Mountain Risks
2007-2010
A Marie Curie network

Testing different concepts of the equation of motion, describing run-out time and distance of slow-moving gravitational slides and flows.

Th.W.J. van Asch (1,2), A. Daehne (3), A. Spickermann (1,4), J. Travelletti (4), S.Bégueria-Portuguès (5)

Utrecht University, Faculty of Geosciences, Utrecht, Netherlands,t.vanasch@geo.uu.nl, (1), Delft University of Technology, Faculty of Civil Engineering and Geosciences, Water Resources Section, Delft, The Netherlands, (2) University of Modena and Reggio Emilia, Department of Earth Sciences, Modena, Italy (3) CNRS – University of Strasbourg, School and Observatory of Earth Sciences, Strasbourg, France, (4), CSIC - Estación Experimental de Aula Dei, Zaragoza, Spain (5).

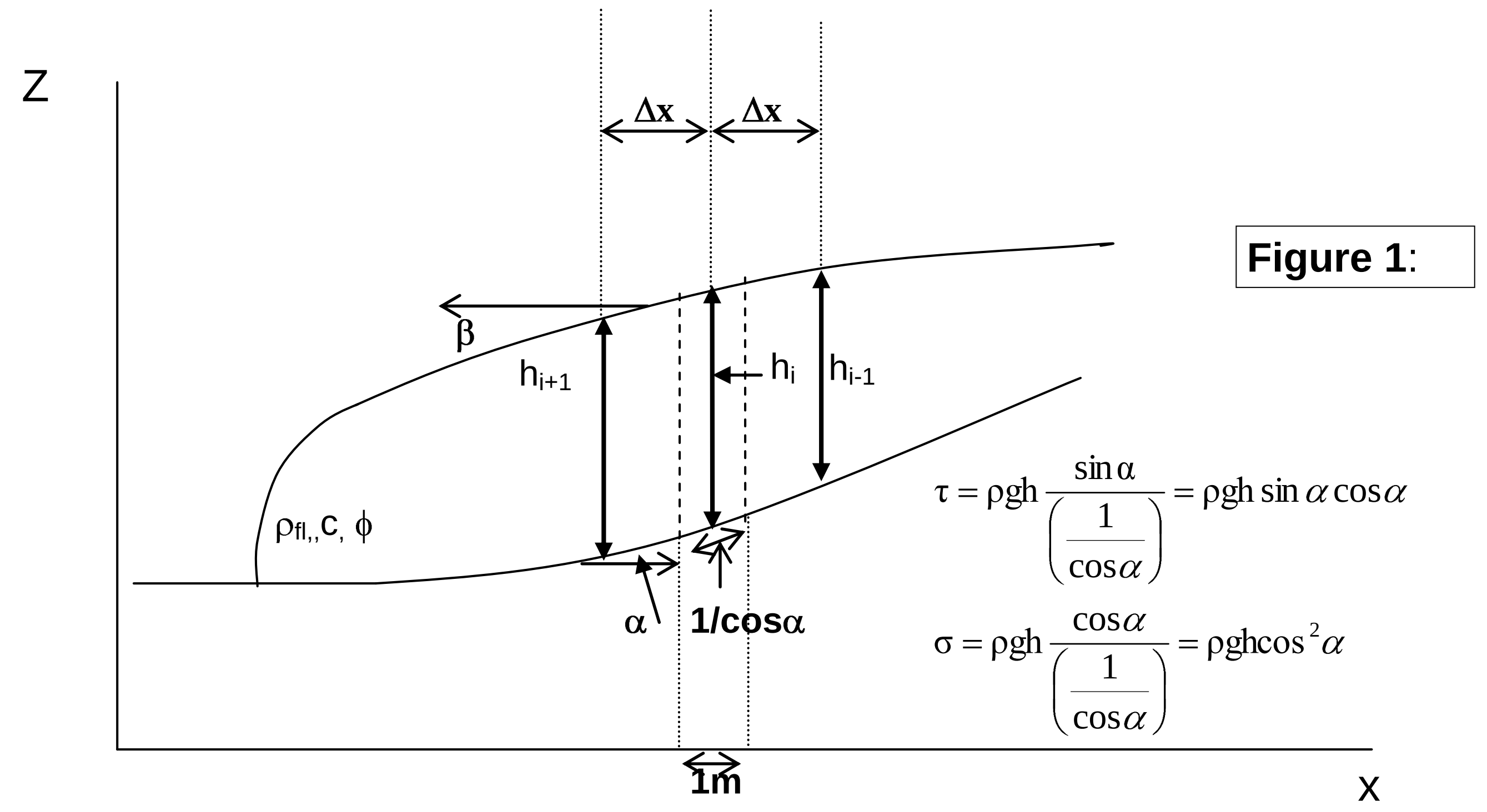
Contact:
Th.W.J. van Asch
Faculty of Geosciences, Utrecht University, Netherlands
Email: t.vanasch@geo.uu.nl

