NUMERICAL MODELING OF SELF-CHANNELING GRANULAR FLOWS AND OF THEIR LEVEE-CHANNEL DEPOSITS. A. Mangeney[1], F. Bouchut[2], N. Thomas[3], and N. Mangold[4], [1]IPGP, CNRS, Université Denis Diderot, 4 Place Jussieu, 75005 Paris, France, mangeney@ipgp.jussieu.fr, [2]Département de Mathématiques et Applications, ENS, CNRS, 45 rue d'Ulm, 75005 Paris, France, francois.bouchut@ens.fr, [3]IUSTI-CNRS, 5 rue E. Fermi, Technopole de Chateau-Gombert, 13453 Marseille, France, nathalie.thomas@polytech.univ-mrs.fr, [4]Laboratoire IDES-Orsay, CNRS, Bat 509, 91405 Orsay, France, nicolas.mangold@u-psud.fr.

Introduction: When not laterally confined in valleys, gravitational flows on Earth and on Mars such as pyroclastic flows or gullies create their own channel along the slope by selecting a given flowing width. Furthermore, the lobe-shaped deposits display a very specific morphology with high parallel lateral levees. Such channeled flows leaving a levee-channel morphology in deposits on the slope are observed in very different environments (aerial, submarine) and for flows involving completely different materials [1-3].

This morphology observed on Mars was first interpreted as indicating the presence of water during emplacement [4]. Similarly, assuming a Bingham rheology, *Mangold et al*. [1] deduced from the analysis of levees that the observed gullies over large Martian dunes involve flows with a significant proportion of fluids. These flows occur on slopes of only 10° over length >1 km, values at which dry flows are unlikely. On the other hand, *Treiman and Louge* [2] refer to dry flows to explain the levee-channel morphology of Martian gullies; this possibility is especially pertinent for gullies located on steep hillslopes (>20-25°).

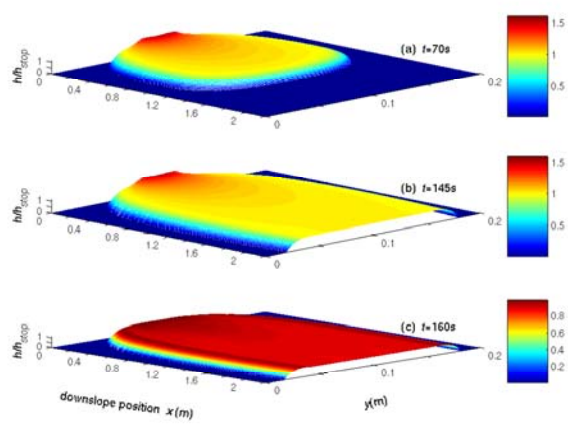
The first question is as to whether the presence of water is a necessary condition for the formation of the levee-channel morphology and how do these levees form. Laboratory experiments show that self-channeling lobes and levee-channel deposits can be obtained using dry granular flows when the slope higher than 20° [5]. In these experiments, particle segregation features are observed to enhance the levee-channel morphology of the deposits. Is it possible to reproduce this morphology without any segregation processes, a situation hardly achieved experimentally ?

Field measurements have been performed on such deposits, but it was not clear as to what extent these measurements provide information on the mechanical properties and dynamics of the flow during emplacement. Which geomorphologic features (such as width or thickness of the channel or levees) are almost independent with respect to time and the distance from the supply and therefore pertinent to characterize the flow?

The aim of this work is to shed light on these questions using a simple depth-averaged model based on Saint-Venant equations and Coulomb type friction. *Mangeney et al*. [6] show that numerical simulations successfully reproduce the self-channeling of the granular lobe and the levee-channel morphology in the deposits without having to take into account mixture concepts or polydispersity. Numerical results suggest that the quasi-static shoulders bordering the flow are created behind the front of the granular material by the rotation of the velocity field due to the balance between gravity, the pressure gradient and friction. Numerical simulations show that measurement of the width and thickness of the central channel morphology in deposits in the field provides an estimate of the velocity and thickness during emplacement.

Shallow granular flows model: Depth-averaged continuum models have been shown to reproduce the basic behavior of the flow on sloping topography under experimental or natural conditions [7-10]. These models are based on the long wave approximation, which is appropriate for granular flows over inclined topography given that the characteristic length in the flow direction is much larger than the avalanche thickness, thereby satisfying the hydrostatic assumption. Using these approximations, the model describes the balance between inertia, gravity, pressure gradients and friction forces acting on the depth-averaged media [6].

