice of the snow drift addition, i.e. the fracture depth.

4.4 <u>SAC Fridolin hut</u>

The Fridolin hut is located at 2111 m a.s.l. in the snowy Glarus Alps at the foot of the 3612 m high Tödi peak. The hut was opened in 1923 and is located in relatively flat terrain on a ridge that is not very pronounced and about 10 to 20 m high (Fig. 10). So far, the hut has never been hit by avalanches. In our 2019 overview study (SLF, 2019), we classified the Fridolin hut site as a category B. Later, a detailed assessment of the avalanche situation showed that there are numerous avalanche release areas above the hut, extending to the glaciated eastern peak of Tödi at 3500 m (Fig.

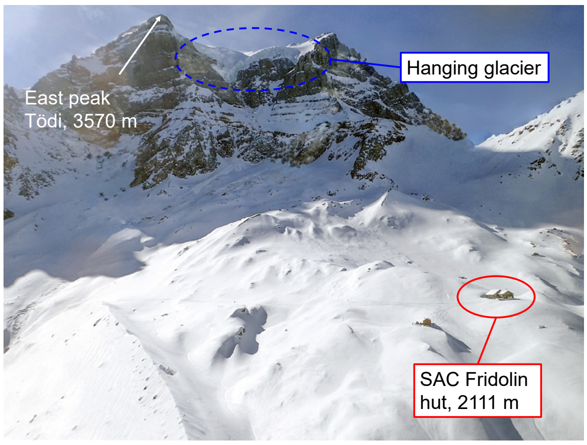

Fig. 10: View of the eastern flank of Tödi with the SAC Fridolin hut (photo S. Margreth).

