Prediction of the Rainfall-Induced Landslides: Applications of FLAME in the French Alps

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Abstract

This work presents an innovative approach to predict changes in landslide displacement rates for early warning purposes. The forecasting tool associates a statistical impulse response (IR) model to simulate the changes in landslide rates by computing a transfer function between the input signal (e.g. rainfall) and the output signal (e.g. displacements) and a simple 1D mechanical (MA) model (e.g. visco-plastic rheology) to take into account changes in pore water pressures. The models have been applied to forecast the displacement rates at three landslide sites (South East France), among the most active and instrumented landslides in the European Alps. Results indicate that the three models are able to reproduce the displacement pattern in the general kinematic regime with very good accuracy (succession of acceleration and deceleration phases); at the contrary, extreme kinematic regimes such as fluidization of part of the landslide mass are not being reproduced. This statement, quantitatively characterised by the Root Mean Square Error between the model and the observations, constitutes however a robust approach to predict changes in displacement rates from rainfall or groundwater time series, several days before it happens. The variability of the results, depending in particular on the fluidization events and on the location of displacement data, is discussed.

Keywords

Early-warning system • Rainfall-induced landslides

108.1 Introduction

Forecasting the displacement pattern of continuously active landslides is a challenge for scientists and risk managers. Changes in displacement rate over time are mostly controlled by hydro-meteorological triggers (e.g. rainstorms, rapid snowmelt) and the consequent increase of pore water pressure, and by geodynamic triggers (e.g. earthquakes, changes in landslide geometry and stress conditions, changes in material rheology).

Most of the landslide monitoring systems consist of measurements of rain, pore water pressure and displacements (van Asch et al. 2007).

The most used and reliable approach to forecast the time of failure at single slope scale makes use of displacement (and its derivative, velocity) observations. Other approaches consider the use of rainfall thresholds to analyse the relationship between the triggering precipitation and the movement. The threshold may correspond to a critical value (usually, duration and intensity) over which the probability of landslide occurrence is higher. Other threshold models are based on dynamic temporal analyses of the rainfall pattern, as the FLaIR model (Sirangelo and Versace 1992). However, the aforementioned methods do not explicitly consider observed and measured landslide quantities, as they are

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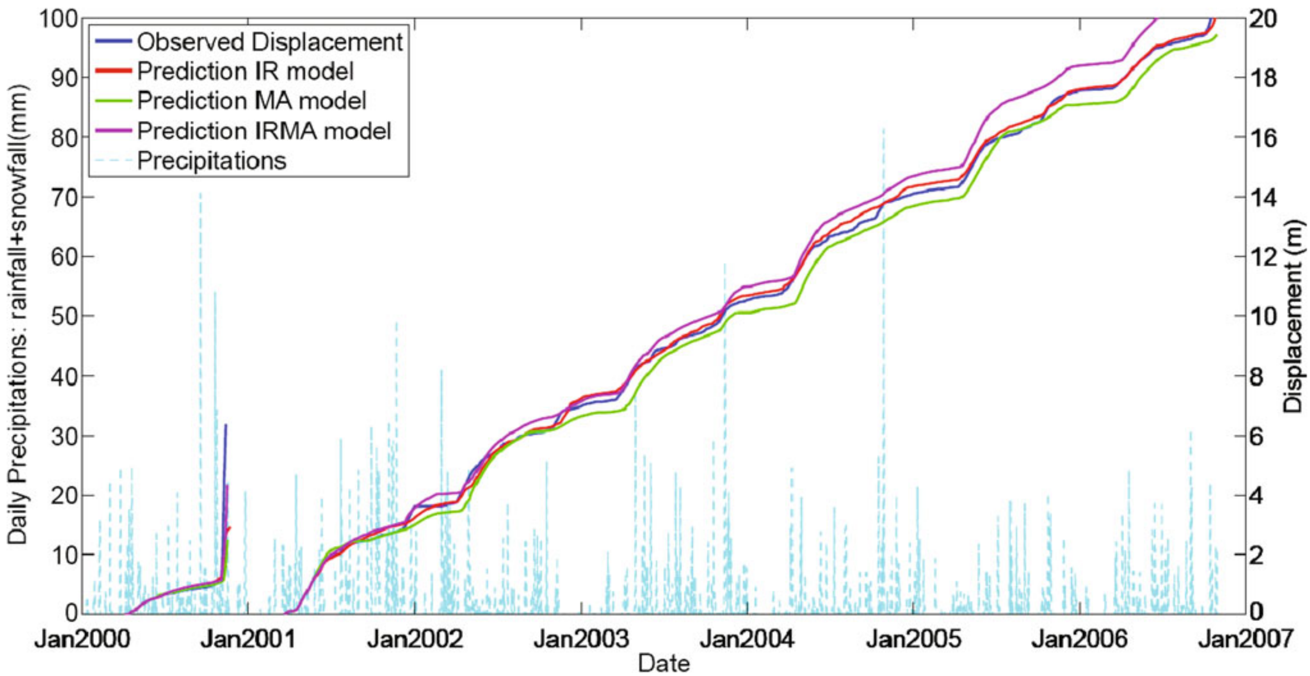

