UAV-based remote sensing of the slow-moving landslide Super-Sauze

U. Niethammer, S. Rothmund & M. Joswig
Institute for Geophysics, Universität Stuttgart, Stuttgart, Germany

ABSTRACT: In this paper we present the results of a remote sensing approach based on unmanned aerial vehicles (UAV), which enables high-resolution acquisition of slow moving landslides. We introduce the concept of a low cost UAV system and the image-processing based evaluation of the acquired photographs. In October 2008 a series UAV-borne photographs was acquired. These photographs have been combined to an ortho-mosaic of the Super-Sauze mudslide. The achievable ground cell resolution was in the range between 3 cm to 8 cm. A comparison between the achieved ortho-mosaic and an airborne ortho-mosaic from 2007 has been carried out. In the period between May 2007 and October 2008 displacements, varying between 2.7 m and 55.4 m have been detected and different structures, indicating variable deformation and sedimentation processes at the surface of the slope have been identified.

1 INTRODUCTION

"There are many problems in predicting the behaviour of slow moving landslides" (van Asch et al. 2007). For the understanding of the complex behaviour of slow-moving landslides many morphological, hydrological and geophysical studies are required. Especially for slow moving landslides high-resolution information of the sliding surface is of great interest (Henry et al. 2002).

Remote sensing information of landslides acquired by conventional airborne and spaceborne sensor systems is available for a few decades. However, due to the high costs to this methods and the limited spatial and temporal resolution scientists are beginning to turn to unpiloted aerial vehicles (UAV) as a low-cost alternative.

During our UAV pilot studies in 2006 at the Heumoes landslide (Austria, Vorarlberg) it turned out that reliable and flexible UAV-based remote sensing campaigns should be processed independent, especially if short-term campaigns have to be managed. So we started the comprehensive research of UAV-based remote sensing especially for monitoring landslides in 2007.

Our research focused on the development of a reliable low-cost UAV solution and on the image processing chain generating ortho-mosaics. In recent and further studies we will show the potential of this approach for displacement analysis and geophysical mapping of soil moisture and fracture processes.

2 STUDY AREA

The Super-Sauze mudslide is located on the North-facing slope of the Barcelonnette Basin (Southern French Alps). The landslide has developed in a torrential basin located in the upper part of Sauze torrent, on the left side of the Ubaye valley. It is one of the persistently active landslides (since the 1970's). It extends over a horizontal distance of 850 m and occurs between an elevation of 2105 m at the crown and 1740 m at the toe with an average of 25° slope. Its total volume is estimated to be 750,000 m^3 and velocities range from 0.01 m up to 0.4 m.day^{-1} (Malet et al. 2003).

3 FLIGTH MISSIONS

In July 2008 we ran a first test for a remote controlled quad-rotor remote sensing platform at the Super-Sauze mudslide. The achievable altitude over ground was in the range between 20 m and 200 m. The covered area was about 300 m x 100 m. In October 2008 we performed a second mission in order to cover the whole sliding area of 850 m x 250 m.

4 FLIGTH HARDWARE

Quad-rotor systems basically enable close-range photographs of any desired area. Compared to

conventional helicopters, quad-rotors do not require mechanical steering of the rotors, and an expensive and large rotor-unit is not required. Especially in steep alpine terrain difficult landings always may be occur and a fast exchange of the rotors is often necessary. Our developed quad-rotor system consists of an inertial measurement unit (IMU), including three acceleration sensors, three gyroscopes, a three-axis compass, a pressure sensor, and is regulated by basic PID-loops. For some time now there have been open source software-projects available providing a good basis to manage this PID-regulation (UAVP, 2008), (mikrocopter, 2008). In our studies we developed a robust and reliable flight-frame, and enhanced an open source project (mikrocopter, 2008) by modifications of the software and the electronic circuit.

Table 1. Characteristics of the developed quad-rotor system.

Diameter	60 cm
Total weight	2100 g
Payload	500 g
Flight time	12 min
Material costs	1000 €

Figure 1. Quad-rotor for remote controlled picture surveys.

5 GROUND CONTROL POINTS

Well visible ground control points (GCPs) were required for the image processing. Each GCP references a known world-location to the visible location in the acquired photograph. This GCP information was necessary, since image rectification and image geocoding had to be carried out. In our campaign we marked 199 GCPs on the sliding area. The spatial measurement of the GCPs was managed within some centimeter deviation using a DGPS system. The DGPS measurement was performed in cooperation with University Louis Pasteur, Strasbourg.

