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A new technique for the detection of large scale landslides in glacio-lacustrine deposits using image correlation based upon aerial imagery: A case study from the French Alps

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ABSTRACT

Landslide monitoring has benefited from recent advances in the use of image correlation of high resolution optical imagery. However, this approach has typically involved satellite imagery that may not be available for all landslides depending on their time of movement and location. This study has investigated the application of image correlation techniques applied to a sequence of aerial imagery to an active landslide in the French Alps. We apply an indirect landslide monitoring technique (COSI-Corr) based upon the cross-correlation between aerial photographs, to obtain horizontal displacement rates. Results for the 2001–2003 time interval are presented, providing a spatial model of landslide activity and motion across the landslide, which is consistent with previous studies. The study has identified areas of new landslide activity in addition to known areas and through image decorrelation has identified and mapped two new lateral landslides within the main landslide complex. This new approach for landslide monitoring is likely to be of wide applicability to other areas characterised by complex ground displacements.

1. Introduction

Landslide monitoring is a very important part of any landslide hazard assessment, providing a measure of the rate and direction of slope movement in order to quantify any potential landslide risk. Different types of monitoring techniques can be employed, depending on the scale and frequency of observations required; they include in-situ instrumentation, but these provide movement data at a single location on the landslide; and are often difficult to install on very active landslides. Other options include remote ground based monitoring such as ground based radar (Monserrat et al., 2014), terrestrial laser scanning (Jaboyedoff et al., 2012; Delacourt et al., 2007; Teza et al., 2008) and multi-temporal terrestrial photography (Gance et al., 2014; Travelletti et al., 2012), but these require a clear line of sight in order to monitor the entire landslide effectively. By contrast, satellite and airborne remote sensing platforms offer better visibility and coverage of the ground surface by virtue of the vertical imaging geometry. Monitoring has been performed using digital photogrammetry applied to aerial imagery (Casson et al., 2003; Fabris et al., 2011), radar interferometry (Wasowski and Bovenga, 2014) and comparison of LiDAR derived elevation models (Daehne and Corsini, 2013). More recently, image matching has been applied to aerial and satellite imagery to monitor slope movement, by comparing two remote sensing images of a landslide from different dates to identify and quantify surface changes. This type of image matching or image correlation approach has been applied to landslide monitoring using aerial stereo-pairs and satellite imagery in this area, like aerial stereo-pairs used in La Clapiere landslide to understand its dynamics (Booth et al., 2013; Casson et al., 2003; Delacourt et al., 2007) and LiDAR point cloud data (Travelletti et al., 2012). However, there are no examples that use aerial photography and image matching as the basis for landslide monitoring. There may be occasions when satellite imagery or high resolution topographic data are unavailable, either due to the age of the movement or simply through a lack of data coverage. In these circumstances, the use of aerial photography can offer opportunities for landslide monitoring, whereby aerial imagery from two different dates can provide the basis for identifying and measuring landslide movement.

In this study, we present the application of an image matching technique to the study of an active glacio-lacustrine landslide in the French Alps, using *aerial photography* as a basis for the image correlation. This contrasts with previous studies that have princi-

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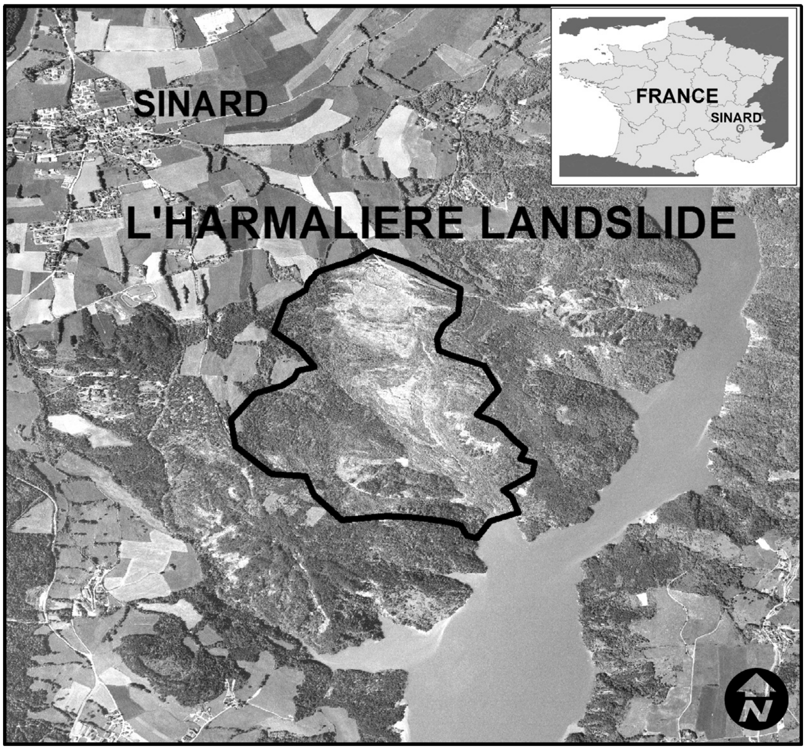

