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Ground deformation monitoring in Shenyang city and Fushun pit mine (Northeastern China) by Advanced InSAR analysis

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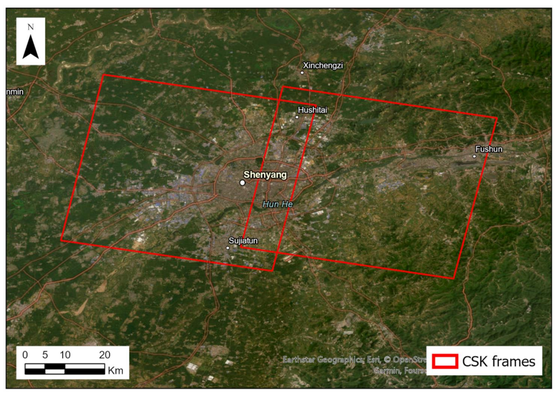
Abstract

The heavy industrial district in the Shenyang municipality in Northeast China plays a relevant role in the economic and social development of the region. The hard mining activities have a strong impact on local environment due to continuous ground excavations related to coal and iron extraction. Therefore, Shenyang is subject to multi-hazard exposure including subsidence, landslides, ground fissure and building inclination. In particular, starting from the ESA DRAGON-4 project, we began to study Shenyang city and the Fushun open pit mine employing multi-source remote sensed data. One of the most important adopted methodologies consisted on the use of the Advanced InSAR (A-InSAR) technique able to provide ground velocity and displacement time series with millimetric accuracy per year. In the framework of the Dragon-5 project, we went on to monitor such areas, and to achieve this goal, a new COSMO-SkyMed (CSK) images dataset (descending track), operated by the Italian Space Agency (ASI), was required to extend the investigated period using the Persistent Scatterers Interferometry (PSI) technique. A-InSAR results confirm the previous ones from the Dragon-4 project indicating landslides around open-pit mines, building instability, and structural damages. Furthermore, the South railway station in Shenyang shows subsidence motion at different rates along its structure.

InSAR Data Processing and Results



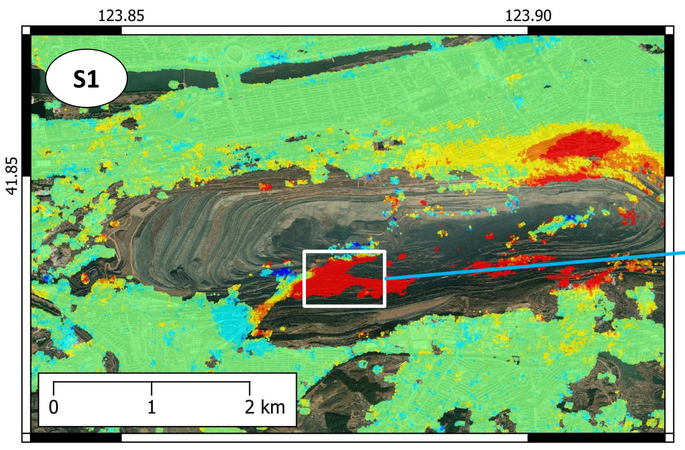
Where we are: Map overview of the area analysed by InSAR techniques. Red rectangles refer to the CSK image footprints.