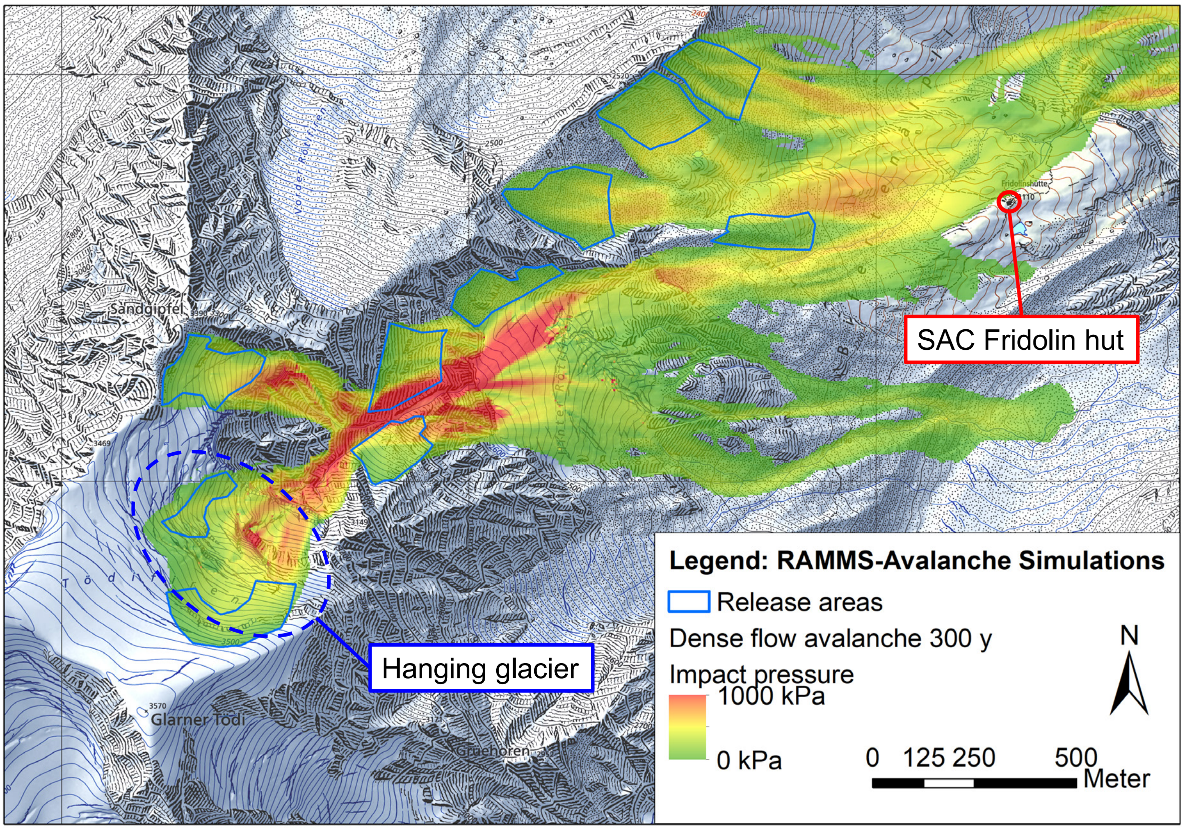

Fig. 11: Overview of the eastern flank of the Tödi with simulations of 300-year dense flow avalanches carried out with RAMMS::Avalanche (Christen et al., 2010). The maximum avalanche pressure is shown. According to the simulations, the Fridolin hut is not reached by 300-year dense flow avalanches (data © swisstopo).

11). A hanging glacier about 600 m wide overhangs the almost vertical eastern flank of the Tödi (Fig. 10) and regularly produces ice avalanches with a volume typically less than 20,000 m^3. However, the maximum potential volume of ice avalanches is about 5 million m^3. The avalanche simulations carried out showed that the hut is very favorably situated with respect to dense flow avalanches. Even 300-year dense flow avalanches are deflected away from the hut, in part very narrowly, by the not prominent ridge (Fig. 11). Snow masses breaking off from the summit of the Tödi develop into large powder snow avalanches which can reach the hut with small powder avalanche pressures of about 2 to 3 kPa. Today, snow avalanches and not ice avalanches are decisive for the hazard. A glaciological study (VAW, 2020) showed that the hanging glacier at the eastern peak of the Tödi is a cold glacier that is currently still frozen to the glacier bed. Increasing air temperatures due to climate change could lead to more meltwater, a warming of the glacier bed and possibly to the destabilization of the whole glacier (Failletaz et al., 2015). In a worst-case scenario, an ice avalanche with a volume of several million m^3 would have to be expected. This could lead to a more severe threat to the Fridolin hut than today. To detect a potentially dangerous evolution in the future, the hanging glacier is monitored. In the case of the Fridolin hut, climate change may result in an increase of the hazard caused by ice avalanches rather than snow avalanches.

5. CONCLUSIONS

Our overview study (SLF, 2019) showed that about 43% of the 153 huts of the SAC may be at risk of avalanches. This raises the question how the risk has changed over time or will change in the future due to climate change. The SAC huts are particularly subject to the effects of climate change due to their exposed location in the high mountains and their elevation above the treeline, often above 2500 m. Our research shows that climate change has the greatest impact on avalanche risk to SAC huts when the decisive avalanche paths are glaciated. As the volume and surface area of a glacier decrease, the topography can become steeper or flatter. This can lead to new release areas or, as in the case of the Trift hut, to larger ones. Existing release areas can also become smaller or disappear completely. Due to the retreat of a glacier, the characteristics of an avalanche path can change for the better or for the worse as in the case of the Hollandia hut, where the area for avalanches to runout increased so that the hazard decreased. Climate change may also lead to changes in the activity of ice avalanches as demonstrated for the Fridolin hut. Hanging glaciers that produce dangerous ice avalanches may disappear, or a glacier that is now cold and frozen to the bedrock may be destabilized by warming of the glacier bed and break off as an ice avalanche (Failletaz et al, 2015).

In unglaciated areas, the effect of climate change on avalanche risk is more difficult to quantify. Below an elevation of about 2300 m, there is a clear trend that overall avalanche activity will be lower by the end of the century (Mayer et al. 2023). How climate change will affect avalanche activity at higher elevations, on the other hand, is less clear. The number of dry-snow avalanches is projected to decrease and the number of wet-snow avalanches to increase. Whether the extreme snowfalls will change, and if so, to what extent, is unclear (Le Roux et al., 2023). It should also be noted that the possible increase of runout distance due to a potentially higher fracture depth may be compensated by the effects of greater friction due to the warmer snow cover and smaller snow erosion due to lower snow depths in the track. We therefore assume that the effects of climate change on avalanche risk are in the range of other uncertainties of hazard assessments. The example of the Cavardiras hut has shown that the choice of the position and size of a release area or the choice of friction parameters generally have a much greater influence on the runout length of avalanches than a possible climate-related increase in fracture depth.

