MONITORING UNDERGROUND MINING SUBSIDENCE IN SOUTH INDIANA WITH C- AND L-BAND INSAR TECHNIQUE

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ABSTRACT

In the state of Indiana over 1500 million tons of coal were extracted from underground in the past 150 years. As a consequence, today many of the long-abandoned mines pose a serious risk to the local. When the abandoned mine shafts collapse, the ground above can drop as much as several feet along with everything on it. Thus it is essential for a long-term-wide-range monitoring technique to map the ground subsidence over the local mining area. In this study, we try to evaluate the mining area ground subsidence with interferometric synthetic aperture radar (InSAR) technique, which is famous for its capability of wide-area and high-precision monitoring. Furthermore, for better understanding the ground motion with respect to difference RADAR frequencies, we use data with different wavelengths in this project, C-band and L-band respectively. The result shows that overall the monitored area were stable but we can still detect ground movements at the location of a few mining spots.

Index Terms— mining, subsidence, InSAR, C-band, L-band

1. INTRODUCTION

The southwest part of the state of Indiana has a long history of mining that can trace back to 165 year ago. Lying within the Illinois Basin that provides abundant reserves of mine and coal, this region has provided an estimated 1500 million tons of coal and the total undermined surface area is about 400 square kilometers. One of the substantial threats with underground mining is confined to old abandoned underground mines, which may lead to a variety of ground conditions over a great extent, including sinkholes, sags, and troughs. In some areas extensive subsidence may eventually create swampy conditions. Even a century later after some of the mines were abandoned, they poses serious risks to local properties, and a number of subsidence events were reported in recent years [1, 2, 3].

On the other hand, it has already been demonstrated that SAR interferometry provides an ideal tool for monitoring ground subsidence over a large area and long time period, standing as an auxiliary tool for evaluating the location and extent of subsidence [4, 5, 6, 7]. The technique is especially known for its capability of long-term, wide-range and high precision monitoring. It has already been proved that the technique can provide up to centimeter accuracy over some 1,500 square kilometers all at once, which made it an ideal tool for finding ground subsidence over a big area for a further investigation. In this study, we applied C-band ERS-1&2 and L-band ALOS images for InSAR technique to give an overview of the subsidence during the monitoring period.

The C-band ERS data was one of the pioneer in the history of SAR satellites, and it still possess the most abundant data archive. The ERS mission lasted for almost 20 years and covered almost every corner of the earth, making it one of the best data archives for long-term InSAR analysis. In addition, to compensate the fact that ERS C-band data might not get high coherent interferograms over vegetated and mountainous area, we also use ALOS L-band data that has relatively high temporal and spatial coherence in these areas. However, the L-band data do not have a longer time span comparing with ERS data, thus the study time is limited by the acquired time of ALOS data.

For the purpose of studying the local ground subsidence, we processed a number of interferograms in both bands and cross-check the results at those where abandoned underground mines were located. We also tried to apply the multi-temporal technique for ERS C-band data for digging out more information from the data. The result shows that the studying area were overall stable with some small scale ground movements at the location of a few mining spots that required further investigation.

2. DATA AND AREA OF INTEREST

The city of Evansville and Boonville lies on the north bank of Ohio River, the borderline between Kentucky and Indiana. This area is the major underground coal mines in South Indiana. The city reached its peak annual production by underground mining in 1920s, but soon after the surface mining surpassed deep underground mining in production. As mining operations ended at the old underground mines, most of them were simply sealed up and abandoned, leaving large voids below the surface. When those mine shafts collapse after decades, the ground above can drop as much as several feet. Buildings in the subsidence area are often severely dam-

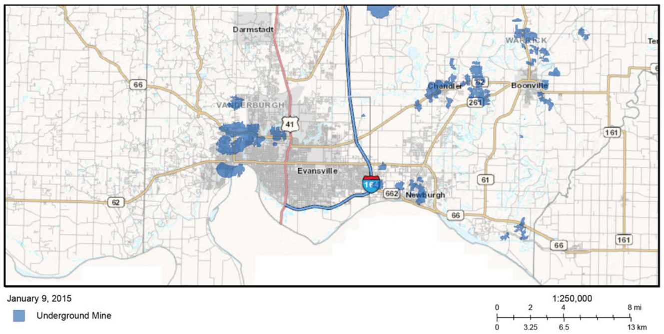

Fig. 1. Underground Coal Mining locations near Evansville and Boonville, on South border of Indiana, USA. Data Source: Provided by Indiana Coal Mine Information System http://coalminemaps.indiana.edu/

aged. Several reports was posted about the damage of local houses and roads. We opt to monitor the city of Evansville and Boonville and the region in between for past subsidence activities.