6 IMAGE ACQUISITION

A low budget digital compact camera that supports manual camera settings was used. For all flights the camera was fixed to ISO 200 at F2.8 and a focus of 6.2 mm. These ratings revealed an average shutter speed of 1/800 s.

Table 2. Camera Practica Luxmedia 8213

Sensor size	1 / 2.5"
Resolution	3264 x 2448
Lens	F2.8 to F5.2
Focus	6.2 mm – 16.6 mm
Shutter speed	1/2000 s
Sensitivity	ISO 50 – ISO 1600
Weight	110 g
Total costs	100 €

7 SINGLE IMAGE PROCESSING

7.1 Lens rectification

In the wide-angle range one can often observe barrel distortion, especially for poor cameras. The barrel distortion can be corrected by a third degree polynomial correction approach:

$$r_{src} = \left(a r_{dest}^3 + b r_{dest}^2 + c r_{dest} + d \right) r_{dest} \qquad (1)$$

r_{src} and r_{dest} refer to the normalized radius of an image pixel and the coefficients a, b, c describe the lens distortion parameters. This approach is available within an open source project (Hugin, 2008) and was applied to all acquired photographs.

7.2 Projective ortho-rectification

The plane projective rectification can be applied by the following equations (Luhmann, 2000):

$$X = \frac{a_0 + a_1 x + a_2 y}{1 + c_1 x + c_2 y} \qquad Y = \frac{b_0 + b_1 x + b_2 y}{1 + c_1 x + c_2 y} \qquad (2)$$

X, Y are object coordinates, x, y are image coordinates, and a_0, a_1, a_2, b_0, b_1, b_2, c_1, c_2 are transformation coefficients. With this approach, object- and image-coordinates of at least four GCPs per picture are required. The coefficients a_0, a_1, a_2, b_0, b_1, b_2, c_1, c_2 were obtained solving the system of equations:

$$X_i = a_0 + a_1 x_i + a_2 y_i - c_1 x_i X_i - c_2 y_i X_i$$
$$Y_i = b_0 + b_1 x_i + b_2 y_i - c_1 x_i Y_i - c_2 y_i Y_i \qquad (3)$$
$$i \in \mathrm{N} \cap i \in [1..4]$$

7.3 Manual ortho-mosaic processing

All single images had to be combined to one large ortho-mosaic. In our studies this was performed after the manual plane projective rectification of each photograph. Especially on steep slopes the applied plane image rectification was weak and large errors occurred. Those errors could be minimized by the comparison of any visible GCP location in the photograph to the DGPS-measured location within a raster-based geographic information system (GIS). Weak areas were cut manually before the final assembly of the rectified images was performed. Uniformly colored mosaics were of great interest since a representative analysis of the data had to be possible. This was managed by a radiometric color-balance correction in conjunction with an image-blending algorithm.

In our studies the ortho-mosaic processing was performed within the software OrthoVista (OrthoVista, 2008). Furthermore the acquired ortho-mosaic was geocoded, being able to perform a displacement analysis within a raster-based geographic information system.

8 BUNDLE BLOCK PROCESSING

Creating high-resolution, large-scale ortho-mosaics and digital terrain models (DTMs) by photogrammetric analysis, the bundle block adjustment method can be applied.

This procedure requires a horizontal overlap between the individual images of approximately 60 % and a vertical overlap of approximately 30 % (Linder, 2006). In our actual studies this requirement wasn't reachable. In order to meet these conditions an autonomous flying UAV is required. However, stereographic image analysis seems to be manageable without having autonomous UAVs and will be carried out in our further analysis.

9 MORPHOMETRIC ANALYSIS

Morphometric changes principally are quantified by subtraction and correlation of digital terrain models (DTMs), as well as correlation ortho-photo sections from different periods.

In May 2007 an aerial LIDAR scan of the Super-Sauze mudslide was acquired. During this campaign a DTM, and an ortho-photograph were created. The achieved spatial resolution of the DTM data is 1.0 m, the resolution of the ortho-photograph is at about 0.25 m.

All morphometric analysis was managed by the comparison of the geocoded ortho-photograph from May 2007 and the geocoded ortho-mosaic of our UAV-based campaign in October 2008.

