Avalanche dynamics: On-site studies, modeling and practical applications

Scientific Report 2005 to the Swiss National Science Foundation

Summary

Zwei Nassschneelawinen bestätigten die Beobachtungen aus dem Winter 2004 zum Pflügemechanismus. Bei zwei Trockenschneelawinen verschiedener Grösse wurde in den Fliessspuren wie in den Ablagerungen ein klarer Unterschied zwischen einem schnellen, fluidisierten Anteil und dem viel langsameren, dichteren Fliessanteil festgestellt. Explizite Berücksichtigung des fluidisierten Anteiles könnte erhebliche Auswirkungen auf die Lawinengefahrenkartierung haben. Die zahlreichen Scherflächen, die in den Fliesslawinenablagerungen gefunden wurden, zeigen eine beträchtliche Kohäsion des granularisierten Lawinenschnees, zumindest in der Schlussphase der Bewegung. Dies ist insbesondere für die Formulierung zweidimensionaler Modelle von Bedeutung.

D.I. wirkte als Instruktor an einem Kurs der SUPSI über Lawinengefahrenkartierung mit. Kursmaterialien wurden auf der Website des Projektes auf Französisch und Deutsch zugänglich gemacht.

Die theoretischen Arbeiten in Zusammenarbeit mit dem EU-Projekt SATSIE zur Modelierung von Fliessregimewechseln (fluidisiert / nicht fluidisiert) und Entrainment wurden fortgesetzt.

Two wet-snow avalanches confirmed observations made in the winter 2004 on the ploughing mechanism. In two dry-snow avalanches of different sizes, a clear difference was found, both in the flow traces and the deposits, between a fast, fluidised part and the much slower dense-flow part. If the fluidised part is taken into account in hazard maps, significant changes are to be expected. Numerous faults found in the deposit of the dense flow testify to a considerable amount of cohesion of the apparently granular avalanching snow, at least in the final phase of the flow.

D.I. contributed as instructor to a course on avalanche hazard mapping at SUPSI. Course materials in German and French have been made publicly accessible on the project's website.

The theoretical work on the modelling of flow-regime transitions (fluidised / not fluidised) and entrainment has been continued in coordination with the EU project SATSIE.

Abbreviations

B.K. Bernhard Krummenacher (GEOTEST AG)

B.T. Bernardo Teufen (tur GmbH)

H.G. Hansueli Gubler (AlpuG GmbH)

D.I. Dieter Issler (NaDesCoR)

Field work (H.G., B.T., D.I., B.K.)

On February 7, 2005 a campaign was conducted on the **Taferna avalanche** of February 5, near the hamlet of Glaris and just opposite the Breitzug avalanche that we investigated in the winter 2004. A team from SLF participated in the field work, making it possible to conduct a complete survey from the release area to the runout zone. This dry-snow avalanche showed a pronounced separation into a fast, dilute fluidised phase that eventually developed a weak suspension layer, and a significantly slower dense-flow phase. Scour marks along the winding, rather narrow channel showed clearly that only the fluidised phase climbed 5–10 m above the gully bottom on the outside flanks of the channel whereas the deposits of the dense phase, which could be found along almost the entire channel, did not appreciably sway out in the curves. A rough analysis shows that the fluidised phase may have been faster than the dense phase by a factor of two. This agrees quite well with recent Doppler radar measurements on much larger avalanches at Vallée de la Sionne and Ryggfonn.

In contrast to the clear separation of the two phases in the track, the deposit in the runout zone showed a more gradual transition, which may, however, be due to a saltation layer on top of the dense flow masking the difference between the deposit types: Snow pits in the area of deep deposits showed a relatively thin surface layer of easily recognisable, well rounded snow clods, whereas the deeper layers revealed their particulate texture only after dyeing with ink or careful removal of the somewhat weaker interstitial snow. At the very distal end of the deposits, a gradually thinning layer deposited by the suspension layer could be identified for about 15 m. Its mass represented a negligible fraction of the total avalanche mass.

