

BACK-CALCULATION OF SMALL AVALANCHES WITH THE 2D AVALANCHE
DYNAMICS MODEL RAMMS: FOUR EVENTS ARTIFICIALLY TRIGGERED AT THE
SEEHORE TEST SITE IN AOSTA VALLEY (NW ITALY).

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ABSTRACT: Avalanche dynamics models are widely used to simulate extreme avalanches for hazard mapping purposes; they are well developed and calibrated on numerous real events. Only recently have small avalanches been studied, mainly for problems related to the safety of ski runs and roads. For small avalanches the physical processes within the avalanche flow are important, as they are not included in the calibrated Voellmy friction coefficients μ and ξ . Presently, researchers have started to develop avalanche dynamics models that include the physical processes associated with granular characteristics of the avalanche. Snow entrainment and deposition processes along the avalanche path are likewise modeled. In this work, we use one of these newly developed models, RAMMS, to back-calculate four well-documented avalanches artificially triggered at the experimental test site of Seehore in Aosta Valley (Northwest Italy), operative since 2009. The events are mostly small-size dense slab avalanches, triggered for scientific investigations. Snow characteristics and flow characteristics were recorded with field work, laser scan measurements, photogrammetry and specific instruments on an obstacle placed along the track to measure impact forces. The collected data are used to tune the RAMMS input parameters in order to reproduce the real events. We present the simulations results and highlight the importance of including erosion and deposition parameters in the investigation of small avalanches.

1. INTRODUCTION

Avalanche dynamics models are widely used to simulate extreme avalanches for hazard mapping purposes; they are well developed and calibrated on numerous real events (e.g. Barbolini et al, 2000). Only recently have small avalanches been studied, mainly for problems related to the safety of ski runs and roads. For small avalanches the physical processes within the avalanche flow are important, as they are not included in the calibrated Voellmy friction coefficients μ and ξ (Salm, 1993). Presently, researchers have started to develop avalanche

dynamics models that include the physical processes associated with granular characteristics of the avalanche (Naaïm et al., 2003; Bartelt and Buser, 2009; Buser and Bartelt, 2009). Snow entrainment and deposition processes along the avalanche path are likewise modeled (Naaïm et al., 2003; Sovilla et al, 2006 e 2007; Christen et al, 2010a).

In this work, we use one of these recent models, RAMMS developed by the WSL-SLF of Davos (CH), to back-calculate four well-documented avalanches artificially triggered at the experimental test site of Seehore in Aosta Valley (North-western Italian Alps) operative since 2009. This model was used by other authors (see for ex. Casteller et al. (2008) and Christen et al. (2010b)) to back calculate avalanches of larger dimension. This is the first work where small avalanches of release volumes of about 200 m³ are simulated with an avalanche dynamics model.

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2. STUDY AREA

The test site, called Seehore, is located in Aosta Valley in the North-western Italian Alps. The slope, with an elevation difference of about 300 m (from 2300 to 2570 m asl), has a mean slope angle of about 28° and a NNW aspect. Avalanches are artificially released on a routine basis to secure the ski-runs, as the site is located within a ski resort (MonterosaSki). The site is instrumented with a steel obstacle, which measures the effect of avalanches impacting on it. Figure 1 shows an overview of the test site, while we refer to Maggioni et al. (in press) and Barbero et al. (in press) for a detailed description of the test site and of the instrumented obstacle.



Figure 1. Winter view of the test site Seehore from North-East: on the slope in the shadow an avalanche, which reached the ski run, is well visible.

3. RAMMS MODEL

RAMMS is a 2D avalanche dynamics program developed by the researchers of the WSL-SLF of Davos (CH) which models the flow behavior with two different approaches: the classical Voellmy-Salm model (Voellmy, 1955) and the new random kinetic energy RKE model (Bartelt and Buser, 2009; Buser and Bartelt, 2009).

We refer to Christen et al. (2010a) and Bartelt et al. (2012) for a detailed description of the program.

In this work we used the second approach, which is based on the production, transport and decay of the kinetic energy of the random motion associated with the mass of flowing snow granules. This model can track the evolution of velocity within the avalanche and therefore allows a more realistic modeling of entrainment

and deposition processes, which are fundamental in small and medium avalanches.