Our investigations do not confirm that a general increase in avalanche risk for SAC huts has occurred or has to be expected as a result of climate change. It should be noted that many huts have been enlarged over time and have thus become more exposed to avalanches. Furthermore, many huts were built in locations that were optimally chosen for mountaineering, but not optimal in terms of avalanche risk. Most huts were built at a time when there were neither systematic hazard assessments nor avalanche simulations. Therefore, it is not surprising that our overview study (SLF, 2019) showed that about 43% of the SAC huts might be at risk of avalanches. With the results of the overview study and the avalanche strategy (Delang, 2021) adopted by the SAC, important instruments have been created to reduce the avalanche risk of the SAC huts in the long term.

REFERENCES

Bartelt, P.; Buser, O.; Vera Valero, C.; Bühler, Y.: Configurational energy and the formation of mixed flowing/powder snow and ice avalanches. Annals of Glaciology, 57, 71: 179-188. doi: 10.3189/2016AoG71A464, 2016.

BFF und SLF: Richtlinien zur Berücksichtigung der Lawinengefahr bei raumwirksamen Tätigkeiten. Bundesamt für Forstwesen (BFF) und Eidg. Institut für Schnee- und Lawinenforschung (SLF). Bern, EDMZ, 1984.

CH2018: CH2018 – Climate Scenarios for Switzerland, Tech. rep., MeteoSwiss, Eidgenössische Technische Hochschule Zürich (ETH), University of Bern (Unibe), National Centre for Climate Services (NSSC), and Swiss Academy of Science (scnat), 2018.

Christen, M., Kowalski, J., and Bartelt, P.: RAMMS: Numerical simulation of dense snow avalanches in three-dimensional terrain, Cold Regions Science and Technology, 63, 1-14, https://doi.org/10.1016/j.coldregions.2010.04.005, 2010.

Delang, U.: Strategie für den Lawinenschutz von SAC-Hütten und Biwaks. Schweizer Alpen-Club SAC. 11 pp. 2021.

Faillettaz, J., Funk, M., and Vincent, C.: Avalanching glacier instabilities: Review on processes and early warning perspectives. Reviews of Geophysics, 53(2), 203-224. 2015.

Gibello, L.: Hüttenbau im Hochgebirge. Ein Abriss zur Geschichte der Hüttenarchitektur in den Alpen. SAC Verlag. 143 pp. 2014.

Grab, M., Mattea, E., Bauder, A., Huss, M., Rabenstein, L., Hodel, E., Linsbauer, A., Langhammer, L., Schmid, L., Church, G., Hellmann, S., Délèze, K., Schaer, P., Lathion, P., Farinotti, D., and Maurer, H.: Ice thickness distribution of all Swiss glaciers based on extended ground-penetrating radar data and glaciological modeling, J. Glaciol., 67, 1074-1092, https://doi.org/10.1017/jog.2021.55, 2021.

Le Roux, E., Evin, G., Eckert, N., Blanchet, J., and Morin, S.: Projection of snowfall extremes in the French Alps as a function of elevation and global warming level, EGUsphere, 2023, 1-17, https://doi.org/10.5194/egusphere-2023-335, 2023.

Mayer, S., Hendrick, M., Michel, A., Richter, B., Schweizer, J., Wernli, H., and van Herwijnen, A.: Changes in snow avalanche activity in response to climate warming in the Swiss Alps, Nat. Commun., submitted, 2023.

Salm, B., Burkard, A. und Gubler, H.U.: Berechnung von Fliesslawinen. Mitteilung des SLF Nr. 47, 1990.

SLF: SLF Gutachten G 2019.21: Grobbeurteilung der Lawinengefährdung der SAC-Hütten. Unpublished report. 2019.

Strapazzon, G., Schweizer, J., Chiambretti, I., Brodmann Maeder, M., Brugger, H., and Zafren, K.: Effects of climate change on avalanche accidents and survival, Front. Physiol., 12, 639433, https://doi.org/10.3389/fphys.2021.639433, 2021.

VAW: Beurteilung der Gletschergefahren im Kanton Glarus: Bericht über die Einschätzung aktueller und künftiger Risiken durch Gletscher. VAW Bericht Nr. 8021-VAW-2020-08. Auftraggeber Departement Bau und Umwelt, Kanton Glarus, Abt. Wald und Naturgefahren. Unpublished report. 2020.