Results 2015 from SP 4 FoU Snøskred: Work Package 3 — Slushflows

Project nr : 20140053-400 **Title :** Slushflows

Total budget (kNOK)	From Dept. Of Oil and Energy (kNOK)	Costs per 2015-12-31 (kNOK)
300	300	121

Task 1: Setup of snowcover model for testing a wet-snow avalanche index
Install SLF's one-dimensional snowcover model SNOWPACK at NGI and convert the data from the automatic weather station at Fonnbu so that it can drive SNOWPACK for simulations of the snowcover evolution at the station. The results can be compared to data from snow pits.

Task 2: Establishing contacts for an international slushflow research project
The objective is to establish initially informal contacts to research institutions in the Scandinavian countries, Russia and Alaska interested in slushflow research. These contacts should later form the platform for launching a dedicated international research project.

Task 3: Back-calculations of slushflow events
Test existing dynamical models for other gravity mass flows for applicability to slushflows by back-calculating well-documented events.

Task 4: Coupled weather/snow cover model
Weather data from automatic stations are to be interpolated/extrapolated to locations where slushflows are possible and to be used as input to a snowcover model. Output from that model is to be used for assessing the slushflow hazard.

Har prosjektet oppnådd de oppsatte mål: **Ja:** X **Nei:** X

Begrunnelse for eventuelle avvik og beskrivelse av korrigerende tiltak:

Tasks 1 and 4: At the beginning of 2015, work on WP3 was deliberately deferred until the beginning of the second half of the year, i.e., to the end of the WP leader's parental leave. At this point, the very high workload of the avalanche group made it impossible, however, to complete the more extensive tasks 1 and 4 (also, Task 4 depends on Task 1). In the work planning for 2016, this work is scheduled for February and March, and the involved researchers have set off the necessary time.

Dato	Prosjektleder	Dato	Fagleder
	For Christian Jaedicke:		
2016-01-29	Dieter Issler	2016-02-03	Christian Jaedicke

NGI

Title: WP3 – Slushflows
Project Manager: Christian Jaedicke
Project Members: Galina Ragulina, Erik Lied, Helge Smebye, Peter Gauer

TASK 1: SETUP OF SNOWCOVER MODEL

In 2014, the purely technical problems of running SNOWPACK with weather data from Fonnbu were solved. In the reporting period, routines for periodically and automatically extracting these data from the corresponding database have been written and tested. Completion of this task requires a detailed investigation of why the simulations of the snowcover evolution often produce erroneous results. It will probably be necessary to find suitable criteria for deciding whether a measured value is reasonable or needs to be rejected. This work is planned for early 2016.

TASK 2: ESTABLISHING CONTACTS FOR AN INTERNATIONAL SLUSHFLOW RESEARCH PROJECT

In the project description, it was stipulated that Memoranda of Understanding (MoU) on joint slushflow research would be signed with other institutions active in slushflow research. Closer consideration of the resources NGI will be able to invest in this branch of research and the low degree of research activity internationally led us to conclude that a more realistic goal would be to establish an international network of researchers and institutions interested in slushflows. This would be the first step to raise awareness of the slushflow problem in the international cryospheric research community and with governmental institutions involved in the mitigation of natural hazards.

In the beginning, the scope of the network is to obtain an overview of ongoing activities and to foster personal contacts that will facilitate joint research projects and public awareness campaigns at the subsequent stage.

Over 50 individuals from Norway, Sweden, Finland, Iceland, Russia, Kazakhstan, Germany, Greenland, the Czech Republic, the United States including Alaska, and Japan were identified and contacted. The response has been very positive, and most respondents welcomed NGI's proposal of organizing an international workshop on slushflows.

In 2016, we will set up a web site for the Circum-Arctic Slushflow Network and plan the first workshop, to be held in 2017. Also, to mirror the changed orientation of this task, it will be termed "Circum-Arctic Slushflow Network" henceforth.

TASK 3: BACK-CALCULATIONS OF SLUSHFLOW EVENTS

See Deliverable D3.4 below for overview and results of this task.

TASK 4: COUPLED WEATHER/SNOW COVER MODEL

This task depends on Task 1 being completed. It will be given high priority, however, as soon as Task 1 is completed.

OTHER ACTIVITIES

During 2015 a master thesis was started on recent slushflow events in Norway. The work is mainly focused on a geographical approach studying several events and their topographical as well as meteorological triggering conditions. One of the main questions addressed is why a slushflow occurred in one catchment and not in adjacent catchments, which experience the same meteorological conditions. Field studies of the sites and modeling of the snow cover conditions are used as methods to answer these questions. The thesis is supervised by Christian Jaedicke and Erik Hestnes and will be completed in June 2016.

