APPLICATION OF DINSAR AND GIS FOR UNDERGROUND MINE SUBSIDENCE MONITORING

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ABSTRACT:

This research used both ERS and Envisat images to investigate the feasibility of differential radar interferometry (DInSAR) for mine subsidence monitoring in Tang Shan, Hebei Province, China. DInSAR results are analyzed and validated with the aid of Geographic Information System (GIS) tools. The drawbacks of using interferometric measurements for mine subsidence monitoring are discussed. The repeat-pass tandem and Envisat DInSAR results are presented.

1. INTRODUCTION

Interferometric synthetic aperture radar (InSAR) systems exploit the phase differences between two SAR images acquired over the same area. Useful topographic information, such as digital elevation model (DEM), can be derived. Differential InSAR (DInSAR) has been further used to measure the deformation of the ground terrain. A number of experiments have demonstrated that InSAR is very useful in such fields as earthquake-related deformation, volcanic motion, ice-sheet shift, urban settlement. [Massonet and Feigl, 1998; Rosen et al., 2000]

Compared with the conventional approaches (such as GPS monitoring), using of InSAR and D-InSAR in surface deformation monitoring can cover a large area on the earth, and the result can be obtained in a relatively short time. The cost of InSAR is lower and it is very useful for the rural area or the dangerous places where we can’t easily arrive. Finally, because the cloud and the light have no effect on the Synthetic Aperture Radar images, the images can be obtained every times when the SAR satellites pass the area. The feasibility and capability of DInSAR for underground mine subsidence monitoring have been tested in the UK [Wright, P. and R. Stow.1999], France [Carnec, C. and C. Delacourt, 2000], Germany [Wegmuller, 2000]. In these studies, the images acquired by the two ERS satellites are the only data source.

This paper reports the progress of the ongoing ESA CAT-1 project (ID 4527). We used radar images acquired by the ERS and Envisat satellites to investigate the use of radar interferometry for mining-induced subsidence monitoring in Tang Shan, Hebei Province, China. Successful DInSAR results are exported to the GIS and mine subsidence regions extracted. The DInSAR results are analyzed and validated against other spatial information, such as TM images and mine plans.

2. REPEAT-PASS DINSAR

Repeat-pass space-borne DInSAR has been used to derive ground displacement maps. Two SAR images acquired from two slightly different positions, at different revisit times, are used to measure the phase difference, or so-called interferogram, between the two acquisitions.

As shown in (1)[Liu Guo-xiang,2006], the phase change in the interferogram is the composite of systematic phase(also termed flat-earth trend phases)from the reference surface, Φ_{flat}, topographic information, Φ_{topo}, surface displacement between the two acquisitions, Φ_{disp}, atmospheric delay, Φ_{delay}, and noise, Φ_{noise}.

$$\Phi = \Phi_{flat} + \Phi_{topo} + \Phi_{disp} + \Phi_{delay} + \Phi_{noise} \quad (1)$$

DInSAR requires the removal of phase signatures that are contributed by the flat-earth and topography, and so isolating the ground displacement component. The Φ_{flat} can be predicted using the satellite state vectors or baseline data and based on the interferometric geometry, and then subtracted from the initial interferogram. The Φ_{topo} can be simulated and eliminated by introducing DEM information. The atmospheric component, Φ_{delay}, is primarily due to fluctuations of water content in the atmosphere between the satellite and the ground, it is difficult to eliminate because the absence of the weather-information and the limited resolution of the SAR sensors. We can use filter to enhance the signal-to-noise level.

3. STUDY AREA AND USED DATA

Tangshan City and Kailuan Mining Area, located in east of China, are selected as the experimental district.Tangshan city is the main coal city in China. Since 1970s, underground mining extended to downtown area. Especially since 1990s, underground mining has induced large area of land surface subsidence; many buildings, road and pubic establishment were damaged. Kailuan Mining Area has been exploited for 123 years, the mining area covers 670 km^2, and the subsidence area, affected by underground coal mining, covers 208 km^2.[Wu Lixing,2005]

Figure 1 is TM image of Tangshan test site. 4 ERS images spanning from 1996 to 2000 and 3 ENVISAT spanning from 2004 to 2006, were combined to produce interferograms (table1&table2). Two different approaches were applied to construct the differential interferogram: three-pass method using

