DLR e.V. German Remote Sensing Data Center
Oberpfaffenhofen, Muenchener Str. 20, 82234 Wessling, Germany

Sivas Cumhuriyet University, Mining Engineering Department
Assoc. Prof. Dr. Yavuz GÜL
58140-Sivas
Turkey

Your reference
Your letter
Our reference

Your correspondent Achim Roth

Telephone 0049 (0)8153 28-2706
Telefax 0049 (0)8153 28-1458
E-mail tsx.science@dlr.de

17 May, 2023

Completion of TSX proposal MTH3798

To whom it may concern,

This is to certify that the TerraSAR-X science proposal **MTH3798** (Deformation Prediction with Satellite Images in Open Pit Mines) has been completed and closed in 2023. The final report has been provided on March 10th, 2023 by the PI Prof. Dr. Yavuz Gül.

Sincerely

Achim Roth
(TerraSAR-X Science Coordination)

User License for the Utilisation of TerraSAR-X / TanDEM-X Data and Products for Scientific Use

between

DLR

and

the Principal Investigator

Assoc. Prof. Yavuz GÜL

Proposal ID: MTH3798 **issued on** 09.12.2021

As the duly empowered representative of Sivas Cumhuriyet University**, I hereby declare to have read and approved the terms and conditions and unconditionally accept that any activity related to the project be governed by them.**

Date: 09.12.2021

Name: Prof. Dr. Hakan Yekbaş

Signature: H. Yekbaş

Y.G.

User License for the Utilization of TerraSAR-X / TanDEM-X Data and Products for Scientific Use

The project leader (PI) named on the front page of this document is the responsible person for the exclusively scientific use of the TerraSAR-X / TanDEM-X data allocated under the proposal displayed on the frontpage. The PI's activities are considered to cover the total time period of the project approved by the German Aerospace Centre (DLR). This includes the subsequent preparation of the results concluding with the submission of the final report to DLR.

The PI shall fulfill the commitments specified herein.

Data Rights

1. Data in the sense of this licence are any TerraSAR-X or TanDEM-X data and any derived products.
2. DLR as German Space Agency is the owner of the TerraSAR-X and TanDEM-X satellites. It administers this ownership as trustee for the Federal Republic of Germany. All data provided by these two satellites are therefore attributed to DLR.
3. DLR retains the title to and ownership of all primary and any derived products to the extent that the contribution of TerraSAR-X / TanDEM-X is substantial and recognisable.
4. DLR will provide TerraSAR-X / TanDEM-X data and will grant a non-exclusive, non-transferable right to use these data for the purpose of the proposed and approved investigation. The right of use includes the transfer of the data to the Co-Is, listed in this agreement.
5. All intellectual property rights created by the PI in the course of the project shall belong to the PI. The PI grants DLR an irrevocable free-of-charge non-exclusive license to use such intellectual properties solely for its own scientific use.
6. The PI undertakes to clearly mark all TerraSAR-X / TanDEM-X data in such a way that DLR's copyright is plain to all, as follows: "© DLR <*year of reception*>". Analyzed information, irrespectively of the form in which it was produced, should include a reference to TerraSAR-X / TanDEM-X as the data source.
7. DLR will provide the agreed amount of data to the PI to ensure the successful completion of the proposed investigation. DLR reserves the right to decide on the most appropriate timing and order.
8. DLR reserves the right to suspend or to terminate the delivery of TerraSAR-X / TanDEM-X data in the event that the funding of the operations and of the associated processing facilities cannot

Y.G.

LIST OF INVESTIGATORS (PRINCIPAL AND CO-INVESTIGATORS):

Name, first name, affiliation, full address, **citizenship and signature** per Co-investigator

Yavuz GÜL, Sivas Cumhuriyet University, Department of Mining Engineering Faculty of Engineering Sivas Cumhuriyet University 58140 Sivas/TURKEY, Turkish Citizen [signature]

Bekir POYRAZ, Sivas Cumhuriyet University, Department of Mining Engineering Faculty of Engineering Sivas Cumhuriyet University 58140 Sivas/TURKEY, Turkish Citizen [signature]

