A Multi-Temporal Image Correlation Method to Characterize Landslide Displacements

J., TRAVELLETTI [a], J.P. MALET [a], J. SCHMITTBUHL [a], R. TOUSSAINT [a], C. DELACOURT [b] & A. STUMPF [c]

[a] CNRS - University of Strasbourg, School and Observatory of Earth Science, Strasbourg, France.
[b] European Institute of Marine Studies, University of Western Brittany, Brest, France.
[c] ITC, Faculty of Geo-Information Science and Earth Observation, University of Twente, Enschede, Netherlands.
Contact: julien.travelletti@eost.u-strasbg.fr / jeanphilippe.malet@eost.u-strasbg.fr

Objectives

This work presents a method to characterize the displacement pattern of slow moving landslides from multitemporal optical, very high resolution images by using Digitial Image Correlation (DIC) (DELACOURT et al., 2007). The method is applied on the Super-Sauze mudslide (South French Alps) (Figure 1), which exhibits velocities from 0.01 to 0.4 $m.d^{-1}$ (MALET et al., 2002). The performance of the method is discussed by analyzing the displacement pattern during an important acceleration in the period May–July 2008.

Image Acquisition

The monitoring system consists of a low-cost Nikon D80 camera (1000 USD) installed on a concrete pillar located on a stable crest in front of the mudslide (Figure 1). The camera is controlled by a data-logger (CR10) and the power is provided by a 40 W solar panel. Every four days, 4 photographs are registered at 11:00 a.m., 12:00 p.m., 13:00 p.m. and 14:00 p.m.. Each photograph (6 Mb) is stored in a native file format without any loss of information.

DIC: Digital Image Correlation Technique

The DIC method determines the maximum of cross correlation between small zones extracted from the images. The maximum corresponds to the displacement (translation) vector of the considered zone. By changing the zone of interest, it is then possible to determine displacements at various positions inside the photographs (CHAMBON et al., 2003).

The use of a multi-resolution correlation algorithm is motivated by the necessity:
- to avoid incoherent results due to changes in landslide surface aspect (soil moisture changes, soil surface weathering) and changes in illumination
- to identify and characterize heterogeneous distributed displacement fields.

The correlation technique is based on:
- successive degradations of image resolution for changing the physical size of the interest zone. The correlator starts at the lowest resolution image for determining global displacements, then the location of the maximum cross correlation is used as a start point for the next correlation with a higher resolution to determine local displacements.
- correlation of gradient values by using an edge detection algorithm (Sobel or Prewitt operators), applied on the images to identify object texture (through an estimation of the gradient image intensity function).

Conversion of Pixel Displacement to Ground Surface Displacement

Because stereoscopic view of the mudslide is not possible, a method using projective transformation is used to associate the pixel coordinates of the image plane (in 2D) to ground coordinates (E, N, Z) of the local coordinate system (in 3D) using DEMs interpolated from airborne LiDAR datasets (Figure 2) (HEEGER, 1998). In the conversion, the global morphology of the mudslide is assumed nearly invariant in time.

Results

Displacements in the Image Plane

The accuracy in pixel displacements is estimated on stable areas outside the landslide (Figure 3, red square); in this area, the residual pixel shift is less than 1 pixel after correction of slight rigid movements of the camera.

The amplitude and direction of pixel displacements point out distributed displacement (Figure 3). During the acceleration period, the kinematics of the upper part of the landslide is more important than the lower part in terms of pixel velocity, assuming that a pixel in the upper part covers a larger ground surface (about 5.10^{-2} m^2) than a pixel in the lower part (2.10^{-3} m^2). The maximum velocity is observed at the beginning of June 2008.

Displacements in the Ground System

The close to null displacements observed in the stable area allow to estimate an average accuracy of 0.10 m in the ground surface coordinate system. The displacement fields are coherent with the topography and previous knowledge on landslide kinematics (MALET et al., 2002) (Figure 4A, B, C, D, E). The displacements vary temporally and spatially. The difference in horizontal displacements between the upper part (10.5 m in 4 days) and the lower part (1.1 m in 4 days) is clearly noticeable (Figure 4A). The displacement maps show that the kinematics is mainly controlled by the buried topography.

