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Romanian Space Agency
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ASSESSMENT OF ROSIA JIU MINING AREA THROUGH TERRASAR-X NEW IMAGING MODES

V. Poenaru(1,2), A. Popescu (3), C. Patrascu (3), Roxana Cuculici (4)

(1) Romanian Space Agency, (2) University of Agronomic Science and Veterinary Medicine, (3) University Politehnica of Bucharest, (4) Bucharest University, Faculty of Geography Department of Regional Geography and Environment

ABSTRACT

The paper evaluates new Staring Spotlight mode capabilities to monitor the mining activities impacts on the environment to ensure an effective management and to prevent possible natural and technological hazards. The societal and environmental impacts are huge such as: the topographic alteration, changes in the soil structure and vegetation coverage, influence on the underground water resources and on the rain water draining regime and air pollution. Rosia Jiu opencast test site is affected by subsidence phenomena caused by the closing of the hollows remained from the underground exploitation of lignite and by altering of the hidro-geological conditions, due to the applying of a forced and high intensity dewatering of the aquifer system within the area. A methodology based on deformation maps is designed for monitoring of the elastic deformation, early warning stage and detection of the risk occurrence. Intense mining activities from the summer - autumn seasons implied as interferometric pairs to have very low coherence making almost impossible to find PS candidates.

1. INTRODUCTION

Monitoring of the environmental impact of mines and heavy industries are important to assess the potential risks for the human health and biodiversity. The problem is especially serious in Eastern European countries where many mines have been abandoned or inactive. The impacts of the active mines on environment consists of surface land occupancy and their temporary or longer period taking out of the economic usage as result of the storage of material produced at the waste stripping, mining works excavation and from the selection - sorting installations for coal.

Rosia Jiu opencast is one of the active open pit mines affected by subsidence phenomena caused by the closing of the hollows remained from the underground exploitation of lignite and by altering of the hidro-geological conditions, due to the applying of a forced and high intensity dewatering of the aquifer system within the area [1]. In this view, the test site Rosia Jiu opencast has a particular specification: underground rock excavation equipment, human settlements located on two sided at distances of 100-150m, configuration and negative rates of three limits of the opencast. Recent studies in the test area is focused on the water sources distribution and contamination monitoring, socio-economic aspects [2], spoil heaps stability [3], functional reintegration of the degraded geomorphological systems [4] and coal deposits management [5].

The satellite data provide a new perspective to analyze and interpret environmental impact assessment as a function of topography and vegetation. Very high resolution SAR data (TerraSAR-X HR Spotlight and new Staring Spotlight) contribute effective to land degradation detection and monitoring by using InSAR technique. The feasibility of this technique for environmental impact assessment caused by mining activities depends on subsidence rates (deformation gradient) in combination with the influence of decorrelation due to land use or vegetation and of the atmospheric signal in the interferogram. The significant extent of mining operation suggests that the InSAR based degradation monitoring techniques could be applicable.

In this context, paper assesses new Staring Spotlight mode capabilities to monitor the impact of mining activities on the environment to ensure an effective management and to prevent possible natural and technological hazards. Secondly, the interactions with land surfaces and vegetation coverage are evaluated to arrive to a detailed understanding of the scattering mechanism and its impacts on the SAR image (i.e. geometry, applicability of processing gain for coherent contribution of backscatter). A non-coherent multi-temporal analysis is carried out for persistent scatterers and coherent scatterers stability evaluation.

2. MATERIAL AND METHOD

2.1 Description of the test area

Rosia Jiu opencast test site is part of Motru-Rovinari coal basin (Fig. 1) which is located in southwest of Romania, in the Getic Piedmont, stretches between Jiu Valley (est) to Motru Valley (west). It is the biggest coal basin of the country holding most of the reserve of lignite (71%). From a structural point of view, the geological deposits are placed in the internal flank of the Carpathian Foredeep (Getical Depresion) situated in the south of Meridional Carpathian Mountains. Carpathian hills of moderate heights (200-600 m) are crossed by strong hydrological network oriented NS.