Fatih POYRAZ, Sivas Cumhuriyet University, Geodesy Division Deport of Geomatics Engineering Faculty of Engineering Sivas Cumhuriyet University 58140 Sivas/TURKEY Turkis Citizen [signature]

Kemal Özgür HASTAOĞLU, Sivas Cumhuriyet University, Geodesy Division Deport of Geomatics Engineering Faculty of Engineering SIVAS Cumhuriyet University 58140 SIVAS/TURKEY Turkish Citizen [signature]

Template for TerraSAR-X report submission:

Proposal ID: (e.g. LAN1344)
MTH3798
Principal Investigator: (name, surname, affiliation)
Yavuz Gül (Department of Mining Engineering, Faculty of Engineering, Cumhuriyet University, Sivas, Turkey)
Report type: (select the report type)

Progress report			Final report	x	

General issues: (maximum 1000 characters)

Deformation and landslide tracking in mine sites are generally performed by methods such as Global Navigation Satellite System (GNSS), Geometric Leveling, Laser Imaging Detection and Ranging (LIDAR), and Unmanned Aerial Vehicle (UAV) photogrammetry. In addition, point deformations can be measured by using crack measuring pins, inclinometers, extensometers, and micro-seismic geophones. Depending on the preferred method, deformation tracking includes some negativities in terms of time, work load, work safety, and cost. Among these methods, although inclinometers, extensometer, and GNSS for determining point-based deformation give sensitive results, they produce point values. It requires a large number of point tracking in order to monitor the whole of the large mining sites and high costs arise due to complex data management. Although the ground LIDAR and UAV photogrammeters allow the determination of areal deformations, they produce varying results according to the features of the equipments used. These methods can be used in a limited way due to their high costs and disruption of production activities in the mine site.

With the development of remote sensing technology in order to eliminate some of the problems in existing methods, the interferometric artificial aperture radar (InSAR) method has begun to be used as a new method in the investigation of deformations occurring on the earth. This method is based on the determination of deformations with the high-quality topography information. High resolution images are taken with signal processing technique by detecting the delays of the reflected and returning signals from the satellite. Unlike the existing methods, it provides a much wider working area and gives results in the range of centimeter precision. This method has some disadvantages as well. There are various techniques available in the InSAR method. Among these, the most preferred Differential Artificial Aperture Radar Interferometry (DInSAR) and Fixed Scatterers Interferometry (PSI, PSInSAR) techniques are highly effective in slowly developing deformations and landslides. Especially with the PSI technique, deformations can be detected with the centimeter accuracy. PSI technique deals with permanent reflective pixels (buildings, infrastructure, and other man-made structures, rocks, etc.). Artificial Aperture Radar (SAR) images used in the technique can be matched very precisely with the permanent scattering/reflective dots (PS). The disadvantage of this method is that it is not effective enough in sudden and rapidly developing deformations and landslides. The constant change of topography, especially in mining sites, makes it very difficult to provide sufficient PS points.

This method uses spatial correlation of interferometric phase to find pixels with low phase change for analysis in all terrain types, whether or not there are prominent objects such as buildings. Coherence maps of the interferograms are used to determine the permanent scatterer (PS) points. If a target shows more fit than a suitable value, this point is selected as the PS candidate. PS points in city areas are generally man-made objects (buildings, roads, bridges, poles, ports, etc.) (Poyraz and Hastaoğlu, 2020). The number and frequency of PS points is one of the most important factors for accuracy in determining deformation with the PSI technique (Poyraz et al., 2020).

The PSInSAR technique has been widely used in recent years in deformation monitoring studies. The PSInSAR technique was used in many deformation monitoring studies such as monitoring tectonic movements in the Western Anatolia Menderes region (Arıkan et al., 2010), the examination of earthquake-induced surface movements, monitoring the landslides, monitoring the displacements in volcanic areas (Hooper et al., 2007), in geological or urban areas (Meisina et al., 2006), and in subsidences occurring in the mining areas (Abdikan et al., 2014).

Figure 1. The general view of the study area is given.

