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An analysis of terrain properties and the location of surface scatterers from persistent scatterer interferometry

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ABSTRACT

Standard interferometry poses a challenge in heavily vegetated areas due to decorrelation of the radar signal. To alleviate this problem, we implement StaMPS, a persistent scatterer (PS) technique, to obtain a more spatially complete signal in the Cascade Range of the Pacific Northwest. In addition to comparing the spatial extent of the signal from standard Interferometric Synthetic Aperture Radar (InSAR) and StaMPS, we further analyze the selection of scatterers over several terrain types in the Cascades, and systematically vary StaMPS parameters to minimize the selection of false positives and negatives. Utilizing the best parameters, we correlate the location of persistent scatterers to geologic units, and vegetation density derived from Light Detection and Ranging (LiDAR) data. Our findings indicate that persistent scatterers most frequently occur on young, rough basaltic to andesitic lava flows and to a lesser extent on older, reworked basaltic andesitic lava flows exposed as boulder fields in the forests. Very few or no scatterers were found over water, permanent snowfields, evergreen forest, or unconsolidated pyroclastics. Over 90% of the scatterers are located in areas with no or very sparse vegetation cover. Based on surface roughness and the percentage of bare earth within the radar footprint, we are able to predict where PS InSAR is most likely to be successful on natural terrains.

1. Introduction

Interferometric Synthetic Aperture Radar (InSAR) is a remote sensing technique that utilizes satellites to study ground deformation with millimeter precision (e.g., Rosen et al., 2000). By interfering the radar chirps backscattered from the surface from two different satellite passes, one can measure the phase change of the signal related to the surface deformation over a period of time (e.g., Massonnet et al., 1993). Standard InSAR, however, has several challenges, the greatest being the decorrelation of the radar signal in rural and mountainous settings (Zebker and Villasenor, 1992). Decorrelation requires that other processing techniques be used to obtain a more spatially complete deformation pattern.

One such technique is the permanent or persistent scatterer (PS) method, a method that identifies scatterers (buildings, rock outcrops, etc.) with stable radar scattering characteristics through time that are called persistent scatterers (e.g., Ferretti et al., 2000, 2001; Lyons and Sandwell, 2003; Hooper et al., 2004, 2007). With the persistent scatterer (PS) method, one can create a time series of the phase change on the most stable scatterers. The phase is shown only on those chosen pixels, which allows the deformation signal to be recovered in areas that were decorrelated using standard InSAR.

Despite the application of PS InSAR in several settings, such as Ancona, Italy (Ferretti et al., 2001), Long Valley Volcanic Caldera, California (Hooper et al., 2004), San Francisco Bay, California (Bürgmann et al., 2006), Volcán Alcedo, Galápagos (Hooper et al., 2007), and North Anatolian Fault, Turkey (Motagh et al., 2007), few studies have evaluated the surface characteristics where PS InSAR is most successful. To better understand the surface characteristics of stable scatterers in a natural setting, we examine the location of PS pixels in the densely vegetated, volcanic terrain of the Oregon Cascades (Fig. 1). The Cascade Range in the Pacific Northwest presents several important targets for the study of volcanic processes and the assessment of natural hazards. Our study's geographic focus is the Three Sisters volcanoes, an area in central Oregon that has been continuously uplifting since 1996 (Wicks et al., 2002; Riddick and Schmidt, 2011). Because the deformation was not discovered until 2001, and the volcanoes are located in a wilderness area that limits installation of ground-based geodetic instruments, InSAR is the only dataset that can fully resolve the spatial and temporal evolution of the deformation since the onset. InSAR data has resolved a deforming region ~5 km west of the Three Sisters volcanoes that is uplifting due to the inflation of a

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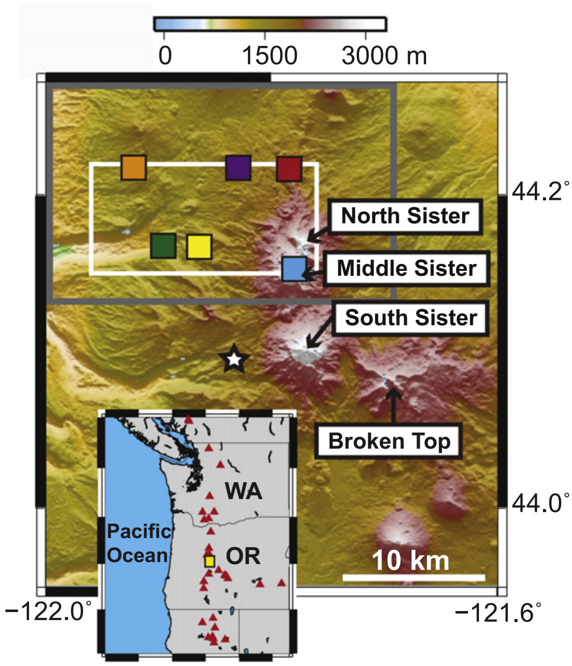

