Snow profiling at Weissfluhjoch

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ABSTRACT: Systematic snow and avalanche research in Switzerland started shortly after 1932, when the Swiss snow and avalanche commission was founded and the cable-way from Davos to Weissfluhjoch/Parsenn was built. The researchers went out in the surroundings to examine the snow pack. They also documented avalanche accidents and verified the warning procedures. A short overview is given to the methods, techniques and results of snow profiling at that famous place and else were. The story is described thru the decades. Swiss military alpine services adapted snow profiling methods and gauges. They became orderly ones, also abroad. The civil network for avalanche warning was refined and time profiles were designed for snow cover evolution at the stations. In the late 1970ies, stability checks as Rutschblock test came back from military to the institute.

Acceptable practices in snow cover examinations and site selection involve thinking in the power of ten, following the measurements error propagation and taking into account temporal and spatial variations of the snow cover. It is explained, why digging snow pits is not superfluous until our days, beside the consideration of electronic gauges and model outputs. Depending on the application, different types of snow profiles are necessary, say scientific ones and quick pits for field evaluation.

KEYWORDS: Weissfluhjoch research station, snow metamorphism, Swiss ramsonde, avalanche formation, pattern recognition, avalanche warning.

1 INTRODUCTION

Two years after the creation of the Swiss snow and avalanche commission in 1932, a group of scientists started their research at Weissfluhjoch, above Davos. At that time, the commission also launched snow projects at five other places in Switzerland, namely Col de Jaman, Trübsee, Elm, Simplon and Ritom. The scientists came from the Universities at Zurich and Berne as well as from ETH Zurich. In Davos they got support from the local physical-meteorological observatory, which was founded in the year 1907 by Carl Dorno, a doctor of medicine and bio-climatologist.

Beside snow experiments in the laboratory, field survey of the undisturbed snow cover was one of the most important tasks. Snow profiles were carried out and the characteristics of the different snow layers were classified. In early 1936, Robert Häfeli, an engineer from the geological institute of ETH Zurich, developed the Swiss ramsonde, a gauge adapted from soil engineering to examine the mechanical properties of the snow layers (Häfeli, 1937). The idea was to survey the undisturbed snow cover without opening the snow pack and so to get information about the structure of the snow layers and their stability without digging a snow pit, i.e. quasi remotely, shortening the procedure. These fundamental tasks were executed mainly in the surroundings of the Weissfluhjoch station. The first documented ram profiles were collected on 31 January 1936 in flat terrain at Höhenweg (2220 m a.s.l.), half way down to Davos. Worth to notice, that only one day later, on 1st February 1936, the first slope profile with the ramsonde was executed at Felsenweg (2520 m a. s. l.), some 500 m to the south of Weissfluhjoch, on a 35 degree steep westward looking slope above the ski piste to Strelapass.

In 1939 the Weissfluhjoch team members went to military services. In the alpine troops, the Davos specialists organized snow and avalanche courses and they were pleased to teach about their perceptions and experiences. They managed instructions for field observations. Instruments and equipments were improved and acquired. A network of high alpine stations, mostly situated at strategic meaningful passes, was established. Former research places were integrated as well as military turntables at Andermatt and Alp Grüm. After a command of General Guisan in December 1939, the Weissfluhjoch station became the center of the military avalanche service (LAWZ).

In the meanwhile (since 1937) and parallel to the military service, the bureau of the Swiss ski association (SSV) in Berne published weekly snow and avalanche reports for ski tourists.

Häfeli (1942) outlined the tasks for further snow research. He defined three main projects: alpine meteorology (continuation of observation

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at ever once established stations was accentuated), snow crystallography (measurements of air permeability and thermal conductivity of snow in the cold laboratory) and snow mechanics (plasticity and stress behavior under controlled labor temperatures but also in field tests). The importance of practical application was pointed out and a list of possible stakeholders was annexed.

In autumn 1945, Melchior Schild became head of the civil avalanche service, which from now on was part of the Swiss federal institute for snow and avalanche research at Weissfluhjoch. The majority of the military stations became civil ones. The service was monopolized.

De Quervain (1950) developed various methods for measuring strength and hardness of snow layers. The ratio between strength and stress defines snow stability. Crucial for avalanche formation is the interaction between new snow, wind, temperature and snow cover. The profile series of a winter were designed together with snow depth curves and the pertaining meteorological data as the so called ‘time profile’. A statistical avalanche forecasting model was promoted (Jaccard, 1965). Ramprofile classes were defined (de Quervain and Meister, 1987) and it was showed, that in 26 percents of the Weissfluhjoch avalanche periods (especially those of low intensity) the snow cover plays a dominant role for avalanche release. A model was developed for windblown snow loads in lee zones (Meister, 1989). The profile classes later slightly were modified (Schweizer and Wiesinger, 2001).