Due to the fact that data on this avalanche were collected and stored by a large number of individuals from different institutions who were kept busy by the further development of the winter, a complete analysis and synthesis has yet to be done. In particular, the velocity of the fluidised and dense phases should be estimated from the scour marks in the curves and a rough mass balance attempted. This work is high on the project agenda for 2006.

During the Taferna campaign, two short but quite massive dry-snow avalanches occurred in the Parsenn skiing area, on the **Schwarzhorn SE flank** and—just facing it—on the **Totalphorn NW flank**. They were mapped and photographically documented.

An event occurred in the **Breitzug** path around February 9, with very similar characteristics as in 2004. This time, security considerations allowed a thorough investigation of the deposit zone and parts of the track. Due to a warm spell, the snow masses picked up along the path transformed the flow into a predominantly wet-snow avalanche. The rapidly made observations in 2004 could be confirmed through snow pits and trenches at several locations. At least in the final phase of the flow, the ploughing front of the avalanche disrupts the snow cover over a distance of just a few metres. The fragments are pushed in front of the avalanche and are rapidly rounded or coalesce with other clods; mixing into the body of the avalanche proceeds relatively slowly,over distances over a few tens of metres.

Around the same time as the Breitzug avalanche, a quite large (but by no means extreme) avalanche was released from the **Salezerhorn**, descended through the Salezertobel gully and came to rest near the edge of the long avalanche shed that protects the main road into Davos along the lake. The release area is much less exposed to direct sunlight than the Breitzug, so the avalanche was initially dry, but picked up humid snow along its path. This explains why the main deposits show the jagged heaps and fingers as well as shear failure planes typical of wet-snow flows, but also a very extended distal area with much shallower deposits scattered with quite large blocks. Our work concentrated on this fluidised phase; some of the main lessons learnt thereby are the following: (i) Even large blocks (up to 80 cm diameter) seem not to roll or be dragged, but to impact the snow cover at a grazing angle, as evidenced in a snow pit that cut through such a block and showed its peculiar embedding in the deposit. (ii) The original snow cover was only partially entrained by the fluidised phase on the alluvial fan, hinting towards a continuous erosion process (at the macroscopic level), as opposed to the front-dominated ploughing mechanism encountered in wet-snow avalanches. Entrainment was significantly deeper on the flanks of the gully, which is much steeper than the alluvial fan. (iii) A cut through the largest block on the deposit of the fluidised phase showed a stratified interior embedded in non-stratified snow as in a shell. Apparently, pieces of the original slab are transported without colliding very violently. However, the mechanism responsible for such hovering transport cannot be directly inferred from the deposits only.

In the adjacent **Dorfberg** area, a peculiar wet-snow avalanche descended on March 20. In the track, it entrained the entire snow cover and also some soil over most of its substantial width. In its centre part, the deposit consisted of well-rounded snow clods of similar size, many of which contained soil particles in one half and pure snow in the other. Moreover, soil entrainment was absent on the right side; the rather sharp boundary between dirty and clean deposits showed that diffusion-like mixing due to the agitation of the snow balls was very limited despite the very granular nature of this avalanche. Another interesting observations is the virtual absence of deposits in all the track (nearly all other avalanches observed by us left a similar amount of snow behind in the steep track as they entrained near the front).

During the summer 2005, the ground cover was classified in **geomorphological surveys** carried out in selected paths with avalanche events during the winter 2005, namely the Breitzug and Salezertobel paths and the Schwarzhorn SE flank, Parsenn. Responding to the main questions in the other parts of the project, a table of attributes was set up beforehand that served as a fixed matrix for assigning numerical values to each geomorphological unit. At lower altitudes, vegetation plays the central role whereas the density and distribution of boulders and bedrock is the main factor at high altitudes with scarce vegetation. Surface roughness cannot be inferred from topographic maps. We therefore tested a model that resembles the description of fissure surfaces due to Barton (1982). Each surface unit is assigned an index value ranging from 1 to 5. A similar procedure was tested for scree slopes, assigning index values according to block sizes and inter-block distances.