4. AVALANCHE DATA

The four avalanches considered in this work were artificially triggered at the Seehore test site on 27th March 2010, 7th December 2010, 5th and 19th March 2011. They were mostly small dense slab avalanches. Snow and flow characteristics were recorded by field work, laser scan measurements (only on 27th March 2010 and 5th March 2011) and specific instruments installed on a steel obstacle placed along the track to measure impact forces. The collected data were then used to tune the RAMMS input parameters in order to reproduce the real events. Figure 2 reports the avalanche outlines of the events when laser scanning was carried out and only the deposits (recorded with GPS) and the release areas (estimated from videos) for the other two events, while figure 3 shows the test site after the avalanche release in those dates.

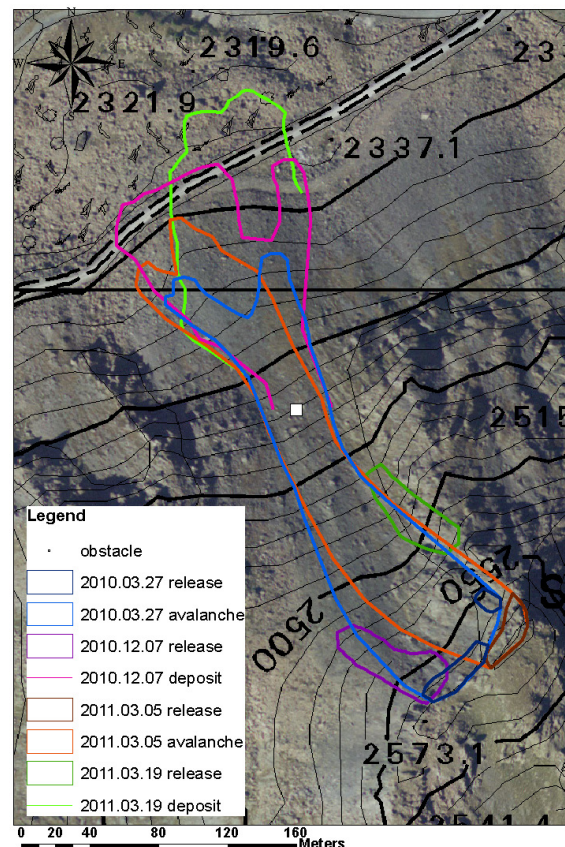


Figure 2. The four artificially triggered avalanches considered in this work.

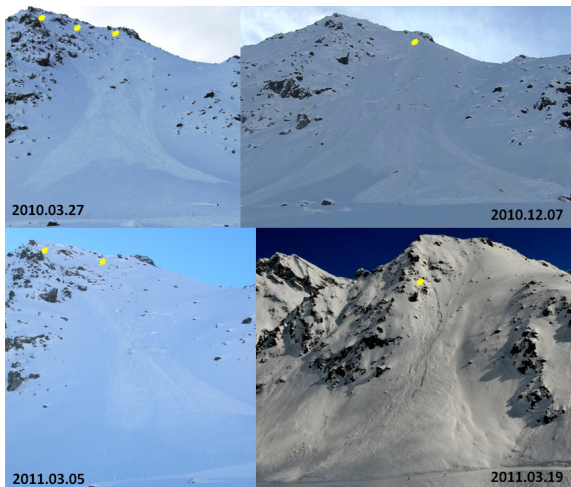


Figure 3. The avalanches triggered at the test site analyzed in this work. The yellow signs shows the triggering points.

4.1 Avalanche 27th March 2010

On 27th March 2010, three avalanches were artificially released from the helicopter, using the Daisybell system. The first shot generated a small slab avalanche that flew well confined in the little couloir on the right, the second one a slab avalanche with a release width of about 40 m and the third shot released a small portion of the slope above the second release. They were all dense avalanches. The fracture depth was about 25 cm, slightly irregular along the fracture line, probably due to the wind blowing the previous days. Field works allowed to record the snowpack structure, showing 25 cm of new snow with a density of 180 kg/m^3 at the surface. Before and after the events, terrestrial laser scan measurements were made to get information about the deposit and the snow erosion and deposition along the track, simply by comparing the surfaces scanned before and after the release (Prokop, 2008). The snow deposit presented a dual-lobe shape with a maximum deposition of about 1 m on the left lobe at about 2380 m asl.

