The vertical resolution obtained on these profiles is about 0.1 *pixels* corresponding to 0.5 d.

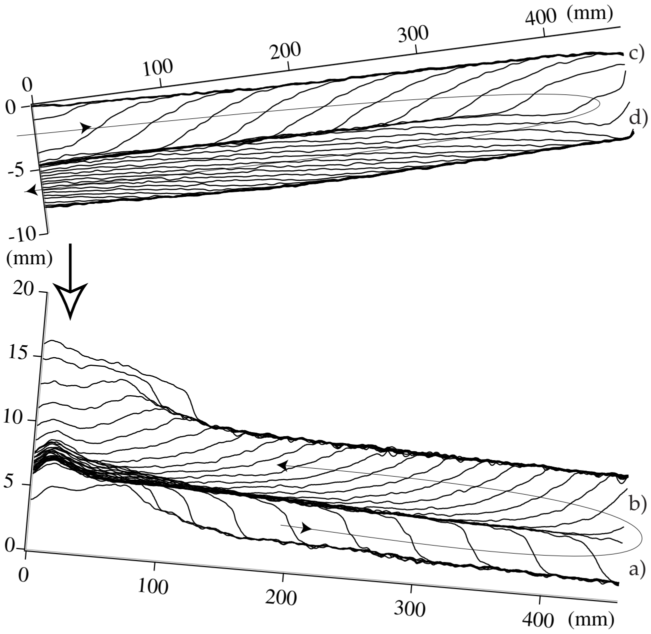

FIG. 3. Evolution in time of the free surface profile ($\delta t = 200\ ms$). Bottom : (a) the sand falling from the reservoir accumulates and an avalanche spontaneously starts whose front propagates downward the pile. (b) Once it reaches the boundary, the sand stops flowing and a stopping front propagates upward the pile. Top : in the reservoir, the volume of grains decreases also at a constant rate. (c) An avalanche spontaneously starts and propagates upward the pile. (d) When it reaches the side boundary, a stopping front propagates downward the pile.

The four fronts – Figure 3 a) presents the classical avalanche, observed here at the bottom of the hourglass : the sand accumulates in a bump which starts flowing when the slope becomes locally larger than φ_{start}. It creates an avalanche which propagates at a constant speed c, keeping a steady shape (Fig. 3 a). The avalanche presents a sharp front separating the rolling grains from the static pile. In the classification proposed on figure 4 a), it is called a "start-down" front, "start" meaning that the region in motion invades the static one and "down" that the front propagates downward.

When this front reaches the cell's boundary, grains are flowing along the whole profile which presents a constant slope. This corresponds to a steady homogeneous flow. Then the sand accumulates at the boundary, and the surface angle becomes locally smaller than φ_{stop} so that the grains stop. This induces a stopping front propagating upward the pile ("stop-up" front on fig. 4 b). Figure 3 b) shows that contrarily to the starting front, the stopping front is much smoother and its shape changes in time. More precisely, its length increases and its angle becomes closer and closer to the stopping angle φ_{stop}.

In the upper part of the experiment (Fig. 3 c), the grains flow out so that the local angle becomes larger than φ_{start}. They start falling down and an anti-avalanche occurs, which moves upward the sandpile. This "start-up" front (Fig. 4 c), has the same properties than the previous starting front : it propagates at a constant speed, keeping a steady shape.

Again, when the front reaches the upper boundary, the local angle decreases below φ_{stop} : the grains stop and a stopping front propagates downward (Fig. 3 d). This "stop-down" front, shown in fig. 4 d), presents the characteristics of the "stop-up" front : its shape evolves (it is stretched in time) and its slope decreases toward φ_{stop}.

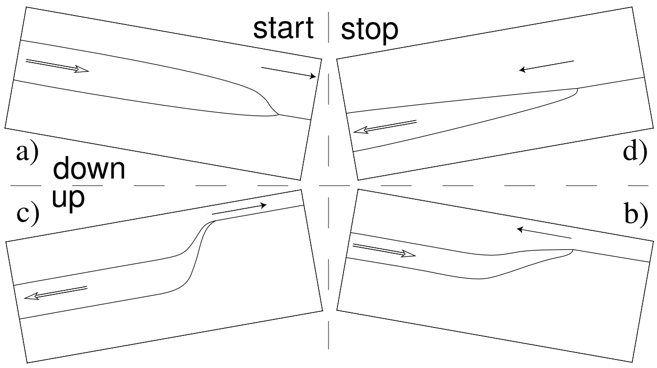

FIG. 4. Results of the numerical integration of a complete version of the model. The four fronts are labelled by a-b-c-d, corresponding to figure 1, but disposed following the start/stop-up/down classification.

Symmetries and mechanisms – The filling experiment presents avalanches with already two fronts : the intuitive "start-down" front, but also a "stop-up" front. These two fronts are perfectly antisymmetric, starting being reversed to stopping and downward to upward. Now the emptying experiment can be seen globally as the antisymmetric of the filling one. We then effectively observe anti-avalanches presenting two other fronts ("start-up" and "stop down"), again perfectly antisymmetric one with respect to the other. But comparing the two experiments, the fronts are also antisymmetric for one of the two characteristics : starting being reversed to stopping or upward to downward. This leads to two possibilities of classification for these four symmetric fronts : either two fronts propagating downward and two upward, or two starting and two stopping fronts. This corresponds to the matrix presentation of figure 4.

The two classifications correspond to common characteristics of the fronts. The two fronts propagating downward the pile appear to have a moving free surface above the static one and slightly mobilize the pile, roughly as if they were flowing on a hard static bottom (Fig. 1 a and d). On the contrary, the two upward fronts have a free surface deep under the static one (Fig. 1 b and c). This property is directly related to the the conservation of matter. For a front propagating at a constant speed c, it tells that the flux of grains Q_0 far from the front is equal to the front height times the front velocity :