During the surveys, we used the GPS mapping system Trimble GeoExplorer XT, a hand-held device that displays the map and allows to give attributes to the measured points, lines and polygons by means of an electronic pen. The attributed values are directly stored in ArcGIS. The suitability of this surveying device was thoroughly assessed and documented.

Theoretical work (D.I.)

Work begun in the preceding reporting period on the modelling of flow-regime transitions from the dense-flow regime at low shear rates to a fluidized regime at high shear rates and on the formulation of entrainment in depth-averaged avalanche models was continued in 2005. Both topics were presented (as a talk and a poster, respectively) at the 2005 General Assembly of the European Geophysical Union in Vienna.

The main problem in extending the Norem–Irgens–Schieldrop (NIS) model to variable density and flow-regime changes is to find a mechanism that leads to a new (lower) equilibrium density when the shear rate exceeds the fluidisation threshold, e.g., due to an increase of the slope angle. This is achieved if, at a fixed shear rate above threshold, the dispersive pressure normal to the flow plane and the dispersive shear stress both grow with increasing density, but the shear stress grows more slowly than the normal pressure. The ratio of the two stresses, the effective friction parameter, then increases as the material expands (i.e., the density diminishes). Most early theories of granular matter do not show such an effect, but predict the effective friction parameter to be independent of the density. However, both a numerical study in two dimensions by Campbell and Gong (*J. Fluid Mech.* **164**, 1986) and an analytical investigation, based on kinetic theory, by Pasquarell et al. (*J. Engng. Mech.* **114**, 1988), also in 2D, found a quite pronounced density dependence in precisely the way that is needed for fluidisation. The conclusions from these studies should remain valid qualitatively but not quantitatively in three dimensions and with polydisperse particles. At this point of the development, some similar density dependence of the model parameters has to be assumed and to be tested in back-calculations. The mathematical formulation of the model will be completed in early 2006, the numerical implementation as soon as possible thereafter.

After a clear answer concerning the "entrainment force" term had been obtained, we studied the effect of entrainment on the velocity profile. For a somewhat artificial steady-state flow situation, we found an analytic solution of the equations with entrainment. The key to the solution is the boundary condition that requires the shear stress at the interface between the snow cover and the avalanche to be equal to the shear strength of the snow cover (if it fails in a brittle way). Quite reasonable entrainment rates are obtained for a medium-sized avalanche with typical parameters. In this case, the adimensionalised velocity profiles with and without entrainment do not differ radically. This will ease the inclusion of entrainment in depth-averaged models like NIS. In the so far elusive hope of finding analytic solutions for more realistic conditions, we have not yet submitted the paper; a draft version is appended to this report.

Know-how transfer (D.I., B.T.)

The project website http://www.tur.ch/nfp/index.html has been enhanced. In particular, the lecture notes on avalanche modelling, presented by D.Issler at the European Summer University 2004 course on avalanches in Courmayeur (Italy), was translated into German and made accessible together with the French version.

D. Issler taught a unit on powder-snow avalanche modelling in the course "Valanghe: dinamica, zonazione di pericolo e sistemi di difesa, Modulo 1" organised by SUPSI (Scuola Universitaria Professionale della Svizzera Italiana) and SLF in Rodi-Fiesso (TI) from June 16 to 18, 2005. The lecture notes will be made accessible on the website in early 2006.

Work on the vademecum for avalanche practitioners on unusual avalanche events, including detailed documentation, back-calculations and critical discussion on the lessons to be learnt from these events, has been continued, albeit at a somewhat slow pace. The work will be completed in 2006.