4.2 Avalanche 7th December 2010

On 7th December 2010, the helicopter released with the Daisybell system a mixed avalanche, that run over the ski run at the bottom of the slope. The event started as a dense slab avalanche but shortly developed also an important powder component. The primary release zone (below the explosion) was about 20 m wide and the fracture depth around 30-50 cm.

Secondary releases, at 2460 m asl on the left and at 2430 m asl on the right of the main path, occurred while the avalanche was flowing down. The snow pit showed that the fresh snow depth was equal to 40 cm, with a density of 130 kg/m^3 . This event was one of the largest recorded during the experiments carried out in the test site. The ski run was covered by the avalanche deposit for a length of about 80 m; a maximum deposition depth of 1.5 m was measured on the ski run.

4.3 Avalanche 5th March 2011

On 5th March 2011, the helicopter equipped with the Daisybell system firstly released a small sluff on the right side of the slope and then a small avalanche from the top, at 2570 m asl. This slab avalanche showed mostly a dense behavior but also a small powder component was visible. The release zone was about 40 m wide and the fracture depth around 30 cm. A small secondary release was triggered by the main avalanche flow at around 2460 m asl on the left side of the main path. The snow density of the surface layer (30 cm thick) was 180 kg/m^3 . Before and after the events terrestrial laser scan measurements were made to get information about the deposit and the snow erosion and deposition along the track, simply by comparing the surfaces scanned before and after the avalanche event. The deposit presented a slight dual-lobe shape with a maximum deposition of about 1.4 m on the left lobe, at an elevation of 2375 m asl.

4.4 Avalanche 19th March 2011

On 19th March 2011 an avalanche was triggered by helicopter with explosive. It was a dense slab avalanche that run over the ski run. The starting zone was at a lower elevation (2520 m asl) than the usual triggering points (Fig. 3), as the wind overloaded only the lower part of the slope, due to its peculiar blowing direction. The release area was about 20 m wide and 70 m long. The slab was about 1 m thick with a mean density of 340 kg/m^3 . Evident traces of erosion were observed along the track. This event detached the upper part of the obstacle, carrying it downslope for 25 m. This fact means that the avalanche impact pressure was higher than 50 kPa. In fact, the obstacle was on purpose made of one upper element connected to the foundation with a

connection system projected to resist to impact pressures of up to 50 kPa (Barbero et al., in press).

5. RAMMS SIMULATIONS

We performed numerous simulations, varying the input parameters in order to find their best combination to reproduce the real events (see Tab. 1). Parameters as fracture depth, height and density of erodible snow were chosen according to field measurements and observations.

In the simulations we used a value of 0.5 for the erosion coefficient (ef) when we thought that a basal erosion process was predominant and higher values for frontal entrainment. The values related to the random kinetic energy (generate, decay and R_0) were chosen according to the available literature (Christen et al., 2010a), taking into account the snow temperature recorded in the snow pits.

Table 1. Input parameters for the four simulated avalanches.

	2010.03.27	2010.12.07	2011.03.05	2011.03.19
fracture depth (m)	0.25	0.4	0.3	0.6
release volume (m ³)	224	710	204	1324
density (kg/m ³)	350	300	300	350
μ_0	0.6	0.5	0.6	0.5
ξ_0 (m/s ²)	2000	2000	2000	2000
ef	0.5	0.7	0.5	1
He (m)	0.25	0.4	0.6	0.9
ρ_e (kg/m ³)	180	130	180	250
generate	5	5	5	5
decay	1.2	1	0.65	1
R_0 (kJ/m ²)	2	2	2	2
DEM res (m)	3	3	3	3
grid res (m)	2	2	2	2

The deposits simulated by RAMMS were compared to the outline of the avalanches obtained either from laser scan or GPS measurements. For the events triggered on 27th March 2010 and 5th March 2011 we compared also the erosion and deposition depth calculated by RAMMS with the laser scan measurements.

