Satellite radar reveals land subsidence over coal mines

Huanyin Yue, Guang Liu, Zbigniew Perski, and Huadong Guo

Satellite-based synthetic aperture radar interferometry could be an effective monitoring technique for geologists and regulators who oversee underground coal mining.

Extracting coal from underground mines generally leads to subsidence of the overlying land within a period of days to years. Underground mines are by their nature hidden from casual view. Land subsidence can give important clues as to the extent of a mine and its impact on the land.\(^1\) \(^2\) Local governments can use this information to ensure miners are staying within permitted areas and to monitor environmental effects. Regulators and geologists conventionally monitor land subsidence with in situ field techniques that require expensive, time-consuming measurements on the ground that can be difficult or impossible to perform in steep mountain ranges and other inhospitable terrain.

Here we show the feasibility of monitoring land subsidence caused by coal mining with multi-band differential synthetic aperture radar interferometry (DInSAR).\(^3\) In synthetic aperture radar (SAR) interferometry, airborne or spaceborne detectors scan Earth’s surface with radio waves to create a topographical map of the ground. DInSAR compares SAR interferometry data taken hours, days, or years apart and can show subtle topographical changes. We use DInSAR techniques to compare scans of land over coal mines on different dates to reveal land subsidence on scales as small as a few centimeters.\(^4\)

We mapped land subsidence that occurred from 1993 to 1997 in the Fengfeng coal mine area in Hebei province in China using spaceborne SAR data. We used C band data from the Advanced Synthetic Aperture Radar (ASAR) on the Environmental Satellite (ENVISAT) and L band data from the Japanese Earth Research Satellite (JERS) and Advanced Land Observing Satellite Phased Array L type Synthetic Aperture Radar (ALOS PALSAR). JERS does not have a precise orbit. We set up a dynamical coordinate system using the radial, cross-track, and along-track directions for JERS SAR interferometric processing\(^5\) to adjust the spatial baseline and obtain an accurate DInSAR result. We also reduced the positional error with an external digital elevation model.\(^6\)

We performed optical leveling at the same time as the ASAR data acquisition in order to test the DInSAR results. In Dashucun coal mine, 104 lithic benchmarks of known elevation were installed in an area of 3km\(^2\). The leveling started on 10 April 2006 and finished on 5 August 2007. Figure 1 shows a subsidence contour map derived from the leveling data.

Figure 2 shows the 17 differential interferometric results, filtered to reduce noise: data from JERS (a–j) ASAR (k–o), and ALOS PALSAR (p–q). C band SAR needs a much smaller spatial and temporal baseline than L band SAR, and the subsidence center will always lose information because of decorrelation. But C band is more sensitive to deformation. This means C band is suitable for low-velocity subsidence with a short temporal baseline, while L band will have the advantage over longer time spans. L band subsidence detection is less accurate than C band. But the L band frequencies are more coherent in SAR interferometry. Thus time series L band SAR data gives more effective DInSAR results.

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Figure 2. Land subsidence results derived by differential synthetic aperture radar interferometry (DInSAR) processing over different time intervals. Advanced Synthetic Aperture Radar (ASAR) on the Environmental Satellite, Japanese Earth Research Satellite (JERS), and Advanced Land Observing Satellite Phased Array L type Synthetic Aperture Radar (ALOS PALSAR) data included.

The DInSAR results were overlaid on the leveling contour maps (see Figure 3). The black lines on the maps mark the coal mine boundaries. The subsidence positions on the leveling contour maps and the differential fringes are consistent with each other. Because the DInSAR result can only reflect the deformation of the line-of-sight direction, we derived the vertical deformation from the line-of-sight component divided by \( \cos 23^\circ \).

Comparing these DInSAR results with the maximum value measured by leveling, we can see that they are also consistent with each other. Our experiment shows that the regional position and magnitude of subsidence over all coal mines detected by the DInSAR technique are reliable.

In summary, we show that coal mining-induced land subsidence can be feasibly monitored with the DInSAR technique. Both C band and L band can track mining area subsidence, but C band has more restricted conditions. In order to effectively monitor mining area subsidence with the DInSAR method, a good baseline composed of several detailed interferometry data sets taken in the same season is required, especially in rural areas. Our future work will include time series SAR interferometry, and establish a more appropriate model to describe the nonlinear rate of coal mine subsidence over time. Subsidence tends to occur not at a steady rate, but rather quickly at first and then more slowly as time goes on. A better nonlinear model that takes

Figure 3. Comparison between the DInSAR results of ASAR and leveling results in Dashucun coal mine. The leveling data is in millimeters.
this into account will help us reduce atmospheric effects and other noise, thus enabling the use of SAR data taken over longer time periods and with larger spatial baselines.

Author Information

Huanyin Yue  
National Remote Sensing Center of China  
Beijing, China

Guang Liu  
Center for Earth Observation and Digital Earth  
Chinese Academy of Sciences  
Beijing, China

Liu Guang is an associate research fellow of the Center for Earth Observation and Digital Earth (CEODE), Chinese Academy of Sciences. His interests focus on airborne and spaceborne InSAR technology.

Zbigniew Perski  
Polish Geological Institute  
Carpathian, Poland

Huadong Guo  
CEODE, Chinese Academy of Sciences  
Beijing, China

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