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DELIVERABLE D3.4

BACK-CALCULATIONS OF SLUSHFLOW EVENTS

Background

Presently, there are no operational slushflow models available that were developed specifically for this phenomenon. Bozhinskiy and Nazarov (1998) presented a two-layer model for slushflows and tested it under idealized conditions in a uniform channel, but no further publications on the model or specific applications are known to us.

In this situation, it appears useful to test whether models developed for other types of gravity mass flows might be applicable to slushflows. Given the nature of slushflows, models with a hydraulic approach appear to be most promising in this context, i.e., models for snow avalanches and for debris flows. Indeed, debris flows and slushflows share most of the physical processes occurring in the flow, except for the density ratio between solid and fluid, which is in the range 0.5–0.9 for slushflows and 1.5–2.5 for debris flows. Furthermore, slushflows may evolve into debris flows if they entrain large amounts of soil along their path. Advanced debris flow models are based on mixture theory in order to capture the important effects of changing water content (Pitman and Le, 2005; Pudasaini, 2012). However, such models are not operative yet, and we do not have access to them. In the simpler framework of one-phase models, one may consider visco-plastic models for mudflows like BING (Imran et al., 2001) or snow-avalanche models based on a combination of granular and hydraulic concepts (Voellmy, 1955).

In the present study, we concentrate on the latter approach, partly because only a 1D depth-integrated model of visco-plastic flows is available. A similar 2D depth-integrated model is under development at NGI (Kim, personal comm., 2015), and it may be of interest to apply that model as well in the near future.

Choice of event

For meaningful back-calculations with a dynamical numerical model, both the initial conditions and the boundary conditions must be known with sufficient degree of certainty. The necessary initial conditions comprise the release area and at least the average release depth. Ideally, the data to be compared comprise the run-out distance, the velocity and the flow depth as a function of time at several locations along the path. In particular, it is not sufficient to use the run-out distance alone, as customarily has been done in the calibration of snow-avalanche models.

Presently, we do not have slushflow observations where all these quantities have been measured or can be extracted from the available raw data. So far, the best-documented event is the one on 2010-05-16 in Skarmodalen, for which the front velocity could be determined over a distance of approx. 600 m in the middle section of the path (see Figure 1 and Deliverable D3.1 from 2014). The flow depth remains unknown, however, and the release depth can only be roughly estimated as approx. 1.5 m.

