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LANDSLIDE CHANGE DETECTION AND DISPLACEMENT TRACKING USING NANOSATELLITE IMAGERY: LA MONTAGNA LANDSLIDE, SOUTHERN ITALY

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EXTENDED ABSTRACT

Le frane si muovono con velocità variabili da pochi millimetri all'anno a diversi metri per secondo. La distribuzione spaziale e la variazione temporale della velocità identificano la cinematica del fenomeno e sono strettamente correlati con la magnitudo dell'evento. La valutazione della pericolosità da frana non può prescindere dalla conoscenza della magnitudo e quindi della cinematica del fenomeno che è particolarmente rilevante anche nell'ambito della pianificazione e progettazione delle eventuali misure di mitigazione. Nell'ultimo decennio, l'implementazione delle tecniche di monitoraggio terrestre e l'avvento di nuovi prodotti acquisiti da satellite o da piattaforme aviotrasportate hanno reso più semplice l'esecuzione di ricostruzioni cinematiche di breve e medio periodo. Tra i nuovi prodotti disponibili, risultano di particolare interesse le immagini ortorettificate ad alta risoluzione (3 m GSD, RGB-NIR) acquisite con cadenza giornaliera da sistemi di nanosatelliti. Tali piattaforme rappresentano l'evoluzione low-cost dei satelliti per esplorazione spaziale e garantiscono tempi di rivisitazione estremamente bassi in funzione della densità della costellazione (che attualmente conta più di 150 unità). Data l'elevata risoluzione e frequenza di acquisizione, tali piattaforme restituiscono dati che possono essere di grande interesse per il controllo del territorio e in particolare per l'analisi evolutiva di eventi di frana. In questo quadro si inserisce questo lavoro, che ha come obbiettivo quello di analizzare il potenziale impiego di questi prodotti per l'analisi morfologica e il tracciamento degli spostamenti finalizzato alla caratterizzazione cinematica di frane attive. Il caso di studio è rappresentato dalla frana del monte La Montagna in Italia meridionale, già interessato nel recente passato dalla frana di Montaguto. Tale frana si configura infatti come un fenomeno di retrogressione dell'orlo dell'area di alimentazione della frana di Montaguto e, al momento, ne rappresenta la parte più attiva. Coinvolge un volume stimato in 300000 m^3 ed è caratterizzata da una lunghezza di circa 390 m e una larghezza di poco più di 100 m. Per questa analisi, sono state selezionate 12 scene acquisite tra il 14 ottobre 2018 e il 31 marzo 2019. Come primo step della nostra analisi, le immagini a colori sono state sottoposte ad analisi visiva finalizzata alla ricostruzione del limite di frana. Una volta ricostruito per ogni scena, è stata determinatala differenza di elongazione del corpo di frana lungo un profilo longitudinale arbitrariamente selezionato. Successivamente, coppie di immagini sono state sottoposte ad analisi visiva finalizzata al riconoscimento di oggetti (gruppi di pixels) soggetti a spostamento tra le due immagini. Una volta riconosciuti, sono stati digitalizzati, in ambiente GIS, i vettori spostamento. I moduli di tali vettori sono stati utilizzati per ricostruire la curva di spostamento cumulato nel periodo di riferimento. Tale curva ha permesso l'identificazione di due episodi principali di spostamento avvenuti nel mese di novembre e successivamente nel mese di gennaio. Lo spostamento totale nel periodo di riferimento è stato stimato in circa 20 m. L'analisi è stata validata considerando i dati registrati da una stazione estensimetrica ubicata nella parte alta del fenomeno. Il confronto delle curve di spostamento ha sottolineato le potenzialità di utilizzo delle immagini acquisite da costellazioni di nanosatelliti per scopi di caratterizzazione e monitoraggio di fenomeni di frana.

