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Morphological and kinematic evolution of a large earthflow: The Montaguto landslide, southern Italy

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ABSTRACT

We studied the geomorphological evolution of the Montaguto landslide, a 3.1×10^3 m long earthflow in the southern Apennines of Italy. Following an analysis of the different methods and techniques available to measure surface modifications caused by a large earthflow, we selected a combination of monitoring techniques compatible with the Montaguto case study. We exploited: (i) visual interpretation of aerial and satellite imagery, (ii) quantitative analysis of six digital elevation models (DEMs) covering the landslide area, and (iii) a large set of high-accuracy three-dimensional topographic measurements captured by three robotised total stations (RTSs). Integration of the results obtained from the different monitoring techniques allowed us to investigate the long (multi-decadal) and short (seasonal) term evolution of the Montaguto earthflow in the 58-year period (1954–2011). The examination of the available aerial, satellite and hill-shade images revealed a cyclic, long-term behaviour of mass movements of different types in the Rio Nocelle catchment occupied by the recent Montaguto earthflow. The combined analysis of the six DEMs allowed measuring the material eroded from the landslide crown area ($V\sim1.4\times10^6$ m^3) and deposited in the landslide toe area ($V\sim1.2\times10^6$ m^3) in the period from 2005 to June 2011. The analysis of a large set of high-accuracy topographic measurements revealed the kinematical characteristics of different sectors of the active earthflow, and allowed the reconstruction of the temporal and spatial evolution of the moving failure. The insights obtained are significant for the geo-mechanical modelling of similar earthflows, regional landslide mapping, and the evaluation of hazard and risk posed by large earthflows in southern Italy or similar physiographic regions.

1. Introduction

Earthflows are a type of mass movement common in different geographical regions (Hutchinson, 1970; Keefer and Johnson, 1983; Flageollet, 1988; Dikau et al., 1996; Flageollet et al., 1999), and are particularly abundant in hilly and mountain areas underlain by weak, fine-grained rocks (Zhang et al., 1991; De Long et al., 2012). Earthflows exhibit an hourglass shape in plain view, with an ample, amphitheatre-like source zone, a narrow and elongated transport zone, and a lobate depositional area characterised by multiple compressional features (Keefer and Johnson, 1983). Active earthflows exhibit seasonal patterns of movement that might be controlled by precipitation (rainfall and snowmelt), groundwater, and air pressure variations (Schulz et al., 2009). The response of earthflows to rainfall or snowmelt is typically delayed, with long periods of cumulated precipitation required to cause an earthflow to move (Kelsey, 1978; Iverson and Major, 1987). Typically, pulses of movements characterise the temporal behaviour of earthflows, which exhibit relatively short periods of intense activity, followed by longer quiescent periods of reduced or no measurable movement (Zhang et al., 1991; Bertolini and Pizziolo, 2008; Van Asch and Malet, 2009; Mackey and Roering, 2011).

Well-known earthflows that have been studied exploiting different temporal and spatial investigation techniques include (i) the 7×10^5 m^3 Super-Sauze earthflow, Alpes de Haute Province, France (Flageollet et al., 2000; Malet et al., 2000, 2005), (ii) the 7×10^6 m^3 Tessina earthflow, Veneto, Italy (Angeli et al., 1994; Avolio et al., 2000), and (iii) the 2×10^7 m^3 Slumgullion earthflow, Colorado, USA (Crandell and Varnes, 1961; Baum and Fleming, 1996; Coe et al., 2003; Parise, 2003). For the Super-Sauze earthflow, Malet et al. (2002) have used a complex monitoring network with total stations (TSs), global positioning system (GPS) receivers and extensometers to identify seasonal trends in the kinematical behaviour of the slope failure during three years. For the same landslide, Travelletti et al. (2008) have compared three digital elevation models (DEMs) obtained from terrestrial laser scanner surveys during five days of a

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controlled rainfall experiment. The comparison revealed distinct changes in the trend of surface movements. To investigate the topographic changes caused by the Slumgullion earthflow, Powers et al. (1996) have studied two sets of aerial photographs covering a 5-year period (1985–1990), and Coe et al. (2009) have compared aerial photographs taken in 1939, 1940 and 2000. To study the kinematic evolution of the Tessina earthflow, Mantovani et al. (2000) have used a network of 25 topographic benchmarks measured by a single robotised total station (RTS). For the same landslide, Van Westen and Lulie Getahun (2003) prepared detailed morphological maps through the interpretation of aerial photographs taken in 1954, 1961, 1969, 1980, 1991, 1993, 1998 and 1999, aided by field mapping in 1998 and 1999, and performed quantitative volumetric analyses using five DEMs derived from 1:5000 scale topographic maps prepared in 1948, 1964, 1980, 1991 and 1993. For the same earthflow, between September and October 2000, Tarchi et al. (2003) completed one of the first successful attempts to exploit ground-based radar interferometry to monitor an active slope failure. Collectively, these examples reveal that the study of earthflows requires the combined exploitation of multiple monitoring and analysis techniques covering short (seasonal) to long (multi-decadal) periods (Mora et al., 2003; Angeli and Silvano, 2004; Corsini et al., 2005; Peyret et al., 2008).