INTRODUCTION

Despite the fact that many authors include inertial terms in the equation of motion for slow moving mass movements, it remains to be seen whether these terms are necessary to describe properly slow moving debris flows or landslides with velocities ranging from 1 to 2 m min^{-1} until 30 mm y^{-1}.

Objective

Compare the performances of two versions of the equation of motion with and without inertial terms for slow debris (mud) flows and landslides



$$\tau = \rho g h \frac{\sin\alpha}{\left(\frac{1}{\cos\alpha}\right)} = \rho g h \sin\alpha\cos\alpha$$

$$\sigma = \rho g h \frac{\cos\alpha}{\left(\frac{1}{\cos\alpha}\right)} = \rho g h \cos^2\alpha$$

Figure 1:

Model description

Landslides and debris-(mud) flows have often been modeled as visco-plastic materials with a laminar flow regime, i.e. as Bingham fluids with constant yield strength and viscosity.

The _AC Model_ is a currently used model with the governing equations of the MassMov2D model (Bégueria at al. 2009), which follows the form of the Saint Venant shallow water equations. It has been applied previously to mass movement modeling by a number of authors.

$$\frac{\partial h}{\partial t} + \frac{\partial (hu)}{\partial x} = 0 \qquad (1)$$

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} = g\left[\sin\alpha_x\cos\alpha_x - k\frac{\partial h}{\partial x} - S_f\right] \qquad (2)$$

$$S_f = \left[\cos^2\alpha_x\tan\varphi' + \frac{1}{\rho g h}\left(\tau_c + \eta\left(\frac{\partial u}{\partial z}\right)^b\right)\right] \qquad (3)$$