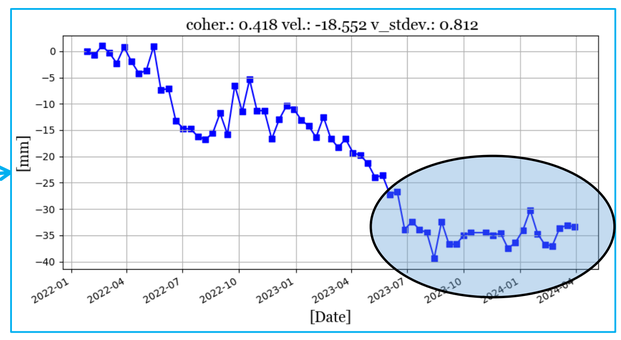
We applied the Enhanced PSI methodologies to SAR image datasets, acquired from the Italian Space Agency (ASI) COSMO-SkyMed satellites, and the SBAS approach to the Sentinel-1 acquisitions operated by the European Space Agency (ESA, see details in Table 1). We obtained mean ground velocity maps and each retrieved coherent pixel's relative displacement time series.
The CSK SAR datasets were processed using the processing chains implemented into the SARscape© software (Sarmap SA), included in the ENVI (NV5©) package. The S1 dataset was processed using the P-SBAS (Parallel SBAS) service implemented into the EarthConsole platform.
A total of 111 images were considered for the western part of Shenyang city, spanning from March 11, 2016, to November 11, 2023, while 142 images were acquired for the eastern part, also interesting the Fushun open pit mine area, and covering the period from February 07, 2015 to December 30, 2023.

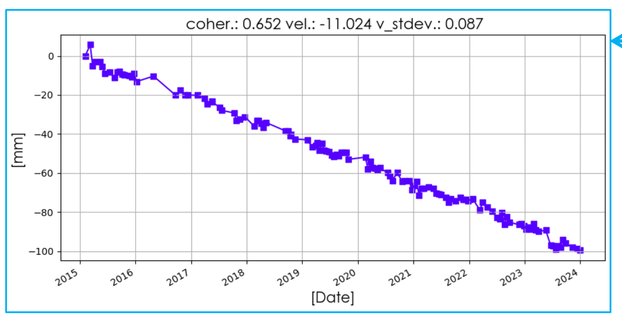
Sensor	Frame	Sensor Mode	Orbit	# of images	Time period (YYYY/MM/DD)
CSK	WEST	STR_HIMAGE	Descending	111	2016/03/11 – 2023/11/11
CSK	EAST	STR_HIMAGE	Descending	142	2015/02/07 - 2023/12/30
S1	105	TOPSAR	Descending	66	2022/01/27 – 2024/03/29
S1	25	TOPSAR	Ascending	72	2021/01/03 – 2023/09/14

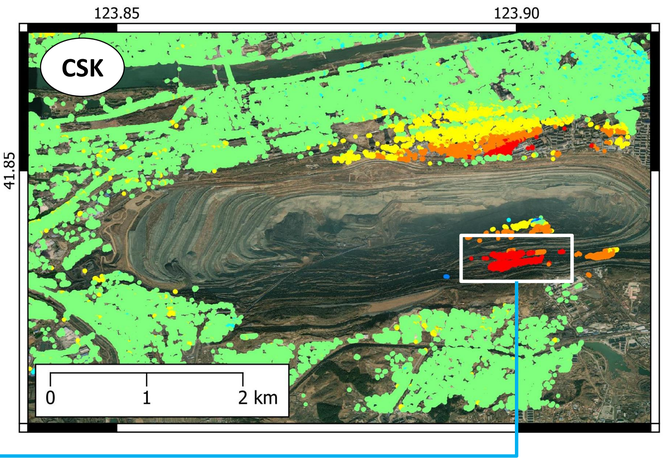
S1 TOPSAR images were considered to complement the previous 2018-2021 analysis. Such data cover the period 2021-2023 and 2022-2024 for the ascending and descending orbit, respectively.