9.1 Analysis of the displacement field

Superficial displacement rates were identified directly by comparison of rocks, stones and parts of the vegetation patches between the ortho-photograph from 2007 and our acquired ortho-mosaic from 2008. This measurement has been performed manually within a raster-based GIS. During the period between May 2007 and October 2008 displacements in the range between 2.7 m to 55.4 m were detected in planimetry (Figs. 2-6).
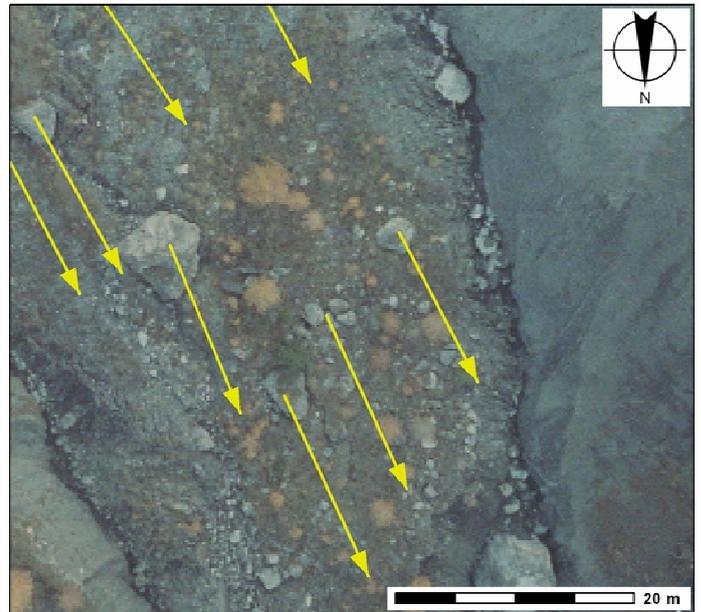
Figure 2. Displacement at the toe of the landslide (May 2007).
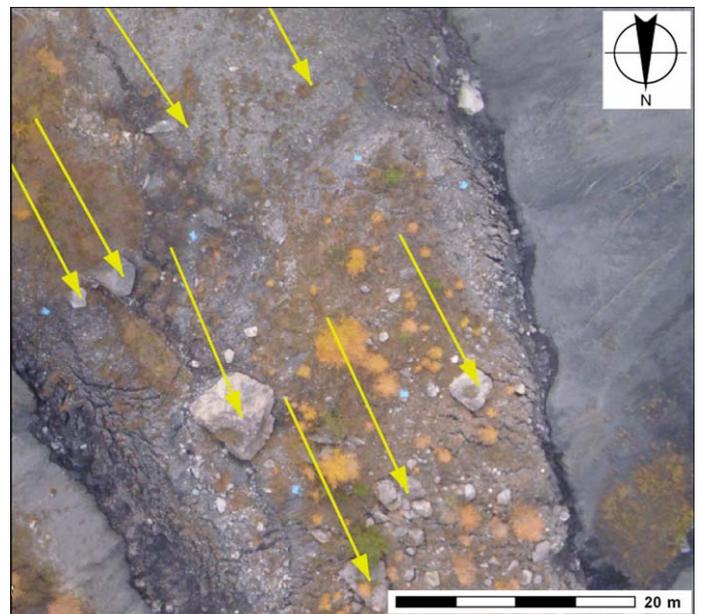
Figure 3. Displacement at the toe of the landslide (Oct. 2008).

9.2 Analysis of fissures

The properties of landslide materials over various scales and the extent to which they are dominated by porous media versus discrete fissure behaviour are currently still poorly characterized (de Montety, 2006). The spatial resolution of the acquired UAV based ortho-mosaic now allows for a detailed large-