Fig. 1. Location and view of the Harmaliere landslide area with its outlines. It is situated near the village of Sinard, within the Drac valley 40 km south of the Grenoble city, France.

pally relied upon satellite platforms to provide the imagery for the comparison. We demonstrate the suitability of COSI-Corr software (Ayoub et al., 2009), to the study of landslide movement based upon aerial photography, rather than satellite imagery or topographic data; and identify the steps, information and conditions necessary for successful application to landslide monitoring. The technique has been applied in the Harmaliere landslide to firstly, identify areas of landslide activity and secondly, obtain horizontal displacement rates on the active part of the landslide.

1.1. Geological context and landslide study area

In France, some of the largest and most problematic landslides in the Alps are associated with Quaternary glacio-lacustrine deposits that infill many of the alpine valleys. These lake deposits typically consist of fine grained finely laminated (varved) silts and clays deposited in dammed lakes impounded by valley glaciers during previous glacial advances. The deposits have been exposed by the local river network that has cut down deeply into these clay formations; consequently, in many places, these deposits make up much of the slope forming materials within the valleys. The geotechnical nature of these deposits is such that this exposure has resulted in significant slope instability (Giraud et al., 1991; Van Asch et al., 2009).

The Harmaliere landslide, documented in this study, is located in the Trieves region of the French Alps, near the village of Sinard in the Drac valley, 40 km south of Grenoble in an area of extensive glacio-lacustrine deposit exposure (Fig. 1). Here the glacio-lacustrine deposits cover an area of 300 km^2 and were deposited in lakes impounded by the Isiere Glacier during the Wurm maximum episode (Van Asch et al., 2009). The thickness of the laminated clays in this region varies from 0 to 250 m, reflecting the uneven nature of the base of the lakes in which deposition took place. The deposits have been exposed by the local river network that has cut down deeply into these clay formations; consequently, in many places, including the Drac valley, these deposits make up much of the slope forming materials within the valleys. The geotechnical nature of these deposits is such that this exposure has resulted in significant slope instability, which poses a hazard to local population centres and infrastructure (Antoine, 1992; Giraud et al., 1991; Van Asch et al., 2009).

The Harmaliere landslide underwent a major initial movement in March 1981 following a period of quiescence. The main initiation event is illustrated in Figs. 2 and 3, the landslide is shown in its pre-failure state on aerial imagery acquired in 1948 (Fig. 2), this contrasts with the second image taken in 1981 (Fig. 3), just after the main activation, where the landslide can be seen to have undergone a major retrocession and advanced down the valley into the Lac de Monteynard (this lake was filled following completion of the Monteynard Dam in 1961 and so not visible in the earlier 1948 images). Since 1981 the landslide has retrogressed repeatedly through a number of episodic events at the head of the landslide in 1988, 1996 and 2001 (Bievre et al., 2011). In between, however the landslide has displayed evidence of mass redistribution throughout the slope and a number of lateral landslide events. Geotechnical investigations of the neighbouring Avignonet landslide indicates that the landslide movement in this area typically involves several slip surfaces at shallow depths of 5–15 m and depths of greater than 50 m (Jongmans et al., 2009). Consequently, a range of slide velocities are observed, as landslides of different depths respond to climatic events, such as rain and snow melt. Bievre et al. (2011) documented velocity variations between a few centimeters to several tens of metres per year across the Avignonet and Hermaliare slides, with a mean regression rate up to 10 m/year measured from aerial photographic analysis (Jongmans et al., 2009, 2008). Importantly, relict landslides are likely to be present in this area; given the length of time river erosion has been acting along the Drac valleys following glacial retreat, the river erosion and downcutting during this period of associated climatic amelioration would have resulted in a long period of landslide activity. Therefore, relict landslides are