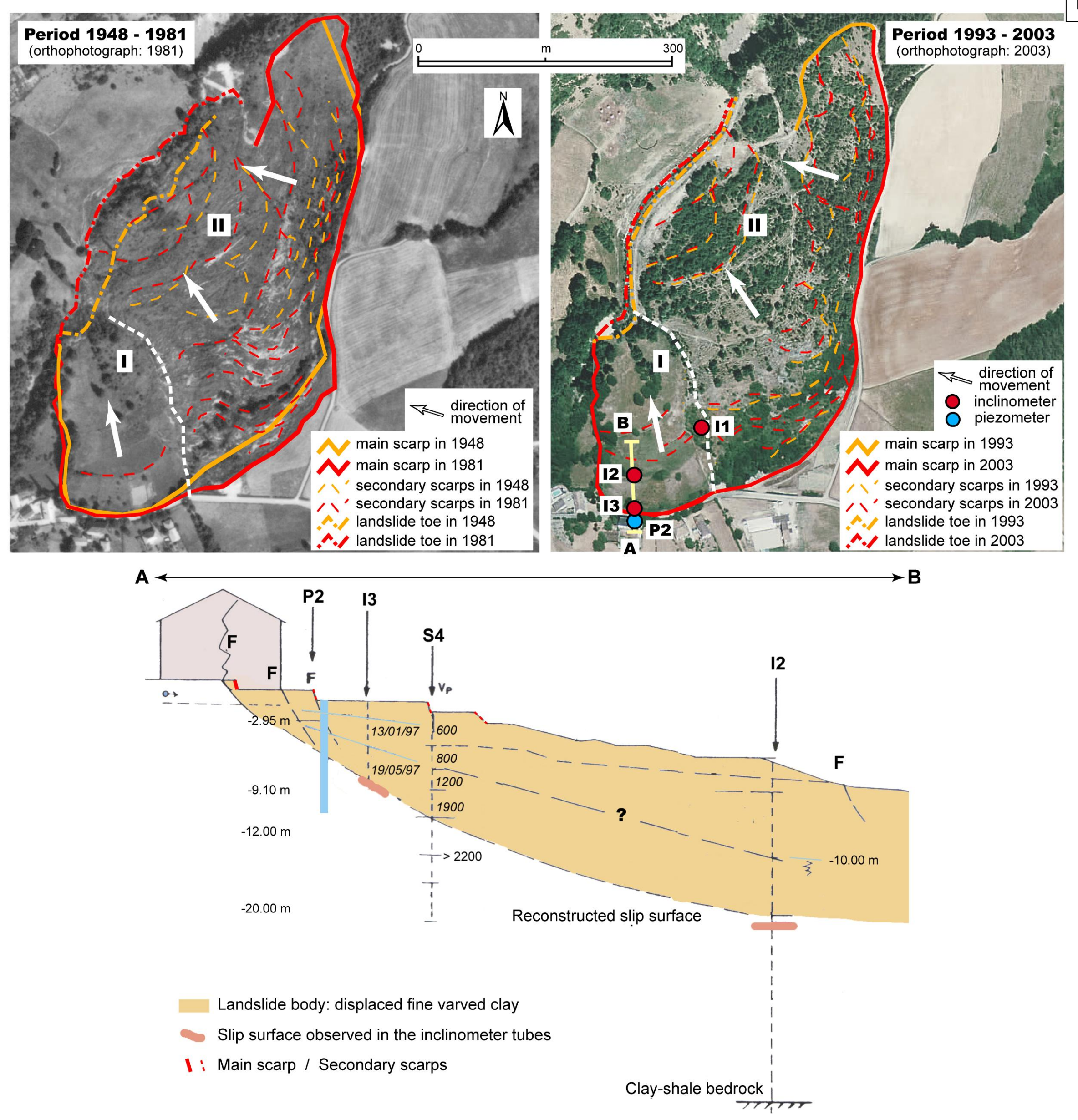
Eq. (1) is the mass balance with vertical height h (see figure 1) and velocity u. Eq. (2) is the momentum balance in terms of acceleration with on the left side respectively the the local or time acceleration, and the convective acceleration. These terms are also used to describe velocity patterns in slow moving landslides. The question arises whether we can delete these terms making it a steady state model (_NA model_) Eq. (4):

$$g\sin\alpha_x\cos\alpha_x + kg\frac{\partial h}{\partial x} - g\left[\cos^2\alpha_x\tan\varphi' + \frac{1}{\rho g h}\left(\tau_c + \eta\left(\frac{\partial u}{\partial z}\right)^b\right)\right] = 0 \qquad (4)$$

A comparison between the AC- and NA-model tested on the Monestier-du-Percy landslide

The two models were applied to the Monestier-du Percy landslide, which developed in varved clays in the French Alps. Along the investigated profile (A-B) in the S-W part (see Figure 2) the slip surface is located at -16 m below the main houses and at -9 m nearby the road. Inclinometer measurements in the nineties showed a mean velocity of about **30 mm y^{-1}**

Figure. 2.



