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A 1D MODEL OF SNOW-GLIDING: THE CASE STUDY OF MONT DE LA SAXE (NW ITALIAN ALPS)

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INTRODUCTION

Snow-gliding is complex to predict and to model, and yet tremendously important as it may have negative effects on forest stands and soil erosion and could drive snowpack dynamics in the pre-glide-avalanching phase. Notwithstanding some advancements have been done hitherto in this area, but only little concerning the modelling of the process. This study aims to contribute to the understanding of the snow-gliding process by presenting a data driven, distributed, physically based and time-dependent 1D model, able to predict the gliding movement of snowpack along a flow line at daily scale. The model is implemented with software Matlab and spreadsheet Microsoft Excel.

The analysis pursues a number of objectives: to create a practical model requiring few, relatively easily available input data, to reconstruct the snowpack physical evolution starting from measured precipitation, considering each single layers (thickness, density, thermal conductivity, temperature and SWE), to evaluate the rate and extent of movement of the snowpack in gliding phase, and to provide a potentially useful tool for the risk assessment in areas subject to gliding, and subsequent avalanching.

In the proposed gliding model several simplifying assumptions were introduced, including absence of traction stress, groundwater flow, wetting and water percolation through the snow, and micro topography of soil is schematized as a sinusoid in absence of soil erosion.

The model is applied during the winter seasons 2010 and 2011 (featuring different snow and weather conditions) to the avalanche site called "Torrent des Marais - Mont de la Saxe" in Aosta Valley, in the Mont Blanc massif area in Val Ferret (Catasto Valanghe Regionale – Regione Autonoma Valle d'Aosta), near Bertone refuge. This area, characterized by intense movement of snow and formation of large cracks sometimes followed by avalanches, was equipped in 2009 by researchers of Dipartimento di Scienze Agrarie, Forestali e Alimentari (DISAFA) of University of Turin with specific sensors to measure snow gliding and soil and snow parameters (Ceaglio et al., 2012a; 2012b).

SNOW GLIDING THEORY

"*Snow gliding*" means that the snowpack moves (slides) on a slope along the ground-snow interface. This slow movement of wet snow depends in particular on the force applied by snow cover in the direction of the slope, the roughness of ground-snow interface, the temperature at the interface and the amount of free water present (Leitinger et al., 2008). This in an important process that could also lead to the formation and release of "*glide snow avalanches*". These usually mobilize large volumes of snow and can therefore have a very high destructive potential.

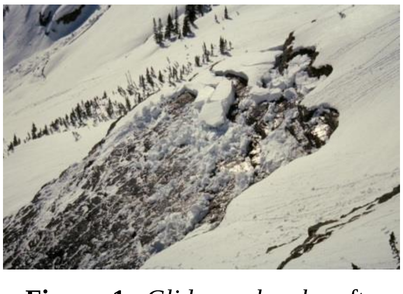

Figure 1: *Glide avalanche* after *gliding* of snowpack (photo Utah Avalanche Center).

There are three basic prerequisites for *gliding* (McClung & Clarke, 1987; Clarke & McClung, 1999; Jones, 2004):

- smooth or low roughness ground-snow interface (e.g. rocks or grass);
- temperature at ground-snow interface of 0 °C, ensuring presence of loose water. The irregularities of soil surface tend to be filled in from water, allowing the snowpack to glide (McClung & Clarke, 1987);
- slope angle greater than 15° (for roughness typical of alpine areas).

SNOW GLIDING MODEL

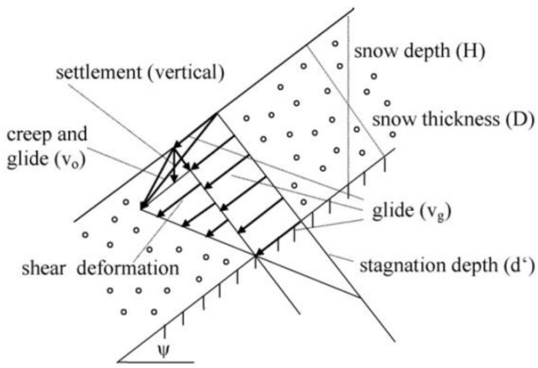

Figure 2: Components of creep and glide and geometric construction of stagnation depth (by Höller et al., 2008).