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ABSTRACT

Landslides move with spatial and temporal variable velocity. This parameter, being representative of the landslide magnitude, has to be considered in hazard evaluation and mitigation measurement planning, so that it is of dramatic importance to accurately describe landslide kinematics. In the last decade, a new low-cost satellite platform has started acquiring daily data of the earth surface in the form of RGB-NIR images. In this paper, we explore the potential of using these products to make a change detection morphometric analysis and track surface displacement of the actively moving La Montagna landslide in southern Italy, through visual analysis of 12 scenes acquired between October 2018 and March 2019. We validated the reconstructed displacement time series through a comparison with monitoring data acquired using an extensometer. Results from our analysis underline the potential of using satellite imagery characterized by very high revisiting cycle to reconstruct landslide kinematics.

KEYWORDS: *landslide, kinematics, change detection, nanosatellite, optical imagery, displacement, Montaguto*

INTRODUCTION

Landslides exhibit velocity that range between few millimeters per year to several meter per seconds (e.g. CRUDEN & VARNES, 1996). The temporal and spatial variability of movement rate identify the kinematics of the event that is representative of its magnitude. An accurate evaluation of the hazard level accounts for events magnitude, factors controlling movement and potential near future evolution. In this condition, a detailed knowledge of landslide kinematics is of basic importance and can contribute to mitigation measures design.

The availability of improved ground-based monitoring techniques (e.g. low cost sensors and Gb-InSAR; GUERRIERO *et alii*, 2017B; SHULTZ *et alii*, 2017) as well as high to medium resolution remote sensing products and related processing methods, (e.g. optical and SAR satellite imagery; DAEHNE & CORSINI, 2012; CONFUORTO *et alii*, 2017), has provided a range of new opportunity to track landslides displacement at both regional and slope scale. For instance, AMITRANO *et alii* (2019) used sub-pixel offset tracking method and COSMO-SkyMed spotlight images to monitor surface displacement of the Slumgullion landslide in the southwestern Colorado. Stumpf et al. (2017) used multiple pairwise correlation technique and optical Pléiades satellite images to track horizontal displacements of 169 slow-moving landslides in southern French Alps. In addition, the use of remote sensed product like LiDAR data, and related visual/manual and semi-automatic interpretation procedures, has dramatically improved landslide identification and mapping capabilities. Consequently, a large number of landslide inventory map of different type and resolution and with different purposes have been produced (e.g. GUERRIERO *et alii*, 2019). In the last decade, a new low-cost and miniaturized satellite platform, built from non-space components, has been developed. Such satellites, generally called "nanosatellites" or "Doves", have been launched during multiple missions since 2013 and are actively acquiring images of the whole earth surface (Planet Team (2017). Planet Application Program Interface: In Space for Life on Earth. San Francisco, CA. https://api.planet.com). Currently, more than 150 individual "Doves" provides daily high resolution imagery that might be the basis for a number of monitoring project oriented to natural hazards risk reduction. On this basis, we used orthorectified images acquired by PlanetScope nanosatellites to make a change detection analysis and track surface displacement of the upper-western sector of the Montaguto earthflow (southern Italy, GUERRIERO *et alii*, 2014; 2015), which rapidly evolved between the end of 2018 and the beginning of 2019 through the development of a new deep seated landslide inducing the upslope progression of the upper boundary. Throughout the paper we used the term "La Montagna landslide" to identify this new event that can be considered, at the moment, as the most active part of the Montaguto earthflow. Our analysis can be considered as a test of the potential of using recently available, very high revisiting cycles, satellite products for landslide change detection and surface displacement tracking in operational monitoring perspective.

THE LA MONTAGNA LANDSLIDE

The La Montagna landslide is at the upper-western side of the source area of the Montaguto earthflow in southern Italy (Fig. 1).