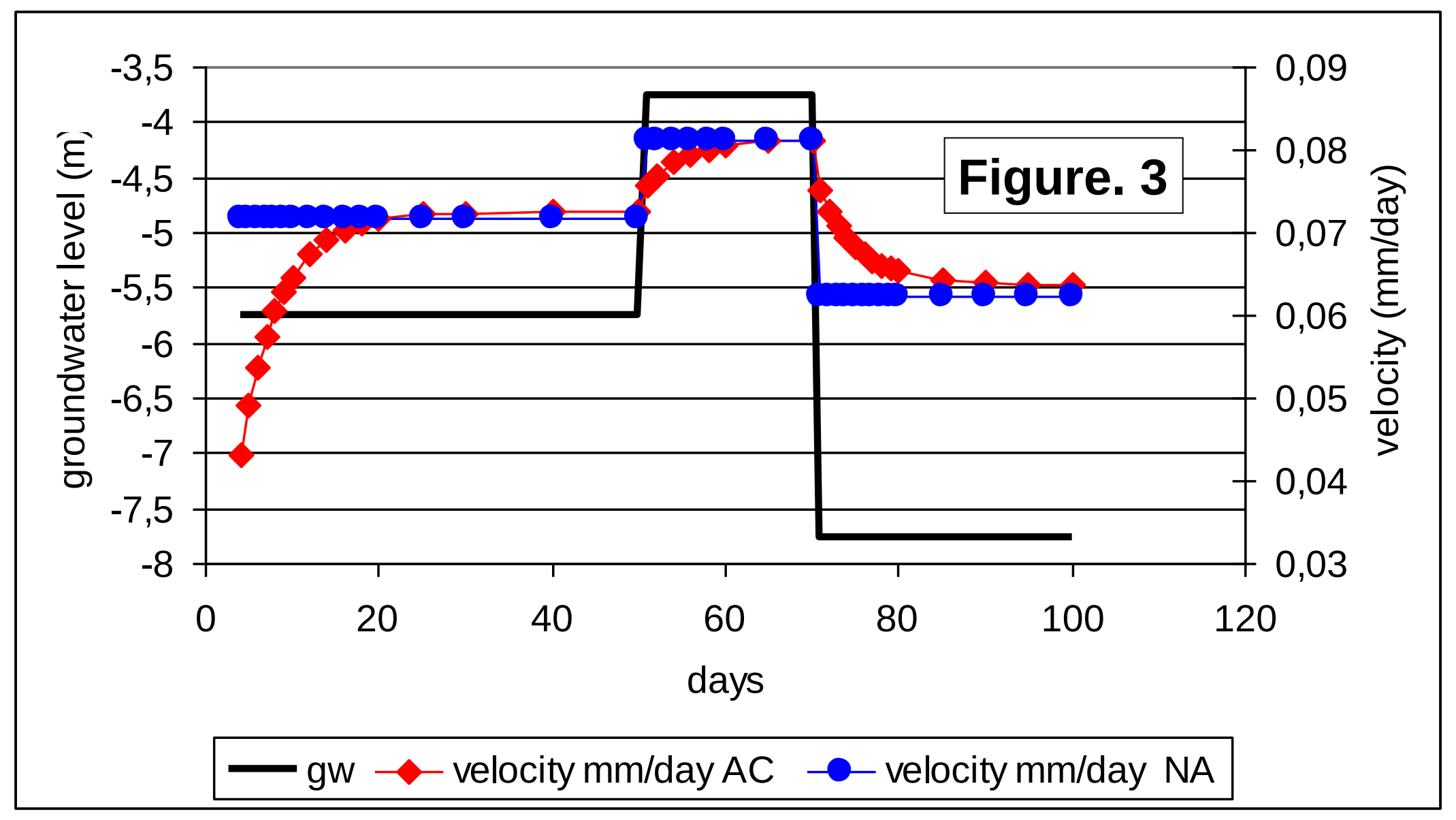


Figure. 3

Fig. 3 shows for the AC-model an acceleration and deceleration with instantaneous rising and falling groundwater (gw) before it comes to a steady velocity, while the NA-model has a direct response to the rise or fall in groundwater.