scaled analysis of landslide materials and fissure structures. In our acquired ortho-mosaic of October 2008 fissure structures are clearly detectable. In Figures 4-5 (reduced resolution), for example, it is evident that despite an apparent movement of the sliding surface, fissures linger on the same place. Based on detailed previous mappings (Flageollet et al., 1999) within this area a buried crest can be identified.
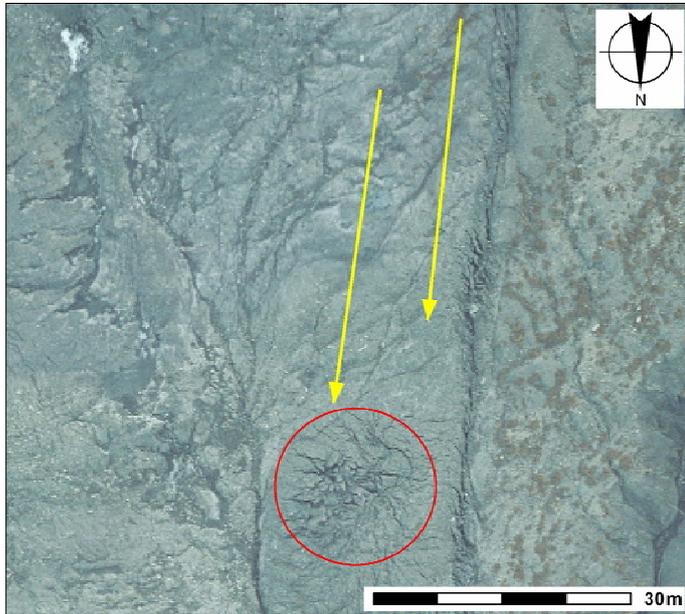
Figure 4. Displacement, fractures and soil moisture (May 2007).
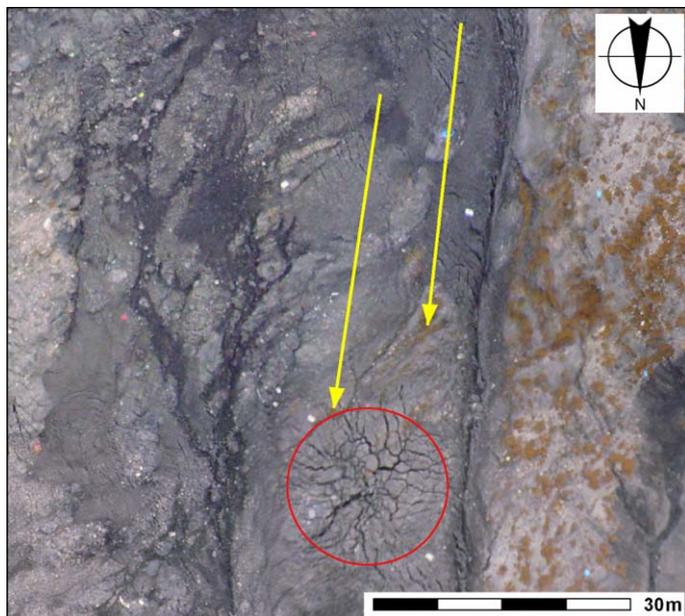
Figure 5. Displacement, fractures and soil moisture (Oct. 2008).

10 HYDROLOGIC ANALYSIS

Infiltration, circulation depths and residence times of landslide groundwater are poorly understood. Such a characterization potentially can be supported with the help of high-resolution remote sensing information of the surface of the landslide. The quality of the acquired photographs possibly allows for an additional, comprehensive soil moisture analysis of the surface of the mudslide.

Figure 5, for example, indicates that the soil moisture of the middle part of the flow is clearly visible.

During our flight campaign in October 2008 soil moisture samples of the landslide were taken. But since this data hasn't been available for this study, yet the relation between these field measurements and the suspected wet areas in the acquired ortho-mosaic has to be carried out in our further studies.

11 RESULTS

During the flight campaign in October 2008 we acquired 1486 airborne photographs. The best 51 suitable photographs were separately rectified and combined to an ortho-mosaic of the entire sliding area (Fig. 6a). The spatial resolution of the resulting ortho-mosaic is in the range of 3 cm to 8 cm.

Analysis of the displacement was possible and errors could be taken into account. The maximum deviation within the boundary of the sliding area reaches 3.9 m and the mean error can be quantified to be 0.5 m.

Varying directions of flow could be determined from visible superficial shift directions (Figs. 2-6). Areas which were characterized by extremely high displacement rates (Fig. 6a, area 3) couldn't be compared, since no clear detectable features were left on the surface. In some areas features also were covered by fine-grained sediments possibly resulting from debris flows (Fig. 6a, area 3, left part and Fig. 6a, area 4).

The upper shelf of the slope (Fig. 6a, area 1), the source area, is characterized by huge blocks and enormous dynamics, e.g. rockfalls. Area 2 in Figure 6a is more or less stable, indicated by the vegetation and the lower displacement rates.