Fig. 108.1 Predicted and observed cumulated displacements for the Super-Sauze landslide from 2000 to 2006

based on a binary classification (e.g. occurrence or not of a landslide). Analysing the temporal component of a landslide constitutes thus a major improvement in the development of forecasting methods, as suspended and dormant landslides can be reactivated in periods of heavy rainfall, while active landslides may show phases of acceleration and deceleration (Flageollet 1996; Corominas et al. 2005).

The objective of this work is thus to present the application of a combined statistical-mechanical model to investigate multi-parametric times series of landslide displacements, pore water pressure and rainfall in order to define possible causal inferences among the triggers and the responses of the slope, and to predict the slope kinematics.

108.2 Forecasting Models

Three combinations of models are tested. The first model uses a statistical impulse response (IR) function (Belle et al. 2013), which allows to predict the changes in the landslide rate by computing the transfer function between an input signal (e.g. time series of precipitation) and an output signal (e.g. displacements). The second model uses a simple 1D mechanical (MA) model which combines a simple 1D infiltration model and a visco-plastic rheology to take into account changes in pore water pressures (Herrera et al. 2009). The third model (IRMA) is a combination of the two previous ones; the IR model allows obtaining the groundwater level from the precipitation time series, and the visco-plastic model is applied using the computed groundwater level time series to simulate the displacements.

The performances of the different combinations of models have been evaluated in a previous study (Bernardie et al. accepted), and the results show that the three combinations are complementary according to the different contexts, and should therefore all be considered in parallel.

108.3 Results and Discussions

In order to test the ability of the methodology to be used in an operative alert system delivering daily warnings in nearly real time, a prediction procedure has been developed and tested. The method has been applied as if the new data were received each morning and treated in real time, on a daily basis. Hence, for each day, the "new" received data are added to the historical time series. The models are calibrated, over time windows with different lengths. The optimal calibration is then used to predict the displacement for the following days, based on the meteorological data of the next days, assumed to be meteorological predictions. The procedure is then repeated for the next day, with a new calibration, and so on.

This methodology has been applied to three landslides located in the French Alps and observed by the OMIV (Observatoire Multidisciplaine des Instabilités de Versants)[1]:

[1] http://omiv.osug.fr/.