5.1 Avalanche 27th March 2010

The real avalanche showed a specific dual-lobe shaped deposit, which RAMMS could only partly reproduce (Fig. 4). It seemed like if a second flow towards right would have started from an altitude of 2410 m asl but it was not able to fully develop. Probably, little differences in the snowpack structure in reality allowed this flow to proceed towards the left, while this could not be taken into consideration in the simulation. The zone with the highest calculated deposition values (60-95 cm) is located at elevations between 2360 and 2375 m asl, while the laser scan measured most of the deposition (60-100 cm) a little above (Fig. 5).

Concerning erosion, RAMMS identified the most eroded areas at altitudes between 2420 and 2380 m asl (Fig. 6), while the real events generated the most erosion between 2460 and 2410 m asl (Fig. 5). The eroded snow was in a range of 15-20 cm as measured by laser scanning and around 20-25 cm as calculated by RAMMS.

Except for the missing second lobe in the deposit, the results are very close to the real event.

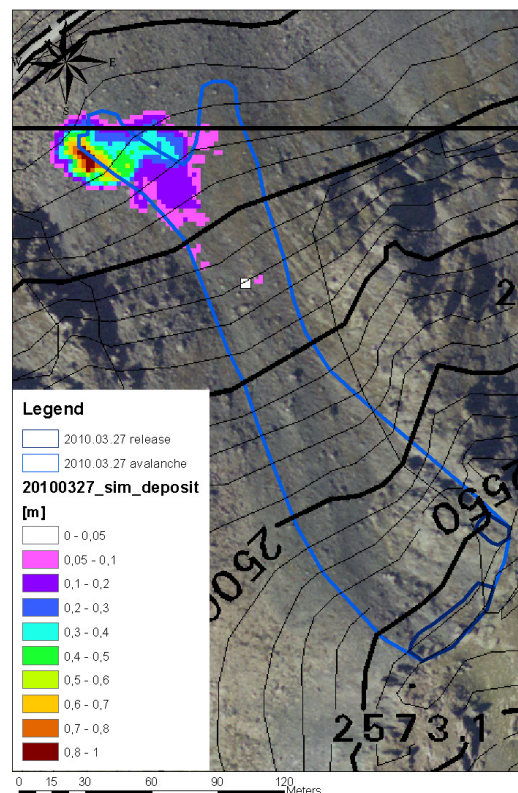


Figure 4. Deposition calculated by RAMMS for the avalanche triggered the 27th March 2010.

5.2 Avalanche 7th December 2010

As for this avalanche we do not have precise measurements of the deposit but only sparse data taken with snow probing, we referred, for comparison, mainly to the shape of the deposit and to the runout distance. The output of RAMMS fits to the real event concerning the runout distance and the prevalent flow direction (Fig. 7). The calculated avalanche crossed the ski run with a width of 75 m, similar to the real value, though a little bit shifted to the left. The maximum calculated deposition height is 140 cm, also similar to the real case (about 150 cm). Instead, the little deposit on the right is not described. Probably, this little lobe was related to the secondary release at around 2430 m asl, which is not included in the calculation, as considered not influencing the dynamics of the main avalanche flow.

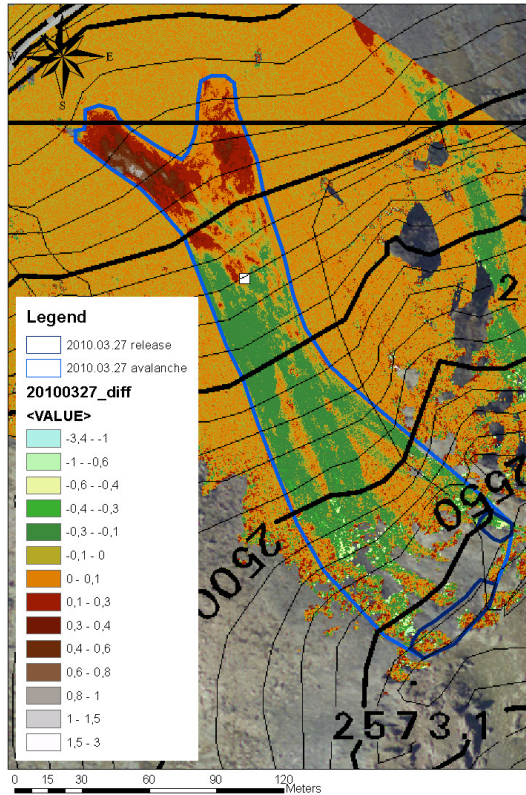


Figure 6. Laser scan data for the avalanche of 27th March 2010: erosion and deposition are shown in green and brown/grey, respectively.