Kangal Coal Open Mine located in Kangal district of Sivas; It meets the coal needs of the Kangal Thermal Power Plant. The enterprise is located in the southern part of the district (39° 03' 45''N, 39° 19' 36''E). The largest settlement in the region is Hamal Village. The business area is 29 km from Kangal District. Kangal District is 80 km from Sivas, and to Malatya; It is located at a distance of 154 km (Figure 1). In the Kalburçayırı region, where production is made, coal is in the form of two veins with a thickness of 7 m. The thickness of the cover on the upper seam is 42 m, and the thickness of the intermediate cover between the two seams is 20 m. As a side rock of coal; limestone, clayey limestone and marl. The operating method applied in the coal field is done with an electric excavator-truck couple and a dragline with a bucket capacity of 70 yd3 (Gül, 2006).

Delivered data: (maximum 1000 characters)

For the TerraSAR-X satellite; within the limits shown in Figure 2, 92/spot_016R HH High Definition Spotlight images were obtained from 12072022 to 19102022 (10 images). 14082022 was chosen as the main image. For the Sentinel-1A satellite; within the limits shown in Figure 3, S1A_SLC_21_Frm_DSC VV Stripmap images were acquired from 09072022 to 25102022 (10 images). 26082022 selected as the main image.

Schedule: (maximum 1000 characters)

Evaluation of the study area with satellite radar images was made with TERRASAR-X HighResolution Spotlight (Descending) images managed and used by the German Space Agency. In order to find the movements in the LOS direction, firstly, interferograms were obtained by using Delft Object-Oriented Radar Interferometric Software (DORIS) (Kampes vd., 2004; Kampes ve Stefania , 1999). SRTM (Shuttle Radar Topography Mission) data was used to eliminate the effect of topography on interferograms. Persistent Scatterers (PS) points were determined from the obtained interferograms using the Stanford Method for Persistent Scatterers (STAMPS) (Hooper vd., 2010) software and LOS movements in the satellite view direction were obtained. The master_select code written for the selection of a picture that can be the best master image of the program was run and the master image was selected from the pictures with track number 92. The master_select code selects the baseline distance between radar images, the time of the images, and the image that can show the best consistency as the primary (master) image to create their combination.

Comments: (maximum 1000 characters)

The aim of this study; For a certain date range, the TerraSAR-X satellite, high-resolution 10 paid satellite radar images to be obtained from its descending orbit will be compared with the Sentinel-1A satellite, descending satellite radar images that correspond to approximately the same dates.

The LOS data of the low-resolution Sentinel-1 satellite in descending orbit, which corresponds to approximately the same date range, and the LOS data of the high-resolution TerraSAR-X satellite were compared. Approximately the same velocity values were found. Figure 4. TerraSAR-X LOS map and Figure 5. Sentinel-1A LOS map.

Table 1 TerraSAR-X and Sentinel-1A satellite average LOS velocities

Point	TerraSAR-X average LOS (mm/year)	Sentinel-1A average LOS (mm/year)
GPS_1	-42.0	-44.4
GPS_2	4.7	-4.9

Detailed report: (maximum 12000 characters)
In this study, deformations in the Line of Sight (LOS) direction were determined by using Permanent Scattered Interferometric Synthetic Aperture Radar (PSInSAR) method in the Kangal Coal Open Mine (Sivas-Turkey) region located in the southern part of Kangal district. German Space Agency's TERRASAR-X HighResolution Spotlight satellite radar images and European Space Agency's SENTINEL-1A Stripmap satellite radar images were used to detect movements in the LOS direction. The results obtained are given in Table 1. The main differences between Sentinel-1 and TerraSAR-X satellites are; We can list TerraSAR-X satellite data as ordering (SAR mode, coverage area, etc.), high resolution, high gain, and precise orbit information. However, the Sentinel-1 satellite is still in an advantageous position with its short transit times (6 days when Sentinel-1A and Sentinel-1B satellites are evaluated together) and regular repeat transitions in large areas (Gisinger et al., 2021). Generally; Monitoring of low roughness areas where detailed surface information is required, examination of deformations, landslides, and landslides caused by infrastructure (building, road, dam construction) activities in residential areas, monitoring of ports and ships, monitoring of floods, water regime and agricultural activities in wetlands with short wavelength It is done via satellites using X band. In larger areas; In the monitoring of landslides, volcanic events, glacial movements, earthquakes, and deformations between earthquakes, satellites using C and L bands with long wavelengths are preferred (Bischoff vd., 2017; Vellotto vd., 2016; Meyer, 2021; Wang vd., 2021).