The identified displacement vectors were converted to daily displacement rates and compared to previous displacement measurements (Malet et al. 2002), (Fig. 6b). The acquired displacement rates of our studies are up to ten times higher in the source area, and in the remaining part of the landslide approximately two times higher than the actual average rates (Fig. 6b). This deviation might be explained by stronger dynamics in recent years. The location of the area of the strongest dynamic (Fig. 6a, area 3) agrees very well with the boundary of the average displacement map (Fig. 6b).
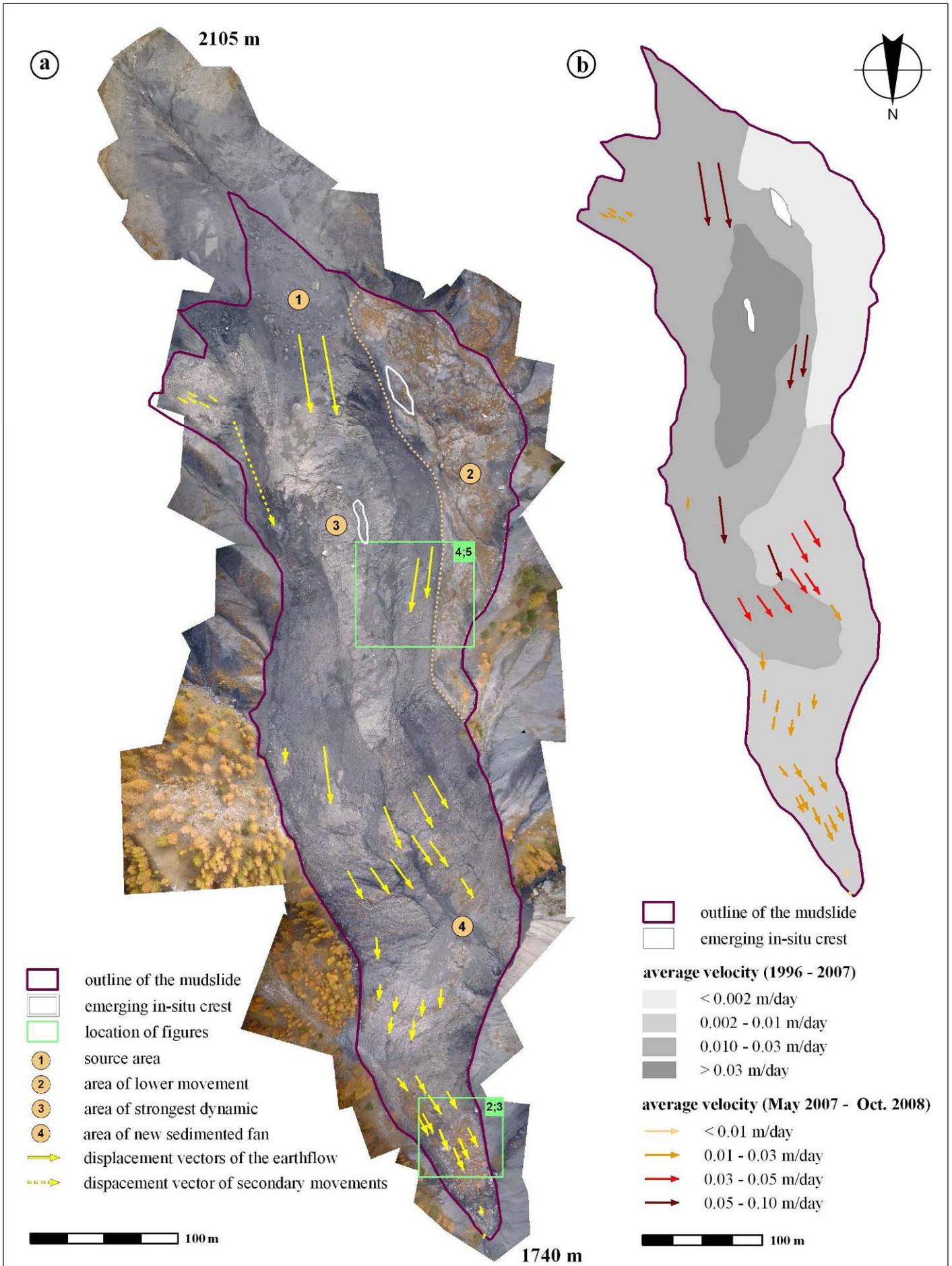
Figure 6. Kinematics of the Super-Sauze landslide. (a) Ortho-mosaic of October 2008, displacement vectors (May 2007 – October 2008). (b) Mean average velocity map (1996 – 2007) related to the displacement rates (May 2007 – October 2008).