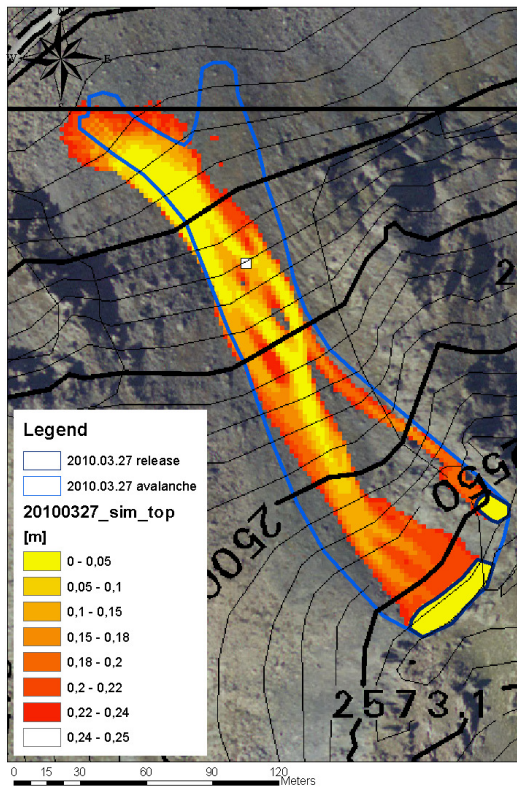


Figure 5. Depth of the top layer for the avalanche of 27th March 2010. By subtraction (from the value of $H_e = 25$ cm) the erosion can be calculated. Maximum erosion in yellow.

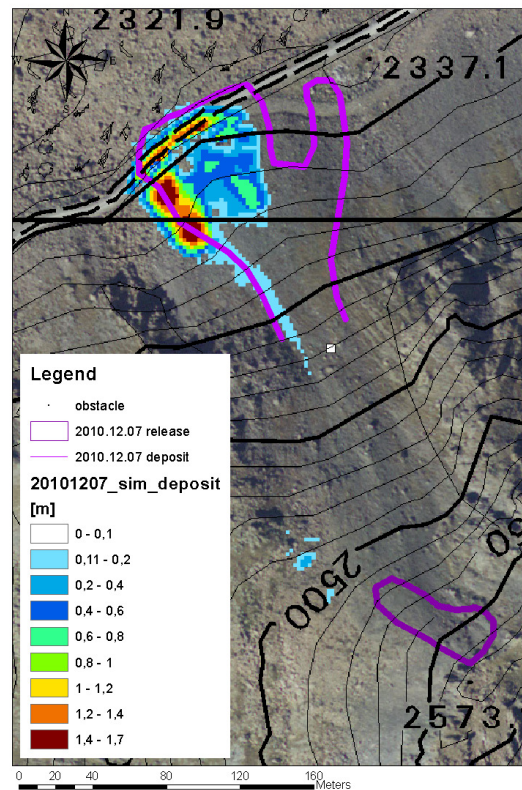


Figure 7. Deposition calculated by RAMMS for the avalanche of 7th December 2010.

5.3 Avalanche 5th march 2011

The calculated avalanche perfectly fit to the real avalanche path in the release and track zone, while in the deposition zone some differences are evident (Fig. 8). RAMMS was able to

reproduce the real dual-lobe shape but the calculated deposit are more elongated in the cross direction, while the real deposits followed the down-slope direction.

Concerning erosion, RAMMS calculated the most important erosion between 2460 and 2380 m asl with most values between 20 and 40 cm (Fig. 9). The laser scan measurements shows the same pattern (Fig. 10): the most eroded area was between 2460 and 2410 m asl with values around 20-40 cm. Also the maximum values, though not so significant as localized on very small portions, are consistent: 45 cm for RAMMS and 60 cm for laser scan.

The maximum pressure calculated at the position of the obstacle is 23 kPa, right equal to the pressure measured by the load cells placed on the obstacle (Segor et al., 2012).

