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Numeric and analogue modelling of a simple ice flow model: a preliminary comparison study

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Introduction: The "ice-flow model" is considered to be the most exhaustive explanation for Antarctic meteorites stranding surfaces formation [1]. A combination of low surface temperatures (preventing sinking due to radiation induced ice melting), high ablation rates (allowing meteorites exhumation) and low surface velocity is the common characteristic of nearly all meteorite traps.

The ice flow (both in terms of velocity and direction) is closely linked with bedrock topography, both on a local and regional scale. Presence of submerged or emerged obstacles determines the meteorite-bearing ice deformation pattern. Other then bedrock type and morphology, ice flow is also affected by ice thickness, basal conditions (slip conditions) and rheological-mechanical properties. Climatic changes represent another factor of variability since they vary the snow precipitations over the ice sheet and some of the parameters determining the flow regime, as temperature and therefore viscosity.

One of the main goals of present glaciological studies is the investigation of ice flow in relation to the presence and characteristics of bedrock obstacles using numerical and analog modelling techniques. The analogue modelling technique aims to analyse geological or geomorphological processes through physical models built at a reduced geometrical scale in laboratory and deformed at reasonable scale of times while numerical modelling technique aims to describe ice flow through physical equations discretized by means of numerical techniques and solved with the help of calculators.

Analog modeling: Analog experiments were performed at the Tectonic Modelling Laboratory of the CNR-IGG (Florence, Italy).

Polydimethilsyloxane (PDMS) is used to simulate glacial flow in analog models; this material properly simulates the rheological behaviour of ice [2]. Models are built inside a Plexiglas box with dimensions of 70cm x 20cm x 10cm.

The models are scaled to nature conditions allowing a comparison between laboratories and natural models. The use of such a technique allows to analyse, even quantitatively, the dynamics and the parameters controlling the deformational processes of ice during its flow. The geometrical scaling ratio was of 2*10-5, such that 1 cm in the model represented about 500 m in nature.

In order to measure the progressive ice deformation during the experiments, passive grids of carbon-black particles are printed both inside and on the model surface using the unbaked photocopy method.

In the present test a submerged obstacle with dimensions 3cm x 10cm x 2 cm is placed inside the Plexiglas box which is inclined of 3˚; the PDMS is allowed to flow by opening the front end of the box.

Numerical modeling: A fully three-dimensional Finite Volume numerical method for ice dynamics is used for the numerical modelling. The model is based on the hypothesis ice to be a visco-plastic fluid. The free-surface evolution in time is accounted for and the full pressure field (hydrostatic and hydrodynamic component) is calculated. Moreover no simplification on the stress field are applied.

This numerical method is used to investigate the pressure and velocity fields together with the free surface evolution in time. The numerical model is applied to the test case described above for studying the dynamics of PDMS flow in the presence of a submerged obstacle. A dynamic viscosity of 2000 Pa s gives the best fit between measured and calculated velocities. To be noticed that the analog test was performed at a temperature greater then 20˚C so that the PDMS viscosity is likely to be much smaller then 30000 Pa s. In order to avoid perturbations at the inflow and outflow boundaries a longer domain is considered in the simulation. The computational domain is partitioned into 10338 control volumes in the shape of parallelepipeds with non-uniform dimensions.

Numerical modelling are developed at Environmental Science Department of the University of Milano.

Experimental results: The interaction between physical and numerical modelling can improve the knowledge of the phenomena under investigation; numerical investigation can, on one hand, give information about the optimal experimental design; physical modelling can, on the other hand, give a good control for the numerical results.

In the present work attention was focused on the influence of a submerged obstacle on the dynamics of a viscous fluid like PDMS. It has been shown that the obstacle influences the flow lines with both internal and external velocities being perturbed in such a way that the fluid is forced to avoid the submerged barrier; this effect is more prominent for internal and bottom layers. The velocity profiles show an important decrease in correspondence of the obstacle for both surface and deep layers. The good agreement between calculated and measured velocities confirms the value of the two modelling techniques and the possibility of fruitful interactions. Future works could investigate the influence of obstacle with different sizes and shapes on the dynamics of viscous flow. Moreover, the use of Glen's law in the numerical model will allow the investigation of the differences between a Newtonian viscous fluid like PDMS and a non-Newtonian one like ice. Finally, real case applications could be studied with the two modelling techniques.

References:

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