# INSAR TIME SERIES ANALYSIS OF COAL MINING IN ZONGULDAK CITY, NORTHWESTERN TURKEY

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## ABSTRACT

This paper presents preliminary results of the subsidence monitoring of a coal-mining field in Zonguldak Province using Interferometric Synthethic Aparture Radar (InSAR) time series. It is a coastal urban area in northwestern Turkey that is prone to human-induced environmental problems such as collapse due to the coal-mining. Severe deformations have been known since the 1900s. Many people have lost their lives, and many buildings have been damaged in the region. The aim of this study is to investigate the subsidence that causes damage in dwelling units and mining areas.

For this purpose, ENVISAT ASAR images were acquired in two different geometries (one ascending and one descending track), which cover the same areas. Persistent Scatterer Interferometry (PSI) and Small Baseline Interferometry (SB) time series have been analyzed and compared. Time series were constructed using the Stanford Method for Persistent Scatterers (StaMPS) package with both PSI and SB approaches. Between 2003 and 2010, the deformation was estimated to be approximately 20 to 140 mm in the urban areas near the Kozlu mining area. Areas of subsidence in the rural regions were also revealed at Karadon and Uzulmez. The maps of underground mining tunnels show that these surface deformations are most probably due to mining.

## 1. INTRODUCTION

InSAR has become a widely used geodetic technique to measure the surface deformation of large areas. Conventional InSAR is used to estimate small-scale movements at mm to cm accuracy [1]. On the other hand, long temporal and geometric baselines cause spatial decorrelation. To overcome these limitations, different approaches are proposed [2], [3], [4], [5]. The goal of this paper is to monitor the mining subsidence in Zonguldak Province and determine the deformation using the radar time series analysis. In the urban area of the study region buildings are strongly affected and damaged. Some parts are still under serious risk due to unorganized extension of urbanization. Between 1986 and 2003, 5630 roof falls happened in Kozlu mine [6], and more than 70 people lost their lives in Zonguldak region between 2000 and 2010. It is necessary to observe the area due to continuing collapses that have happened frequently in the last decade [7]. Monitoring this area is thus of high importance to the government, mining industry and environment.

In the Zonguldak region, subsidence was monitoring by previous InSAR studies [8], [9]. One pair of JERS images from 1995 was first studied, and 204 mm/132 days of deformation around the Kozlu coalfield was extracted. Furthermore, about 130 mm/132 days of deformation was observed at Karadon and Uzulmez area (Fig. 1). Another study was done for the periods 2005 and 2006 with 15 Radarsat images. In the urban area near the Kozlu, 55 mm/15 months of deformation was measured by time series of Radarsat images. Differential InSAR (DInSAR) results were validated with 3 GPS points which were observed in 4 epochs between October 2005 and October 2006. 8.2 cm/13 months of maximum vertical deformation was obtained [9]. Surface deformation is also known to be taking place in the Uzulmez and Karadon mining fields, but they could not be detected by the previous DInSAR studies using C-band Radarsat. 30-40 mm/ 46 days of deformation was extracted using L-band

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PALSAR data in Uzulmez and Karadon regions [8]. Two periods of leveling study were also done at Kozlu region, and 25 to 75 mm deformation was computed from 10 months of measurements [10].

One of the main problems in conventional DInSAR is the atmospheric error. Long temporal baselines also change the variations of the terrain. In this case study of monitoring surface subsidence, we compared the PSI and SB techniques using Envisat ASAR images which cover the Zonguldak area, Turkey. We processed ascending and descending data with StaMPS to extract the displacement in the line of sight (LOS). Detailed description of the PSI and SB methodologies used can be found in [10], [11]. The two time series where PSI and SB methodologies were applied provided similar results. Areas of subsidence with slower rates were also revealed at Karadon and Uzulmez regions with C-band Envisat images. Despite the lack of high coherence in these regions, deformation was estimated.

## 2. STUDY AREA AND DATA SET

Zonguldak province has the largest coal mine which is located at the western Black Sea coast of Turkey (Fig.1). The study area has a size of about 16 km x 13 km and a steep topography (56% of the land is covered with mountains). The altitude changes between 0 and 1000 m [3]. 52% of Zonguldak city is covered by forest, which is a challenge for C-band InSAR monitoring. Moreover, there is precipitation in all seasons. Rainy season is mostly in autumn and winter, and have 70% mean humidity. According to the seismic hazard map of Turkey, Zonguldak region is located within a second-degree earthquake zone.


