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

Scientific Report 2004 to the Swiss National Science Foundation

Summary

Insgesamt war der Winter 2004 in der Region Davos ungewöhnlich lawinenarm. Aus der Untersuchung einer grossen Nassschneelawine im Januar ergaben sich jedoch interessante Einblicke in den "Pflügemechanismus" an der Lawinenfront und die Bildung grosser Schneeknollen. Eine relativ kleine Trockenschneelawine im Februar 2004 transportierte in der fluidisierten Schicht aussergewöhnlich grosse Schneeblöcke und gibt hinsichtlich der Ablagerungsverteilung Rätsel auf.

Angaben über ungewöhnliche Lawinenereignisse aus unserer Umfrage in der Schweiz wurden kritisch ausgewertet, interpretiert und nachgerechnet. Diese Arbeiten werden im zweiten Projektjahr fortgeführt und zu einem Vademecum für Praktiker zusammengefasst.

D.I. wirkte als Instruktor an der Europäischen Sommeruniversität 2004 über Lawinen mit. Die dafür geschaffenen Kursmaterialien werden auf Französisch und Deutsch auf der Website des Projektes allgemein zugänglich gemacht.

In Zusammenarbeit mit dem EU-Projekt SATSIE wurden Erweiterungen des Norem-Irgens-Schieldrop-Modelles auf Fliessregimewechsel (fluidisiert / nicht fluidisiert) untersucht und die Massen- und Impulsströme in höhengemittelten Lawinenmodellen mit Entrainment analysiert.

Avalanche events were unusually rare in the winter 2004 in the area of Davos. Nevertheless, a large wet-snow avalanche provided interesting insights into the "plowing" mechanism at the avalanche front. A fairly small dry-snow avalanche in February 2004 carried huge blocks in its fluidized layer; its deposit distribution remains enigmatic, however.

Data from an inquiry on unusual avalanche events in Switzerland were evaluated critically, interpreted and back-calculated. This work will be continued in 2005 and summarized in a vademecum for avalanche practitioners.

D.I. was an instructor in the European Summer University on avalanches. His hand-outs are being made publicly accessible in French and German on the project website.

In collaboration with the EU project SATSIE, extensions of the Norem-Irgens-Schieldrop model were proposed to describe flow-regime transitions (fluidized / non-fluidized) and the mass and momentum flow in depth-averaged avalanche models with entrainment analyzed.

Abbreviations

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

Two campaigns were conducted in the winter 2004, one on the Breitzug avalanche of January 13 and the other at Inneralp, Davos Monstein, where the largest of several small avalanches released on February 22 was studied in detail. The winter 2004 in the area of Davos was quite unusual in that very few avalanches were released, or else they were covered by new snow before the avalanche danger had subsided enough to permit field work.

The Breitzug path is one of the large paths of Davos and also the site of large and frequent debris flows. The January 13 event was a wet-snow avalanche that purged only about 50-70% of the potential release zone. It was therefore not safe to dig profiles and do comprehensive measurements right after the release; soon thereafter more humid snow fell and barred further field work. Nevertheless, a number of photos could be taken from the opposite side and a short visit made on the rim of the deposits. This yielded interesting insight into the snow entrainment mechanism in wet-snow avalanches: The avalanche snow had eroded some soil in the track and was therefore brownish. Just in front of the 1-3 m deep dirty deposits, clean snow was piled up for another 2-10 m along the slope. The clean-snow deposits were rather sharply separated from the dirty ones, but had quite similar texture with rounded snow blocks composed of smaller snow clods. Between the snow blocks, large cavities were found. The snow cover apparently was mobilized at the very front of the plowing avalanche, but not immediately mixed into the main flow. The structure of the deposit tongue strongly resembled images taken in recent chute experiments at the University of Pavia with dry or humid granular materials. Furthermore, the formation of snow clods must be a rapid process for the accumulated clean clods appear to represent only the snow mass entrained over the last few tens of meters.

The avalanche at Inneralp was a small dry-snow event with a rather long runout of the dense bulk deposit and an even more extended thin deposit from the fluidized layer, with several large snow blocks rafted nearly to its outermost reaches. Detailed investigation of the deposits (including dyeing of snow pits to highlight snow texture) revealed several puzzling aspects, among them their shape and width-to-length ratio: One branch of the dense part of the avalanche formed a 10 m short, but more than 30 m wide and almost 2 m deep deposit of very compact, tough snow (with inclusions of icy snow clods). The overflowed area on the alluvial fan showed little evidence of entrainment from the snow cover. Two young larch trees a mere 10 m behind the deposit were apparently undamaged, limiting the peak avalanche pressure to probably less than 5 kPa and the density to 50 kg/m^3 at most. These observations would indicate that the avalanche was strongly fluidized when it passed these trees, but most of it came to an abrupt stop as a short, compact mass 20 m further down. We do not know of similar observations and cannot satisfactorily explain such a rapid solidification, but another consistent interpretation of the deposit structure cannot be offered either. We hope that future observations will shed light on this enigmatic event.

Theoretical work (D.I.)