Fig. 1 - Overview of the western source area of the Montaguto earthflow, where the La Montagna landslide occurred on April 18, 2019. The red dot indicates the position of the extensometer. Photo taken from an Unnamed Aerial Vehicle (UAV) looking north toward the main scarp

It consists of an upper deep seated (>15 m) translational slide evolving into a downslope flow after transformation of landslide translational block into debris. This occurs as a consequence of extensional deformation and toppling at the slope knickzone. The La Montagna landslide involves an estimated volume of 300000 m^3 of fine-grained flysch material. It is approximately 390 m long, has a maximum width of 110 m and its depth is estimated in approximately 18 m.

Field observations indicate that, according to the evolutionary model of PINTO *et alii* (2016), landslide geometry is controlled by slope geologic structure. In other words, the La Montagna landslide is bounded by discontinuities and moves mainly along thin (5 to 10 cm) clay layers where the slip surface is developed. Landslide displacement occurs along these well-defined lateral boundaries that are better expressed from a structural point of view at the upper translational slide. Along the lower flow, lateral strike-slip faults materializing landslide flanks are not fully developed as in the source area. The main episode of movement occurred between the last week of October and the first week of November 2018. During this episode, the upper block moved of approximately 15 meters.

METHODS

Overall, 12 4-band analytic scenes acquired by PlaneScope nanosatellites between October 14, 2018 and March 31, 2019, were used for our analysis. The nanosatellites are 3U CubeSats (10×10×30 cm) equipped with a RGB, red (610–700 nm), green (500–590 nm), and blue (420–530 nm), and a NIR, near infrared (720–1300 nm), sensors. The ground sampling distance (GSD) is of approximately 3 m and downloadable scenes are orthorectified. These features make satellite scenes suitable for a change detection analysis and tracking surface displacement of the La Montagna landslide.

As a first step of our analysis we used color ortorectified images as a basis for a visual interpretation of the landslide boundary in a GIS. The mapped boundary was subsequently used to extract quantitative data about landslide toe advancement. As a second step, we measured the displacement of natural and artificial objects (i.e. rocks accumulation, landslide blocks, etc...) on the landslide surface, visible in successive sets of satellite orthoimages. For this purpose, digital orthoimages were converted from RGB to grayscale. Objects consisting of groups of pixels were recognized on the basis of their geometry and color (i.e. Digital Number) distribution. Corners of object were visually picked from a computer display, displacement was manually measured in a GIS and displacement vectors were constructed.

Displacement data derived from displacement vector reconstruction were validated using monitoring data acquired at the upper translational block. On September 29, 2018, after several field recognitions that underline the presence of evolving deformational structures at the upper translational landslide block, we installed an Arduino based instrumentation station equipped with an extensometer and a rain gage (see GUERRIERO *et alii*, 2017, for details, Fig.1). Data registered at the station consist of a displacement time series that we used for the comparative validation of data derived by the interpretation of satellite imagery.

RESULTS AND DISCUSSION

Figures 2, 3 and 4 report results from our analysis of landslide morphometric change and surface displacement tracking. Especially, figures 2 and 3 show our interpretation of grayscale orthoimages in terms of landslide boundary and displacement of identified object that moved between successive scenes. Figure 4 shows a simplified map underlining the morphometric change of the landslide boundary (i.e. surface) and a graph reporting kinematic data in terms of toe advancement (grey line) along a predefined longitudinal profile and displacement of the upper translational block (purple line). In addition, for validation purpose, data acquired using an Arduino based instrumentation station are reported (black line).

The landslide toe consistently shifted downslope between October 14, 2018 and Mach 31, 2019, with two main episodes of advancement. In this period, the source area did not change its shape since its upper boundary did not moved upslope. The gray curve of the graph in figure 4 indicates that the first episode of advancement occurred between October 31 and November 12, 2018, while the second episode occurred between January 17, and March 31, 2019. All of the landslide body moved in the period of image acquisition and a number of displacement vectors were reconstructed within the landslide (Figs. 2, 3). The upper block of the landslide moved consistently downslope in the monitoring period. We estimated a total displacement of approximately 20 meters in the period of acquisition of the scenes with a main episode of movement tracked between November 5 and 10, 2018. This information is consistent with data measured by our monitoring station. Especially, the purple curve of the graph of figure 4, representing landslide kinematics derived by satellite image interpretation, is very similar to the black curve of the same graph representing the kinematics of the landslide as measured by our extensometer. Major differences are the total displacement accumulated during the major episode of movement and displacement temporal distribution. Our interpretation of such differences are related to the chance of tracking displacement of recognizable objects moving with the landslide in successive orthoimages, which is function of the displacement magnitude. In other words, it is not possible to track displacement lower than the single sided pixel dimension that is a limiting factor for slow moving landslide analysis.