3 SAR images for ERS data and two-pass method using two ASAR images plus an external DEM for Envisat data.

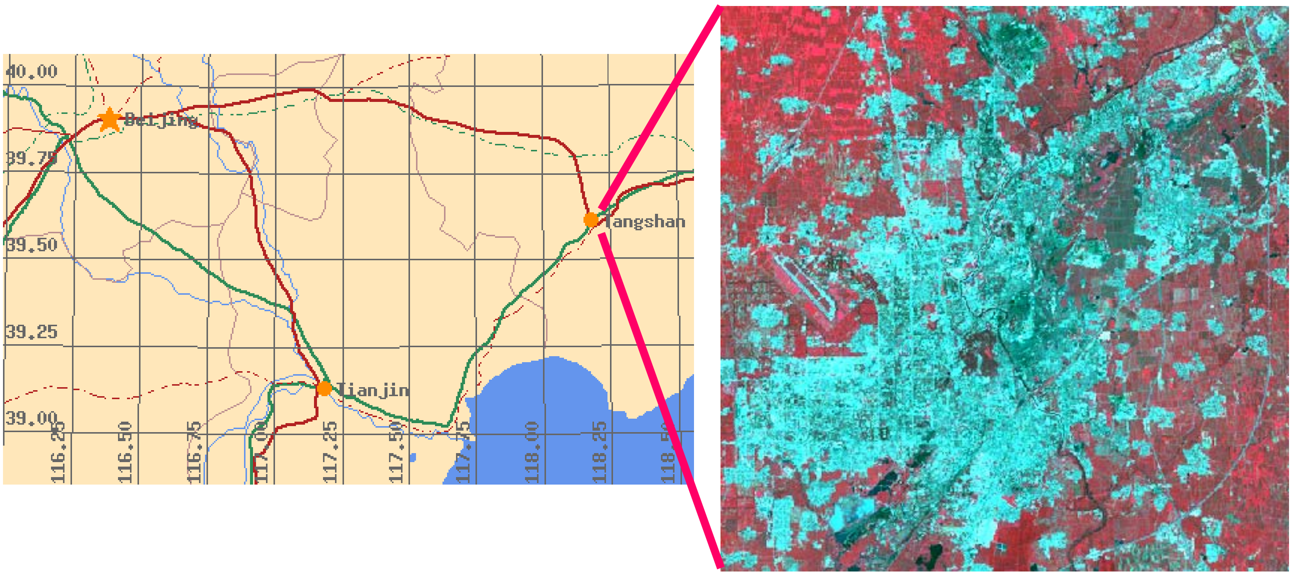

Figure 1 The TM image of Tangshan test site

Mission	Track	Frame	Orbit	Date	Perp. baseline/m		Temporal baseline/d	
ERS2	175	2799	23710	19960127	8		-625	
ERS2	175	2799	13055	19971019	0		0	
ERS2	175	2799	16061	19980517	413	0	211	0
ERS2	175	2799	26582	20000521		150		735

Table1 ERS1/2 SLC SAR data

Mission	Track	Frame	Orbit	Date	Perp. baseline/m	Temporal Baseline/d
ENVISAT	268	783	9841	20040117	130	-240
ENVISAT	268	783	13348	20040918	0	0
ENVISAT	268	783	20863	20060225	92	515

Table2 Envisat SLC ASAR data

4. INTERPRETATION OF INSAR RESULTS WITH THE AID OF GIS

After reviewing the available software for InSAR processing it was decided that DORIS InSAR Processor developed by the Delft Institute for Earth-Oriented Space Research (DEOS), DORIS is free software (for non-commercial scientific purpose) that runs on UNIX/Linux platforms. [Kampes, B., 1999].It can generate interferometric products and end-products from Single Look Complex radar data provided by ESA. Scenes generated by ERS1, ERS2 and Envisat satellites can be processed.

Interferogram unwrapping was performed using the SNAPHU software developed by Curtis W. Chen [Curtis W. Chen ,2002] and integrated as module with DORIS.

The differential InSAR results were exported to and post-processed in the GIS. The mine subsidence regions can be seen clearly and the color coding indicates the magnitude of subsidence, as shown in Figure2. A further advantage of using the GIS is that ground deformation can be analyzed and visualized in various ways.

