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Detection of uranium mill tailings settlement using satellite-based radar interferometry

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ABSTRACT

The feasibility of monitoring erosion and settlement of earthen covers on uranium mill tailings impoundment was evaluated using synthetic aperture radar (SAR) coherence analysis, differential radar interferometry (DInSAR) and multi-temporal interferometry. A total of 13 ERS-1/-2 SAR images were acquired between August 22, 1996 and December 14, 2000 over two uranium mill tailings sites located in north-western New Mexico, USA. These SAR datasets were screened based on meteorological conditions at the time of acquisition, eliminating those acquired during (a) rain and thunderstorms, (b) mist or fog or, (c) during overcast conditions. Preliminary coherence analysis allowed us to better understand the dynamics of land disposal sites, to identify useful and relevant time domains and define the appropriate parameters for subsequent InSAR analyses. DInSAR allowed us to measure differential settlement of tens of mm over two 3 to 4 month periods. The Small BAseline Subset (SBAS) technique identified spatial variations in the rate of settlement ranging from approximately 1 mm/yr to 10 mm/yr. Although the extent of the analysis was limited by the availability of archived SAR data, the results demonstrated that monitoring using on-demand SAR data should yield reliable measurements of surface displacements earthen covers.

1. Introduction

Engineered earthen covers are used at land disposal sites to prevent or minimize releases of a variety of hazardous substances to the environment, such as radionuclides and hazardous organic and inorganic chemicals. The performance of the covers can be degraded by generalized or localized erosion (gully formation) and settlement of the underlying waste material (e.g., National Research Council, 1997). Standard methods of monitoring such covers and overall stability consist of visual inspection and may include elevation surveys of a few locations where tailings are settling, but site-wide elevation surveys to detect areas of ponding or incipient gully formation are not typically performed.

In recent years, radar interferometry or InSAR techniques have been recognized as an effective, low-cost technique for detecting and monitoring ground movements related to landslides, subsidence, and other natural hazards (e.g., Necsoiu and Hooper, 2009; Wasowski and Bovenga, 2014). Ideally low topography, no atmospheric artefacts and favourable environmental conditions (i.e., less vegetation, no snow cover, rain or overcast) allow radar signal coherence (e.g., radar phase) to be preserved between pairs of radar images over longer time intervals. In these conditions Differential Interferometric Synthetic Aperture Radar (DInSAR) could be successfully used to capture slow movements (cm/year). However, these conditions limited the use of DInSAR from a fully operational basis (Colesanti et al., 2003). Multi-temporal InSAR techniques, like Small BAseline Subset (SBAS) (Berardino et al., 2002), overcome some of DInSAR limitations. These techniques and their modifications are specifically designed to identify and quantify mm-level movement of area-based natural features (e.g., rock outcrops and boulders) and localized man-made structures (e.g., highway-related objects). The dimensions of the reflectors are usually smaller than the resolution cell and their coherence remains high for large temporal and geometrical bases. The SBAS technique exploits phase unwrapping by (1) assuming a certain type of correlation (similarity) between the movement of one pixel and that of the neighbouring ones and (2) making no assumptions on the type of movement (i.e., slow or fast and linear or nonlinear motions). These movements are equally well reconstructed by the SBAS algorithm, given that the spatial unwrapping step can be carried out.

A number of DInSAR studies documented the movements and settlement of underground mining sites (e.g., Stow and Wright, 1997; Herrera et al., 2007; Perski et al., 2009; Ng et al., 2010). Fewer multi-temporal InSAR studies focused in monitoring surface movement for open-pit mining (Wegmuller et al., 2007; Paradella et al., 2015), slope stability of waste piles (Pinto et al., 2014; Paradella et al., 2015), and tailing impoundments (Riedmann et al., 2013; Colombo, 2013). To our knowledge, the study presented here is the first that uses a combination of coherence, conventional and multi-temporal InSAR techniques focused on the stability of uranium mill tailing impoundments.

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The availability of satellite and digital elevation model (DEM) data, while essential, does not guarantee success in detecting line-of-sight displacement in a test area. Data coverage depends on the number of scatterers within the area of interest, which in part depends on ground conditions and the geometry of the satellite with respect to the ground target. In particular, the scatterer distribution is difficult to infer without significant data processing (for more on these issues please also see Wasowski and Bovenga, 2014). A major focus of this research was to determine if sufficient scatterers are present on the covers of uranium mill tailings impoundments to permit InSAR analyses.

2. Background

2.1. Site description

Two uranium mill tailings sites located in north-western New Mexico – the Bluewater site and the Grants Homestake site – were subjects of our investigation. The locations of these sites, along with the area covered by the SAR data, are shown in Fig. 1. Both sites are located in the Grants-Bluewater Valley on the northeast flank of the Zuni Mountains on the western edge of the San Juan sedimentary basin. The bedrock at the sites consists of Paleozoic and Mesozoic age carbonate and detrital formations and is covered with a veneer of recent basalt flows and alluvial deposits. The original land surface elevations are in the range of 1980 to 2010 m above mean sea level. The climate at both sites is semiarid with mean annual precipitation of 280 mm.