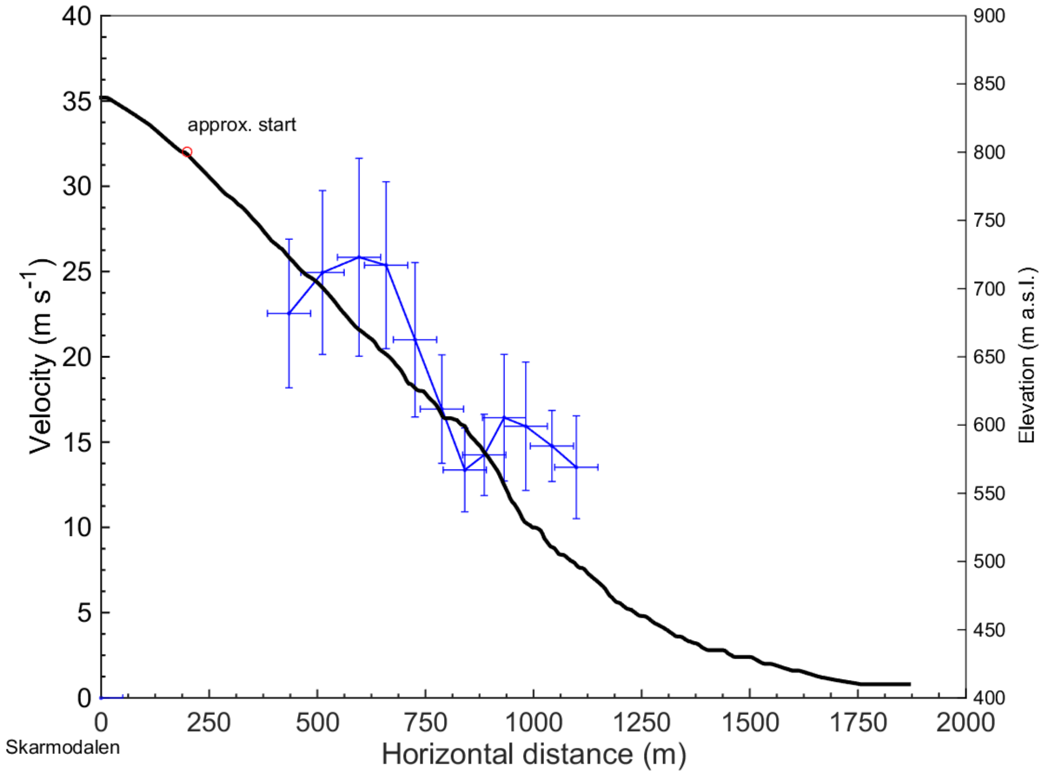

Figure 1. Measured front velocity of the slushflow in Skarmodalen, 2010-05-16. From Deliverable D3.1 in the 2014 report on WP3.

Brief description of the numerical model.

We chose the two-dimensional dynamical model RAMMS (RApid Mass Movement Simulation) from the WSL Institute for Snow and Avalanche Research SLF in Switzerland (Christen et al., 2010) to back-calculate the slushflow event in Skarmodalen on 2010-05-16. The model is a depth-averaged model based on Voellmy's (1955) friction law. Originally developed for dense snow avalanches, it has been used for the simulation of debris flows for several years (e.g. Hussin et al., 2012)—however, with values of the friction parameters that differ fundamentally from those recommended for snow avalanches.

The model is described in detail in the literature. Suffice it therefore to say that it solves three depth-averaged equations, one for the mass balance and two for the momentum in the *x* and *y*-directions, respectively, which are everywhere tangential to the terrain and project onto a regular orthogonal grid. The output of the model are the flow depth and depth-averaged velocity at all grid points at regularly spaced time intervals (e.g., every second) as well as the maximum values of these variables over the entire simulation at each grid point.

The bed shear stress, $\boldsymbol{\tau}_b$, is given by

$$\boldsymbol{\tau}_b = -\frac{\mathbf{u}}{\|\mathbf{u}\|}\left(\mu g_z h + \frac{g}{\xi}\frac{\mathbf{u}^2}{h}\right),$$

where **u** is the velocity vector tangential to the terrain, h is the local flow depth, and g the gravitational acceleration. The first term describes friction of the Coulomb type with a friction coefficient μ. The second term describes "turbulent" friction; without the first term, it would lead to a Chézy-type expression for the velocity in a stationary state.

Results

In our slushflow simulations, we used $\mu = 0.05$ and ξ in the range 1000–3000 m s^{-2}. The low μ value can be argued for, as it accounts for the reduction of the solid friction due to the pore-water pressure. Moreover, slushflows are well known to travel long distances in very flat terrain (2–4°). This is only possible if $\mu < \tan\theta$, with θ the slope angle in the direction of steepest descent; thus, $\mu \leq 0.05$ holds at least for the most mobile slushflows. This is about an order of magnitude smaller than in typical snow avalanches.

It was not possible to determine a more precise value of μ from the observation because the run-out area of the slushflow was not visible from the photographer's location. However, an upper limit can be inferred from the energy balance at several locations. The largest possible μ-value results if one neglects "turbulent" friction by setting $\xi = \infty$. Moving from rest to some point, the slushflow loses specific potential energy $g\,\Delta z$. This loss equals the gain in specific kinetic energy, $\frac{1}{2}u^2$, plus the work done against friction, $\mu_{\text{eff}}\, g\,\Delta x$. Calculating from the fracture line at $x \approx 200$ m, $z \approx 800$ m a.s.l. to the last visible point at $x \approx 1150$ m, $z \approx 500$ m a.s.l. with $u \approx 14$ m s^{-1} leads to $\mu < \mu_{\text{eff}} \approx 0.3$. Between the fracture line and the point of peak velocity $u_{\max} \approx 26$ m s^{-1} at $x \approx 680$ m, $z \approx 670$ m a.s.l., one obtains $\mu < \mu_{\text{eff}} \approx 0.2$ instead. Thus, a value of for μ below 0.1 appears plausible.

Assuming $\mu = 0.05$, different values of ξ were tested for their impact on the maximum velocity reached be the simulated slushflow. The value $\xi = 2000$ m s^{-2} produced the best correspondence of the observed maximum velocity of approx. 25 m s^{-1} (Figure **2**).