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The coal deposit has a monocline structure oriented in the NW direction with slope on SE and presents a major instability in the natural environment, the slope processes expanding themselves very much (Fig. 2).

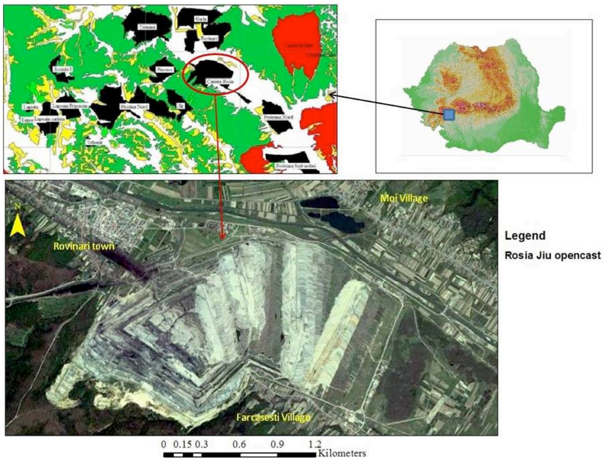

Figure 1. Rosia Jiu opencast area. Coal exploitation in the Oltenia region: black - coal exploitation perimeters, red - protected natural areas, dark green - hardwood forests, light green - selvedge and scrubs, yellow - pastures and agricultural lands with significant vegetation.

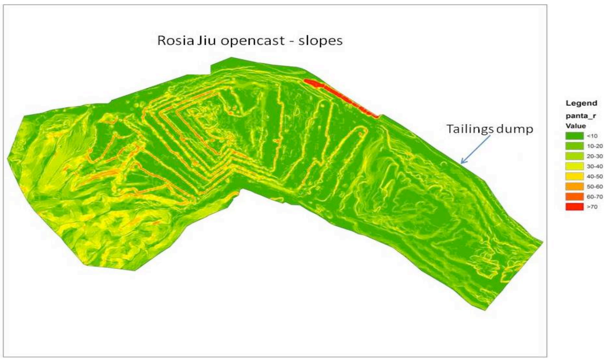

Figure2. Excavations in the rock strata with inclinations ranging from 10^0 to 90^0.

2.2 Dataset and processing details

A set of 12 Staring Spotlight VHR TerraSAR-X complex data acquired between Julys to December 2014 were used in this study. The SAR images have VV polarization, a resolution of 0.45m x 0.16m and an incidence angle of 37^0. The multi-temporal information was used to observe the changes in backscattering coefficient which are relevant in land use/land cover monitoring. For processing and validation purposes, a Digital Elevation Model and a thematic map image acquired by Landsat 8 OLI satellite were used.

Layer stacking analysis.

The dynamic nature of mining subsidence is dependent on mining technology and the time of its activity. Therefore, it is important to predict the extent and magnitude of the mining subsidence with reasonable accuracy. Many studies were focused on longwall coal mining and continuous subsidence [6], [7], [8], [9]. Block cave mining produces discontinuous subsidence due to high draw intensity that conducts to large differential movements controlled by geological faults, rock mass heterogeneity and irregular surface topography. Thus, numerical models required for understanding of the mining site conditions such as proper representation of the geology and rock mass properties can be applied to assess land deformations.

In this paper, an approach based on the Interferogram stacking technique [10] was proposed to extract average displacement maps. This class of algorithms mitigates the influence of the atmospheric phase screen on the phase and subsequent influence on the final deformation estimate, leading to average displacement rates with an increased sensitivity to measurements given the noise removal [11]. The basis of this approach lays in weighting of the interferometric stack and combining the result to get an average displacement map.

The average deformation rates for the Rosia Jiu area are computed assuming linear displacement rates in the scene, caused by the continuous excavation in the area.