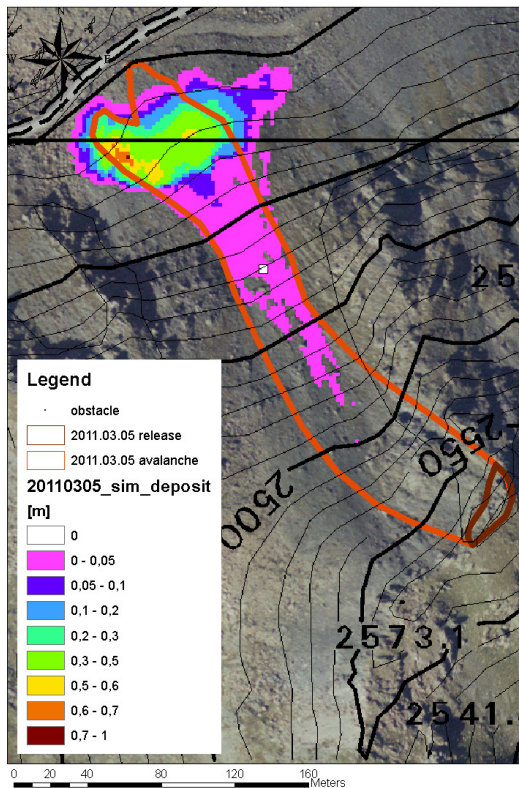


Figure 8. Deposition calculated by RAMMS for the avalanche of 5th March 2011.

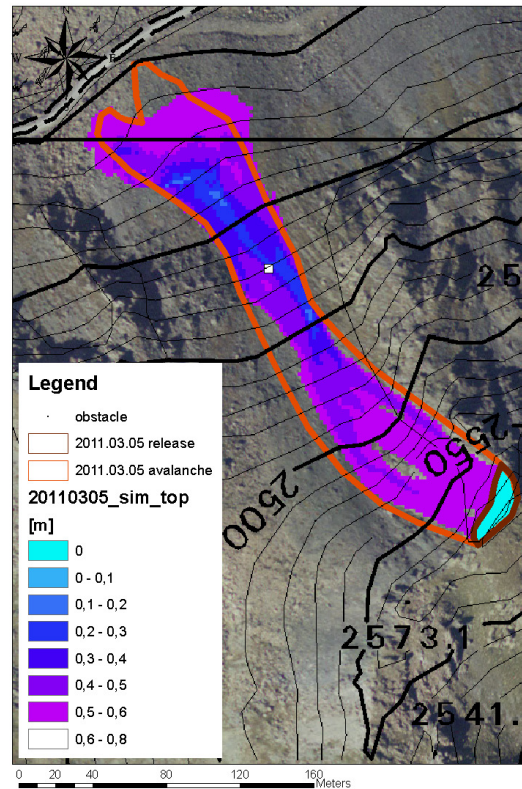


Figure 9. Depth of the top layer for the avalanche of 5th March 2011. By subtraction (from the value of $H_e = 60$ cm) the erosion can be calculated. Maximum erosion in blue.

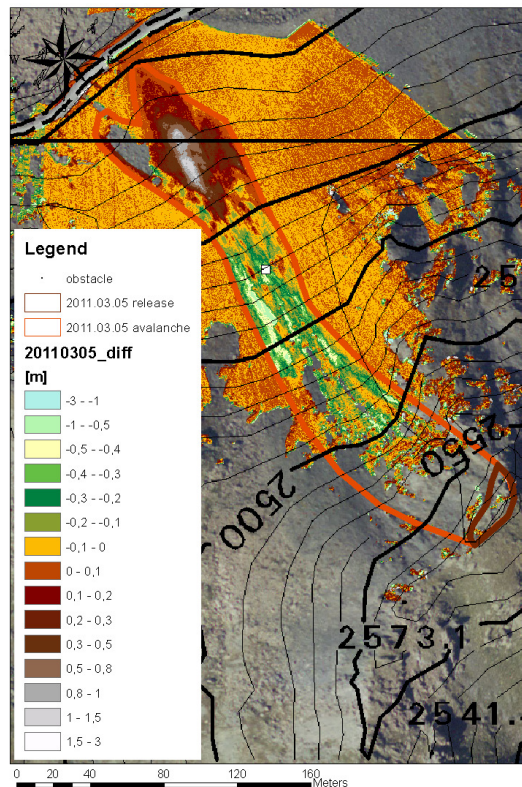


Figure 10. Laser scan data for the avalanche of 27th March 2010: erosion and deposition are shown in green and brown/grey, respectively.

