Remote sensing of ground deformation

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An unconventional synthetic aperture radar interferometry technique can be used to measure deformation of vegetated regions.

Synthetic Aperture Radar Interferometry (InSAR) is a remote sensing technique that provides precise measurements of land surface deformation over large areas and at high spatial resolution.\(^1\)\(^-\)\(^5\) Land surface deformation is the changing shape of the ground (topographic changes) along fault lines caused by earthquakes. Deformation maps, which are important from a disaster mitigation perspective, of an area can be obtained by taking the difference of the phase measurements from InSAR images acquired at two different points in times. The phase difference is known as an interferometric phase or interferogram.

Different components of interferograms are produced by different sources. One such component is introduced by the topography of an area and can be removed using an external digital elevation model (DEM) to give a differential interferogram. The effect of the Earth’s curvature also needs to be modeled and removed to produce a flattened interferogram. However, InSAR fails to measure the deformation in vegetated areas because these areas suffer from significant backscattering effect changes over time. This effect leads to a decrease in coherence between the different phase measurements and is known as temporal decorrelation.

The technique of persistent scatterer interferometry (PSI)\(^6\) addresses the decorrelation problem by identifying persistent scatterer (PS) points at which the deformation is estimated over long periods of time. PS points tend to be man-made structures, such as buildings and bridges, or natural features, such as large rocks or facets, within an area of vegetation. The returned signal amplitude from the PS points is high and constant over time. Here, we use a PSI approach whereby time series of interferograms are analyzed to investigate temporal variations in the backscattering behavior of the PS features. This is in contrast to conventional InSAR techniques in which only a few images are used. Most PSI methods involve an initial selection of PS points—known as candidate pixels—that are chosen based on amplitude information. Subsequent and detailed processing of phase information is used to identify the final PS points.

Our study area—in the La González basin of the central Venezuelan Andes (see Figure 1)—is covered by dense vegetation ideal for PSI-based measurements. The region is a typical pull-apart basin that lies on a releasing bend of the right-lateral strike-slip Boconó Fault System.\(^7\) We focused on measuring surface deformation caused by the interaction between the right-lateral movement of the Boconó fault and the active regional northwest to southeast shortening across the mountain range.

We used PSI, specifically the Stanford Method for PS (StaMPS), to address the temporal decorrelation problem in our study area by identifying features for which deformation was estimated over a long period of time.\(^8\) This algorithm uses the spatial correlation between pixels and works well even in areas that lack man-made structures. The final PS pixels are identified by making an estimate of the phase stability of candidate pixels, through phase analysis.\(^8\) The ground deformation rate is then

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estimated using the results of the time series analysis and by applying the phase information from the PS pixels.

The available radar dataset (see Figure 2) for our study consisted of 10 Envisat Advanced Synthetic Aperture Radar (ASAR) images collected between 3 January 2003 and 5 August 2005. The subset of the data frame that covers our study area is indicated in Figure 1. In our PSI processing, an image that maximizes the stack coherence (a function of temporal and perpendicular baselines and of Doppler centroid frequency) was selected as the master.\textsuperscript{9,10} Nine single master interferograms were then generated. We used the Shuttle Radar Topography Mission (SRTM) DEM to remove the main topographic contribution to the interferometric phase. We identified 53,864 PS pixels during processing and we constructed a velocity map (see Figure 3) from the time series analysis results. We estimated and removed all sources of atmospheric, topographic, and orbital errors from our results, and show that the area undergoes significant deformation that is likely caused by tectonic activity. We estimated the maximum deformation rate in the area to be 40mm per year (see Figure 3). However, deformation in this area is complicated, as illustrated in Figure 4. Points

\textbf{Figure 2.} Acquisition geometry of the available radar data in the area. Acquisition time versus spatial baseline. Solid lines represent the generated interferograms.

\textbf{Figure 3.} Estimated line-of-sight deformation rate for the area within the black rectangle shown in Figure 1. The deformation time series of points A and B are shown in Figure 4.

\textbf{Figure 4.} Deformation time series at points A (top) and B (bottom) whose locations are shown in Figure 3. InSAR: Synthetic Aperture Radar Interferometry. LOS: line-of-sight.

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A and B (locations shown in Figure 3) are moving away from, and towards, the observing satellite at rates of 17 and 5 mm per year, respectively.

We have successfully used the StaMPS PSI method to detect and measure ground deformation caused by tectonic activity in the La González basin, Venezuela, which is covered by dense vegetation. We plan to decompose the line-of-sight deformation rate into horizontal and vertical components by using at least two different imaging geometries. This may allow us to separate different tectonic regimes that are active in this region.

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References