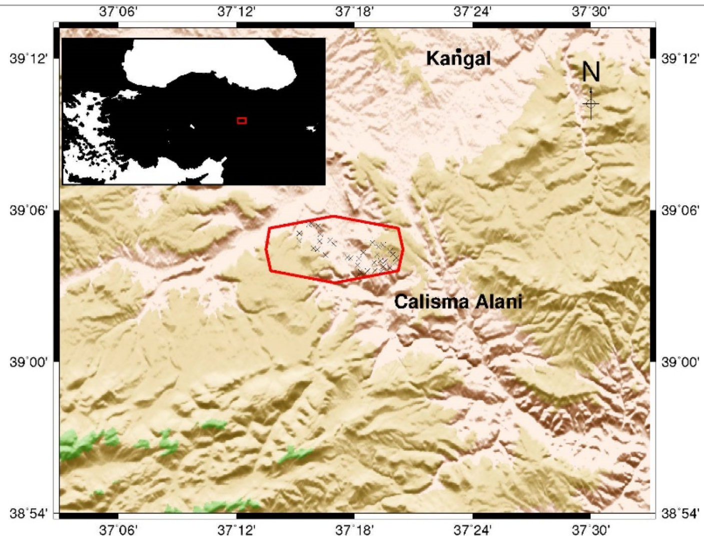
Image results: (only JPG, TIFF and PDF accepted; maximum size 10 MB)	
Image title	**Filename**
Figure 1. General view of the study area	