New methods with automatic measurements of hardness and strength of the snow cover has been developed in the last few years (Pielmeier, 2003). Although the predictability of avalanches will remain a probabilistic one (Schweizer, 2008) and verification is influenced by subjective fixing (Meister, 2008), snow and avalanche research is important also in the future. Progress in snow research may appear small in outcomes nowadays, but the effort still is worth.

2 WEISSFLUHJOCH LOCATION

Weissfluhjoch is situated in the center of the Davos ski area at the top end of the cable way up from Davos Dorf. About one million ski tourists visit that place per winter. The altitude difference to the Davos valley floor (1550 m a.s.l.) is about 1000 m and timberline at 2000 m a.s.l. The main avalanche rupture zones are oriented east, but other aspects are numerous too. The place, which is the name of the pass under the Weissfluh, is the terrain crossing between upper Schanfigg (the valley from Chur to Arosa) and the southern Prättigau (the valley from Landquart to Silvretta).

Weather is dominated by winds from northwest or south, the first bringing the main amounts of precipitation, the second characterizing dry periods of Föhn. The region belongs to an intermediate climate type with wet, ocean influenced northern weather and dry inner alpine one. The air-line distance in north-east direction to Galtür in Austria, which was a center of avalanche activity in February 1999, is 33 km, that one in south direction to St. Moritz in the Engadine 37 km.

The well known test site of Weissfluhjoch (2540 m a.s.l.) is situated some 500 m to the south-east of the institute building in the upper part of the Dorftälli. It is easy to access from top, say by walk within 15 minutes or by ski within 3 minutes. The place is more or less sheltered behind a gentle anti valley bump. Snow depth accords to the surroundings, which has been documented many times: by manual probing, by remote sensing techniques as air photogrammetry or space based ones (Mätzler and Meister, 1985).

The automatic weather station consists of two parts: wind station (at ridge crest above the institute building with stair access from the uppermost floor; measuring wind, temperature and radiation parameters) and snow station (at test site; measuring snow parameters). The system has been adopted 1993 for ENET (the supplement network of automatic weather station of the Swiss national meteorological agency, SwissMeteo) and 1998 for IMIS (the high alpine network of automatic weather stations for the Swiss alpine cantons).

The year amount of precipitation is about 1200 mm, thereof 75 percent falling as solid precipitation. Taking into account the last 73 hydrological years (1936/37 to 2008/09), the mean maximum snow water equivalent (SWE) is 854 +-208 mm and normally reached at the end of April. The maximum snow depth ever observed was 366 cm (9 March 1945). It is told, that each month (also each summer month) it snows at least once at Weissfluhjoch. The mean onset of snow for the permanent winter snow cover is 18 October (range 6 September – 25 November) and its mean disappearance is 8 July (range 3 June – 15 August). The 73 available snow depths of 1st January vary between 38 cm (1st January 1949) and 222 cm (1st January 1975).

From 1987/88 to 2001/02 (15 winters) at 34 percents of all days at least one avalanche has been observed in the surroundings of Weissfluhjoch (~100 km^2), 46 percents were avalanche free and at 20 percents, no observation was possible because of bad visibility with fog or storm. Questions rise whether a) avalanches are seldom events, b) northern light studies executed at the equator are solid ones and c) consolidated findings at a single place like Weissfluhjoch can be led over for alpine wide warnings for natural hazards as it is done with nationwide avalanche bulletins.

3 METHODOLGY OF SNOW PROFILING

The method of snow profiling depends on the purpose of the snow examination, on the place of interest, on the available instruments and on time to carry out the work. In principle snow profiles are taken on horizontal ground, sometimes on slopes. We also differ between periodic, equal time spaced snow cover examination (at the same place) and such by special occasion (e.g. when an avalanche happened).

3.1 Snow profiles at horizontal test sites

Test site snow profiles are executed biweekly. The method has been developed at Weissfluhjoch in the mid 1930ies and described by Zingg (1964). It remained more or less the same until nowadays: ramsonde profile, layer profile (hardness, grain shape, grain size, liquid water content), snow temperature profile and total snow water equivalent profile (split into biweekly vertical increments between the coloured threads, exposed to the snow surface each time). The work has to be carried out accurately, because most of the readings are single readings only. On the other hand, it is important to work fast, because air temperature penetrating through the open pit could modify the results.

During the first four winters (1936/37 to 1939/40) samples were brought to the cold laboratory and all depth profiles for cohesion (fracture strength) and coefficient of air permeability exists for that time, in 10 cm increments.

