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Investigation of the influence of rheological properties on laminar and turbulent geophysical flows characteristics

Julia Zayko (1), Alexander Yakubenko (2), and Margarita Eglit (3)

(1) Lomonosov Moscow State University, Moscow, Russian Federation (juliazaiko@yandex.ru), (2) Institute of Mechanics, Lomonosov Moscow State University, Moscow, Russian Federation (yakub@imec.msu.ru), (3) Lomonosov Moscow State University, Moscow, Russian Federation (m.eglit@mail.ru)

Geophysical gravity-driven mass flows, such as snow avalanches, debris flows and landslides, can pose hazards to people and property. In this context they are investigated by field observations, laboratory experiments, theoretical and numerical modeling.

There are three types of mathematical models for dense geophysical flows: the first one accepts the flow as a moving material point, the second one is based on the depth-averaged equations for a continuous medium, and the third one takes into account the flow structure not only along its body, but also in a direction normal to the slope. To construct models of the third type one needs to know rheological properties of the flow. The motion of the geophysical flow can be laminar or turbulent. In case of the turbulent regime, equations for turbulent characteristics of the flow are required.

In this work we construct models of the third type, and numerically investigate dense geophysical flows taking into consideration the rheological properties of the flow, the flow regime (laminar or turbulent), and the process of slope material entrainment by the flow. We assume that the entrainment takes place when the shear stress on the flow bottom equals the slope material shear strength.

First, the results concerning laminar flows at long homogeneous slopes are presented. We use analytical formulae for velocity profiles in Newtonian and Herschel-Bulkley stationary flows to clarify the influence of non-Newtonian rheology on the flow characteristics, and to validate our numerical codes. Then, we numerically investigate the process of the slope material entrainment by laminar flows with various rheological properties.

The second part of the work is devoted to the numerical modeling of turbulent geophysical flows. We solve RANS (Reynolds Averaged Navier-Stokes) equations, using two different turbulence models: the LPY three-parameter turbulence model developed by Luschik, Paveliev and Yakubenko, and the SST k-omega model (the shear-stress transport-model). Simulations results obtained by these two models for stationary flows turned out to be close. In particular, the influence of the flow material yield stress on the turbulent flow dynamics was studied by comparison the turbulent flows of the Newtonian fluid and the Bingham fluid with different yield stress values.

The third part of the work presents numerical modeling of turbulent flows, which entrains the slope material. These results were obtained using the LPY three-parameter turbulence model.