The most widely used and probably the most complete theory to describe the mechanisms of snow gliding is still the theory presented by McClung and Clarke in 1987 (Jones, 2004). Their model is based upon a constitutive equation that relates the local basal shear stress at the ground-snow interface, τ, with glide velocity, U_0: $\tau = \frac{\mu \cdot U_o}{2\,(1-\nu) D^*}$ where D^* is the stagnation depth, a geometric construction depending only on the ground-snow interface geometry and water distribution at the interface (Figure 2).

Several scripts were written in Matlab in order to describe the different processes that influence the snowpack physical evolution: snow accumulation (depending on precipitation and air temperature); snow melt ("Degree Day method", Mockus 1964); monthly temperature altitudinal lapse rate; fresh snow density (Bras, 1990); accumulated snow density (Martinec, 1956, and a coefficient for a new layer); snow thickness (depending on snow on site at first day of analysis, snow accumulation related to new snowfall, possible snow melt and increase in snowpack density; every day the model stores the value of snow water equivalent of each layer); thermal conductibility of the snow (Yen, 1981); snow temperature (varying linearly until the freezing depth; below this level the temperature remains constant at 0 ° C, Kondo & Yamazaki, 1990); infiltration flow (Groppelli et al., 2011); amount of free water at the interface (difference between the amount of water present at the end of the day and the maximum amount of water storable in the ground); evaluation of glide velocity.

RESULTS: *SNOWPACK THICKNESS*

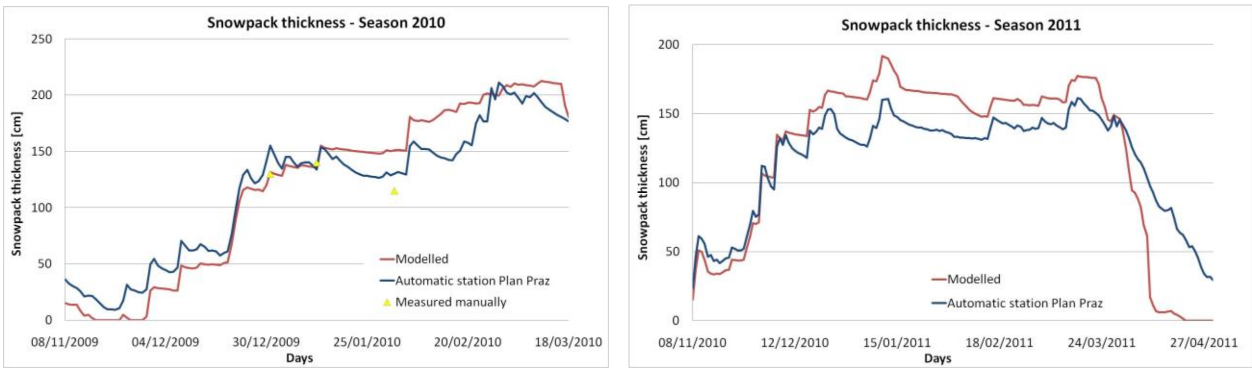

Figure 3 and 4: Comparison between snowpack thickness measured at the automatic station Pré-Saint-Didier Plan Praz and manually and thickness simulated by the model - Season 2010 and Season 2011.

RESULTS: *CUMULATIVE SNOW GLIDE*

The presented model was initially applied to the first winter season, 2010. There were made different simulations with four calibrations parameters: cohesion, friction angle, topographic terrain wavelength and amplitude. In this way there were discovered the groups of parameters that lead to the best simulation of cumulative displacement and they were used to simulate also the other season, 2011. Then the simulations were improved considering a time dependent friction angle, an anticipation of the simulation period and with a new calibration of parameters for season 2011.

Season 2010:

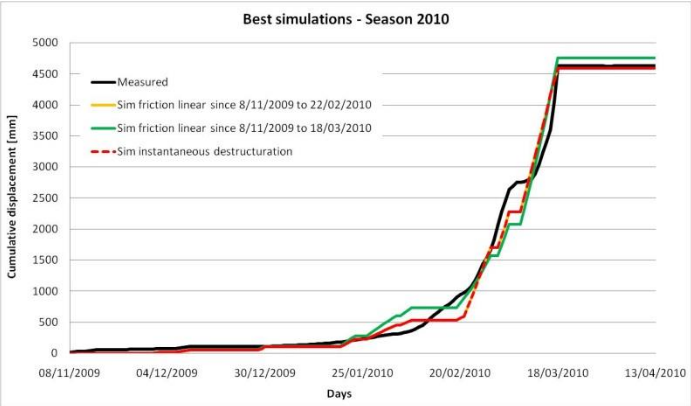

Figure 5: Comparison between cumulative snow glide measured and the three best simulations of Season 2010: simulation with friction angle varying linearly from the first to the last day, simulation with friction angle varying linearly from the first day 22 February 2010, simulation with instantaneous destructuration on 22 February 2010.

