A new method for measuring deformation on volcanoes and other natural terrains using InSAR persistent scatterers

Andrew Hooper,[1] Howard Zebker,[1] Paul Segall,[1] and Bert Kampes[2]

Received 12 October 2004; accepted 15 November 2004; published 10 December 2004.

[1] We present here a new InSAR persistent scatterer (PS) method for analyzing episodic crustal deformation in non-urban environments, with application to volcanic settings. Our method for identifying PS pixels in a series of interferograms is based primarily on phase characteristics and finds low-amplitude pixels with phase stability that are not identified by the existing amplitude-based algorithm. Our method also uses the spatial correlation of the phases rather than a well-defined phase history so that we can observe temporally-variable processes, e.g., volcanic deformation. The algorithm involves removing the residual topographic component of flattened interferogram phase for each PS, then unwrapping the PS phases both spatially and temporally. Our method finds scatterers with stable phase characteristics independent of amplitudes associated with man-made objects, and is applicable to areas where conventional InSAR fails due to complete decorrelation of the majority of scatterers, yet a few stable scatterers are present. *INDEX TERMS:* 1243 Geodesy and Gravity: Space geodetic surveys; 1294 Geodesy and Gravity: Instruments and techniques; 6924 Radio Science: Interferometry; 8494 Volcanology: Instruments and techniques. **Citation:** Hooper, A., H. Zebker, P. Segall, and B. Kampes (2004), A new method for measuring deformation on volcanoes and other natural terrains using InSAR persistent scatterers, *Geophys. Res. Lett.*, *31*, L23611, doi:10.1029/2004GL021737.

1. Introduction

[2] A major limitation in our ability to model volcanic processes is the lack of deformation data for most active volcanoes. While conventional InSAR has proven very effective in measuring deformation in regions of good coherence [e.g., *Massonnet et al.*, 1995; *Amelung et al.*, 2000], it is clear from almost any volcano interferogram that there are large areas on most volcanoes where signals decorrelate and no measurement is possible. If the surface is vegetated, weathers appreciably or is prone to snow coverage, the scattering properties change with time and result in temporal decorrelation, i.e., the loss of interferogram coherence with time [*Zebker and Villasenor*, 1992]. Another limitation of existing InSAR methods is the lack of temporal resolution in the data. While to a large extent this limitation is a function of how often SAR data are acquired, there are two other aspects of conventional InSAR that limit the number of scenes from which interferograms can be produced. The first is the distance between the spacecraft tracks at the two times scenes are acquired, known as the perpendicular baseline. A non-zero baseline leads to a difference in incidence angle which alters the scattering phases, a phenomenon referred to as spatial decorrelation [*Zebker and Villasenor*, 1992]. As the baseline increases, spatial decorrelation also increases. A second limitation results from the changes in squint angle, the angle with which the spacecraft is looking forward or backward. A change in squint angle alters the SAR Doppler frequency and leads to additional decorrelation. Although these non-temporal causes of decorrelation can be reduced somewhat by filtering, there are critical values of baseline and squint angle difference beyond which there is complete loss of interferogram coherence [*Zebker and Villasenor*, 1992].

[3] The degree of decorrelation of radar signals depends on the distribution of scattering centers within a pixel. If the phase of a pixel were determined by just one stable point scatterer, the decorrelation would be reduced to zero. Although this is never the case for real surfaces, there are pixels which behave somewhat like point scatterers, and for which decorrelation is greatly reduced. Hence, in an interferogram some pixels will exhibit less decorrelation than others. It is possible to avoid many limitations of conventional InSAR by analyzing only pixels which retain some degree of correlation, which we define as persistent scatterers.

[4] A different approach to processing is required to identify and isolate these pixels. This approach was first realized for InSAR applications by *Ferretti et al.* [2000, 2001], with further enhancements by *Colesanti et al.* [2003], and is referred to as the Permanent Scatterers Technique™ in their patented procedure. Other persistent scatterer processing systems have since been developed [e.g., *Adam et al.*, 2003; *Crosetto et al.*, 2003; *Lyons and Sandwell*, 2003; *Werner et al.*, 2003]. In these algorithms, an initial set of PS pixels are identified by analysis of their amplitude scintillations in a series of interferograms. This method works best in urban areas where man-made structures increase the likelihood of finding a non-fluctuating scatterer in any given pixel. The density of PS pixels identified by this technique in natural terrains, however, is generally too low to obtain any reliable results. Our new method uses phase analysis for identification of PS pixels and is successfully applied to a volcanic area where, using the *Ferretti et al.* [2001] algorithm, we failed to find an initial set of PS pixels with sufficient density to be reliable.

[5] In order to estimate and remove nuisance terms, PS processing systems to date must simultaneously estimate the deformation for each PS, which requires a first-order model for the temporal deformation. Once the nuisance terms have

[1] Department of Geophysics, Stanford University, Stanford, California, USA.
[2] Remote Sensing Technology Institute, German Aerospace Center (DLR), Oberpfaffenhofen, Wessling, Germany.

0094-8276/04/2004GL021737$05.00