Measuring local deformation with interferometric synthetic aperture radar

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Small subsidence level changes associated with shallow underground mining can be detected over periods as short as one month.

The Zonguldak coalfield is located along the Black Sea coast about 240km from Istanbul (see Figure 1). The area’s steep, vegetated topography lies between 0 and 1,000 meters above sea level. Underground coal mining has been conducted at Zonguldak since 1848 in the Kozlu, Uzulmez, and Karadon mines at depths of 200–700m below the surface. Recently, subsidence caused by the mining has reached the surface, and destroyed roads and buildings.

Starting in 1996, a GPS- (global-positioning system-) based campaign led by the Bank of the Provinces, Istanbul Technical University, and Zonguldak Karayelmas University was undertaken to characterize the deformation. Although more than 150 baseline measurements were obtained, the subsequent deformation was poorly characterized because most of the measurements from the follow-up campaign in 2003 were lost.

Fortunately, interferometric, synthetic-aperture radar (InSAR) measurements taken by the Japanese Earth Resources Satellite-1 (JERS-1/SAR) include coverage of the area, and provided an efficient and complementary method for characterizing the mining-related deformation.

For a given ground location, InSAR relates ground deformation to changes in the radar phase between measurements. Over a region, the phase differences may be displayed on maps as contours, or ‘fringes,’ of deformation.

We used JERS-1/SAR data obtained on 29 September 1995 and 20 May 1995 for ‘master’ and ‘slave’ images, respectively. The fringe due to topography alone was removed using a digital elevation model (DEM) developed with data from the Shuttle Radar Topography Mission. Automated processing was done using the master, slave, and DEM images, as shown in Figure 2.

Small phase anomalies over distances of several hundreds of meters are evident near the three coal mines (see Figure 3). The largest deformations—about 204mm over 132 days—were found in the vicinity of the Kozlu mine. The deformation there increased toward the Black Sea, reflecting the trend of exploratory excavation in the mine. In the Uzulmez and Karadon

Figure 1. The study area is shown left in a JERS-1/SAR mosaic image, and at right in an advanced spaceborne thermal-emission and radiometer image acquired on 7 June 2005.

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Figure 2. Shown is the InSAR data-processing flow using JERS-1/SAR data obtained on 29 September and 20 May 1995 as the 'master' and 'slave' images, respectively. A digital elevation model based on Shuttle Radar Topography Mission (SRTM DEM) data was used to remove topography effects.

Figure 3. This deformation map of the Zonguldak coalfield shows the locations, based on information from 1990, of existing and planned mining tunnels, which in several cases underly surface subsidence. Mines, deformations in excess of 130mm were seen at multiple locations.

For comparison, GPS measurements were obtained in October and November 2005 in the vicinity of the high-subsidence Kozlu mine, near buildings with damage assumed to be caused by the surface deformation. We would expect subsidence of at least 45mm over that one month interval, given the InSAR results. At sites ZK-01 and ZK-02 (see Figure 3), displacements of 51mm and 61mm, respectively, were found with GPS data. These are consistent with InSAR-based results, equivalent to 43mm and 61mm, respectively, for a one-month interval. These results verify the accuracy of the InSAR ground deformation estimates, which were within 8mm of the GPS estimates, and show that displacement measurements equivalent to less than 8% of the total phase (1cm) are possible.

Based on maps of the 1990 locations of the existing and planned mining tunnels, we determined that the subsidence detected by InSAR coincides with production areas. At Kozlu, mining activities around the year 1995 were responsible. The 2005 GPS data show subsidence has continued in Kozlu coalfield, even after 1995. At Uzulmez and Karadon, some surface deformations were immediately above existing tunnels, while others were above planned tunnels that were, presumably, developed subsequently.

In the future, real-time ground deformation will be measured using phased-array type L-band synthetic aperture radar

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loaded on the Advanced Land Observing Satellite mission, which launched in January 2006. In addition, this study will develop 3D deformation estimates that integrate measurements from GPS, leveling, and several SAR sources.

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References