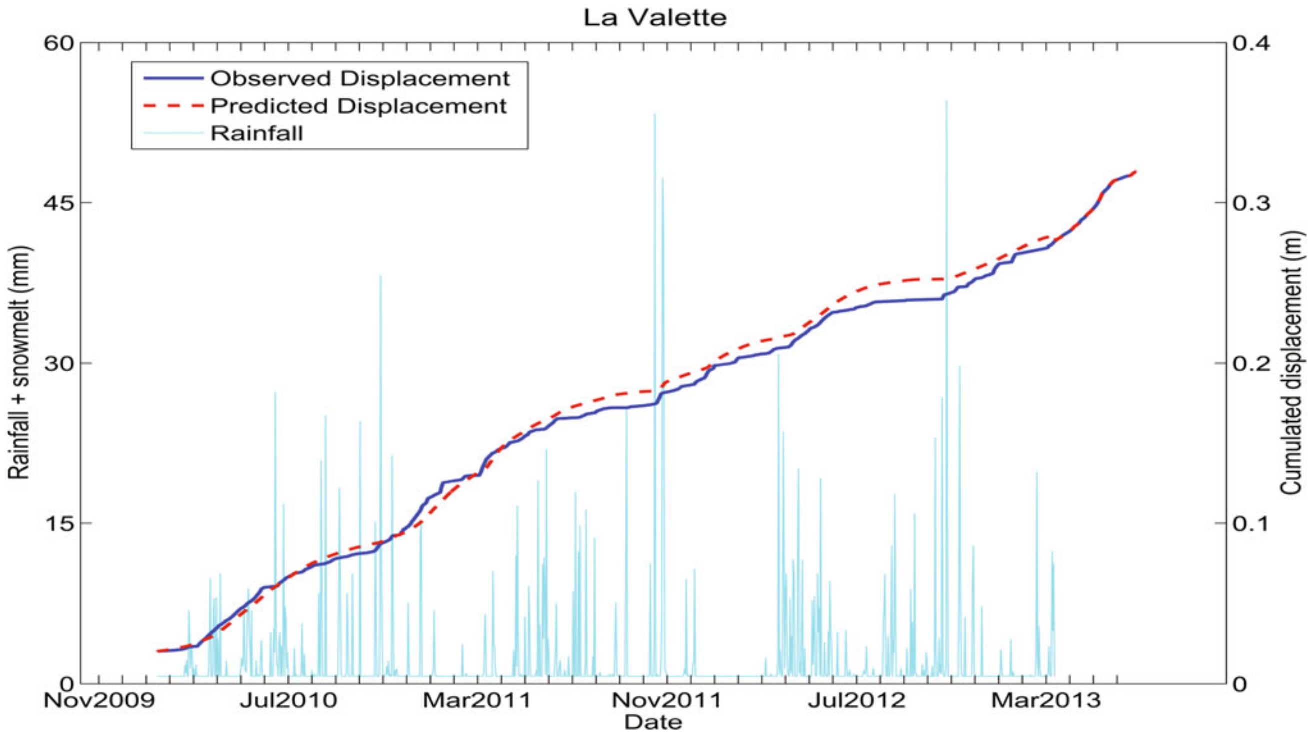

Fig. 108.2 Observation and prediction of displacement at La Valette landslide for the 2009–2013 period (model MA)

