A NEW METHOD FOR SELECTING COHERENT SCATTERERS BASED ON THEIR POLARIMETRIC SIGNATURE

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Abstract

Persistent Scatterers (PS) technique is a useful modification of InSAR that limits interferometric processing only to those pixels that behave consistently over a long period of time. Usually these pixels are selected by setting a threshold on amplitude dispersion or mean coherence. This approach requires a large number of images in order to select PS with high confidence which can be a significant limitation particularly at early stages of data acquisition. We propose another approach for selecting coherent scatterers based on their polarimetric properties. This approach requires only a few quad-pole SAR images. By performing polarimetric analysis we are able to select only those pixels that behave consistently over a studied period and apply standard InSAR processing if network of selected pixels is dense or point processing similar to PS if network of selected scatterers is sparse. As an example we present results of this technique utilizing quad-pole RADARSAT-2 data over San Francisco.

Introduction

Differential Synthetic Aperture Radar Interferometry (DInSAR) is a technique for measuring ground deformation with a high spatial resolution and accuracy over a large area [Massonnet and Feigl, 1998; Rosen et al., 2000]. The differential interferogram is calculated from two Synthetic Aperture Radar (SAR) images acquired by the same or a similar satellite at two different times and displays the line-of-sight (LOS) deformation that occurred between the two acquisitions.

The quality of an interferogram is described by its coherence, which is the magnitude of a cross-correlation coefficient calculated for a master-slave pair of images. Coherence depends on a variety of parameters, including SAR wavelength, incidence angle, perpendicular baseline and land cover. In a densely vegetated environment coherence generally is low, which prevents the formation of a high-quality interferogram and phase unwrapping. For these land cover conditions, Persistent Scatterers (PS) interferometry technique is used instead [Ferretti et al., 2000; 2001]. The PS approach is based on a selection of pixels that are dominated by a single strong scatterer within the pixel and which are consistent over a long period of time. These pixels are usually selected based on their amplitude or amplitude dispersion.

The standard PS approach has also a few disadvantages. In order to confidently select PS pixels it is necessary to have a large number of images. In general, selection of PS pixels with a high degree of accuracy is possible only when at least thirty SAR images are available [Ferretti et al., 2001]. This is not always possible or desirable. Not only is it often difficult or expensive to acquire large numbers of images, but that many images inevitably span large time periods, on the order of years to decades. Hazard estimates for volcanic or seismic monitoring, for example, often requires the production of time series and deformation rates on short time frames, i.e. after the acquisition of only a few images. In addition, the selection of PS pixels is limited to those pixels that have very high amplitude, low standard deviation or satisfy both conditions. In some regions the network of such PS pixels is very sparse, which limits the processing of such interferograms, particularly phase unwrapping.

In this paper we demonstrate a technique that is able to select a larger number of Persistent Scatterers by analyzing their polarization phase difference [Samsonov and Tiampo, submitted to RSE; Evans et al.,
1988; Ulaby et al., 1987]. We designate these Polarization Phase Difference Scatterers (PPDS). We successfully select pixels with predominant single or double bounce scattering mechanisms and exclude pixels with diffusive scattering caused by interaction with vegetation. We also show that the majority of PS pixels selected with the standard approach have primarily single and double bounce scattering mechanisms, suggesting that the two techniques are complementary. The proposed approach requires a set of fully polarimetric SAR images that are presently available from only a few satellites, such as RADARSAT-2, ALOS PALSAR and TerraSAR-X. It is anticipated that the availability and usage of polarimetric data will improve in the future, and the technique proposed in this paper will become increasingly valuable for deformation mapping.

Methodology

The Polarization Phase Difference (PPD) \( \Delta \Phi \) for each pixel is calculated in the following way:

\[
\Delta \Phi = \Phi_{hh} - \Phi_{vv},
\]

where \( \Phi_{hh} \) is the phase of a wave transmitted and received in horizontal polarization and \( \Phi_{vv} \) is the phase of a wave transmitted and received in vertical polarization. The extreme values of PPD equal to either zero and \( \pm \pi \) correspond to deterministic single and double bounce scatterers, e.g. scatterers with a predominant reflective mechanism. The PPD value diverges as the contribution from diffusive scattering increases. The diffusive scattering from vegetation produces PPD values that are randomly distributed in \( \{-\pi, \pi\} \). Thus, by selecting pixels with appropriate PPD values, it is possible to exclude pixels with a diffusive scattering mechanism caused by the interaction with vegetation. The phase information of such pixels varies in an unpredictable way from one acquisition to another and, therefore, can not be used for mapping ground deformation.