A theoretical work (Gubler, 1975) improved the understanding of the correlation between ram hardness and tensile strength. It highlights the dependence of the strength on the inter granular structures.

Later, customized by special snow research, thin section analysis were executed in the laboratory (Good, 1987) and isotopic tracing was probed each time (Martinec, 1987).

3.2 Snow profiles at slopes

The method principally remains the same as in horizontal terrain. Site selection is decisive. The profiles are oriented plomb-vertical.

In the mid 1970ies good experiences has been reported from the military central (now placed at Andermatt) from stability tests. They became part of the snow profiling procedure also at the institute. The Rutschblock test was preferred to the Rutschkeil test, because the test area is not entered during the execution.

Shear frame measurements, which first has been tested in horizontal terrain (Roch, 1966) were integrated to calculate stability indices (Föhn, 1988). We followed the recommendation of abroad (Sommerfeld, 1980) who suggests to execute a set of about one dozen shear

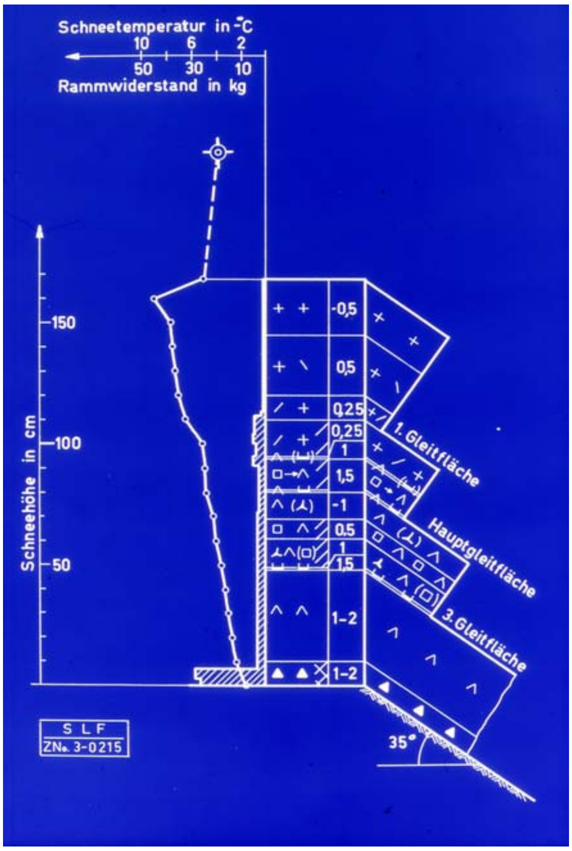

Figure 1. Avalanche rupture line profile at Tavernahang near Weissfluhjoch, Davos; 14 February 1964 (ram resistance in kg, grain shape symbols has been slightly modified since then).

readings for each layer: at the undisturbed parts near the side walls and above the Rutschblock. At that time, it was realized, that the variation in small scale (about 5 m^2 around the test place) may be crucial. With increasing experiences refined measuring techniques were developed, statistical interpretations were improved and the stability index calculated operationally.

Best places to execute slope profiles and tests are small places of about 50 m length, aspect north and 30 to 40 degree steep; mid slope parts, where natural tensile and compressing force neutralize should be preferred. Site selection is easy (and less hazardous) at avalanche rupture lines (Figure 1), say when an a posteriori examination is in question. It depends on the avalanche danger itself – in more or less stable conditions also large, very steep slopes and rocky ridge parts can be tested. Other times, it is better to rope up or to stay in slopes of moderate steepness only. If one profile is executed at a sunny, south looking slope and an other at a shadowed place, this gives good overall inside of the actual avalanche danger situation.

At the beginning (from 1978 to 1982) slope profiling was thought as a accurate method to verify the avalanche danger (which e.g. was published in the avalanche bulletins). Good experiences led to a multi-purpose application: 1983 the first course for slope snow profiling was organized and a small network of 'Hangprofiler' was established in Switzerland. Today, about 50 observers regularly choose a time dependent representative place and collect a slope profile, also biweekly, which they transmit to the avalanche service center at Davos.

4 APPLICATIONS

Applications of Weissfluhjoch test site findings and data are numerous including those by relating them to the avalanche activities in the Parsenn surroundings. The collaboration with the local winter resort company and its piste and rescue services is a fruitful one since 1932. New instruments were tested at the reference plot. Avalanche explosives were probed as well as avalanche beacons. Many guidelines found their origin at Weissfluhjoch, also for avalanche protection measures. The mix of basic research and practical application is unique. Significant results sometimes needs longtime observations, because the variability of snow (in texture, in time, in space) is versatile.