The starting point for this algorithm is a stack of sub-pixel level coregistered and radiometrically calibrated ST TerraSAR-X images. Given the small number of available image samples (10), we generate interferogram using all possible interferometric pairs. No spatial or temporal constraints were included in the processing, to avoid further limiting of the usable data. A graphical distribution of the perpendicular baselines is presented in Fig.3. A total of 66 interferometric pairs have been generated, with an average magnitude of B_{perp} = 150m.

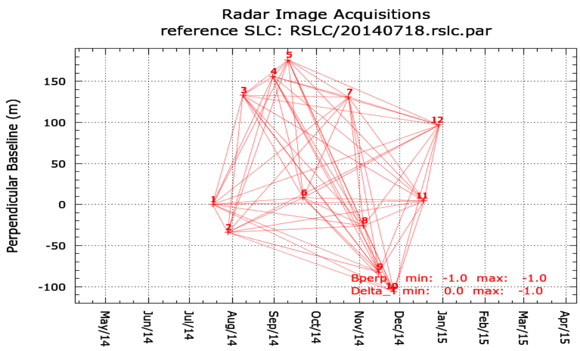

Figure 3. Distribution of perpendicular baselines.

Simultaneously, a PSInSAR analysis was carried out to identify stable scatterers independent of the amplitude associated with them. The deformation is estimated based on similarity of phase history to an existing model of temporal variation. The SAR image acquired on 19th December 2014 is set as master image of the PS layer stack. The graphical distribution of the perpendicular and temporal baseline is shown in Fig.4.

The topographic influence is removed using a DEM obtained from 2 HS TerraSAR-X images acquired in summer season with intense mining activities. The result showed in Fig. 5 has an accuracy ranging from 0.45 to 13.4m (B_{perp} = -135m with ambiguity height = 171m). Leveling measurements covering ninety year time span confirm decreasing trends in the DEM data due to excavations in the rock strata (Fig. 6). Therefore, an external DEM derived from VHR Spot data was used in PSInSAR analysis to increase land deformation estimation accuracy.

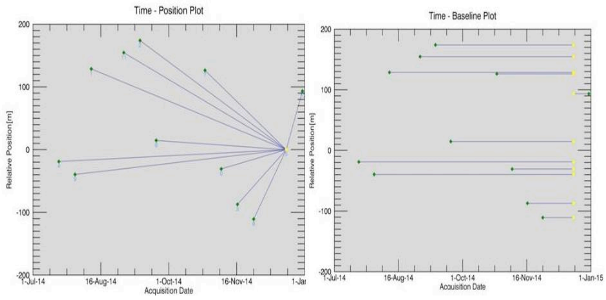

Figure 4. Perpendicular and temporal baselines of the PS layer stacking.

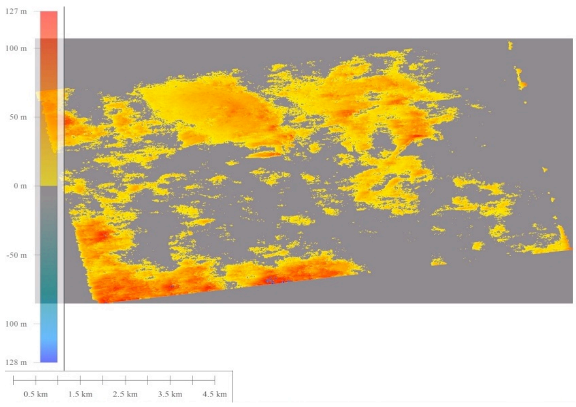

Figure 5. Digital elevation model retrieved from VHR TerraSAR-X data.

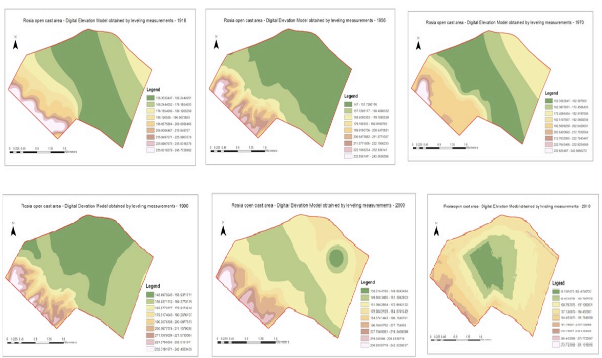

Figure 6. Leveling measurements acquired in 1916, 1956, 1970, 1990, 2000 and 2010.