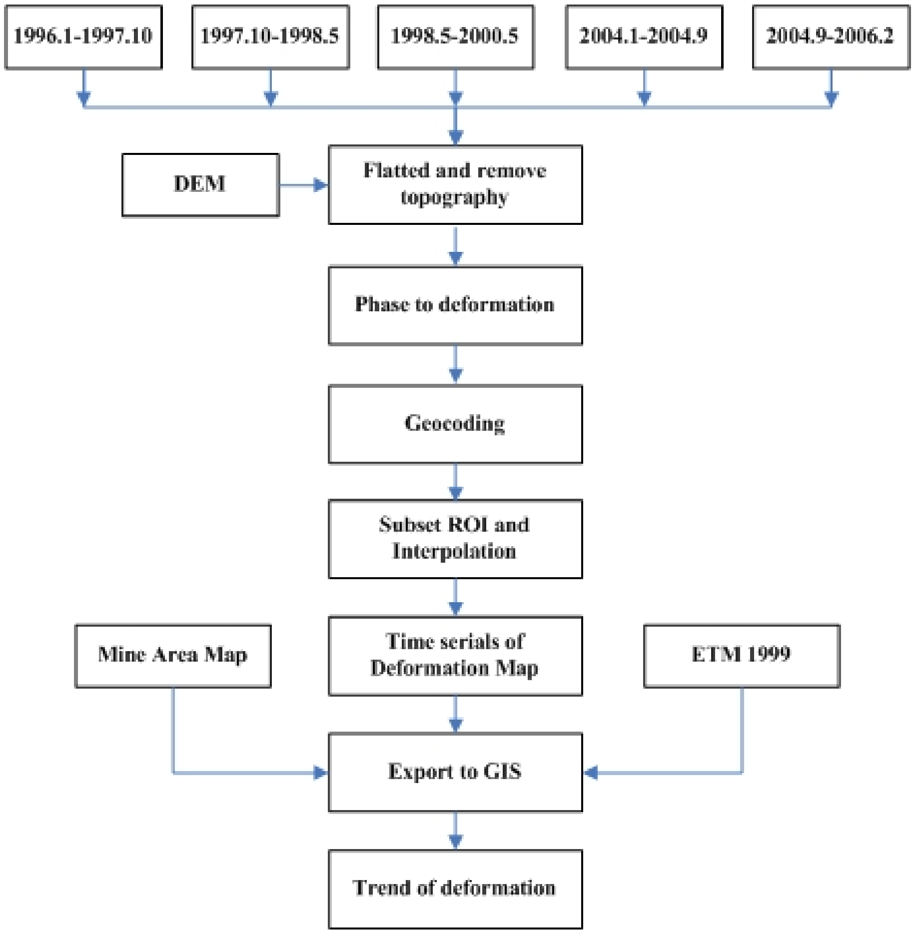

Figure2 Subsidence monitoring method based on time serials of interferograms

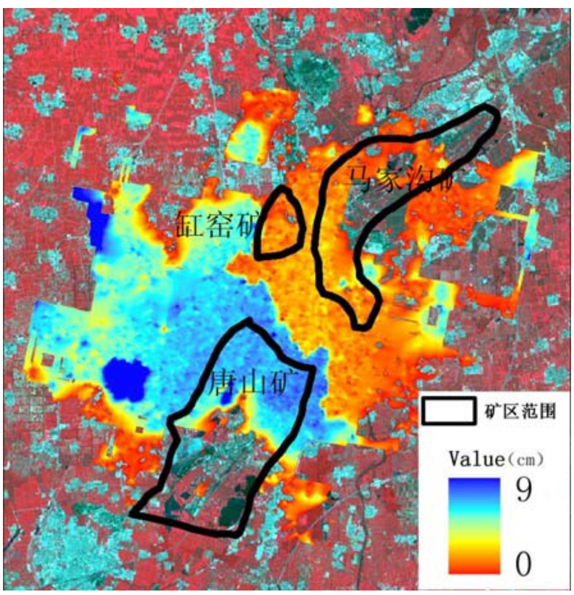

Figure 3 Subsidence 1996.1-1997.10. The subsidence regions can be seen clearly and the color coding indicates the magnitude of subsidence. TM (1999, band: 321) image is shown in the background, and overlapped with the mine area map (solid black line).The largest displacement is 9cm in West of Tangshan, In Tangshan Mine area, it has averagely 7cm displacement, in Gangyao Mine and Majiagou Mine, and it has 1.5cm displacement.