Fushun Pit Mines





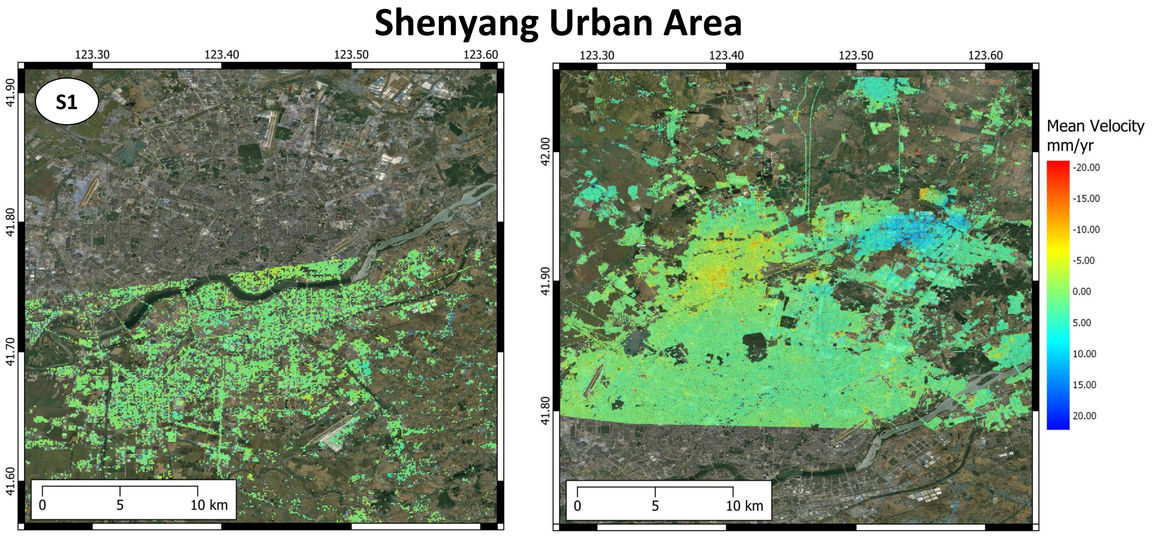




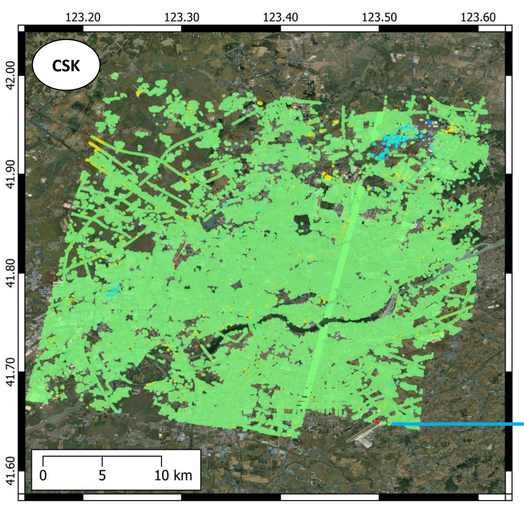
Some small areas show positive values (uplift) probably due to stockpile of excavation debris or swelling of landslide base. S1 time series, for the descending orbit, show an quasi-linear decreasing trend for the investigated temporal interval, quite in agreement with CSK data, but highlighting a stable trend later July 2023.
The SBAS method and the more coherent C-band data allow the detection of more scatterers into the west side of the mine (white rectangle) reaching mean velocity values higher than 25 mm/yr.

CSK data elaborated by means of the Enhanced-PS (EPS) method.
S1 & CSK results show very similar patterns in the area surrounding the open pit mine, with higher density of PS thanks to the very high spatial resolution of CSK. Subsidence phenomena are still ongoing and confirm the findings of the previous SAR analysis. Ground velocity is reaching values on average equal to 12 mm/yr, and peak value of about -20 mm/yr inside the pit (white rectangle). Building instability/subsidence is also detected at the northern edge of the pit.