Two bands of SAR data are used, namely C-band ERS-1&2 data and L-band ALOS data. L-band ALOS data are favored due to its relative lower temporal decorrelation in vegetated areas w.r.t. C-band data, but only 9 images between 2009 and 2011 are available, which is not quite enough for doing a Persistent Scatterers (PS) analysis. On the other hand, we have 36 images of ERS1&2 between 1992 and 2007, but the high temporal decorrelation between images in vegetated areas and the large baselines between images pairs makes it also hard to generate high quality interferograms, let alone time series analysis and interpretation. In our experiments we will apply InSAR technique to all the data available to monitor local ground subsidence and try to find its correlation with local underground coal mining locations.

3. INSAR PROCESSING AND RESULTS

The project follows the standard interferometric process. SAR data were coregistered, geocoded, flattened and DEM removed. For removing DEM the SRTM data were used. Furthermore, for exploiting the ERS C-band data that spans a longer time series with the availability of more than 30 images, the PS technique is applied. In short, the PS processing chain includes the following steps: master image selection, SAR data co-registration, generating reflectivity map and amplitude stability index map, persistent scatterers candidate (PSC) selection, PS point selection, multi-image sparse grid phase unwrapping, atmospheric phase screen (APS) estimation and removal and PS phase reading and displacement estimation. The movement of the PS targets are retrieved as a function of time with respect to the master image selected. By processing the phase of SAR images with PSI algorithm, two results can be retrieved: the three dimensional localization of PS's with metric precision, and the estimated millimeter displacement of PS's along the satellite line of sight. All of the above process was implemented in the SAR processing software, SARPROZ, developed by Dr. Perissin. The final outcome was displayed in Google Earth.

Figure 1 shows the underground mining locations near the city of Evansville and Boonville that lies on the north bank of state line Ohio River. The area was long known for underground mining production since 1880s. Since the 1920s most of the underground mining sites were sealed and abandoned due to companies switching to ground mining. Subsidence accidents have been reported since then.

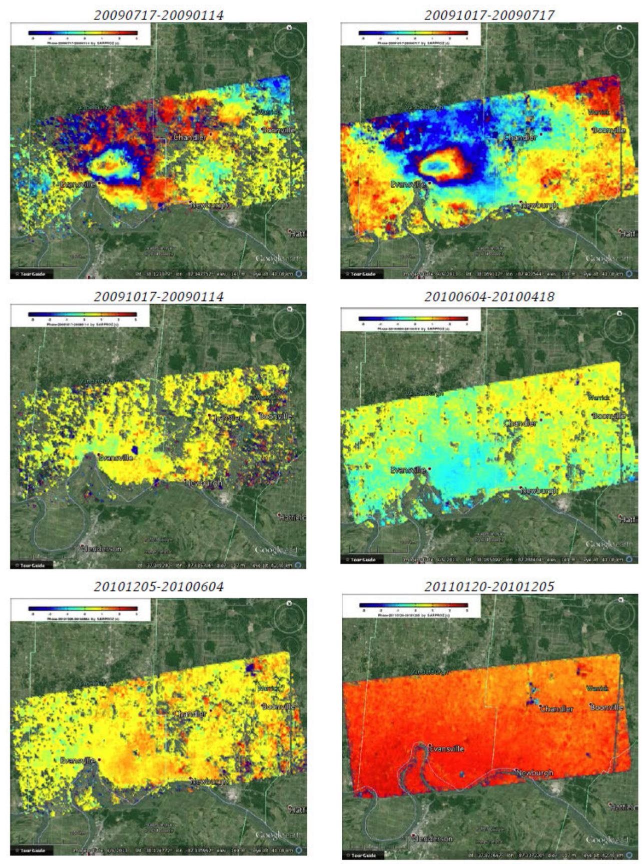

Fig. 2. Interferograms between L-band ALOS image pairs

A first outcome of interferograms are shown in figure 2 and 4, which are the interferograms of L-band ALOS and C-band ERS, respectively. The outcome are geocoded and displayed onto Google Earth and points with spatial coherence lower than 0.6 were discarded. In general, L-Band represents a much better spatial coherence even with long temporal baseline that can extend to one year. On the other side, as far as the interferograms concern, even with 36 images available, C-band interferograms shows a lower spatial coherence on average and only a few ones with a high coher-