Conclusion

Digital Image Correlation (DIC) of terrestrial optical imagery is a powerful and low-cost tool to monitor the displacement pattern of slow-moving landslides. After conversion of pixel coordinates into metric coordinates, the displacement pattern is coherent with the topography and previous knowledge. Acquisition of accurate DEMs is important to improve the accuracy of the computed displacement field in the ground local reference system. Comparisons of displacements with control points measured with DGPS will be used to further validate the methodology. Inversion of the displacement field will be developed to characterize the macroscopic geomechanical properties of the landslide material.

References

CHAMBON, G., SCHMITTBUHL, J., CORFDIR, A., VILOTTE, J.-P. & ROUX, S. (2003): Shear with comminution of granular material: microscopic deformations outside the shear band, Phys. Rev. E, 68, 011304.

DELACOURT, C., ALLEMAND, P., BERTHIER, E., RAUCOULES, D., CASSON, B., GRANDJEAN, P., PAMBRUN, C. & VAREL, E. (2007): Remote-sensing techniques for analysing landslide kinematics: a review. Bulletin de Société Géologique, 178, 89–100.

HEEGER, D. (1998): Notes on Motion Estimation. Available at ftp://white.stanford.edu/users/heeger/psych267/mot.

HILDS F. (2003): Mesure de champs de déplacement par corrélation d'images et applications en mécanique des solides, Notes de cours IPSI. Laboratoire de Mécanique et Technologie, CNRS-UMR 8535, Université Paris 6, France.

MALET, J.-P., MAQUAIRE, O. & CALAIS, E. (2002): The use of Global Positioning System for the continuous monitoring of landslides. Application to the Super-Sauze earthflow (Alpes-de-Haute-Provence, France), Geomorphology, 43, 33–54.

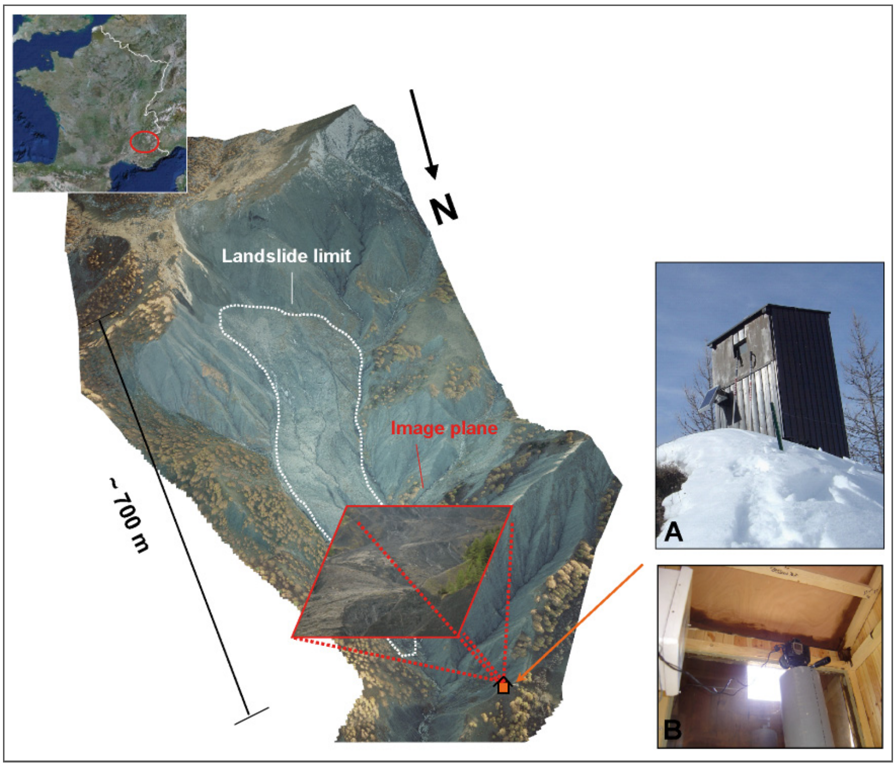

Fig. 1: View of the Super-Sauze landslide towards the South. The orange square represents the location of the camera (in a hut, A) where a high resolution camera is installed (B). The red square represents the image plan of a photograph taken by the camera.