5.4 Avalanche 19th March 2011

The calculated avalanche stopped below the ski run at the same elevation of the real one, but it flew all the way straight down, while the real one turned to the right at about 2410 m asl (Fig. 11). We think that in this case, almost at the end of the ski season, the presence of previous avalanches was crucial and influenced the flow direction. RAMMS used the DEM obtained in summer condition, therefore those old depositions were not considered. We could not include them into the simulation as we did not make laser scan measurement during this test. We observed evident signs of erosion up to 1 m along the track, at altitude around 2400 m asl. Also RAMMS identified an area of eroded snow of 1 m (the maximum available erodible snow) between 2410 and 2570 m asl. The calculated pressure at the position of the obstacle was around 100 kPa, compatible with the fact that the upper part of the obstacle was detached from the foundation.

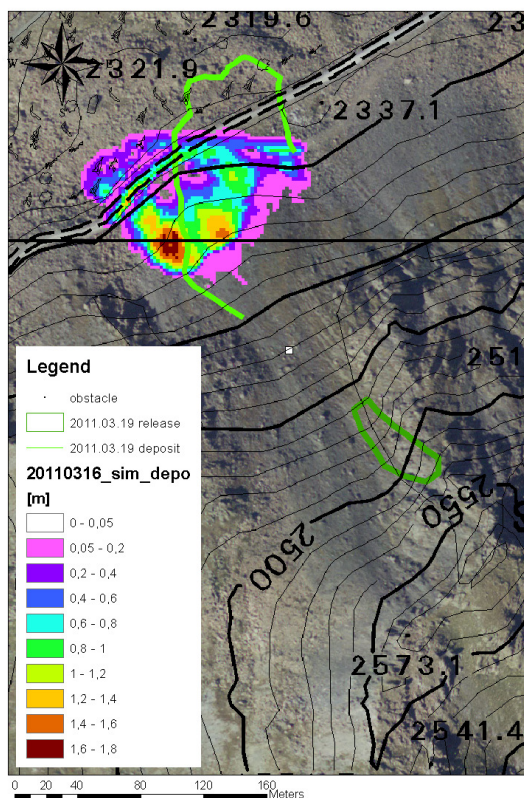


Figure 11. Deposition calculated by RAMMS for the avalanche of 19th March 2011.

6. DISCUSSION AND CONCLUSIONS

We presented the simulations results obtained with the RAMMS model that include the RKE parameters. We highlight here the importance of including erosion and deposition parameters in the investigation of small avalanches. In fact, in our cases, without the RKE terms that model the deposition process along the path, the simulated avalanches always flew too long.

The choice of the parameters is still crucial but now μ and ξ are closer to their physical meaning and are not anymore only calibration parameters. In fact, μ and ξ values used in this work are the same as used by Vera-Valero et al. (this issue) for avalanches with much larger release volumes than in our cases.

The model was not so much sensitive to the choice of the RKE parameters, while changes in the erosion parameters (above all e_f) produced large changes in the outputs. Therefore, it is fundamental to understand which kind of erosion occurs to choose the correct parameters. This might be achieved with more instruments placed along the path, such as for ex. FMCW radars, that measure the time evolution of the snow depth at fixed points.

Despite some avalanche features that RAMMS was not able to reproduce, this work showed how that model is able to simulate avalanche with a release volume of only 200 m³. This is maybe one of the very first work considering such small avalanches.

In the specific case, the output might improve if the deposition of older avalanches are included into the DEM. An idea is to simulate the avalanche running on a DEM generated from the laser scan measurements made before the triggering. We could not try it because some areas in the release zone were not well visible from the laser scan.

Other improvements might come from the new *straw test* described in Bovet et al. (this issue) which is able to determined the real erosion and deposition along the track.

7. ACKNOWLEDGEMENTS

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