4.1 Snow compactive viscosity

Mass conservation of seasonal snow can be supposed from the onset of snow to the time, when the snow pack is isotherm at 0 °C. In the Alps, at about 2500 m a.s.l., this happens normally at the end of April. By means of the threads, indicating the settlement of the snow layers, mean compactive viscosity can be calculated and related to other snow parameters.

This was done for the snow profiles at Weissfluhjoch test site with about 2000 readings from 1965/66 to 2008/09 (44 winters) as shown in Table 1. The calculation was executed for biweekly increments, discarding cases with positive differences (by small terrain irregularities and also by the accuracy of the readings).

Normally, there are more than one snow layer classified between the thread increments: the grain type of the dominant one has been selected. Further, it should be noticed, that the start conditions define the grain type, that the real time spans are set right on a day (corresponding to the reading at begin and mid of

Grain type	N	Mean density (kg/m3)	Median viscosity (Pa*s)	Mean layer temperature (°C)
++ *)	76	159	$1.1*10^{9}$	-8.8
⁄ ⁄	174	188	$1.2*10^{9}$	-8.2
• •	341	274	$5.7*10^{9}$	-6.1
□□	854	331	$3.8*10^{10}$	-3.8
∧∧	161	306	$7.4*10^{10}$	-1.9
∨∨ **)	11	226	$2.7*10^{9}$	-6.3
○○	69	364	$2.8*10^{10}$	-0.7
∩∩	237	347	$3.5*10^{10}$	-2.1
◎◎ ***)	67	338	$3.3*10^{10}$	-2.5

Table 1. Snow layer characteristics for snow profiles at the test site Weissfluhjoch (2540 m a.s.l.); 44 winters, 1965/66 – 2008/09; biweekly readings (grain type symbols after international classification for seasonal snow).

each month) and that the standard deviations are significant and not listed here. The results for three grain types need further explications:

*) Fresh fallen snow grains go under a rapid metamorphism and change their feature, texture and mechanical behavior within one to three days. Settlement, density and viscosity therefore is significant different during the beginning of the period than at the end.

**) Layers of surface hoar are thin and measurements seldom outlast more than the observation period, so the results are uncertain;

***) Melt freeze particles correspond to ice layers and so the expected viscosity should be high. Mostly some layers were put together with inter layers of different shape and density.

4.2 Comparison of snow profiling at horizontal test sites and at slopes

The transfer of the findings by snow profiling in the horizontal test site to slope conditions is important for avalanche formation and warnings. Some 800 m to the south-west of the Weissfluhjoch, we found an accurate north facing slope and made profiles. Between 1986/87 and 2008/09 (23 winters) at least one slope profile, mostly gathered at the end of the high winter period (say mid February to mid March) could be set in relation to the time closest test site snow profile. The results are disillusioning because hardly any systematic correlation was found. The widespread scattering concerns all parameters (e.g. correlation coefficients for snow depth = 0.36, for mean ram hardness = 0.18). At both locations, profile class 7 (Schweizer and Wiesinger, 2001) was dominant: 30 percents at test site and 43 percents at slope. Profile class 1 was not found at the test site but in 22 percents of all the time at the slope. Mean stability class was 3.17 +-0.65 at the test site and 2.78 +- 1.17 at the slope.

5 OUTLOOK

Weissfluhjoch station has lost its widespread platform function for snow and avalanche research in Switzerland during the last 10 years: people do not work anymore constantly there, data acquisition was shortened and the series of annual reports is interrupted.

Nevertheless we find it worth to moderately relaunch this famous place with the unique datasets (which, at a reduced level, still exists). After our opinion, the three most important tasks can be listed as follows:

a) In 2011 the 75-year jubilee of the Weissfluhjoch research station will be celebrated. Quantitative climatic studies of the most relevant parameters (snow depths, new snow sums, snow increments, temperatures, winds) should focus on trend analysis. But also qualitative research on the relation between snow cover status and avalanche activity and warnings should be captured.

b) Automatic sensors, similar to the snow micro penetrometer (SMP), could be exposed as prototypes in the test site for controlled remote snow profiling. Later on, the instruments could amend the existing sensors at IMIS stations for proper now casting systems.

c) Intensive field studies should be carried out to develop a method for quick pit profiling, which might be part of a widely accepted in situ now casting system. The Weissfluhjoch ski resort in Davos provide ideal test conditions.

6 CONCLUSION

Systematic snow and avalanche research in Switzerland started about 70 years ago at Weissfluhjoch. Snow profiling was established also in military during the second world war. Most methods are still in use with little modifications. The transfer of the results from the horizontal test sites to the slopes, where avalanches start, still needs much diagnostic skills and empirical sensitiveness. It is proposed to relaunch the place, taking into account the possibilities of electronic gauges and present-day communications links.

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