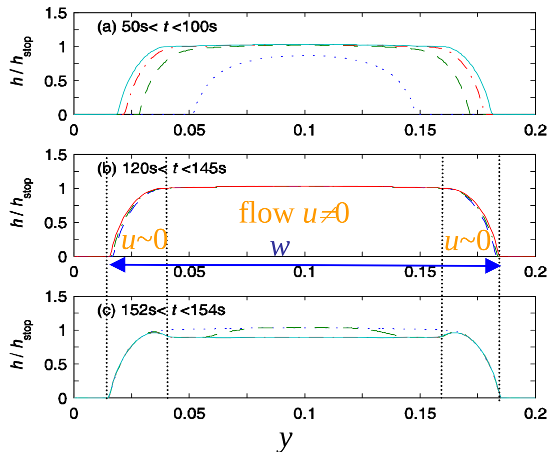
Figure 1: Numerical simulation showing (a), (b) the creation of a self-channeling flow and (c) the formation of levee-channel morphology.



The appropriate flow law to describe dissipation in dry granular flows is still under debate. An empirical parametrization of the friction law suggested by experiments on granular flows over inclined plane is used here [11]. Basically, the idea is that the friction coefficient involved in the classical Coulomb friction law increases with decreasing thickness and increasing velocity. The thickness h_{stop} left on an inclined plane by a steady granular flows when the supply is cut is an empirical parameter of the firction law [11].

We set the initial and boundary conditions in the range of the experiments performed in [5]: at the upper boundary, corresponding to the top of the inclined plane, a flux $Q_0=hu=2.10^{-4}$ m^{2}s^{-1} of granular material is imposed through a width $w_0=4$ cm generating a granular lobe flowing over a plane with inclination angle $\theta=25°$. The numerical domain is $L_x=2.2$ m long and $L_y=20$ cm wide. The supply is stopped at $t_s=145$ s and the total simulation lasts 160 s. At $t=130$ s the front has already left the plane, leaving behind a flow quasi-uniform in the downslope direction for $x \geq 1.2$ m (Figure 1c).

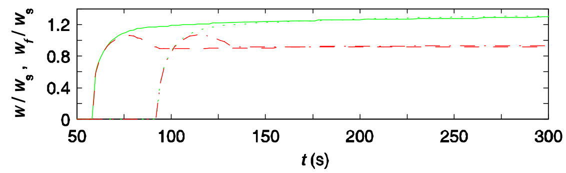
Figure 2: Normalized transverse profiles $h(y)/h_{stop}$ at x=1.2 m, during the flow of the granular lobe, (a) and (b) under constant supply and (c) during the draining phase. The different lines correspond to different



times.

Formation of Channel and Levees: The building of shoulders channeling the flow and the appearance of levee-channel morphology in the deposits have been simulated numerically for the first time (Figure 1) [6]. The main achievement of these simulations is to show that neither mixture concepts nor polydispersity are required to explain self-channeling flows and levee formation. The numerical simulation shows the same evolution as in the experiments. The transverse profiles of the mass thickness obtained at a given downslope position are in very good qualitative agreement with the experimental observations [5, 6]: the front of the flow arrives at the chosen distance and the thickness and width of the cross-section increase until an almost stable profile is reached (Figure 2a). The profiles are then globally stable with time although the width of the flow slightly increases (Figure 2b, 3). When looking at the downslope velocity, two static shoulders occur at the left and right lateral borders of the flow. Finally, as the supply stops, the central part is drained by the downward flow and the thickness between the shoulders decreases (Figure 2c).

Figure 3: Change with time of the total width of the lobe $w(t)/w_s$ (solid gray lines) and of the flowing width



$w_f(x)/w_s$ (dashed lines) at x=1.2 m.

Numerical results provide a possible explanation of the self-channeling process indicating that the shoulders are created behind the front. The fact that the front reaches a steady velocity and shape along the plane seems to be responsible of the width chosen by the flow. In the simplified model used here, the formation of shoulders channeling the flow is shown to result from the balance between a friction force with a friction coefficient depending on the thickness of the flow and the driving forces due to gravity and surface slope.

Pertinent morphological parameters : The total width w of the lobe is shown to increase slightly as a function of time. On the contrary, the width of the flowing channel w_f (where the dowslope velocity is higher than a given threshold) has been proved to be almost constant in time and space. The width of the central channel on the deposit w_c almost corresponds to w_f and therefore provides a pertinent parameter for field measurements. Furthermore, the thickness in the central channel of the deposit h_c almost corresponds to the thickness h_{stop}. Scaling laws show that measurements of these parameters give insight into the dynamics of the flow during emplacement [6]. A next step in that work would be to measure the microtopography of Martian leveed gullies to test these parameters to better determine the relative importance of wet and dry flows in gullies formation.

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