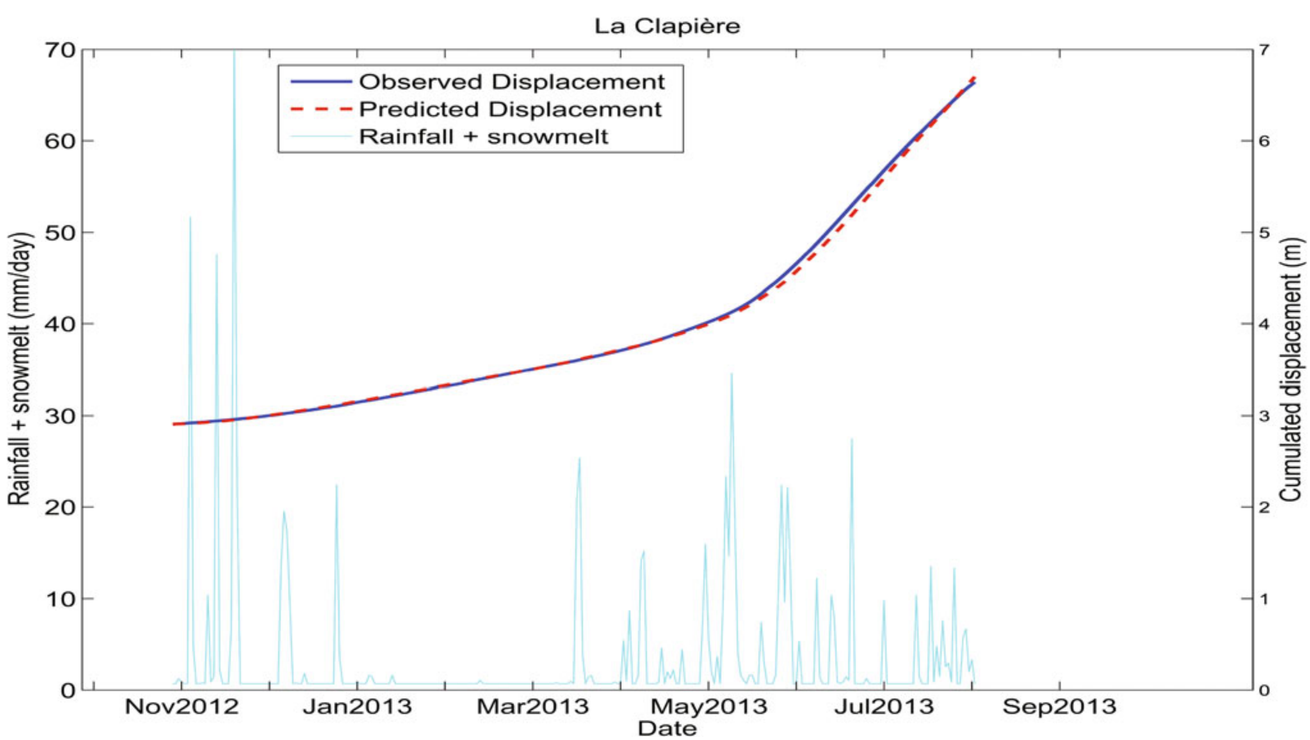

Fig. 108.3 Observation and prediction of displacement at La Clapière landslide for the 2012–2013 period (model MA)