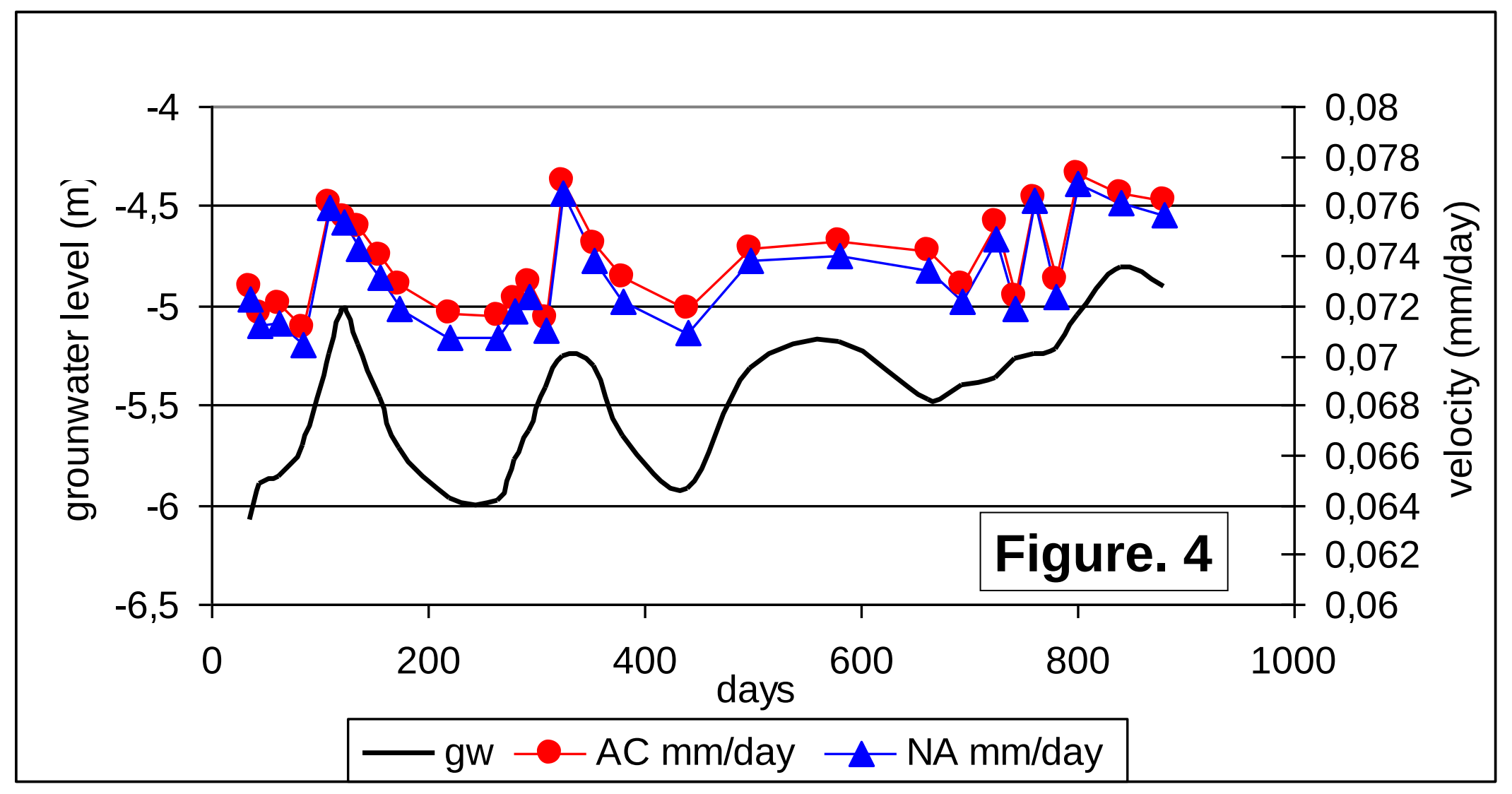


Figure. 4

Fig. 4 shows a real world case. The calculated displacement velocities show minor differences in fluctuations between the AC- and Na-model.

