



# Earthquake-driven acceleration of slow-moving landslides in the Colca valley, Peru, detected from Pléiades images



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## ABSTRACT

Major earthquakes in mountainous areas often trigger rapid landslides. Some observations also suggest that earthquakes can damage landslide prone areas or cause slow-moving landslides to accelerate, with a risk of evolution to rapid landslides in the following months after the earthquake. Here, we use optical images from the Pléiades satellites to detect slow-moving landslides and quantify the effect of earthquakes on the landslide motion. We process multi-temporal Pléiades images acquired in March, April, and July 2013 over an area of 210 km<sup>2</sup> in the Colca valley (South Peru), to obtain two Digital Elevation Models (DEM) and three displacement fields of the area. The processed DEMs have an uncertainty of 0.6 m (1 $\sigma$ ), an order of magnitude better than two global and freely available DEMs (GDEM-v2 and SRTM), whereas the displacement fields have an uncertainty of between 0.11 and 0.18 m (1 $\sigma$ ) in both horizontal directions. Using these data, we detect 9 slow-moving landslides and compare their velocities during the March–April and April–July periods. We find that landslide velocities are highest during the wet season, which suggests a strong groundwater control, and we also highlight a landslide acceleration caused by a regional Mw 6.0 earthquake. The major parameters controlling the acceleration of the slow-moving landslides are the rock type and the distance to the source, suggesting that friction at the basal interface in the weeks after the earthquake is dependent on the shaking intensity.

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## 1. Introduction

Landslides are a major threat in all mountainous regions of the world, with more than 80000 victims between 2002 and 2010 (Petley, 2012). Among these victims, 60% were killed by co-seismic landslides. Understanding the mechanics of landsliding under seismic forcing is thus a major issue. Several processes have been pointed out which could explain the mechanics of co-seismic landslides, including variations in the frictional properties during and after the shaking (Lacroix, Perfettini, Taipe, & Guillier, 2014; Newmark, 1965; Schulz & Wang, 2014; Togo, Shimamoto, Dong, Lee, & Yang, 2014), damage to the landslide body (Dadson et al., 2004; Petley, Dunning, Rosser, & Kausar, 2006), and transient pore water pressure changes due to the shaking (Jibson, Prentice, Borisoff, Rogozhin, & Langer, 1994; Wang, Cheng, Chin, & Yu, 2001; Wasowski, Pierri, Pierri, & Capolongo, 2002). The quantification of all these mechanisms remains difficult due to the paucity of in-situ measurements of landslide triggering by earthquakes.

To overcome this lack of in situ data, the research on landslide triggering by earthquakes has focused on the analysis of earthquake-

triggered-landslide inventories (e.g. Keefer, 1984). The triggering of landslides is controlled by two main families of parameters: (1) the parameters related to the source (magnitude, focal mechanism) (e.g. Meunier, Uchida, & Hovius, 2013; Tataru & Grasso, 2013), and (2) the parameters related to the site (topography, geology, hydrology), (e.g. Lacroix, Zavala, Berthier, & Audin, 2013). Most earthquake-triggered-landslide inventories only include rapid landslides, that occur over periods of seconds to minutes. These datasets do not include slow-moving landslides accelerated by earthquakes, and thus do not capture all earthquake-related landslide activity. We use the term slow-moving landslides to refer to nonturbulent downslope movement of hillslope material, at velocities between 1 m/yr and 100 m/yr (Cruden & Varnes, 1996). A recent study using continuous GPS (Lacroix et al., 2014) showed that the dynamics of slow moving landslides are perturbed during and after the earthquake, but properties controlling this change in velocity are poorly constrained. Difficulties in assessing these properties come from the numerous factors affecting the landslide kinematics (Handwerger, Roering, & Schmidt, 2013; Iverson, 2000; Schulz, Kean, & Wang, 2009; Strozzi et al., 2010), which makes it difficult to extract the response of slow-moving landslides to earthquakes. In this study, we address the issue of this detection and characterization of slow-moving landslides perturbed by a Mw 6.0 earthquake in southern Peru.

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