Fig. 1. Map of the Three Sisters area in Oregon. Inset shows the western US, with the yellow square showing the location of the Three Sisters area. Large gray box shows the small patch area that was processed 175+ times and used in analysis. Small squares within the gray box indicate examples of the terrains used in analysis, which are shown with persistent scatterers in Fig. 3. Orange square: Pleistocene boulder fields. Green square: water. Yellow square: forest. Purple square: Holocene lava flows. Red square: pyroclasts. Blue square: snowfields. The white box indicates the area shown in Fig. 6, which encompasses the only LiDAR data available for the Three Sisters area. Arrows indicate major volcanoes. The deformation is centered at the white star and extends ~20 km by 30 km. Riddick and Schmidt (2011) model the surface deformation as a sill or spherical inflation source located at a depth of 5–7 km. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

deep magmatic sill (Riddick and Schmidt, 2011). However, dense vegetation and winter snow cover presents several challenges for applying standard InSAR to this region. The backscatter characteristics of the ground change significantly over short periods of time. Differential interferograms of our study area have correlated areas limited mainly to the sparsely vegetated lava flows. Because of these challenges, PS InSAR is necessary to provide a more coherent and spatially complete signal of the surface deformation.

The main objective of this paper is to assess how well PS InSAR performs in the Cascades, since the technique has not been applied in this area before. The dense vegetation of the western Cascades causes partial to complete decorrelation in standard InSAR. However, PS InSAR should be capable of finding persistent scatterers on rocky outcrops within vegetated areas that are completely decorrelated with standard InSAR. We evaluate PS InSAR by the selection of scatterers and their locations relative to ground features. We also optimize two parameters used in the selection of PS pixels to ensure that the pixels with the most consistent radar backscattering characteristics are chosen. Furthermore, using the locations of the optimized scatterers, we assess the corresponding ground features using Google Earth, geologic maps, Light Detection and Ranging (LiDAR) data, and vegetation maps. We analyze various terrains: recent Holocene lava flows, reworked Pleistocene lava flows that appear as boulder fields, water, permanent snowfields, unconsolidated volcanic material (pyroclasts), and forest, as well as compare geologic units and vegetation density and type to the PS locations. By evaluating the scatterer locations, we can better predict where persistent scatterer interferometry will succeed and fail on various terrains.

2. Methods

2.1. Persistent scatterer interferometry

We implement the persistent scatterer algorithm called StaMPS (Hooper et al., 2007). StaMPS is a PS technique that accurately determines PS pixels in rural locations, including vegetated regions where other approaches have had less success. Unlike StaMPS, other PS techniques rely solely on amplitude, or the intensity of the backscattered radar wave, to select PS pixels where man-made structures such as buildings typically have the strongest returns (e.g., Ferretti et al., 2001; Lyons and Sandwell, 2003). By using the spatial correlation of interferometric phase to find and select pixels with low phase variance, StaMPS is able to identify stable ground scatterers, such as large boulders or lava flows within vegetation (Hooper et al., 2004, 2007). Other PS techniques also require a model of how the deformation varies in time, whereas StaMPS does not require any previous knowledge of the deformation rates.

We processed SAR data from track 113 of the ERS satellite using StaMPS (version 3.2b3). The SAR dataset includes 14 SAR scenes along a descending track spanning from 1992 to 2001. Several other satellite tracks were processed with StaMPS, but are not presented in this study. We completed an additional 175+ runs for T113 ERS on a small patch within the Three Sisters area where various processing parameters were varied. The master scene was chosen primarily by minimizing the perpendicular baselines between the slave scenes and master, while also taking into consideration the minimization of temporal baselines. The final product from the processing is a time series of the range change at the location of the persistent scatterers. Riddick and Schmidt (2011) interpret the deformation resolved by StaMPS, compare the observed range change pattern with results from standard InSAR, and model the observations of volcanic unrest. In this study, we focus solely on the selection of persistent scatterers and correlate the location of these scatterers with surface characteristics.

StaMPS identifies PS within the SAR frame by looking for pixels with a low phase variance in space and time (Hooper et al., 2007). Because this is a statistical process, there are some pixels that will satisfy the selection criteria, but not be real PS. These pixels are called false positives, and their inclusion will add noise to the phase of the time series results. Some false positives are expected, but minimizing the number of these is essential to obtaining accurate results. By changing the thresholds of parameters to more strictly choose scatterers, we can minimize false positives at the expense of increasing false negatives. This tradeoff between false positives and false negatives is a common concern in persistent scatterer interferometry.

We explore the optimal selection of scatterers by varying those StaMPS parameters that significantly affect the selection process. Here we focus on the maximum standard deviation of the phase noise, σ_ϕ, (weed_standard_dev parameter in StaMPS) and the maximum acceptable spatial density (scatterers/km^2) of selected pixels with random phase, ρ_{rand} (density_rand parameter in StaMPS) (Hooper et al., 2007; Hooper, 2010). These parameters strongly affect the number of PS that are chosen. We keep all other values as defaults and use the amplitude dispersion suggested by Hooper et al. (2007, paragraph 83). We rerun the selection algorithm in StaMPS more than 175 times using a range of values for σ_ϕ between 0.25 and 10 (default is 1), and vary ρ_{rand} between 1 and 100 (default is 20). For each of the StaMPS runs, the number of PS selected are binned by their geographic location within distinct surface terrains. Six terrains are considered: Holocene lava flows, remnant Pleistocene lava flows (boulders), lakes, permanent snowfields, unconsolidated volcanic material (pyroclastics), and