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Large-area landslide detection and monitoring with ALOS/PALSAR imagery data over Northern California and Southern Oregon, USA

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ABSTRACT

Multi-temporal ALOS/PALSAR images are used to automatically investigate landslide activity over an area of ~200 km by ~350 km in northern California and southern Oregon. Interferometric synthetic aperture radar (InSAR) deformation images, InSAR coherence maps, SAR backscattering intensity images, and a DEM gradient map are combined to detect active landslides by setting individual thresholds. More than 50 active landslides covering a total of about 40 km^2 area are detected. Then the short baseline subsets (SBAS) InSAR method is applied to retrieve time-series deformation patterns of individual detected landslides. Downslope landslide motions observed from adjacent satellite tracks with slightly different radar look angles are used to verify InSAR results and measurement accuracy. Comparison of the landslide motion with the precipitation record suggests that the landslide deformation correlates with the rainfall rate, with a lag time of around 1–2 months between the precipitation peak and the maximum landslide displacement. The results will provide new insights into landslide mechanisms in the Pacific Northwest, and facilitate development of early warning systems for landslides under abnormal rainfall conditions. Additionally, this method will allow identification of active landslides in broad areas of the Pacific Northwest in an efficient and systematic manner, including remote and heavily vegetated areas difficult to inventory by traditional methods.

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1. Introduction

Landslides are defined as the movement of a mass of rock, debris or earth down a slope (Cruden, 1991), and can result in enormous casualties and huge economic losses in mountainous regions. Additionally, landslides in the Pacific Northwest can damage habitat utilized by valuable fish species, such as salmon and steelhead. In recent years, many different mapping techniques have been implemented for the cartographic representation of landslide movement. These include landslide inventories, landslide displacement inventories, landslide hazard assessments, and landslide vulnerability assessments (Parise, 2001). Risk analysis and assessment have also become important tools in addressing uncertainty inherent in landslide hazards (Dai et al., 2002). In addition, susceptibility zoning involves the spatial distribution and rating of the terrain units according to their propensity to produce landslides (Fell et al., 2008). Among all of these studies, mapping landslide deformation is fundamental for the assessment and reduction of landslide hazards and risks. In comparison to the traditional investigation and reconnaissance methods, such as GPS, spirit leveling, tilting, optical remote sensing, geological and geophysical investigation methods (Ding et al., 1998; Thompson & Cierlitza, 1993), the interferometric synthetic aperture radar (InSAR) technique has great advantages due to its broad coverage and its high spatial (and sometime temporal) resolution under all weather conditions (Massonnet & Feigl, 1998).

The InSAR technique has been used in various landslide studies, not only for location detection (Bulmer et al., 2006; Cascini et al., 2010; Farina et al., 2006; Pierson & Lu, 2009), but also for deformation monitoring. Various InSAR techniques have been employed, including the traditional differential InSAR method (Calabro et al., 2010; Catani et al., 2005; Strozzi et al., 2005), the short baseline subsets (SBAS) InSAR method (Berardino et al., 2003), the corner reflector InSAR (Fu et al., 2010; Xia et al., 2004), the persistent scatterer InSAR technique (Colesanti et al., 2003; Hilley et al., 2004; Vladimir & Jan, 2011) and ground based InSAR technique (Leva et al., 2003). InSAR-derived landslide deformation patterns further provide insights into the dynamics of landslides, including the interaction of landslides and tectonic motions and the deformation characteristics in relation to the El Nino phenomenon (Calabro et al., 2010; Colesanti et al., 2003; Hilley et al., 2004). However, the application of the InSAR technique to landslide investigations is still a challenging topic. It is difficult to map and monitor landslides in forested regions due to volume and temporal decorrelation, atmospheric delay anomalies, artifacts induced by near surface moisture

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changes and decorrelation due to large deformation gradients (Ferretti et al., 2007; Hanssen, 2001; Massonnet & Feigl, 1998; Samsonov et al., 2011; Yun et al., 2007; Zebker & Villasenor, 1992). In addition, the side-looking SAR imaging geometry causes layover and shadow in mountainous regions. Furthermore, large scale phase trends resulting from baseline errors and atmospheric artifacts make it difficult to detect and monitor landslides over a large region.

In this study, we first introduce a method for automatic detection of slowly moving landslides using InSAR products (Lu et al., 2010), including InSAR coherence maps, SAR intensity images, deformation maps and digital elevation models (DEM). We then apply this method to map active landslides in a large region in the southern Oregon and northern California. The detected landslides are verified by independent InSAR observations from adjacent satellite tracks and some in-situ data. The spatial segmentation for a specific landslide is analyzed in detail, the temporal time-series deformation results are achieved using SBAS technique, and the accuracy of deformation measurements is verified using two independent InSAR observations from adjacent satellite tracks. Finally, the correlation between the time-series landslide motion derived and the precipitation record is analyzed.

