TWO DIMENSIONAL MODELLING OF SNOW TEMPERATURE AND SNOW SETTLEMENT

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One part of snow science deals with the investigation of snow pack properties. There exist a number of physical snow pack models like *Snowpack* which was developed by the SLF Davos or *Safran* and *Crocus* developed by Météo-France. These models are able to predict the evolution of the snow pack and its stability. Unlike to the existing models, a two dimensional snow pack model was developed at the Institute of Mountain Risk Engineering. This model allows the calculation of snow temperatures, settlement and densification of arbitrary chosen cross sections of a slope.

GENERATION OF TWO DIMENSIONAL CROSS SECTION GEOMETRIES

Digital elevation models generated by air born and terrestrial laser scans provide a basis for the geometry definition of a two dimensional snow pack model. The post processing mask of the simulation program allows the definition of an arbitrary intersection of a slope. To draw a two dimensional cross section geometry, snow depth along this intersection can be measured punctually by a supersonic measuring device or laminary by dint of terrestrial laser scans. Figure 1 shows an example for choosing a two dimensional cross section.

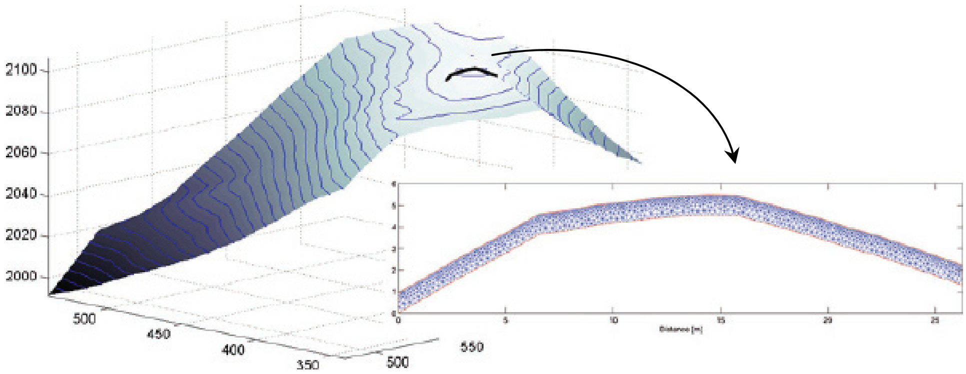

Fig. 1: Generation of a snow pack's cross section geometry

A delaunay-algorithm is used to triangulate the cross section geometry. The mesh size near the snow surface is smaller than near the soil in order to get better calculation results of thermal fluctuations near the surface, influenced by atmospheric conditions and penetrating solar radiation. A discretisation of the geometry is required for the Finite Element Method which solves the partial differential equations of heat transfer, mass balance and snow settlement numerically.

MODELLING OF HEAT TRANSFER WITHIN THE SNOW PACK

The heat transfer within the snow pack can be derived by the heat equation. This equation requires the knowledge of snow density, specific heat capacity, effective thermal conductivity

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and a source term, which describes the influence of short wave radiation penetrating the upper 30 to 40 cm of the snow pack. The energy balance is defined at the surface boundary of the snowpack. Therefore it is required the measurement of wind speed, air temperature, relative humidity and incoming and outgoing long and shortwave radiation. If the long wave radiation measurement is very erroneous, the measurement was replaced by a calculation, based on the Stefan-Boltzmann-equation combined with relative humidity and air temperature. The surface temperature can be simulated using a hybrid-boundary-condition between snow surface and atmosphere. By dint of this boundary condition influences of convective flux and thermal flux can be modelled. The boundary between snowpack and soil is defined by a Dirichlet – boundary condition using measured temperatures of the soil if available or alternatively a constant temperature of about 0°C.

MODELLING SNOW SETTLEMENT AND DENSIFICATION

It is assumed that the settlement is caused by the snow pack's own weight. Therefore the creeping of the snow pack is modelled by the equilibrium condition of the plane strain. The influence of snow metamorphism is not modelled explicitly, but it is implicated indirectly at the definition of the snow viscosity. The viscosity is derived empirically, depending on snow density and snow temperature. As a consequence of the settlement snow densities arise. The densification of the snow pack can be calculated by dint of the mass conservation equation applied on compressible materials. The settlement calculation is combined with an empirical snow drift model. The comparison between measured and simulated snow depth shows that the snow drift model works quite well, but evaluations are only done punctually at the automatic gauging stations.

EVALUATION

Simulation results are compared with measurements recorded by automatic gauging stations installed in *Lech am Arlberg*. One station is placed on a northern slope and the other one is south-east exposed. A data logger saves every 10 minutes long- and shortwave radiation, air temperature, relative humidity, wind speed, snow depth, soil temperature, snow surface temperature and temperatures within the snow pack. The quality of all measured data is sufficient for snow pack modelling, except long wave radiation. Therefore longwave irradiation and emission is modelled by a modified Stefan – Bolzman law.

The continuous measurements of atmosphere and snow pack conditions allow the evaluation of simulated snow temperatures within the snow pack and on its surface. Therefore the two – dimensional temperature field of the snow pack simulation is evaluated at a desired slice correlating to the weather station's position. The snow temperatures in different depths are compared with the measured snow temperatures of a certain time span. The evaluation of the snow settlement and snow drift compares continuous measured snow depths with the simulation. Snow densities are measured by manually digged snow profiles which are used for model parameterization and evaluation.

Unfortunately there is no possibility to measure the laminar temperature distribution within the snowpack and on its surface. The only possibility to verify the simulation is a punctual comparison between measurements and simulation results.

The two dimensional snow pack model is evaluated with data of the winters 2004/05 and 2005/06. The comparison of simulated and measured snow depths and snow temperatures evaluated at the weather stations positions provides a good correlation.

Keywords: snow pack modelling, Finite Element Method, heat transfer, snow settlement