Preliminary conclusions

From a single event, for which not even the run-out distance is known, one cannot conclusively assess whether Voellmy-type models are applicable to slushflows. The one available measurement nevertheless indicates that the dry-friction component of the bed shear stress must be much smaller than in snow avalanches, as expected on theoretical grounds. On the other hand, the turbulent contribution must be sizeable, lest the velocity become much higher than observed. The value $\xi = 2000$ m s^{-2} translates into a friction drag coefficient $C_f \approx 0.01$—a rather plausible value, given the bed roughness and that the fluid is a mixture of water and snow clods.

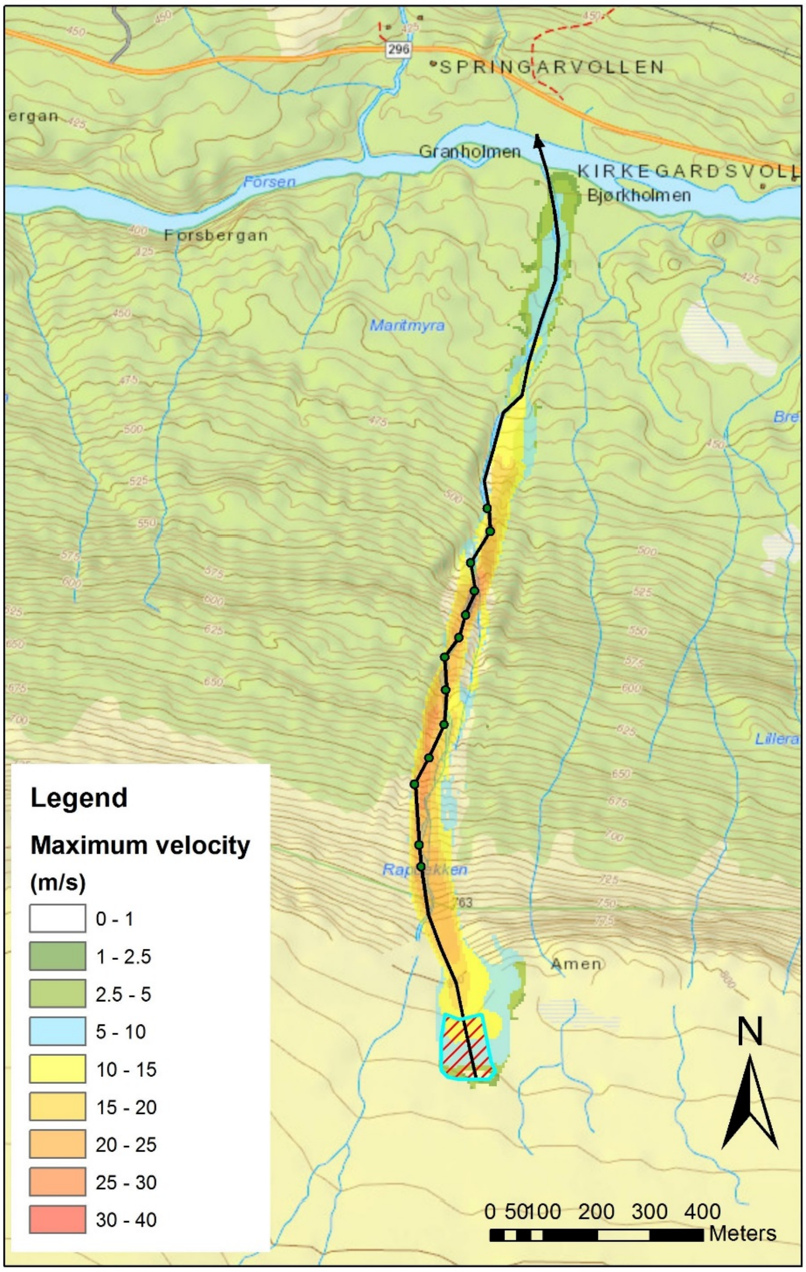

Figure 2. Back-calculation of the slushflow event in Skarmodalen on 2010-05-16 using RAMMS with $\mu = 0.05$ and $\xi = 2000$ m s^{-2}. The chosen release height $d = 1.5$ m leads to a total release volume of approx. 15,300 m^3.

We hope that further, more complete measurements of slushflows will eventually become available and allow a more thorough test of the model. One should expect that the parameter values will show substantial variation, depending on the water content of the slush and the bed roughness. Nevertheless, one may argue that the Voellmy model perhaps is more appropriate for slushflows than for snow avalanches.

References

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