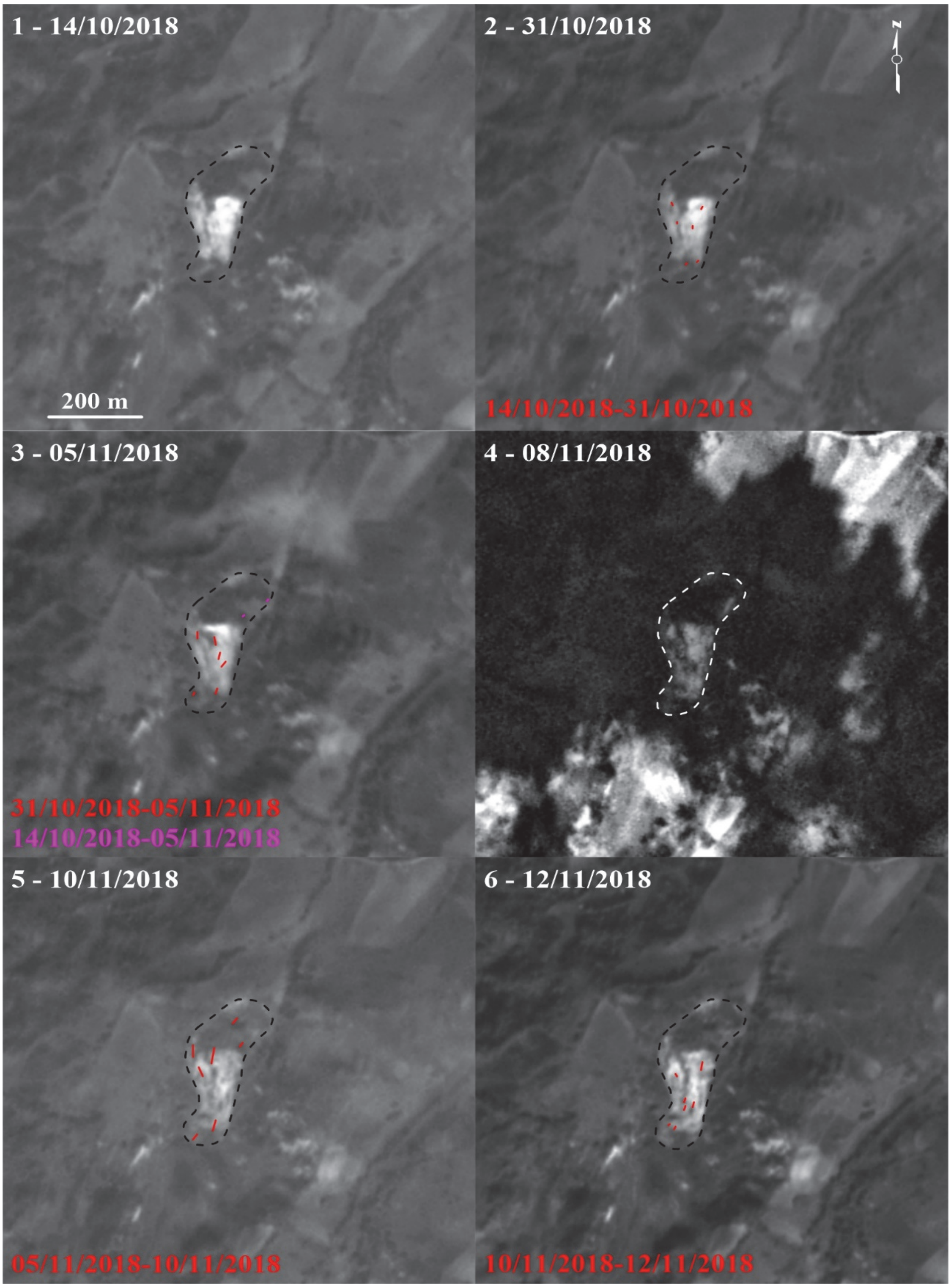

Fig. 2 – Results from visual interpretation of PlanetScope images taken between October 14, 2018, and November 12, 2019. The dashed black lines represent our interpretation of the landslide boundary. Red and purple lines represent displacement vectors derived by visual picking of object (i.e. groups of pixels) recognized at the landslide surface

