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Modelling powder snow avalanches using a depth-averaged turbulent shear model

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Two different mathematical models of fluid mechanics are now being investigated at the WSL Institute for Snow and Avalanche Research in Davos to model powder-snow avalanches. The first approach is to solve the full three-dimensional multiphase (ice-dust, air) incompressible Navier-Stokes equations; the second approach is to apply depth-averaged models to simulate both the formation and independent propagation of the powder cloud. The final goal of both models is to predict the dynamics of powder avalanches in three-dimensional terrain and specifically cloud impact pressures. Both models are driven by the same set of terrain dependent mass and momentum exchanges defined by the flow state (speed, density, height) of the avalanche core. The great advantage of the depth-average approach is computational speed, allowing the investigation of different hazard scenarios involving variable release locations, snow temperature and entrainment depths. This fact has allowed the widespread application of the depth-average model to many historical case studies, including the avalanches measured at the Vallée de la Sionne (VdlS) test site. However, a central modelling problem needs to be resolved: both air-entrainment (cloud height and density) and drag (cloud speed) are intimately linked to the turbulence created during the cloud formation phase.

In this presentation, we present a depth-averaged turbulence model proposed by V. M. Teshukov [1] and extended by Richard and Gavrilyuk [2] and Gavrilyuk et al. [3], Ivanova et al. [5, 6]. The mathematical model is a 2D hyperbolic non-conservative system of equations that is mathematically equivalent to the Reynolds-averaged model of barotropic turbulent flows. The system is non-conservative, extending the classical shallow water equations to contain three independent components of the symmetric Reynolds stress tensor. We simulate the measured powder cloud heights of two VdlS avalanches using both the incompressible Navier-Stokes and turbulent shallow-water models, capturing the unsteady formation of billow height and width measured by ground based photogrammetry [4]. This can only be achieved by making air-entrainment dependent on the vorticity predicted by the turbulence model. We conclude by summarizing why we believe shallow-water type models can be applied for practical hazard engineering problems.

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