Landcover change detection

In order to understand how excavations at Rosia affect the evolution of the landcover in the area, we apply a multi-temporal non-coherent processing technique designated to delineate changes with pixel-level accuracy. The analysis is based on the calibrated radiometric information of the data and is performed stack-wise on the entire stack of ST TerraSAR-X data. Statistically homogeneous areas (characterized by the same behavior of the containing pixels) have been selected using a spatial adaptive algorithm derived from a classical multi-looking technique [12].

Statistically homogeneous pixels are selected adaptively based on their radiometric properties, leading to an improvement of the results compared to classical approaches, such as using a sliding window. Using a fixed neighborhood, a goodness-of-fit testing is performed using samples extracted in the time domain. The Anderson-Darling criterion has been selected, given the increased sensitivity to changes in the tail of the distribution characteristic to radar data.

The test statistic is defined as:

$$A^2_{M,M} = \frac{M}{2} \sum_{x \in \{x_p, x_q\}} \frac{(\hat{F}_p(x) - \hat{F}_q(x))^2}{\hat{F}_{pq}(x)(1 - \hat{F}_{pq}(x))}$$

where $\hat{F}_{p/q}(x)$ represents the empirical cumulative distribution function (CDF) of the analyzed pixel and all analyzed pixels in a considered neghborhood, as well as CDF for a new population computed by merging the analyzed data sets.

3. RESULTS AND DISCUSSIONS

DinSAR technique is useful for monitoring strong terrain displacement that generates an increasing number of fringes compared with atmospheric artifact. The generation of DInSAR deformation maps involves several complex steps such as: image co-registration, satellite orbit calculation, generation of differential interferogram, phase filtering, phase unwrapping, orbital refinement and reflattening, phase to displacement and geocoding. Main problem consisted in how to choose the most suitable ground control points for orbital refinement since the entire test area is affected by deformation phenomena. In Fig.7 is presented ambiguous results due to the highly dynamic character of subsidence induced by activities which imply mass mining methods. Also, the altered terrain topography, involving steep slopes and deep pits lead to the layover of radar signal for specific satellite and pit geometry. Moreover, these results cannot be validated on leveling measurements which are kept confidential by the National commercial company.

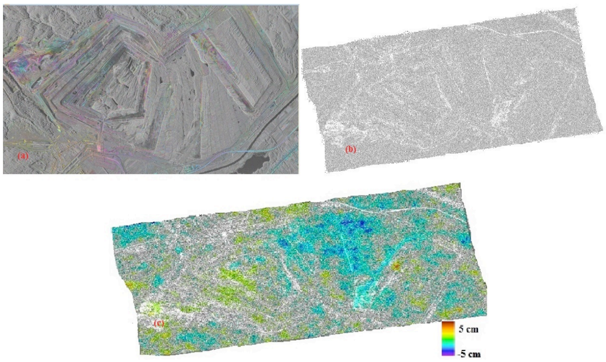

Figure 7. DInSAR results: (a) Differential interferogram obtained from 1807-2907 interferometric pair; (b) coherence and (c) surface deformation.

The monitoring of the deformation phenomena evolution during a time span is possible by PSInSAR analysis. Fig. 8 presents the generated differential interferograms. Due to intense mining activities most interferometric pairs have very low coherence (threshold was set to 0.18), making it almost impossible to find PS candidates for PSInSAR.

The differential interferograms noisy areas lead to phase unwrapping errors by generation of the areas with unreliable deformation measurements. Mean intensity and long term coherence are shown in Fig. 9 and Fig. 10.