Season 2011: with parameters calibrated for season 2010:

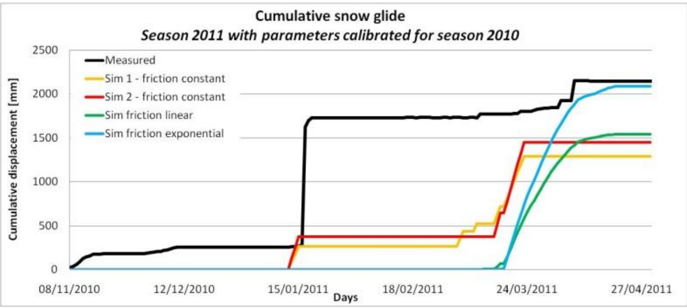

Figure 6: Comparison between cumulative snow glide measured during Season 2011 and the simulations with different groups of parameters calibrated for Season 2010.

The low performance of the model could be related to the simplifying assumptions introduced in the model, but also to the great differences between the two investigated seasons (about displacement and from a meteorological point of view).

Season 2011: with a new calibration of the parameters:

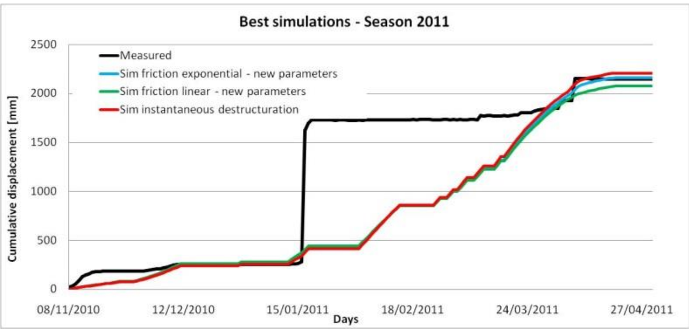

Figure 7: Comparison between cumulative snow glide measured and the three best simulations of Season 2011: simulation with friction angle varying exponentially, simulation with friction angle varying linearly, simulation with instantaneous destructuration on 17 January 2011.

Some problems remain in the simulations of season 2011. Indeed the presented model is able to simulate in a satisfactory way continuous and slow movement of snowpack, but there are some difficulty related to discrete movement, with very high glide rates. On 17 January 2011 was recorded a displacement of about 1.4 meters (62% of total displacement): this kind of displacement could not be considered a typical snow gliding event. The formulations introduced in the model consider lower glide rates and so they were not able to simulate correctly the displacement of January 2011. Instead, the other periods of the season were simulated in a satisfactory way.

CONCLUSIONS

The presented model is practical and requires few, relatively easily available input data. It is able to reconstruct in a satisfactory way the snowpack physical evolution during both winter seasons. Moreover the results display good capacity of the model to reproduce time patterns and final cumulative displacement of the snowpack, despite the great differences in the occurrence of the two investigated events. In particular the model is able to simulate the trend of cumulative displacement and the final value of displacement during season 2010 and the final value of displacement during season 2011.

FUTURE DEVELOPMENTS

The model presented in this study represents a dependable starting point for future researches, that should be focused at including more complex modelling of the different processes affecting snow-gliding, in order to consider also the glide cracks formation and glide-snow avalanche release.

In particular it will be necessary to:

- Introduce in the model mixed formulations between *gliding* and snow avalanche dynamic (in this way the model will be able to reproduce in a satisfactory way also events similar to ones recorded during January 2011).
- Switch from daily scale to hourly scale introducing the equations of water percolation in the snowpack (Brun et al., 1989; Colbeck, 1975).
- Introduce a possible factor of snowpack saturation.
- Improve the schematization of the soil topography.
- Improve the estimation of the air temperature thresholds.
- Extend the knowledge about heat transmission through the snowpack.
- Consider the possible soil liquefaction and erosion.

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