In this work, we present the results of a combined geomorphological and topographical analysis of the Montaguto earthflow, Campania, southern Italy (Fig. 1). The study was conducted integrating different monitoring techniques (Fig. 2), with temporal sampling in the range from 21 years for aerial photographs to 4 h for topographic measurements obtained by a network of three RTSs. The resolution of the analyses ranges from qualitative 2D information using aerial and satellite imagery to quantitative 3D topographic change measurements and volumetric analyses using LiDAR and RTS data.

The paper is organised as follows. In Section 2, we summarise the main characteristics of the techniques available to monitor surface movements caused by large earthflows and similar complex landslides. This is followed by a description of the Montaguto earthflow (Section 3). Next, we present the results of a combined analysis of the surface modifications caused by the Montaguto earthflow and other landslides in the same region during 1954 to 2011. This is achieved through (i) visual interpretation of aerial, satellite, and hill-shade imagery (Section 4), (ii) quantitative volumetric analysis of spatially distributed digital elevation data derived from airborne LiDAR surveys (Section 5), and (iii) quantitative analysis of high-accuracy topographic measurements obtained by the three RTSs (Section 6). We conclude by discussing the results obtained (Section 7), with emphasis on the morphological and

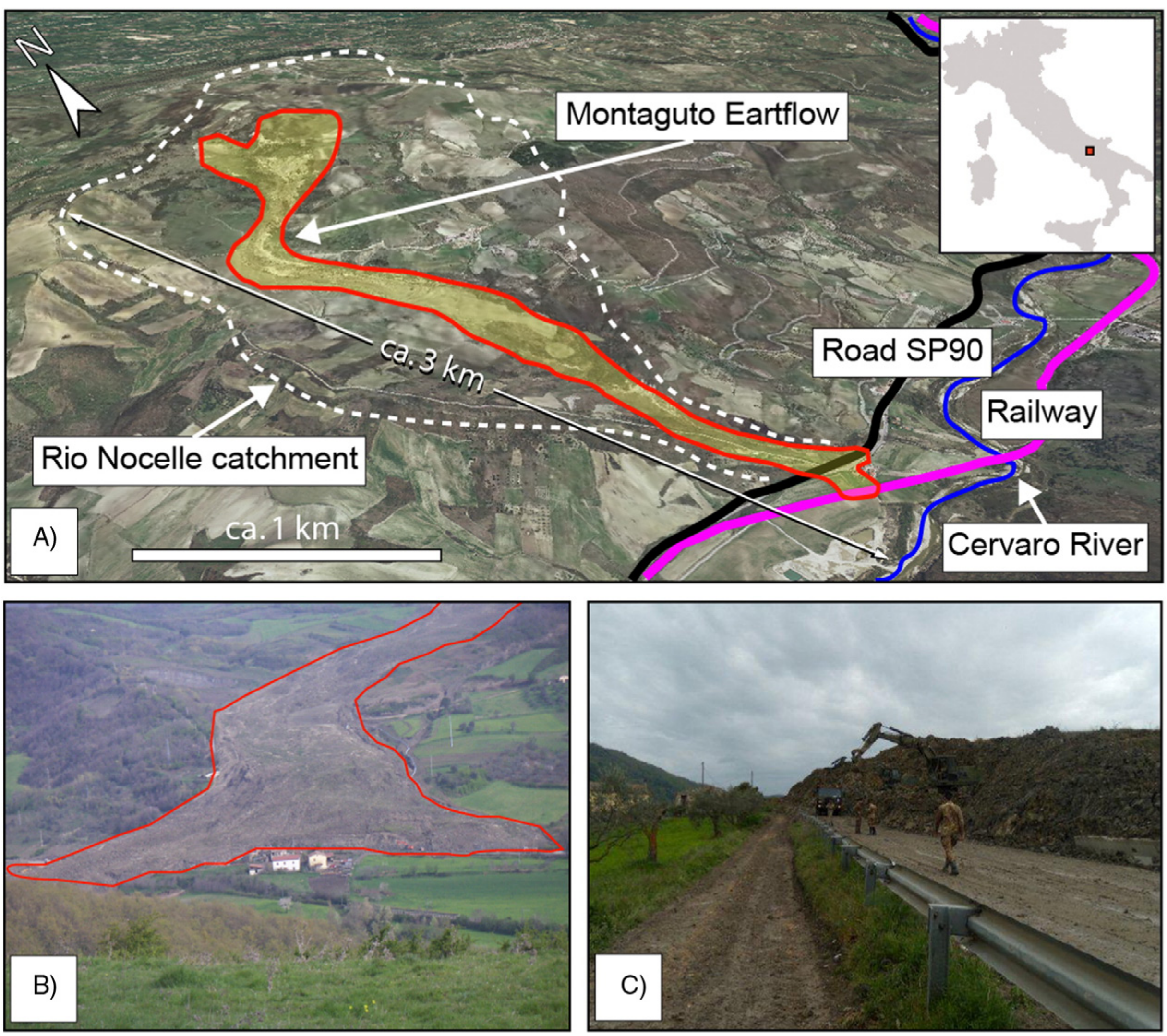

Fig. 1. Location of the Montaguto earthflow, Campania, southern Italy. (A) 3D view. Red square in the inset map: general location of the study area. Red line: landslide boundary. White dashed line: Rio Nocelle catchment divide. Black line: SP90 provincial road. Violet line: railroad. Blue line: Cervaro River. (B) Frontal view of the landslide toe partially covering the SP90 road and the railway line. The photograph was taken in April 2010. (C) Photograph of the landslide covering the SP90 road when the restoration work began at the end of April 2010.