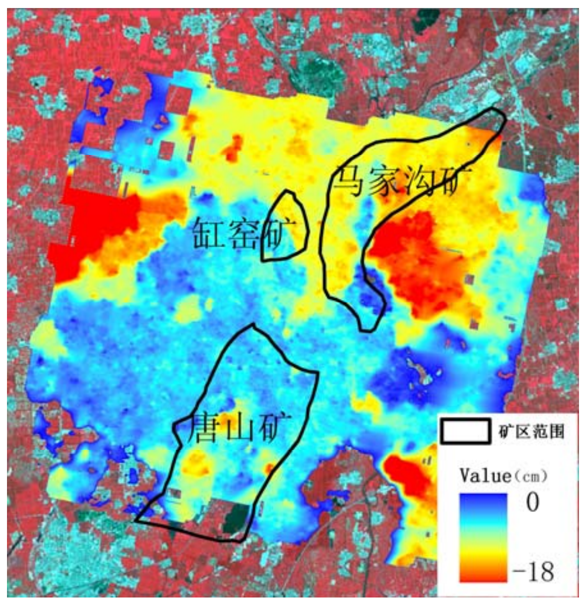

Figure 4 Subsidence 1997.10-1998.5. ETM (1999, band: 321) image is shown in the background, and overlapped with the mine area map. The largest displacement is 18cm near Majiagou mine, in Gangyao mine, it has averagely 8 cm displacement, and Tangshan mine area has 7cm displacement. In west of Tangshan mine area, and it has averagely 3 cm displacement due to the Kast collapse.

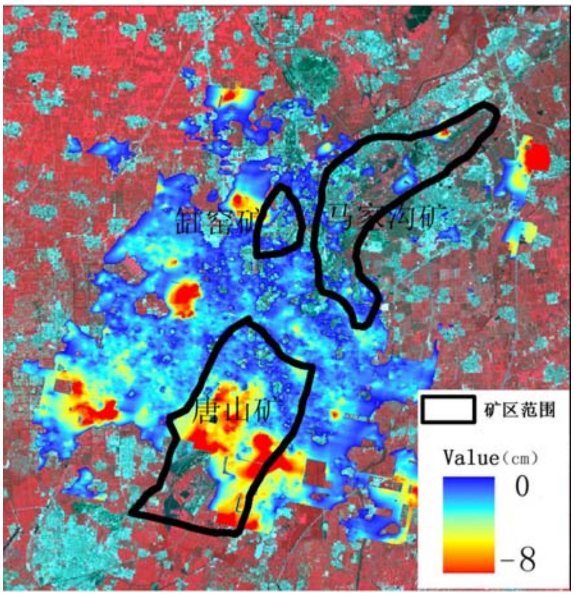

Figure 5 Subsidence 1998.5-2000.5. ETM (1999, band: 321) image is shown in the background, and overlapped with the mine area map. The largest displacement is 8cm in Tangshan mine area, in Gangyao mine and Majiagou mine, it has averagely 1 cm displacement, and in west of Tangshan mine area, and it has averagely 3 cm displacement due to the Kast collapse.

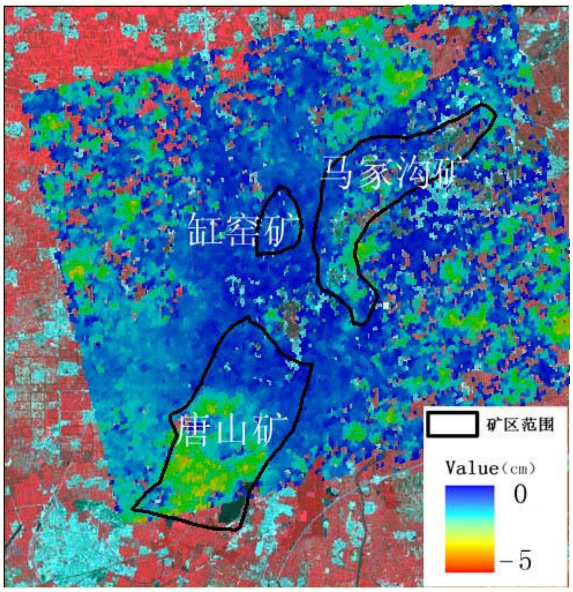

Figure 6 Subsidence 17 Jan-18 Sep 2004. Tangshan is stable except in Tangshan Mine, It forbidden to excavating in cantonal Tangshan, and the South-lake Park was built in the south.