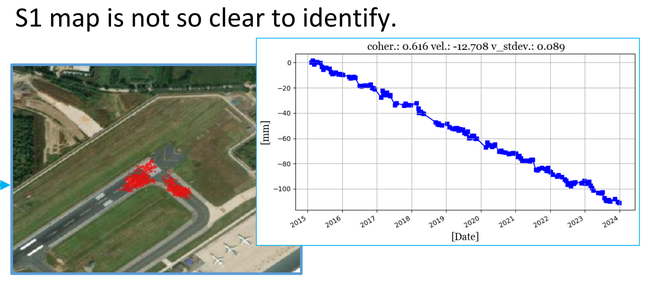
Shenyang Urban Area



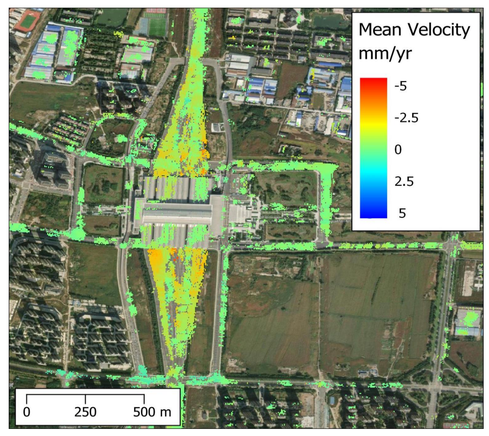
S1 ascending (left) and descending (right) results, obtained by applying the SBAS method. The descending map shows a large area, north to the city centre, affected by high rate of subsidence with localised "hot spots", and an uplifting region on the northeastern sector (to be further investigated). Unfortunately, ascending frame cuts the northern part of the city. Conversely, the last S1 acquisitions, since 2022, descending set do not cover the southern part. The best and up-to-date coverage has been obtained for the time span between January 2022 and March 2024 on descending orbit images.



CSK data have been processed by using the E-PS method (Enhanced PS) that integrates distributed scatterers with the persistent scatterers. Descending outcomes show an area characterised by uplift movement, in agreement with the S1 results. Some spots of subsidence are also present in many areas of the city (at low rate), but the subsiding area visible in S1 map is not so clear to identify.

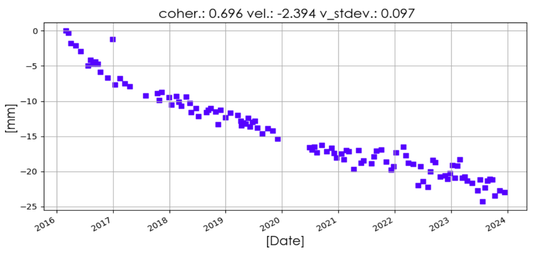


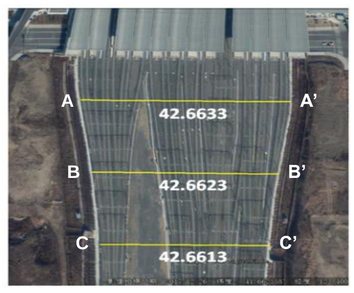
Shenyang Railway investigation



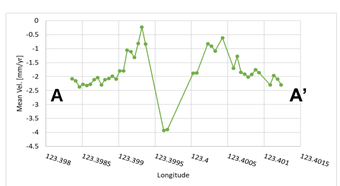
CSK mean ground velocities over Shenyang South Railway Station (eastern frame).

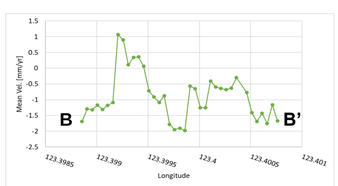
We used CSK data to monitor the ground movements occurred close to the newly-built Shenyang South Railway Station and the nearby high-speed railway tracks. Spatial gradient of deformation velocity have been detected, mainly on the railway tracks just out of the station, with values ranging between 2 and 5 mm/yr (yellow-orange points).

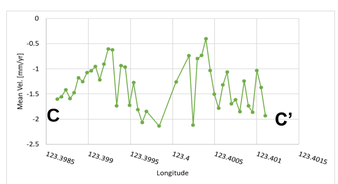




It is worth to note that the deformation seems showing a slight acceleration before mid-2017, followed by a prevalent linear trend.







Acknowledgments

"The COSMO-SkyMed data are provided by ASI through the project card ID 896.*Project carried out using CSK® Products, © ASI (Italian Space Agency), delivered under an ASI licence to use*". **"COSMO-SkyMed Product - ©ASI - Agenzia Spaziale Italiana - 2015). All Rights Reserved".**