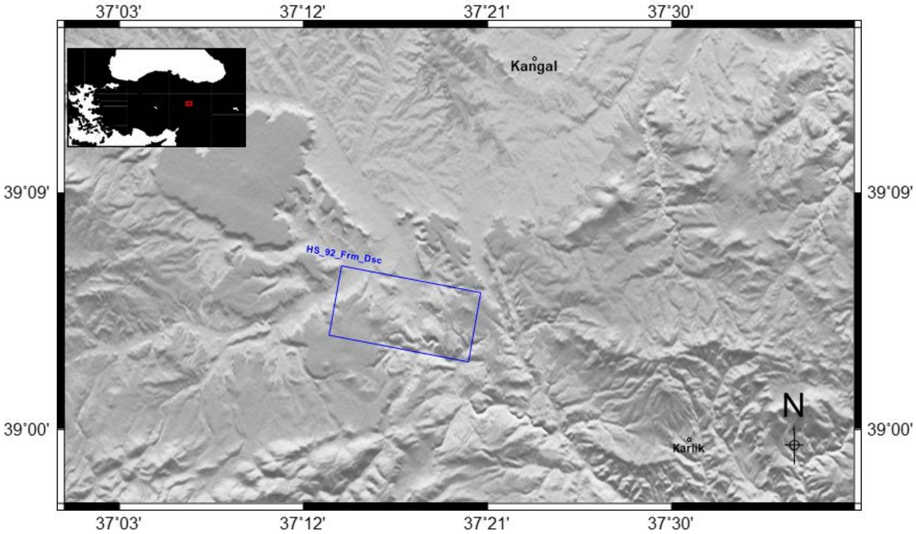
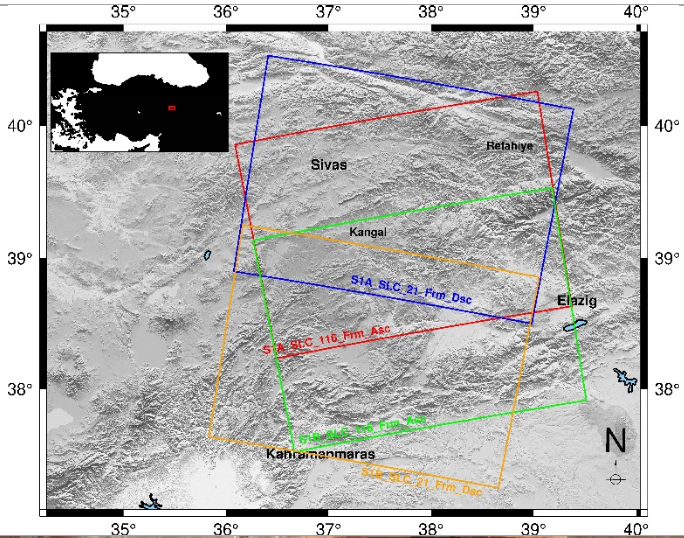
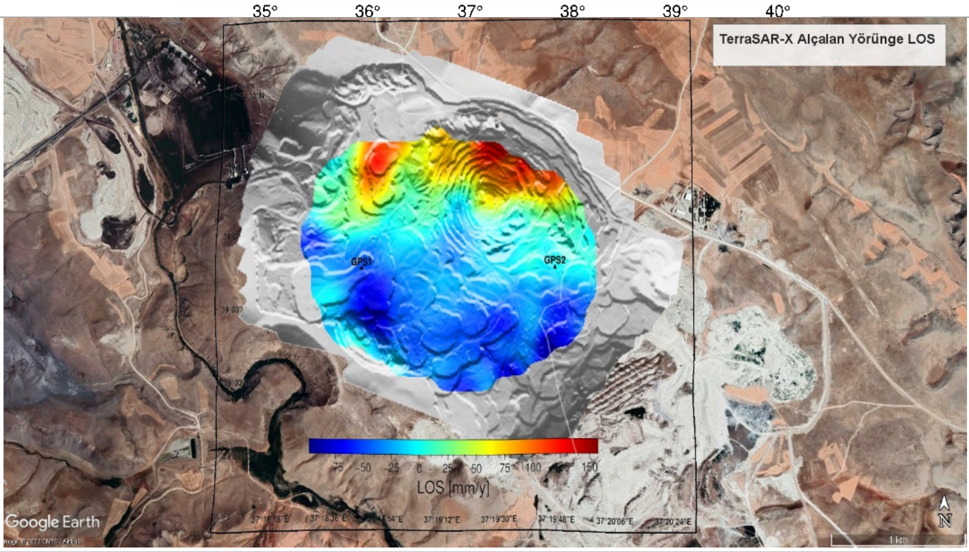
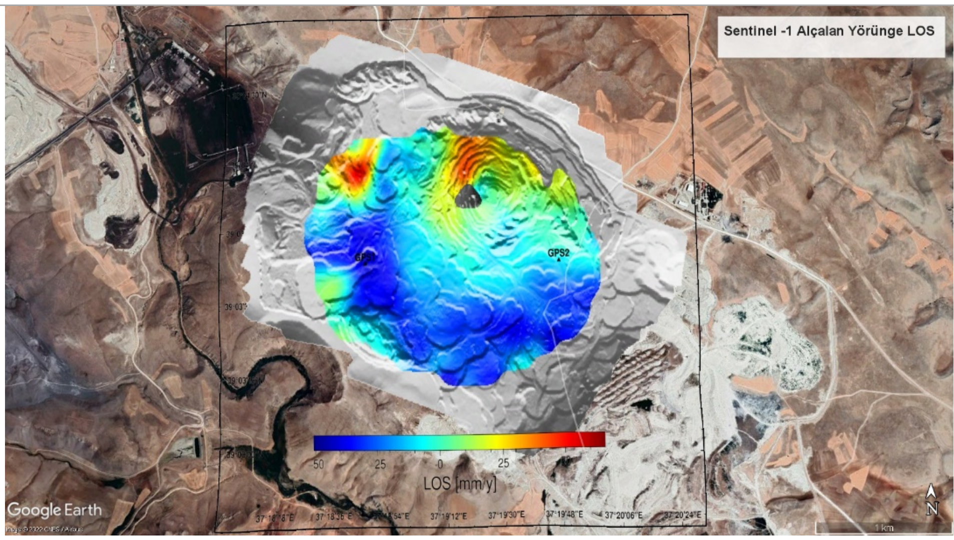
Figure 2. Working area and satellite radar coverage (TerraSAR-X)	
Figure 3. Working area and satellite radar coverage (Sentinel-1)	
Figure 4. TerraSAR-X LOS map	

Figure 5. Sentinel-1A LOS map



Publications:	
Publication title	**Filename**

References:

Abdikan S, Arıkan M, Sanli FB. (2014). Monitoring of coal mining subsidence in peri-urban area of Zonguldak city (NW Turkey) with persistent scatterer interferometry using ALOS-PALSAR. Environ Earth Sci 71: 4081.