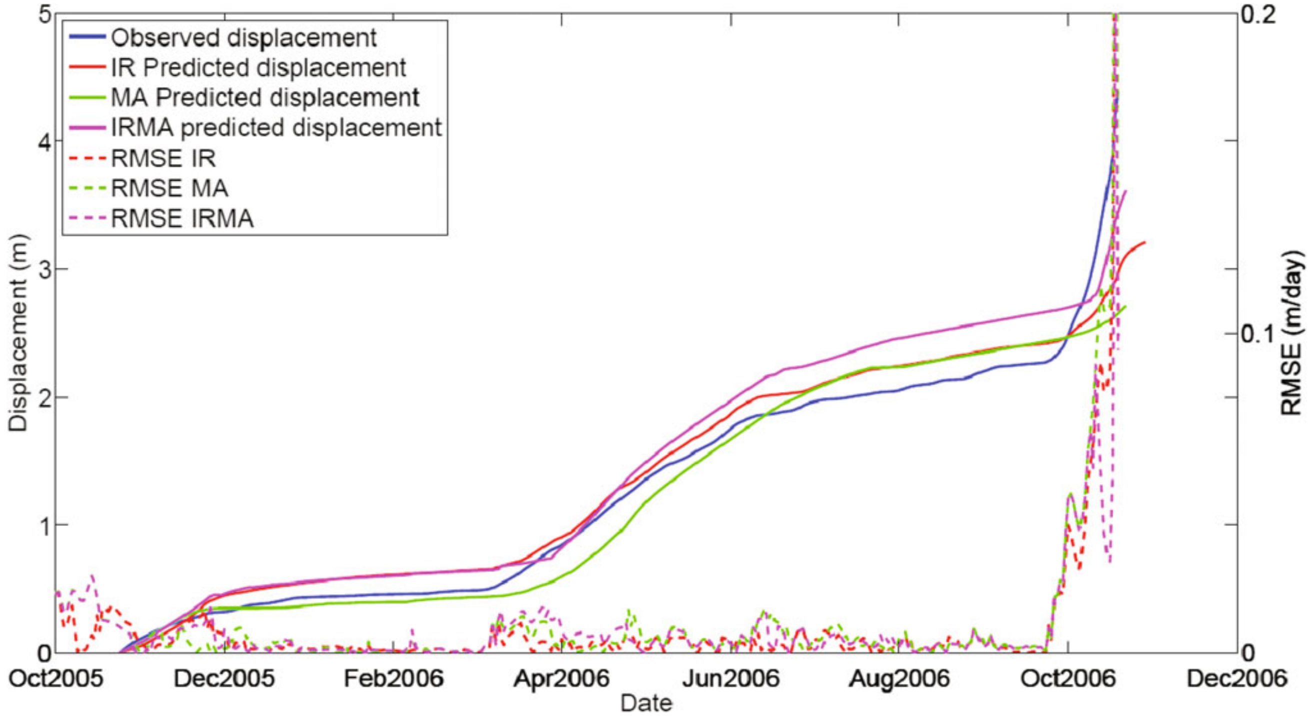

Fig. 108.4 Observation and prediction of displacement before the 2006 fluidization event at Super-Sauze landslide

Table 108.1 Performance of the model, in days before the event, to re-predict the fluidization events which occurred on the Super-Sauze landslide in 2000, 2006 and 2012

Delay in day	2000 fluidization		2006 fluidization		2012 fluidization	
	T1	T2	T1	T2	T1	T2
Observed velocity	11	11	7	19	13	16
Model IR	11	11	3	11	14	16
Model MA	11	11	2	11	N/C	N/C
Model IRMA	8	9	10	19	N/C	N/C

T1 and T2 correspond to the two thresholds used on the RMSE

Super-Sauze landslide, La Valette landslide and La Clapière landslide.

The Super-Sauze landslide is a continuously active landslide, and is typical of flow-type gravitational processes developed in Callovo-Oxfordian clay shales. The different models are able to predict the displacement in normal regime with very good accuracy (Fig. 108.1).

La Valette landslide is also an active landslide within the black marls. The model MA proves to be the most suitable model fort this landslide (Fig. 108.2).

Finally the models have been applied to La Clapière landslide, which is a rock landslide. It reproduces well the displacements in a normal regime with the MA model (Fig. 108.3).

The Super-Sauze landslide has been analysed over 13 years, during which three fluidization events occurred: in 2000, 2006 and 2012, but they diverge some days before the crisis (Fig. 108.4). This divergence is measured thanks to the RMSE (Root Mean Square Error) between the observed velocity and the model. This interesting result suggests that the RMSE variation could be a good indicator of the occurrence of a fluidization event several days before the occurrence of the event itself. It is then essential to find rigorous thresholds for warning the occurrence of a catastrophic fluidization event. The two proposed thresholds are based on the normal law distribution of the RMSE values, with the use of a threshold equal to the mean of the RMSE plus three standard deviation values of the RMSE (T1) and the second one (T2) equal to mean of the RMSE plus one standard deviation values of the RMSE. With these thresholds, the prediction capabilities of the different models are proved to be fairly good in term of time of delay according to the selected threshold (Table 108.1).

We can observe that the delay is similar to the criteria derived from velocities for most of events; for the 2006 and 2012 fluidization events, the T1 thresholds provide better delays than with observed velocities. Moreover, our method has the advantage to be based on the analysis of several parameters (such as precipitation and displacements), making the early warning system potentially more robust.

108.4 Conclusions

The capability to predict the complex displacement pattern (acceleration, deceleration) of landslide is an important issue for early-warning. Most of the current alarm systems are based on simple criteria, such as cumulated precipitation thresholds, which can provide false alarms and make them therefore unreliable for people. Therefore, we developed and validated a methodology to combine meteorological observations with statistical and mechanical models to simulate the kinematics of landslides in their normal regime. Its ability to predict the occurrence of fluidization events makes it a good candidate for an early warning system. The next step is to automatize the procedure, in real time, with direct connexions to sensors and to meteorological parameters, both observed and forecast. Its relative simplicity, with no consideration of complex sites specifications makes it easier to export it to other application cases.

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