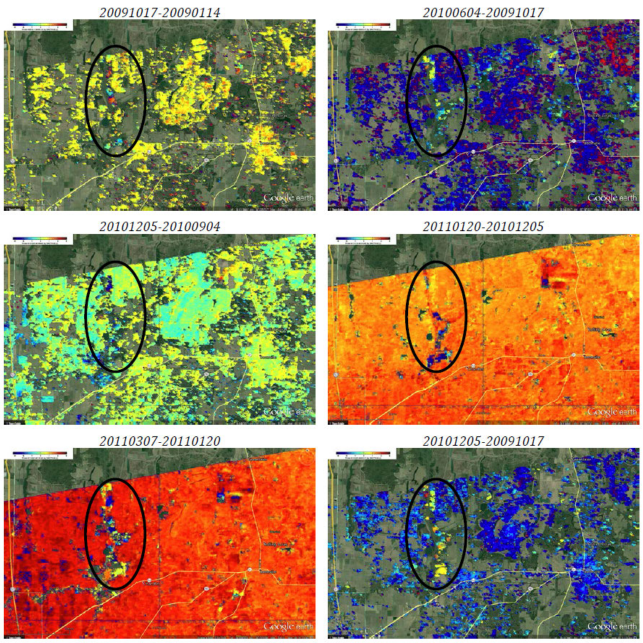

Fig. 3. Interferograms in L-bands, a closer look near the town of Chandler

ence due to the high temporal deccorelation and exceedingly high normal baseline of ERS.
The L-band interferograms are shown in figure 2. From the figure we can see that the ones in year 2009 revealed a significant signal at the city of Evansville with the clear circular fringes. However strong the signal is, we can see the signals in interferogram pair *20090717-20090114* and *20091017-20090717* shows an identical but inversed pattern. This suggested that the strong signal in the first two interferogram pairs are most likely atmospheric delays caused by cloudy and stormy weather, which is also verified from weather historical data. After year 2010 the interferograms show no apparent ground deformation in general.
Meanwhile, most interferograms reveal some continuous movements northwest to the town of Chandler, where a number of underground and on-surface mining sites were located and shown in figure 1. A closer look of the interferograms zoomed in near the town of Chandler is shown in 3. The area circled in black shows consistent signals that indicates some kind of ground motion during the ALOS acquired time period from 2009 to 2011. The next step should be a closer investigation by the help of more data if available and other ground survey techniques to check the area.

For C-band interferograms, due to the unfavorable spatial baselines between images pairs, interferograms generally present a lower quality than L-bands. In figure 4 we represents the best interferograms out of the whole stack. We can observe slight deformation trend going gradually from

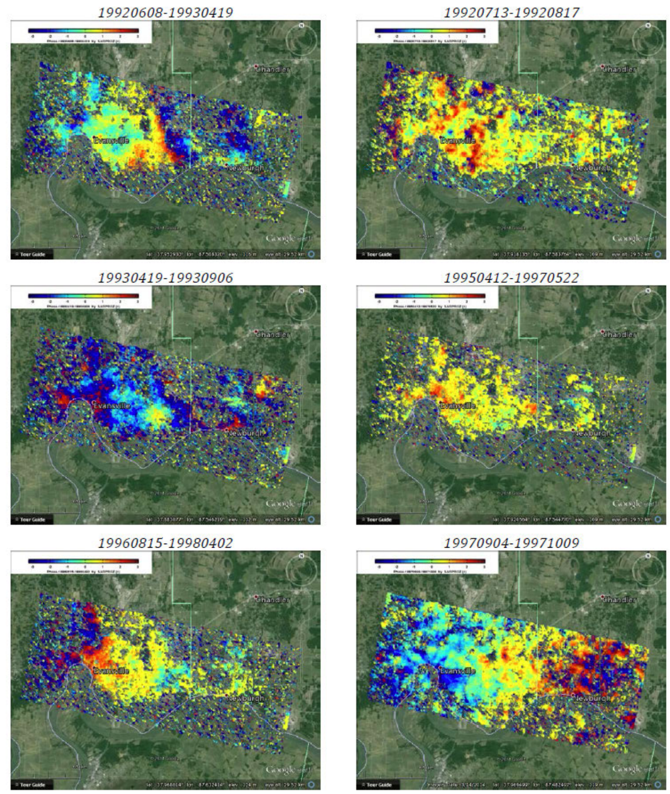

Fig. 4. Interferograms between C-Band ERS1&2 image pairs

the center of city Evansville to its east from most of the six interferograms during the period of year 1992 to 1998. We can also see other phase change on the images but none of them are conclusive for relating to underground mining at this point.