Here we use the normalized Polarization Phase Difference for selection of reliable scatterers whose phase information carries consistent information. This can be done by calculating for each pixel a normalized average of absolute values of PPD for a set of SAR images and by selecting pixels with values close to 0 and 1:

\[
\gamma = \frac{\sum |\Delta \Phi|}{k \pi},
\]

where \( k \) is a number of a SAR image used for processing.

This quantity ranges from zero to one where \( \gamma = 0 \) corresponds to pixels with strictly single bounce scattering and \( \gamma = 1 \) corresponds to pixels with a strictly double bounce scattering mechanism. Furthermore, in order to exclude single bounce pixels corresponding to a reflection from the water surface it is recommended to set a threshold value on pixel amplitude. For example, it is possible to select only those pixels that have intensity values larger than the average value for the whole image. However, the threshold value will vary depending on the amount of water presented in the SAR image.

Results

For this study we collected six Fine Quad Polarization (Q7) RADARSAT-2 images acquired on 26 April, 13 June, 7 & 31 July, 22 December 2008 and 15 January 2009 over a region along the Hayward fault located northeast of San Francisco. The land cover in the area covered by this image consists of regions of dense vegetation, urban areas and open water. The PPD reliable scatterers were selected with \( \gamma \) less than 0.2 and greater than 0.8 and the average intensity was set at twice the mean intensity for the whole image.
These results are shown in Figure 1 along with persistent scatterers selected based on their amplitude dispersion (less than 0.2).

Figure 1: (left to right) a - Amplitude dispersion; b – pixels with amplitude dispersion less than 0.2 are selected as persistent scatterers; c – Average polarized phase difference; d – pixels with PPD close to zero and π are selected as consistent scatterers.

Standard interferometric processing was performed on the images and the topographic phase was removed using 10m NED Digital Elevation Model (DEM) provided by the USGS. In total we created 15 differential interferograms with a maximum perpendicular baseline close to 400 m and timespans ranging from twenty-four days to approximately nine months. Examples of the wrapped differential interferograms are presented in Figure 2 (in YYYYMMDD format) with corresponding values of perpendicular baseline: (a) – 20080426-20080707, -210 m; (b) -20080426-2008731, -142m; (c) – 20080426-20081222, -151m; (d) – 20080426-20090115, -133m.

In order to demonstrate that PPD can be used to describe the pixel reliability, we plotted the distribution of pixels according to their amplitude dispersion and polarized phase differences (Figure 3). Only pixels with high amplitude were considered, since it is assumed that, for these pixels, the amplitude dispersion based on six images is sufficiently accurate. According to this figure, the majority of pixels with PPD values close to zero (single bounce) and to one (double bounce scattering mechanism) also have small amplitude dispersion. This suggests that both techniques (PS and PPDS) are complementary and can be used for cross validation, but the technique proposed here can select reliable pixels even for a small set of available images.
Figure 2: Differential wrapped interferograms with corresponding perpendicular baselines (left to right, in YYYYMMDD format): a – 20080426-20080707, -210 m; b -20080426-2008731, -142m; c – 20080426-20081222, -151m; d – 20080426-20090115, -133m.

Figure 3: Distribution of pixels according to their amplitude dispersion and polarized phase difference. Only pixels with amplitude five times greater than average amplitude for the whole image were selected (modified from Samsonov and Tiampo, submitted to RSE).
Conclusions

In this paper we present a methodology for selection of reliable scatterers based on their polarized phase difference (PPD). Those pixels with a normalized average of absolute values of PPD close to zero and one are considered reliable because they are dominated by single and double bounce scattering mechanisms. Diffusive scattering from vegetation produces pixels with PPD randomly distributed in \([-\pi, \pi]\) interval and with normalized average PPD values far from zero or one. Such pixels are excluded from the interferometric processing.

The analysis of the distribution of pixels according to their amplitude dispersion and polarized phase differences suggests that the majority of pixels that would be selected by a standard PS approach also have normalized PPDS values close to zero or one and, therefore, will be selected by the proposed technique also. However, it is believed that the proposed technique is more accurate even for a smaller set of SAR images. The probability of selecting pixels with a diffusive scattering mechanism as reliable for a set of six images and threshold values of normalized PPD 0.2 and 0.8 is equal to \((2 \times 0.2)^6=0.41\%\), which is very low. This number will decrease exponentially with the number of images available.

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References