Figure 1. Mining tunnels at the study area Zonguldak

Kozlu, Karadon and Uzulmez are three main underground coal-mining areas in the Zonguldak province. Approximately three million tons of coal is produced per year, and about 400 million tons of coal have been produced since 1848. In Kozlu region, there are five coal seams between 200 and 700 m depths under the city.

Zonguldak Province, which is a coastal settlement area, is prone to human-based environmental problems such as subsidence due to the underground coal mining areas. Also at the coastline, some parts of the coal reserves extend under the seabed of The Black Sea. Severe deformations in the region caused by subsidence have been known since the 1900s. Such deformations cause heavy damage on the Earth's surface, and at buildings and roads.

In InSAR processing, we analyzed 26 archived raw Envisat images of descending geometry between 2003 and 2010 (Table 1), and 17 ascending raw Envisat images between 2004 and 2010 (Table 2). Before the time series analysis, raw images were focused with ROI_PAC software [12]. The effects of topography were removed using a 3-arcsecond (~90 m) resolution SRTM DEM.

Table 1. Perpendicular and temporal baselines of descending images

| | Date | TempB (day) | Perp B(m) | | Date | TempB (day) | Perp B(m) |
|---|---|---|---|---|---|---|---|
| 1 | 20031126 | -630 | -272 | 14 | 20060315 | 210 | 150 |
| 2 | 20040204 | -560 | -261 | 15 | 20061220 | 490 | 89 |
| 3 | 20040310 | -525 | 371 | 16 | 20070228 | 560 | 64 |
| 4 | 20040519 | -455 | -55 | 17 | 20070509 | 630 | -160 |
| 5 | 20040623 | -420 | -271 | 18 | 20070718 | 700 | -201 |
| 6 | 20040728 | -385 | 180 | 19 | 20071031 | 805 | 68 |
| 7 | 20040901 | -350 | 313 | 20 | 20081119 | 1190 | -435 |
| 8 | 20041006 | -315 | -43 | 21 | 20090513 | 1365 | -67 |
| 9 | 20041215 | -245 | -162 | 22 | 20090617 | 1400 | 211 |
| 10 | 20050119 | -210 | -355 | 23 | 20090722 | 1435 | -228 |
| 11 | 20050504 | -105 | 495 | 24 | 20090826 | 1470 | 153 |
| 12 | 20050817 | 0 | 0 | 25 | 20090930 | 1505 | -336 |
| 13 | 20051130 | 105 | -312 | 26 | 20100113 | 1610 | -149 |

Table 2. Perpendicular and temporal baselines of ascending images

| | Date | TempB (day) | PerpB (m) | | Date | TempB (day) | PerpB (m) |
|---|---|---|---|---|---|---|---|
| 1 | 20040506 | -455 | 28 | 10 | 20060302 | 210 | 152 |
| 2 | 20040610 | -420 | -979 | 11 | 20060615 | 315 | -642 |
| 3 | 20040715 | -385 | -670 | 12 | 20060720 | 350 | -1458 |
| 4 | 20040819 | -350 | 376 | 13 | 20071122 | 840 | -180 |
| 5 | 20041028 | -280 | -1251 | 14 | 20090917 | 1505 | -159 |
| 6 | 20050106 | -210 | 158 | 15 | 20091126 | 1575 | -277 |
| 7 | 20050210 | -175 | -218 | 16 | 20100415 | 1715 | 44 |
| 8 | 20050804 | 0 | 0 | 17 | 20100729 | 1820 | -483 |
| 9 | 20050908 | 35 | -1610 | | | | |

## 3. TIME SERIES ANALYSIS WITH INSAR

In the case study, we applied StaMPS including both PSI and SB techniques. The main principle of PS technique is to search for the dominant scatterers that are phase-coherent over the whole time series. Amplitude variation is used to select the bright pixels.

In addition, the pixels in all types of terrain were identified based on their phase variation in time and the correlation of their phase in space. In SB approach we selected the interferograms which have small temporal and geometrical baselines. Interferograms with shorter baselines can have high coherence, which enables us to extract deformation more easily.