5. ERROR ANALYSE

As showed in formula(1),the phase is composed of these parts after unwrapping: Φ_{disp}, Φ_{topo}, Φ_{delay}, Φ_{noise}.

Φ_{disp} is what we want to gain, the others are errors. Φ_{delay} is difficult to gain without the surface subsidence, in our study area, atmospheric influence is not obvious, because the change trend of interferograms are not abnormity. According to

$$\sigma\Delta\phi = \frac{4\pi}{\lambda}\frac{B_\perp}{R\sin\gamma}\sigma_h$$

,for ERS, λ is 5.66cm,R is 850km，γ is 23°，if $B_\perp$ is 100m，the error of phase due to error of height can reach to 3.8°,that means 0.3mm displacement in line of sight. According to the formula, the sensitivity of difference of phase to error of height is proportionate increase to baseline, which means small baseline is good for eliminating topography. For our study, the longest perpendicular baseline is 413m that means 2.4cm displacement in line of sight. the shortest perpendicular baseline is 8m that means 0.48mm displacement in line of sight, So, error due to DEM is small when perpendicular baseline is small, it is why this research can gain good result. Φ_{noise} is difficult to quantize the error for interferograms, in general, it is considered not important and ignored it.

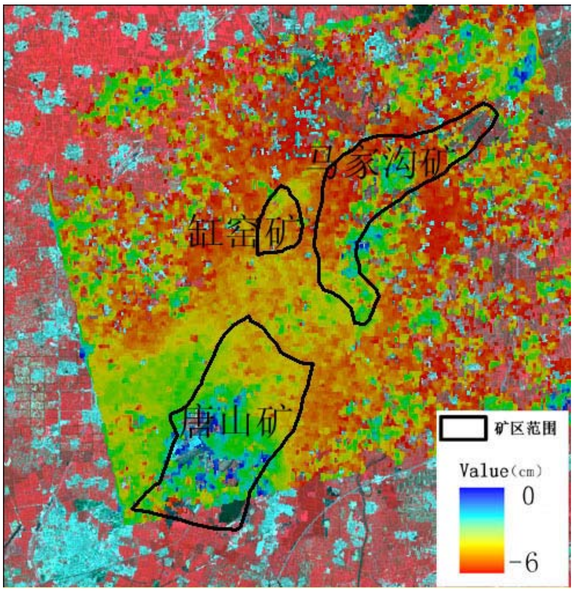

Figure 7 Subsidence 18 Sep 2004-25 Feb 2006. The largest displacement is 8cm in north of Tangshan, which due to construction of Tangshan. In Tangshan Mine, it has averagely 3cm displacement.

6. CONCLUSION

In city zone, even have 2 years spanned, it still has good coherence because of the low vegetation cover of the ground surface. With the aid of GIS tools, mine subsidence regions and the magnitude of subsidence has been extracted.

SAR interferometry plays very important role as the independent tool which allows effectively mapping the recent subsidence and studying its dynamics, and the presented results confirm the applicability of the subsidence monitoring method based on time serials of interferograms.

From the results, we know that Tangshan suffers serious subsidence in 1990's, especially in 1997.10-1998.5, the largest displacement in Tangshan reaches to 18cm.Since 1998,Tangshan has been in the list of state's test sites of repair subsidence due to mine excavate, the subsidence has been controlled.

But the results need more confirmation because of the insufficient amount of data available. The atmospheric influence and DEM error couldn't be ignored in interferometry. Interferograms stack or Permanent Scatterers (PS) technique should be used to eliminate the influence in future.

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The interferometry processing in this project was performed using the freely available Doris software, developed by the Delft Institute for Earth-Oriented Space Research (DEOS), Delft University of Technology. (http://www.geo.tudelft.nl/doris.html).

Data integration is performed using ArcGIS supplied by ESRI.

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