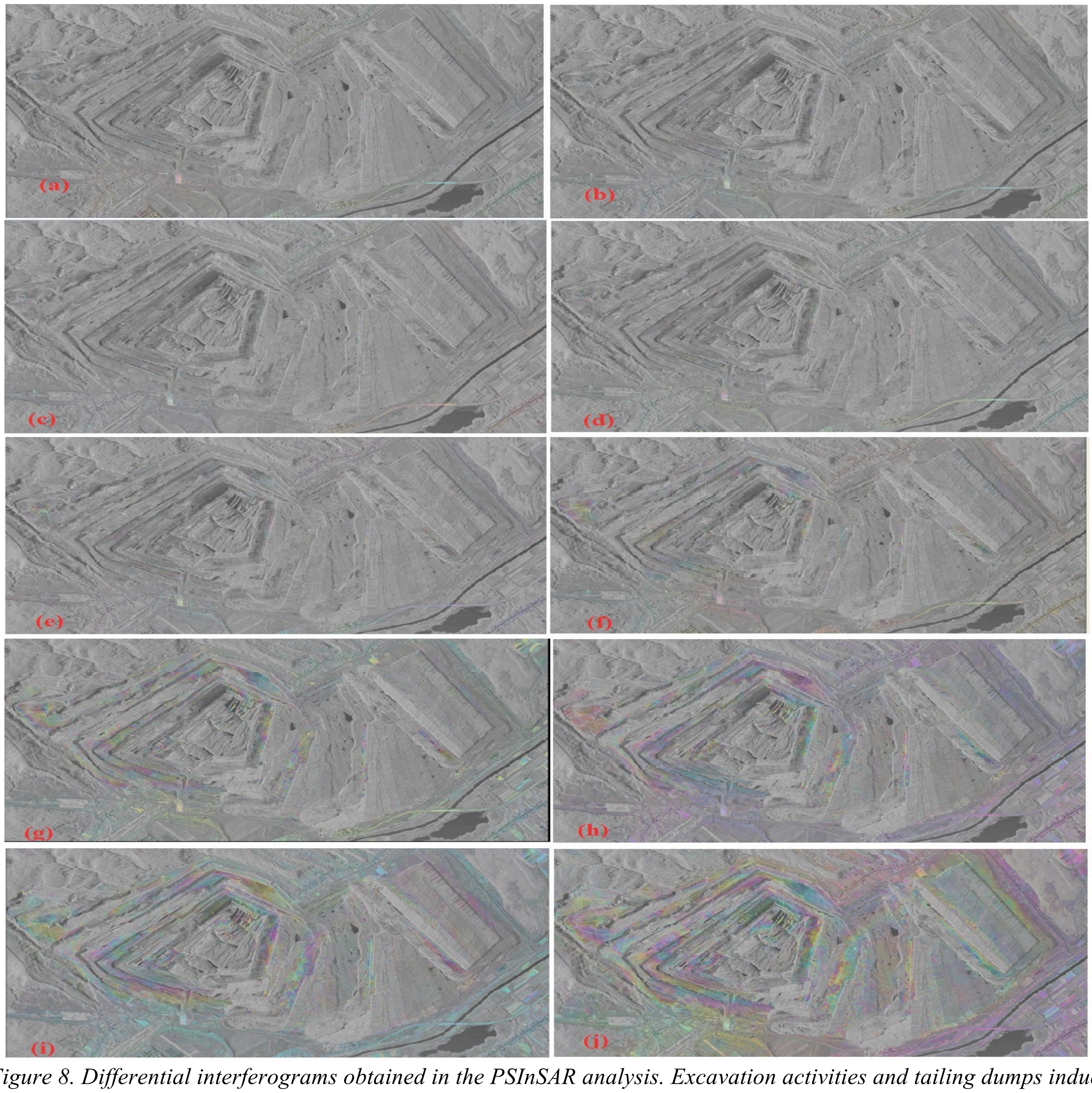

Figure 8. Differential interferograms obtained in the PSInSAR analysis. Excavation activities and tailing dumps induce SAR signal decorrelation during summer- autumn TSX acquisition (a to f cases). Deformation phenomena evolution is highlighted in the cold season when higher coherence is observed.