### 3.1 Persistent Scatterer Interferometry

In the PSI approach, spatially correlated pixels which have stable phases were detected. Master-coregistered interferograms series were created to identify highly coherent potential targets. In StaMPS, Persistent Scatterer Candidates (PSCs) are selected by using an amplitude dispersion index. PS probability was determined for each PSC both using amplitude dispersion and temporal coherence. Then, temporally coherent targets like buildings, roads or rocks were identified based on their phase correlation in a long time period. Finally the technique estimates deformation for all PS points [4].

### 3.2 Small Baseline Interferometry

For the SB approach pixels which have decorrelated phase in a short time period are detected. As an advanced DInSAR method, SB method generates all available multiple small baseline differential interferograms in the data set, and are not produced from just one master. Maximum number of spatial baselines is used and spatial decorrelation is reduced. Atmosphere is estimated using low pass filtering of spatial variables and high pass filtering of temporal variables [11].

## 4. RESULTS AND DISCUSSION

We processed 2 tracks of Envisat data for the region of Zonguldak. 26 images and 17 images were gathered in the descending and ascending geometry, respectively. SLC images were produced by ROI_PAC software [12]. DORIS software was used to compute the interferograms [13], and PSI and SB approaches were processed by StaMPS [14].

For the PSI processing of the ascending track, the image from 4 August 2005 was chosen as master and 13 interferograms were produced. Image numbers 5, 9 and 12 of Table 2 were not used for the PSI processing due to the fact that they have low coherence. Using the same dataset, 32 interferograms were produced for the SB processing. In the SB processing, the maximum perpendicular baseline was limited to 593 m. 5269 (Fig 2-a) and 3114 (Fig 2-b) coherent PS points were identified from the PSI and SB processing respectively.

In the PSI processing of the descending track, 17 August 2005 was chosen as master and 24 interferograms were produced. Image 20 in Table 1 was used only in the SB processing because it has low correlation. When processing using SB, 26 images were used and 73 interferograms which have perpendicular baselines less than 355 m were produced. 5165 (Fig 2-c) and 5219 (Fig 2-d) coherent points were detected using the PSI and SB processing respectively. Spatial decorrelation was removed by multiple interferograms. Phase due to atmospheric delay, orbit and DEM errors was estimated for each process and removed.