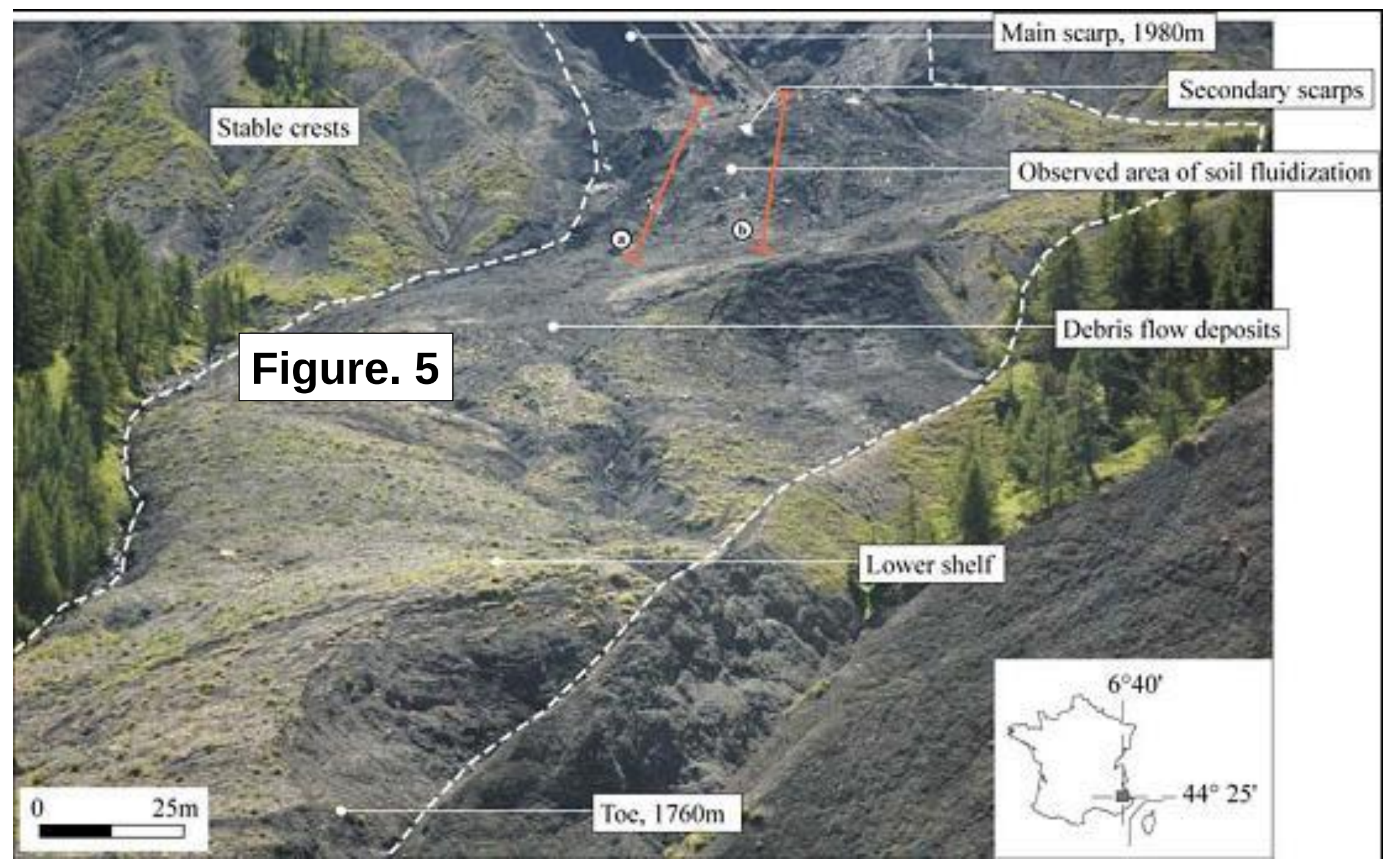


Figure. 5

Slow moving mud flows on top of the Super Sauze mudslide

Figure 5 shows a relatively slow mud/debris flow ,which failed suddenly from a secondary scarp of the Super-Sauze mudslide (Southern French Alps). It flowed on the hill slope in the first 30 minutes with a relative low mean velocity of **2 m.min^{-1}** until a distance of 40 m from the source area, and then continued flowing at a slower mean velocity of **1 m.min^{-1}.**