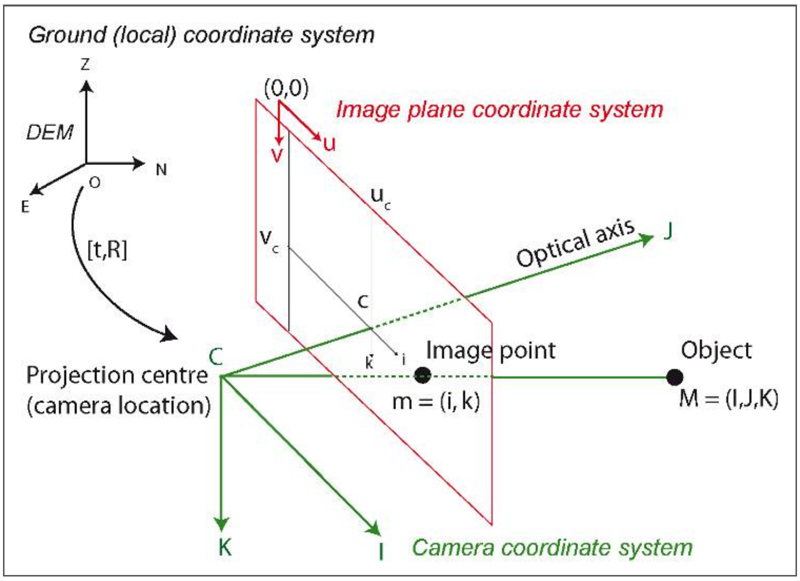

Fig. 2: Coordinate systems used in the conversion procedure.