In addition, a preliminary PS analysis was carried out by processing the ERS data stack in SARPROZ. Figure 5 shows the normal baseline w.r.t. temporal baseline of the 36 ERS images. Note that we can see a few images after year 2000 that have abnormally high temporal and spatial baseline that makes the image impossible for PS analysis, thus these images will be discarded for the PS process. The outcome is shown in figure 6. First of all, due to the low-coherence at most of the vegetated lands in rural areas, we can see that the PS points are located mostly in cities and along the roads. In figure 6, the color scale stands for deformation velocity and range from -20mm to 20mm. The result shows that most of the area is stable without any sigfinicant movement.

4. ANALYSIS AND DISCUSSIONS

From the process and interprete of C and L band SAR images, we can see that most of the areas are overall stable, with minor ground motion going on at a few spots that required

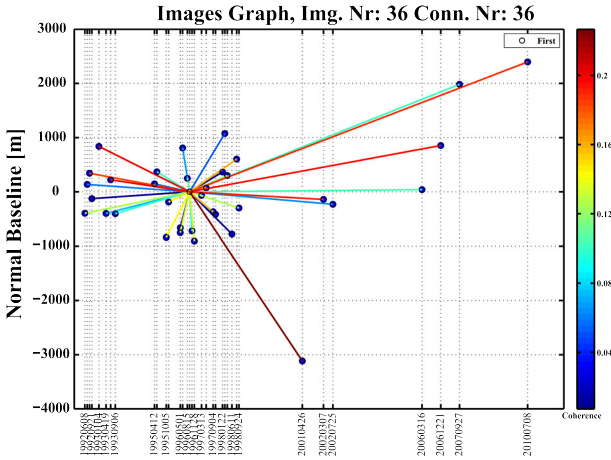

Fig. 5. The temporal and spatial baseline of the available ERS data stack

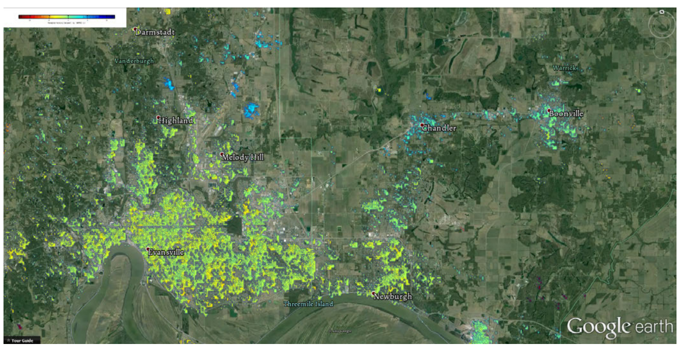

Fig. 6. The velocity map of PSI analysis using ERS C band data stack

further investigations.

By comparing the performance of different bands, L-band SAR images are showing great capabilities in rural and vegetated areas and should be favored for its desirable correlation between image pairs even for long temporal baselines. However, generally speaking, the lack of sufficient number of images made it hard for further PS analysis. On the other side, ERS data make an ideal data stack with sufficient number of images, but the low correlation in rural and vegetated areas and the low spatial correlation due to large baselines also add some difficulties to interferometric process and PS analysis. Furthermore, it is almost unlikely to get convincing results from ERS image after year 2001 due to the uncontrollable spatial baseline.

At this point we plan to extend this study by two aspects. At first place, it is very necessary to compare InSAR outcome with other measuring methods including GPS and leveling data if they are available. At second place, since C-&-L Band data all have their short hands, we also plan to seek other available datasets and different frequencies. For example, we could use the new X-band COSMO or TerraSAR data which have a higher spatial resolution, shorter revisit time and more precise spatial baseline. The result will be more convincing if the InSAR derived deformation from two different datasets confirms each other.

5. ACKNOWLEDGMENT

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