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GPU-based models to perform numerical simulations of lava-flow dynamics

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Lava flows represent a problem particularly challenging for physically based modeling because of the mechanical and thermal features of lava change over time. In order to generate complex trajectories due to the interactions between lava flows and the underlying topography, we need to model the main mechanical features of lava and the way they evolve over time depending on temperature. That challenge has inspired the INGV-CT to develop two different models to study lava-flow dynamics. The first model, named MAGFLOW, represents the top of the evolution of cell-based models for lava-flow simulations. It is based on a cellular automata structure in which the evolution function is a steady state solution of the Navier-Stokes equations and heat transfer (due to radiative losses) and solidification effects are modeled via a temperature dependent viscosity. The model was validated comparing simulated lava flows with the real ones occurred at Mt Etna during the 2001, 2004, 2006, and 2008 eruptions, showing that the code works properly fitting well-constrained eruption data sets. The second numerical model, based on Smoothed Particle Hydrodynamics (SPH) approach, was recently developed by INGV-CT. The SPH method allows us to tackle the different aspects of direct simulation of a lava flow on a real topography, including the numerical resolution of the Navier-Stokes equations coupled with the energy equation with a non-linear rheology (four different rheologies have been implemented: Newton, Bingham, power-law and Herschel-Bulkley) and taking into consideration phase changes. The model allows us to obtain the distribution of solid parts and velocity, temperature and viscosity values across the whole lava flow. For both models the computational cost is however considerable, especially for SPH model, when we need to be able to handle long simulations with millions of particles. To this purpose, we implemented both models on modern graphic processor unit (GPU) by using a NVIDIA CUDA architecture, obtaining a speed-ups respectively of over 40x for MAGFLOW code and 120x for SPH code.