Work focused on two aspects, namely (i) the extension of the Norem-Irgens-Schieldrop (NIS) model to variable density so as to enable flow-regime transitions from the dense-flow regime at low shear rates to a fluidized regime at high shear rates, and (ii) the clarification of several basic issues in the formulation of entrainment in depth-averaged avalanche models. On both topics, the work is not finished but has progressed sufficiently for presentation at the 2005 General Assembly of the European Geophysical Union.

As a first result of the study of the NIS model, it was recognized that the traditional formulation leads to unphysical negative lateral and longitudinal stresses at moderate to high shear rates before fluidization is reached. This problem could be cured with the help of a (physically very plausible) isotropic dispersive stress term and by imposing certain inequalities on the viscometric functions that define the model. A more difficult problem is to specify the density dependence of the model parameters. In a first step, we proposed simple relationships inspired by kinetic theory. They predict, however, that the granular medium will expand indefinitely once the fluidization threshold is reached. Work will continue in 2005 to include rarefaction effects that will limit the expansion to realistic densities between 10 and 50 kg/m³. A rough estimate indicates that fluidization can be reached only on very steep slopes whereas observation clearly shows fluidization to occur often on moderate slopes. We conjecture that aerodynamic effects at the front facilitate the flow-regime transition; work is in progress to simulate the air-pressure distribution along the avalanche surface in a suitably simplified way.

In several recent publications on entrainment in avalanche models, an “entrainment-force” term was introduced ad hoc, which can significantly influence the dynamics at high velocities and entrainment rates. Another controversial issue is whether the entrainment of bed material causes an additional shear stress on top of the usual frictional resistance term or not. In order to clarify these points, we formulated the mass and momentum balance equations with moving boundaries (possibly with discontinuities) in a rigorous way and characterized the possible entrainment mechanisms. In this way, unambiguous answers were obtained: the “entrainment force” vanishes in the usual case of erosion from a stationary bed, but there are momentum exchange terms e.g. at the interface between a powder-snow cloud and the recirculating ambient air. In the next step, the relation between the flow-velocity profile and the entrainment rate will be analyzed from first principles.

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

A project website was initiated in March 2004 at the address http://www.tur.ch/nfp/index.html, with most pages available both in German and English. It will make all project results available to the public.

D. Issler taught a unit on avalanche modeling in the European Summer University 2004 course on avalanches in Courmayeur (Italy), organized by the Pôle Grenoblois Risques Naturels. An extended French version of his lecture, illustrating the use of different classes of models on the example of an avalanche path in Switzerland, was handed out to the participants. Translation of this document into German was largely completed by the end of the year. Both texts will be made available to the public on the project website in early 2005.

In view of the scarcity of avalanche data from the winter 2004, it was decided to collect information on unusual or almost “mysterious”, but sufficiently well-documented avalanches, to critically review the information, back-calculate the events where possible with available models, and to present them, along with our conclusions and recommendations, in a sort of vademecum for avalanche practitioners. The objective is to show under which conditions avalanches may exceed the expectations even of avalanche experts. This collection of case studies should allow practitioners to compare their present case to past events that would otherwise not be known to them. Selected avalanche events date from 1689 (Saas, Prättigau) to 1999 (Lavancher, Vallée d'Aoste, Italy). Work has begun and will be completed in the second year of the project.

Contributions by project participants in 2004

Name	Activity
Dieter Issler	Field campaigns and corresponding reports
	Extension of NIS model, analysis of entrainment process (in coordination with EU project SATSIE)
	Introductory text on avalanche modeling for European Summer University 2004 and project website
	Website design
	Project administration
Hansueli Gubler	Field campaigns Field 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
Eva Frick	Map preparation, literature searches

Summary of publications

Due to the scarcity of data, no definitive results were obtained in the first year of the project and no publications were written. Two short reports on the avalanches investigated in the winter 2004 are attached to this document. After more data has been collected during the winter 2005, the project results will be summarized in a paper. 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 has progressed considerably; it will be presented at the 2005 General Assembly of the EGU and published in peer-reviewed journals. The above-mentioned vademecum on the analysis and back-calculation of remarkable historic avalanches will be made generally available on the website. If time permits, the scientific aspects of this work will be published in a peer-reviewed paper.

Deviations from original workplan

Due to the lack of “worthwhile” avalanches around Davos, the number of field campaigns was much smaller than anticipated in the planning stage. To partly compensate for this, work on the “vademecum” mentioned above was undertaken. As a consequence, only about half of the available funding was used.

Workplan for 2005

In the winter, as many field campaigns as possible will be carried out and analyzed in a similar way as in 2004. In the summer, the corresponding sites will be visited again for the geomorphological measurements. Work on the vademecum will be intensified and selected avalanches in Italy (Lavancher, 1999) and Andorra (Arinsal, 1996) included. The theoretical investigations will be finalized and published in a peer-reviewed journal. Participation in an advanced European Summer University course on avalanche modeling was planned for 2005, but this course (to be taught by members of the SATSIE collaboration) will only be offered in the late summer of 2006.