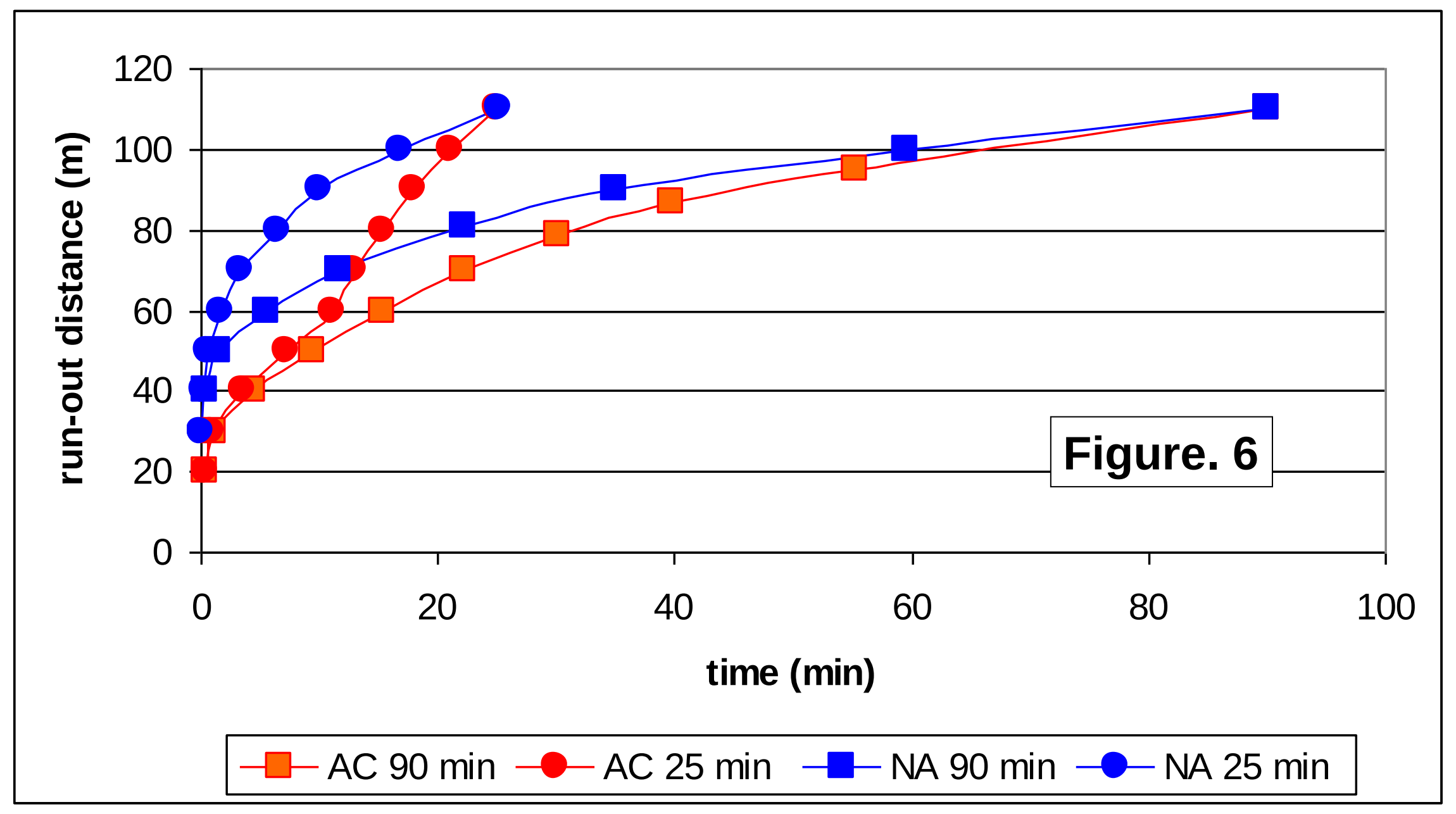


Figure. 6

The models were calibrated on the observed run-out distance (110 m) and time (90 min) AC 85 =kPa s; NA =12 kPa s and on a hypothetical scene (110 m in 25 min) AC=0.2 kPa; NA=24 kPa sec. Fig. 6 shows the different displacement rates between the models. The faster the displacement the larger the differences.