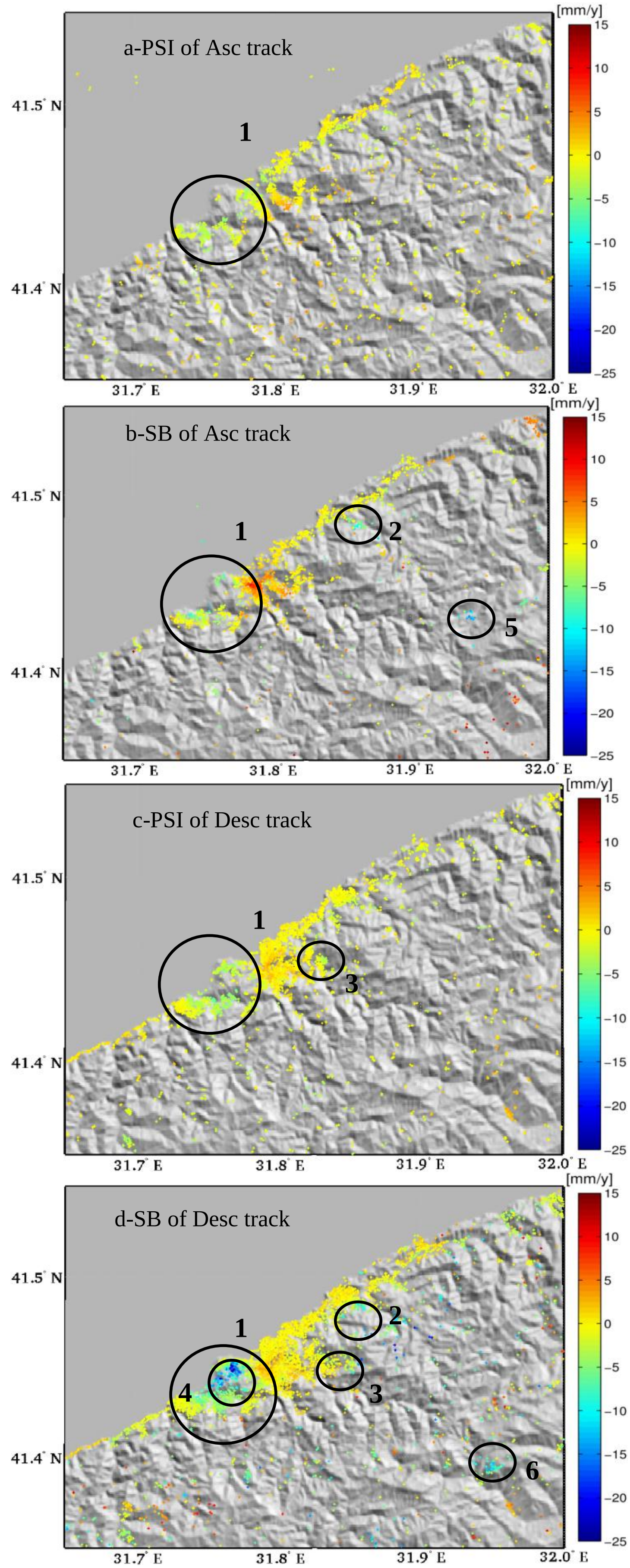


Figure 2. Results of processing, a-Ascending PSI, b- Ascending SB, c-Descending PSI, d-Descending SB