Contributions by project participants in 2005

Name	Activity
Dieter Issler	Field campaigns and corresponding reports Extension of NIS model, analysis of entrainment process (in coordination with EU project SATSIE) Lectures on powder-snow avalanches, lecture notes Project administration. Planning of MSc theses for two students from University of Milano Bicocca (during winter/spring 2006)
Hansueli Gubler	Field campaigns and equipment
Bernardo Teufen	Surveying Davos area for released avalanches Field campaigns Inquiry on unusual avalanches; analysis, back-calculation and reports on selected events
Bernhard Krummenacher	Surveying Davos area for released avalanches Geomorphological terrain analysis
Hans Romang	Website maintenance

Summary of publications

Up to the end of this reporting period, few novel and conclusive results have been obtained for dry-snow avalanches because only two events have been observed. The observations of wet-snow avalanches brought some interesting insight into the entrainment mechanism and the processes leading to particle formation. Unless deeper analysis arrives at more important conclusions, additional results from the winter 2006 are needed before a paper can be published.

The theoretical work (funded jointly by this project and the EU project SATSIE) on flow regime transitions and on the formulation of entrainment in gravity mass flow models was presented at the 2005 General Assembly of the EGU. The corresponding paper on entrainment is essentially completed and will be submitted to a peer-reviewed journal shortly. A report on modelling of flow regimes transition is being drafted at the time of this writing; submission of a condensed version to a peer-reviewed journal is envisaged for the summer 2006. Several chapters of the above-mentioned vademecum on the analysis and back-calculation of remarkable historic avalanches have been drafted, but more work is needed to complete further chapters and to provide a summary and synthesis. If time permits, the scientific aspects of this work will also be published in a peer-reviewed paper.

Deviations from original workplan

Compared to 2004, we investigated about twice as many avalanches, yet this number is still lower than we hoped. In part, this is due to the limited availability of the project members in periods of tight deadlines for consulting work. As a consequence, the funding originally allotted for 2005 was used only in part.

Workplan for 2006

In view of the continued difficulties of permanently surveying the Davos area for avalanches, we grasped the opportunity when two geology students from the University of Milano Bicocca asked to do their MSc theses under the supervision of D. Issler. They will regularly visit the slopes in the skiing areas of Davos and Klosters where avalanches are frequently released as well as some of the larger sites in the Landwasser, Dischma and Sertig valleys. Besides the avalanches that deserve an in-depth investigation, they will also map small avalanches in view of statistical analyses of their runout distances. In the second stage of their work, they will apply some of the new models to the recorded avalanches and possibly also contribute to the vademecum on unusual avalanches. In this way, they will get hands-on experience in avalanche research and help the project where the original team members are most limited due to their other professional commitments. (By the time of writing, about 20 avalanches have been mapped and three avalanches studied in detail.)

In the summer of 2005, we identified a suitable avalanche path near Davos Monstein where an artificial release would create the opportunity for carrying out a number of innovative experiments. After extended negotiations with various institutions, we have obtained the permit for artificial releases. During February 2006, we will study ways of mixing tracer particles into the snow cover at different points of the avalanche path before the artificial release attempt. The main objective is to study the degree of mixing of entrained snow into the body of the avalanche.

The extension of the project to the end of September 2006 gives D. Issler the possibility of teaching in the advanced European Summer University course on avalanche modeling that will be organised by the Pôle Grenoblois d'Etudes et de Recherche pour la Prévention des Risques Naturels (PGRN) and the SATSIE collaboration in Grenoble in mid-September.

Besides this, every effort will be made to complete the documentation of investigated avalanches and the vademecum on unusual avalanches in time so that it can be made available to avalanche practitioners in Switzerland and elsewhere. The draft paper on entrainment will be submitted in early 2006, and a paper on flow-regime transitions is scheduled for mid-2006. Additional scientific papers analysing and interpreting the field measurements are envisaged, but can be planned in detail only at the end of the winter 2006.

Miscellaneous remarks, personnel

Alessia Errera and **Stefano Priano** will participate in the project from January to June 2006 for their MSc theses with the Department of Geology of the University of Milano Bicocca (supervisor: Prof. Giovanni Crosta). During the winter, their main task is to map a large number of avalanches in the Davos area, to participate in the detailed investigation of the most interesting ones, and to report on their observations. They will perform the major part of data analysis and model validation in the spring of 2006, using the newly developed models from the SATSIE project.