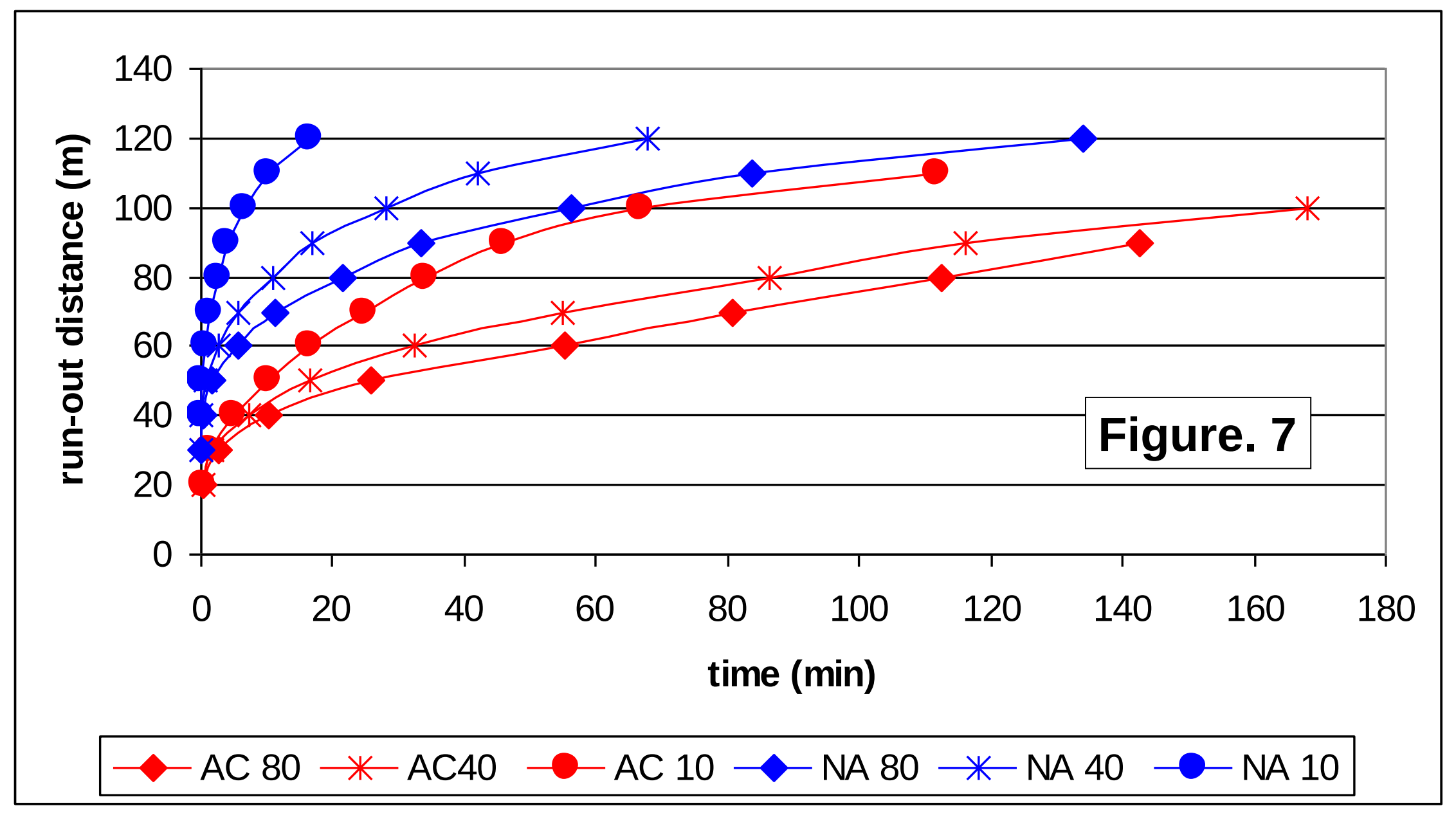


Figure. 7

Fig.7 shows the effect of the viscosity (respectively 80, 40 and 10 kPa s) on run-out time and distance for the AC- and NA-model .

Conclusions

For slow moving landslides there are only slight differences in the performance between the AC-model (equation of motion with inertial terms) and the NA-model (steady state model). Significant differences in run-out time with distance can be observed with relatively rapid moving debris (mud) flows in the order of meters per minute and higher. The NA-model however proved to be a simple, flexible and robust model but should not be used in case of these relative rapid or fast gravitational flows.