12 CONCLUSIONS

In our studies we could show that low-cost UAVs provide high-resolution remote sensing information of landslides. The acquired ortho-mosaic shows great potential for analysis of morphometric and hydrologic behaviour of the studied landslide. Different structures indicated variable deformation and sedimentation processes at the surface of the slope.

The achievable spatial resolution was in the range between 3 cm to 8 cm. The maximum deviation of the UAV-based ortho-mosaic reached 3.9 m and the mean error was quantified to 0.5 m. The comparison between our achieved ortho-mosaic and the airborne ortho-mosaic from 2007 showed displacements, varying between 2.7 m and 55.4 m. The displacement rates of our studies were up to ten times higher in the source area, and in the remaining part of the landslide two times higher than average displacement rates between 1996 and 2007. This deviation might be explained by stronger dynamics in recent years.

The location of the strongest dynamic agreed very well with the average displacement map. Since areas which were characterized by extremely high displacement rates could not be compared to the ortho-mosaic of 2007, this limitation has to be resolved by applying more frequent flight campaigns.

In further steps a stereographic photogrammetric analysis can be applied, providing partial DTMs of the most interesting areas of the landslide. Since comprehensive UAV-based photogrammetric analysis has been carried out by high-quality UAVs and navigation systems (Eisenbeiss et al. 2005), this might be possible, too, using low-cost equipment in our further studies.

REFERENCES

De Montety, V., Marc, V., Emblanch, C., Malet, J.-P., Bertrand, C., Maquaire, O., Bogaard, T.A. 2007. Identifying the origin of groundwater and flow processes in complex landslides affecting black marls: insights from a hydrochemical survey. *Earth Surface Processes and Landforms* 32(1): 32-48.

Eisenbeiss, H., Lambers, K., Sauerbier, M. 2005. Photogrammetric recording of the archaeological site of Pinchango Alto (Palpa, Peru) using a mini helicopter (UAV). In *Proc. of the 33rd CAA Conference, Tomar, Portugal, 21-24 March 2005.*

Fowers, S.G. 2008. *Stabilization and Control of a Quad-Rotor Micro-UAV Using Vision Sensors.* Master Thesis, Brigham Young University, 89 p.

Flageollet, J.-C., Malet, J.-P., Maquaire, O. 1999. The 3D structure of the Super-Sauze earthflow: a first stage towards modelling its behaviour. *Physics and Chemistry of the Earth* 25(9): 785–791.

Henry, J.-B, Malet, J.-P., Maquaire, O., Grussenmeyer, P. 2002. The use of small-format and low-altitude aerial photos for the realization of high-resolution DEMs in mountainous areas: application to the Super-Sauze earthflow (Alpes-de-Haute-Provence, France) *Earth Surface Processes and Landforms* 27(12): 1339-1350.

Hugin 2008. http://hugin.sourceforge.net

Linder, W. 2006: *Digital Photogrammetry: A Practical Course.* Heidelberg, Berlin, New York: Springer-Verlag.

Luhmann, T. 2003. *Nahbereichsphotogrammetrie: Grundlagen, Methoden und Anwendungen.* Heidelberg: Herbert Wichmann Verlag.

Malet, J.-P., Maquaire, O., Calais, E. 2002. The use of Global Positioning System techniques for the continuous monitoring of landslides: application to the Super-Sauze earthflow (Alpes-de-Haute-Provence, France). *Geomorphology* 43(1–2): 33–54.

Malet, J.-P. & Maquaire, O. 2003. Black marl earthflows mobility and long-term seasonal dynamic in southeastern France. In *Proceedings of the International Conference on Fast Slope Movements: Prediction and Prevention for Risk Mitigation*, Picarelli L. (ed.). Patron Editore: Bologna; 333–340.

Mikrocopter 2008. http://www.mikrokopter.de

OrthoVista 2008. http://www.inpho.de

UAVP 2008. http://uavp.ch

van Asch, Th.W.J., van Beek, L.P.H., Bogaard, T.A. 2007. Problems in predicting the mobility of slow-moving landslides. *Engineering Geology* 91(1): 46-55.