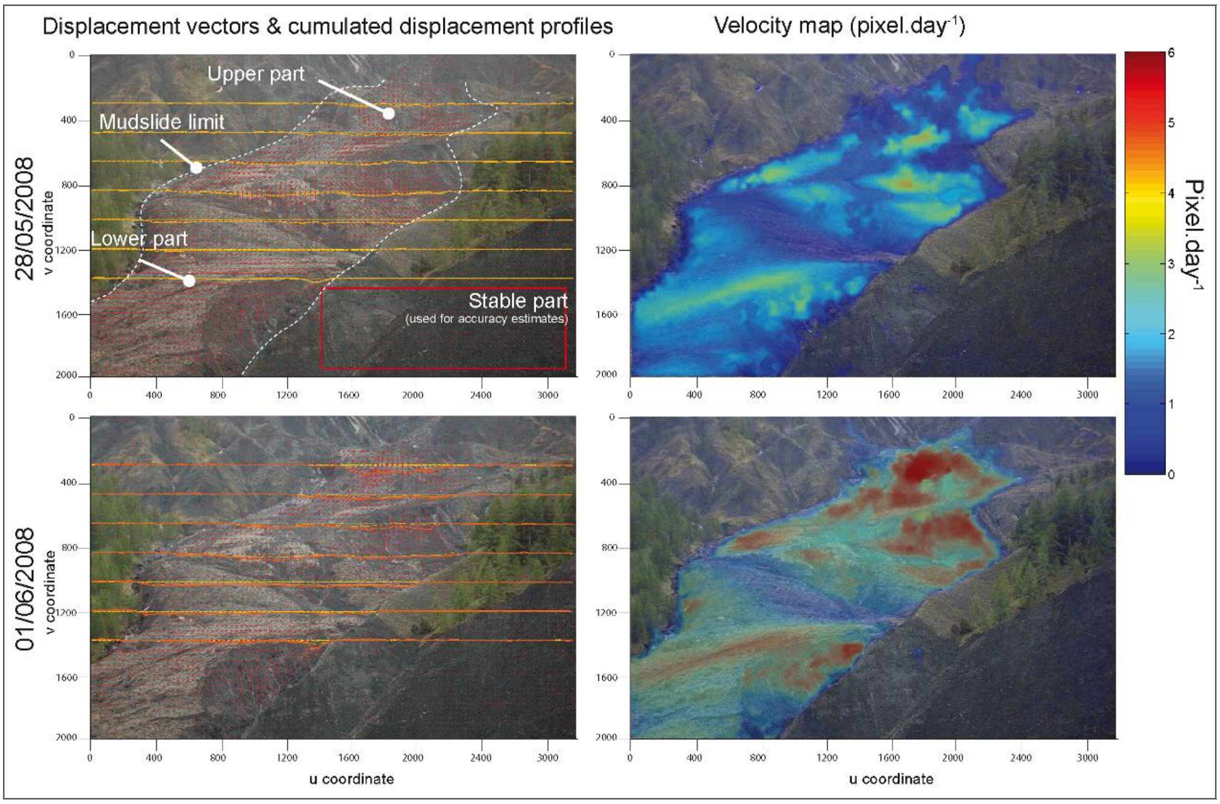

Fig. 3: Displacement vectors, cumulated displacements and velocity maps in the image plane coordinate system. Period: 28th May 2008 – 6th June 2008.

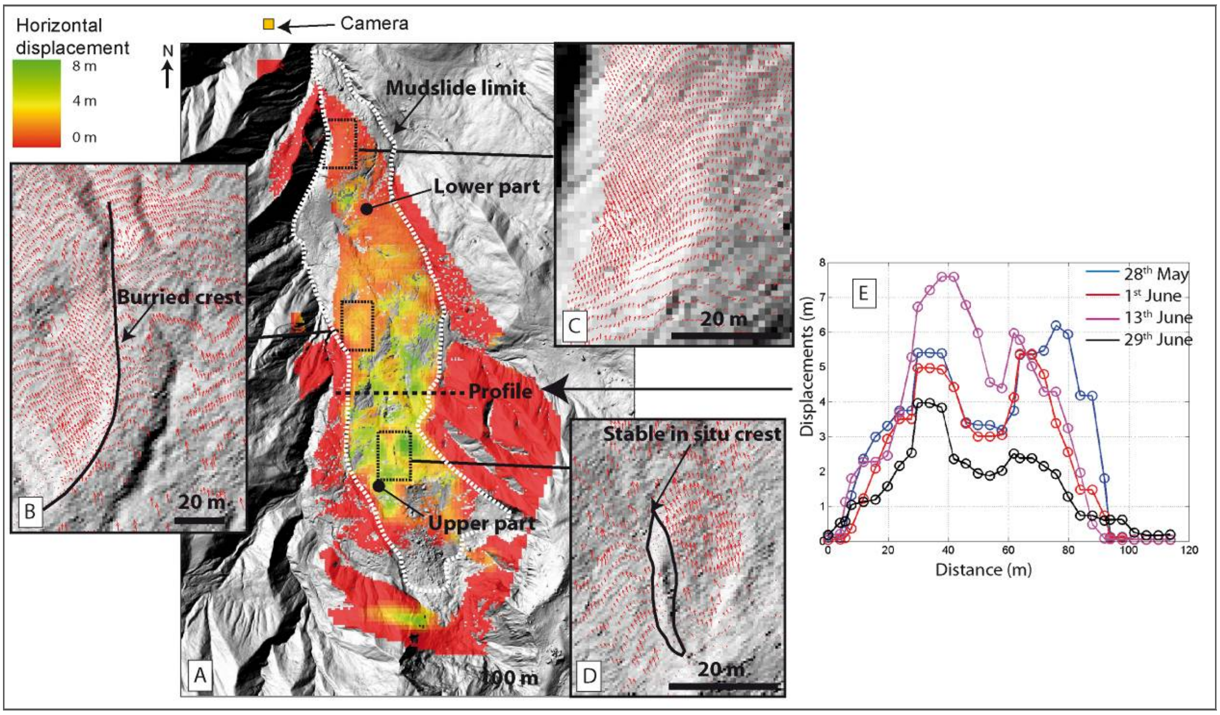

Fig. 4: A) Horizontal displacements in the period 28th May – 1st June 2008, B) Amplitude and direction of displacement vectors nearby a buried crest, C) Displacement vectors in the lower part, D) Displacement vectors nearby an in-situ crest. E) Profiles of cumulated displacements over 4 successive periods of 4 days.