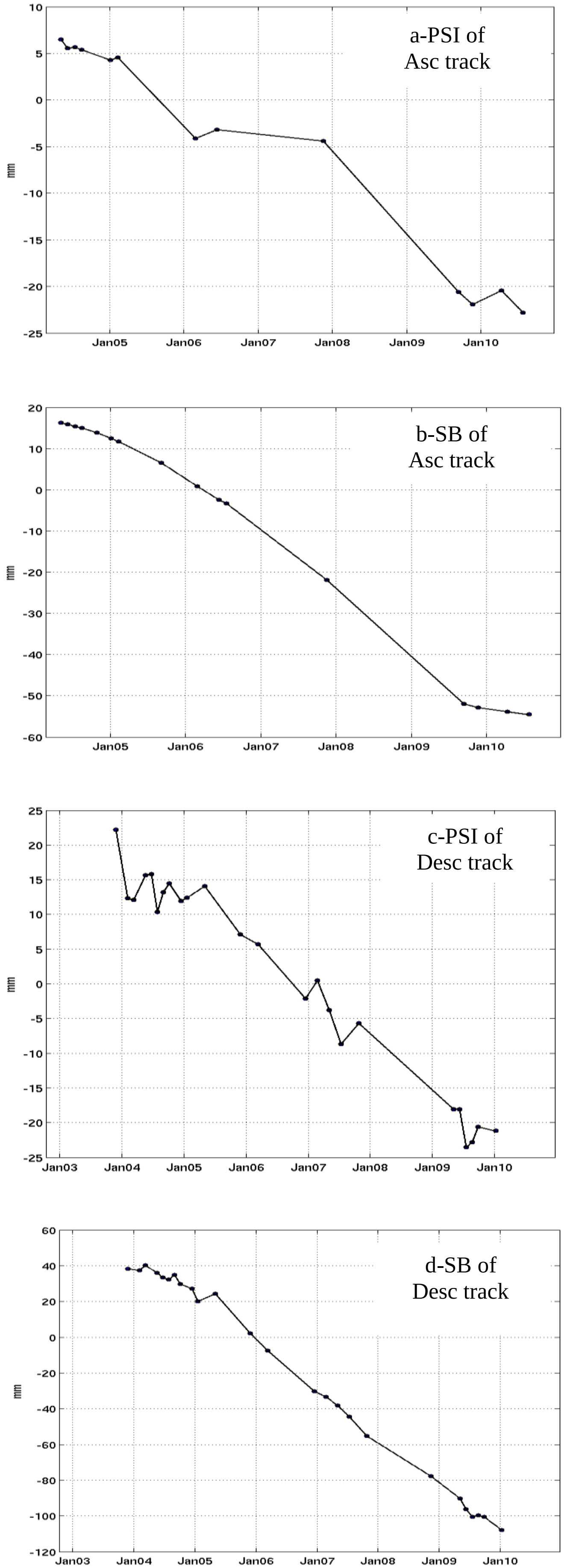


Figure 3. Time series for the area 1 in figure

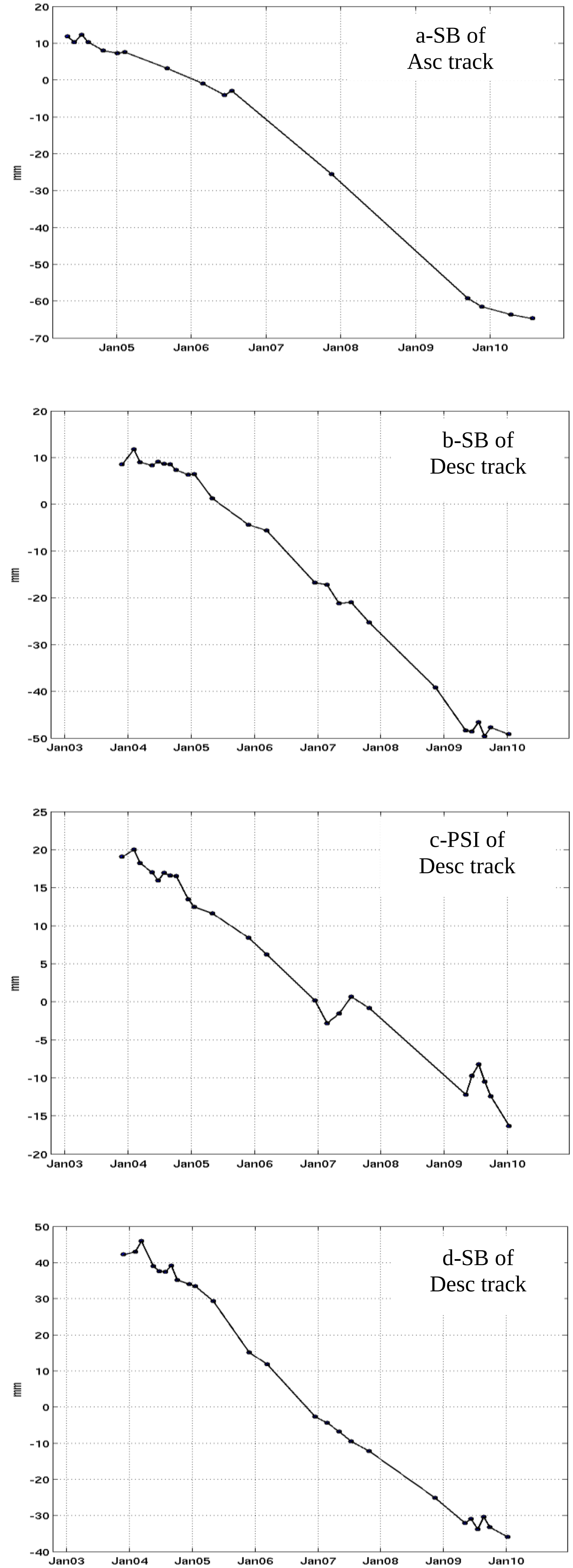


Figure 4. time series analysis: a- area 2 in fig 2b, b- area 2 in fig 2d, c- area 3 in fig 2c, d- area 3 in fig2d

Most of the coherent scatterers are located in the urbanized center of Zonguldak and Kozlu region. It also extends to the coastline of the city. These scatterers mostly belong to buildings, but there are also other scatterers in the port, mine and roads. There are sparsely urbanized towns surrounding the center in Karadon and Uzulmez.

To compare the results we have chosen the same areas in all processes, and analyzed the time series of some points in these areas. Time series of some points in area 1 are showed in Fig. 3 (3a-Ascending PSI, 3b- Ascending SB, 3c-Descending PSI, 3d-Descending SB). The main subsidence bowl of mining is detected by two tracks at Kozlu region, area 1 (Fig 2. a, b, c, d). In area 1, in general similar results were obtained with SB and PSI. Surface deformations are 20 to 140 mm.

Differing from other results, in the SB results of the descending track, the deformation amounts up to 140 mm as the maximum at area 4 (Fig 2-d and Fig 3-d). The eastern city center, Karadon and Uzulmez are more sparsely urbanized. These regions are mostly covered by vegetation that causes low coherence. Due to this reason, Radarsat was not able to monitor displacements from 2005 to 2006 (Fig. 5) [8].