Arikan M, Hooper A, Hanssen R (2010). Radar Time Series Analysis over West Anatolia. European Space Agency (Special Publication) ESA SP-677.

Bischoff, C. A., Basilico, M., Ferretti, A., Molinaro, D., Giannico, C., Ghail, R. C., & Mason, P. J. (2017, April). A comparison between TerraSAR-X and Sentinel-1 PSInSAR data for infrastructure monitoring in London, UK. GRSG 28th International Annual Conference “Applied Geological Remote Sensing.

Gisinger, C., Schubert, A., Breit, H., Garthwaite, M., Balss, U., Willberg, M., ... & Miranda, N. (2021). In-depth verification of Sentinel-1 and TerraSAR-X geolocation accuracy using the Australian corner reflector array. IEEE Transactions on Geoscience and Remote Sensing, 59(2), 1154-1181.

Gül,Y.,(2006), Bazı Açık İşletmelerdeki Değişik Kaya Birimlerinin Taşıma Kapasitelerinin Araştırılması ve Kayaç Özellikleri ile İlişkilendirilmesi. Sivas Cumhuriyet Üniversitesi Fen Bilimleri Enstitüsü (Doktora Tezi),227s, Sivas.

Hooper, A., Segall, P., Zebker, H. (2007). Persistent scatterer interferometric synthetic aperture radar for crustal deformation analysis, with application to Volca´n Alcedo, Gala´pagos. Journal of Geophysical Research 112: B07407. doi: 10.1029/2006JB004763

Hooper, A., Spaans, K., Bekaert, D., Cuenca, M. C., Arıkan, M., & Oyen, A. (2010). StaMPS/MTI manual. Delft Institute of Earth Observation and Space Systems Delft University of Technology, Kluyverweg, 1, 2629.

Kampes, B., Hanssen, R., Perski, Z. (2004). Radar Interferometry with Public Domain Tools. In: Proceedings of FRINGE 2003, December 1-5, Frascati, Italy

Kampes, B., & Usai, S. (1999). Doris: The delft object-oriented radar interferometric software. In Proceedings of the 2nd International Symposium on Operationalization of Remote Sensing, Enschede, The Netherlands (Vol. 1620).

Meisina C, Zucca F, Fossati D, Ceriani M, Allievi J (2006). Ground deformation monitoring by using the Permanent Scatterers Technique: The example of the Oltrepo Pavese (Lombardia, Italy). Engineering Geology, Volume 88, Issues 3–4, Pages 240-259.

Meyer, F. J. (2021). GEOS 657-Microwave Remote Sensing Graduate-Level Course At The University Of Alaska Fairbanks Lecturer: Lecture 13: InSAR for Deformation Monitoring, Automatic Processing Services & Limitations of Traditional InSAR UAF Course GEOS 657.

Poyraz, F., & Hastaoğlu, K. Ö. (2020). Monitoring of tectonic movements of the Gediz Graben by the PSInSAR method and validation with GNSS results. Arabian Journal of Geosciences, 13(17), 1-11. https://doi.org/10.1007/s12517-020-05834-5

Poyraz, F., GÜL, Y., & Duymaz, B. (2020). Determination of deformations by using the PSI technique at a common dump site of three different open-pit marble mines in Turkey. Turkish Journal of Earth Sciences, 29(6).

Velotto, D., Bentes, C., Tings, B., & Lehner, S. (2016). First comparison of Sentinel-1 and TerraSAR-X data in the framework of maritime targets detection: South Italy case. IEEE Journal of Oceanic Engineering, 41(4), 993-1006.

Wang, Y., Bai, Z., Zhang, Y., Qin, Y., Lin, Y., Li, Y., & Shen, W. (2021). Using TerraSAR X-band and sentinel-1 C-band SAR interferometry for deformation along Beijing-Tianjin intercity railway analysis. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 14, 4832-4841.