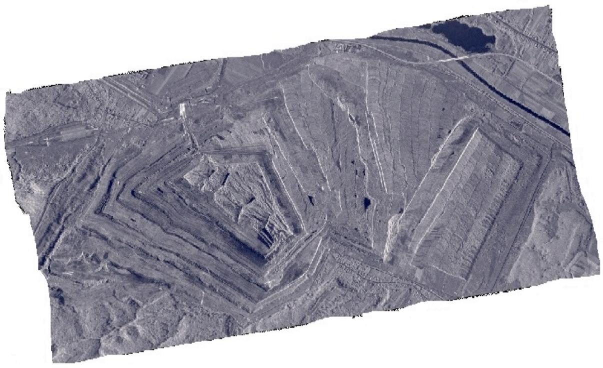

Figure 9. Mean intensity of the PS analysis

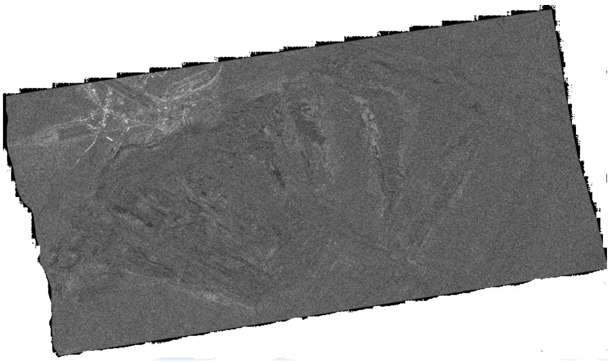

Figure 10.Long term coherence

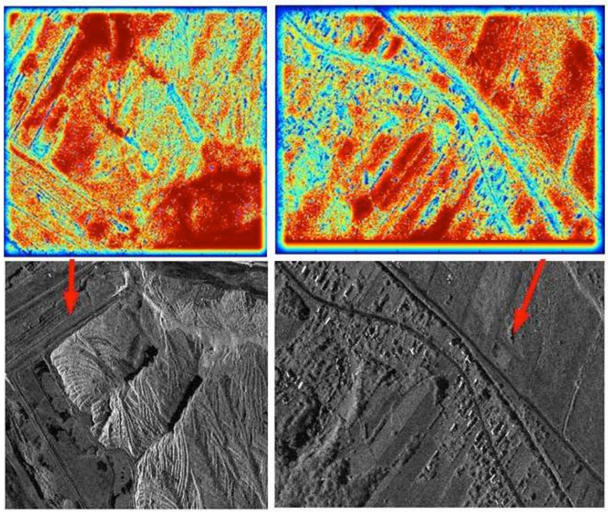

Figure 11. Multi-temporal non-coherent analysis: Blue colour reflects no changes areas while red tones give strong changes.

The Anderson Darling criterion was carried out in Matlab and was applied on TSX intensity data to detect changes in radiometric information. The results shown in Fig. 10 confirm a strong land degradation process in the mining perimeter.

Despite coherence limitations, preliminary results indicate that the TerraSAR-X new imaging modes have the capabilities to assess the impact of mining activities on the environment.

4. CONCLUSIONS

The DInSAR and PSInsar analysis were performed in this paper to evaluate the mining activities impact on the environment. A methodology based on deformation maps is designed for monitoring of the elastic deformation, early warning stage and detection of the risk occurrence. Intense mining activities from the summer – autumn seasons lead to very low coherence in the analyzed interferometric pairs, making almost impossible identification of PS candidates.

A multi-temporal non-coherent analysis based on Anderson Darling statistical criterion was performed for landcover change detection. Reflectivity changes mostly affect agricultural areas and tailing dumps.

Future works will focus on new ST TSX data acquisitions to improve preliminary results. Also, the change detection method will be applied on small areas with high coherence to increase the land deformation estimation accuracy.

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