2. Data and study area

The study region, covering an area of ~200 km by ~350 km in northern California and southern Oregon (Fig. 1), is composed of penetratively sheared metasedimentary interbedded sandstone and

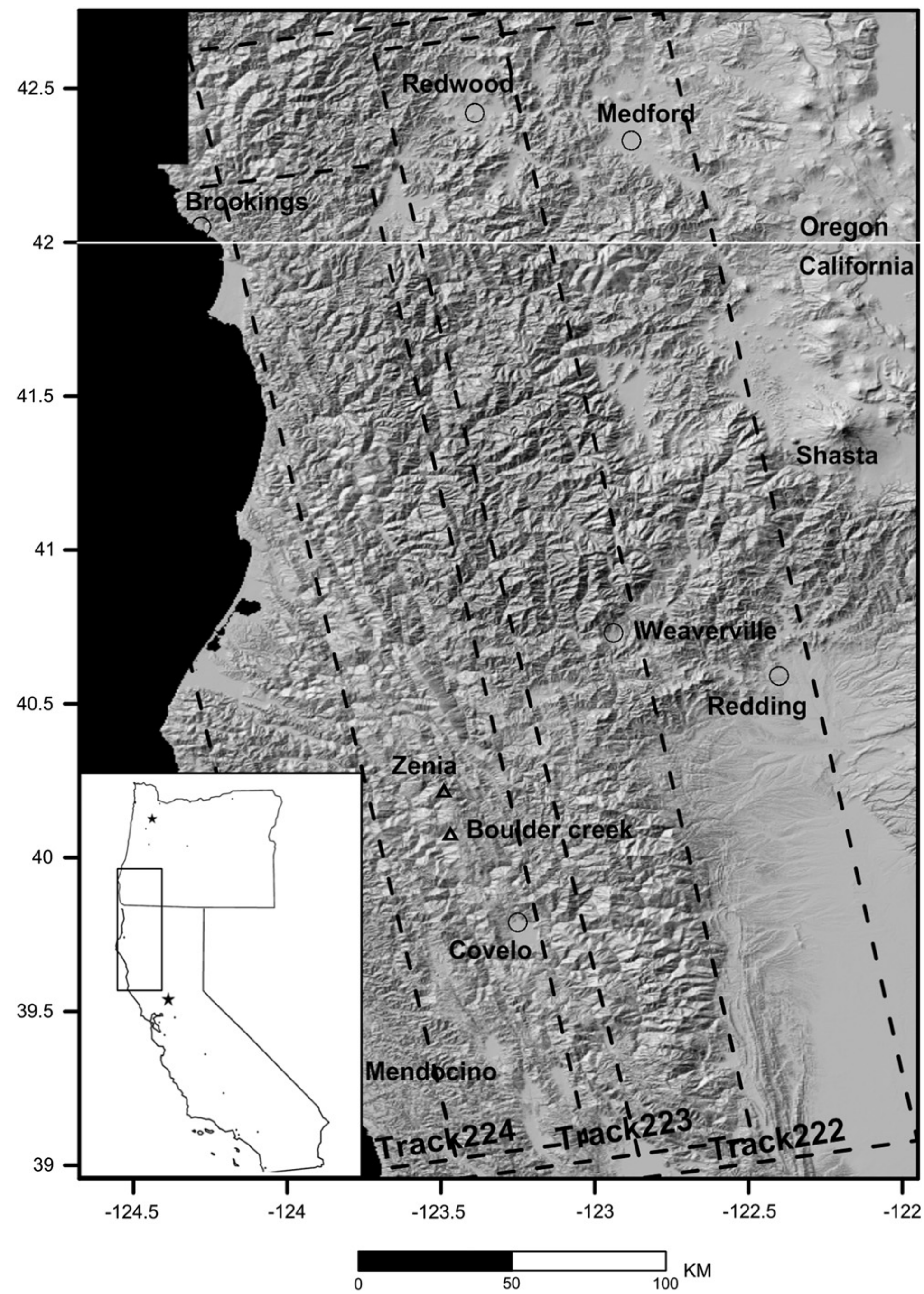

Fig. 1. Shaded-relief image of the study area over northern California and southern Oregon, USA. Dashed polygons represent the coverage of SAR images from three overlapping ascending ALOS/PALSAR tracks 222, 223 and 224. The inset is a sketch map of California and Oregon, and the rectangle represents the study region.