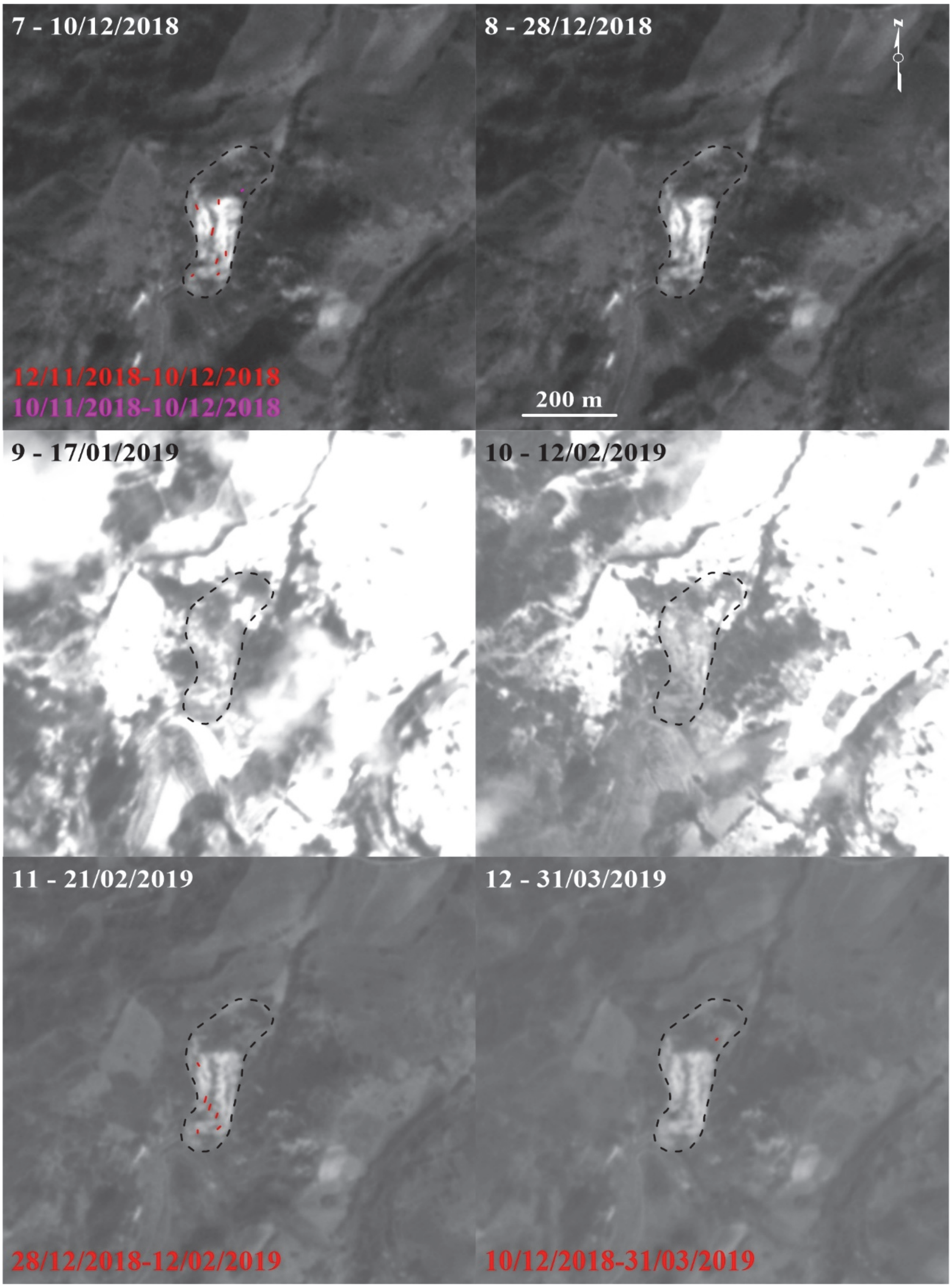

Fig. 3 - Results from visual interpretation of PlanetScope images taken between December 10, 2018, and March 31, 2019. The dashed black lines represent our interpretation of the landslide boundary. Red and purple lines represent displacement vectors derived by visual picking of object (i.e. groups of pixels) recognized at the landslide surface

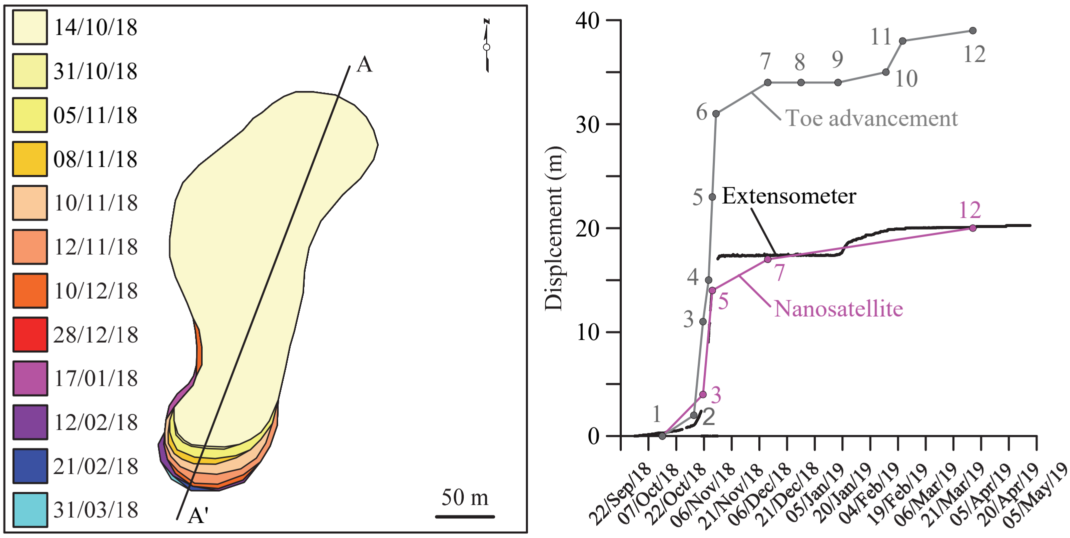

Fig. 4 – Results from PlanetScope image analysis between October 14, 2018, and March 31, 2019: i) map showing landslide enlargement; ii) graph showing a comparison between displacement derived by image analysis and displacement registered at the landslide head using the extensometer and landslide advancement

CONCLUDING REMARKS

Our analysis confirmed that the La Montagna landslide consistently moved between October 14, 2018 and Mach 31, 2019, with two main episodes of advancement, a first occurred between October 31 and November 12, 2018, and a second occurred between January 17, and March 31, 2019.

We estimated a total displacement of approximately 20 meters in the monitoring period. Our test indicates that high revisiting cycle nanosatellite imagery have the potential to support landslide change detection and kinematic analysis through visual identification and tracking of objects dragged by the moving mass and displacement vector reconstruction.

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