2.2. Bluewater tailings impoundment

The Bluewater main tailings impoundment was created by the processing of uranium ores at a mill operated by the Anaconda Company and then Atlantic Richfield Company (ARCO) between 1955 and 1982. The main tailings impoundment was covered by a radon and erosion barrier in 1995 as part of reclamation of the site (U.S. Department of Energy, 1997). Fig. 2 shows the topography of the main tailings impoundment after the cover was placed. The surface of the Main Tailings Impoundment is covered with 4.5 in. of rock, with a median diameter of 1.5 in.

The southern portion of the main tailings impoundment consists of predominantly sandy tailings and the northern portion consists of “slimes”, which are very fine-grained materials from the processing of the uranium ore. The sandy portion of the tailings impoundment has a relatively steep topographic slope and the slimes portion has a very low topographic slope.

2.3. Grants (homestake) mill tailings impoundment

Homestake Mining Company operated a uranium mill at the Grants site from 1957 to 1990. A portion of the tailings from the milling operation was deposited in the large tailings impoundment (Fig. 3). The large tailings impoundment eventually rose to a height of approximately 30 m above the surrounding land. The sides of the large tailings impoundment are covered with at least 20 cm of basaltic rock, with a median diameter of not less than 12 cm (AK Geoconsult, 1993). Based on the latest data (i.e., October 1, 2014) Google Earth™ imagery, the surface of the impoundment is still undergoing modification and also may be undergoing continued settlement as water originally present in the tailings drains and by on-going extraction of pore water to control seepage.

3. Data and methods

A total of 13 ERS-1/ERS-2 SAR images, part from Track 141, Frame 2997 descending orbit mode, were selected and acquired through the Western North America interferometric synthetic aperture radar consortium (WInSAR). These SAR images were acquired between August 22, 1996 and December 14, 2000 (Table 1). These SAR datasets were selected from a larger pool and screened based on meteorological conditions at the time of acquisition, eliminating those acquired during (a) rain and thunderstorms, (b) mist or fog or, (c) during overcast conditions (Necsoiu et al., 2014). Datasets with large perpendicular baselines were also eliminated especially

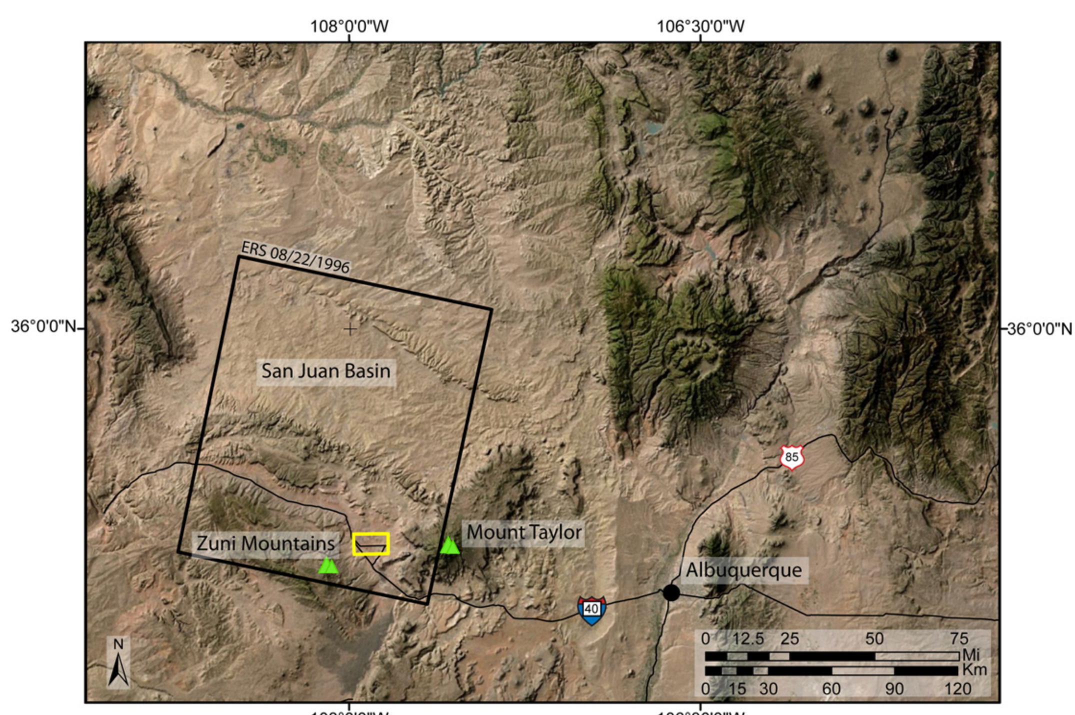

Fig. 1. Location of the study area (yellow rectangle, 133 sq. miles), ~90 miles West of Albuquerque, New Mexico. Black rectangle represents the extent of historical ERS-1/-2 SAR satellite data. Background is a natural colour pan-sharpened Landsat imagery, enhanced with topographic hillshading and colour balancing. Background image credit: USGS, NASA, ERSI Inc.