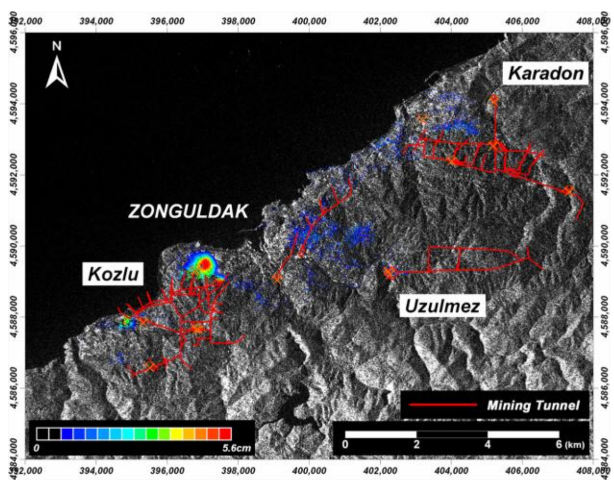

Figure 5. Previous DInSAR study with Radarsat data [3]

In contrast, in some smaller areas of the rural regions of Karadon and Uzulmez, slower rates were also revealed by C-band Envisat data. Maps of underground mining tunnels show that these surface deformations are most probably due to mining where the mining tunnels are located (Fig 1). In the results of PSI (ascending track) subsidence was not identified in Uzulmez and Karadon. On the other hand, in area 2 where Karadon is located subsidence was detected by the SB processing of both descending and ascending tracks (Fig. 2-b, Fig. 2-d). The time series of Karadon region shows deformation rates between 70 mm and 100 mm (Fig. 4-a, Fig. 4-b). In Uzulmez, surface deformation was only detected in descending track. The deformation at Uzulmez changes from 40 mm to 70 mm in both PSI and SB results (Fig. 4-c, Fig. 4-d).

Besides the mining areas, long period deformations were also monitored in villages at south east of Uzulmez. The deformation detected was up to about 80 mm in area 5 (Fig.2-b) and in area 6 (Fig.2-d).

## 5. CONCLUSIONS

In this study, we presented the first PSI and SB results for monitoring mining-based subsidence in Zonguldak, Turkey. Surface deformations have been monitored between 2003 and 2010. It is observed clearly that the main bowl of surface collapse in Kozlu region was detected by both ascending and descending tracks, and the displacements are similar in both cases. The locations of the detected surface deformations are related to the regions where mining tunnels are below the city center, and also in rural areas. A time series of 15 Radarsat images and 4 periods of GPS measurements were analyzed between 2005 and 2006 to monitor mining deformation by [8]. The results are coherent with our results, but it is difficult to compare them precisely because they cover a different (shorter) time period.

The ascending PSI interferograms have high geometric and temporal baselines which cause loss of coherence. Due to this, three images were not used and only 13 of the interferograms were processed. Moreover, there is a lack of SAR acquisitions between 2007 and 2009. PSI of ascending track has more scatterers, but most of them are related to unwrapping errors due to lower number of SAR images. Even then, the time series at Kozlu shows deformation at urban areas. The result of PSI on the ascending track was not successful at Karadon and Uzulmez. The ascending SB processing, however, identified collapses due to mining in Kozlu and Karadon regions where there are more forests than urban areas.

Maximum deformation is observed to be 140 mm in LOS direction at Kozlu region. In Uzulmez and Karadon areas, the displacement was detected by ascending and descending tracks of Envisat, which was not detected by previous studies [8], [9].

At Kozlu deformation region, there are many settlements, as a part of Zonguldak Karaelmas University. High schools and main roads of the city are subject to subsidence hazard. Thus, it is necessary to monitor these regions to make correct decisions on urbanization.

Further studies will be conducted to improve our analysis and to estimate geophysical parameters. Unwrapping error corrections are planned as a next step. In addition to the urbanization and mining areas, other areas of deformation were also identified, which will be investigated. In the rural regions, mining-related deformation could be detected by L-band data. Thus, we will also analyze long time series of ALOS PALSAR images to extract deformation in the rural areas of Zonguldak province.

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