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DISPLACEMENTS OF FUSHUN WEST OPENCAST COAL MINE REVEALED BY MULTI-TEMPORAL INSAR TECHNOLOGY

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Abstract

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Opencast mining, which involves huge quantities of overburden removal, dumping and backfilling in excavated areas, is a classical operation mode of large coal mines worldwide. With the continuous expansion of open pit mining areas, the mining angle has also increased sharply, resulting in frequent landslide disasters and significant safety threats to mining production operations. Therefore, it is of vital significance for the safety of personnel, mining operation equipment and infrastructures to perform continuous displacement monitoring of opencast mines and their surroundings. In recent decades, with the continuous enrichment of satellite Synthetic Aperture Radar (SAR) data resources, Multi-temporal SAR Interferometry (MT-InSAR) technique has become a fundamental tool to estimate surface displacements with high spatial resolution, short temporal revisit interval, wide coverage and millimeter accuracy.

In this paper, multi-temporal InSAR technology is adopted to monitor the line of sight (LOS) displacement of Fushun West Opencast Coal Mine (FWOCM) and its surrounding areas in Northeast China using Sentinel-1 SAR images acquired from 2018 to 2022. The spatial-temporal evolution of urban subsidence and the south-slope landslide are both analyzed in detail. Comparison with ground measurements and cross-correlation analysis via cross-wavelet transform with monthly precipitation data are also conducted to analyze the influence factors of displacements in FWOCM. The monitoring results show that a subsidence basin appeared in the urban area near the eastern part of the north slope in 2018, with the settlement center located at the intersection of E3000 and fault F1. The Qian Tai Shan (QTS) landslide on the south slope, which experienced rapid sliding from 2014 to 2016, presents seasonal deceleration and acceleration with precipitation, with the maximum displacement in the vicinity of the Liushan Paleochannel. The results of this paper have fully taken into account the complications of large topographic relief, geological conditions, spatial distribution, and temporal evolution characteristics of surface displacements in opencast mining areas. The wide range and long time series dynamic monitoring of opencast mines is of great significance to ensure mine safety, production, and geological disaster prevention in the investigated mining area.

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Geological Settings and Datasets

Fushun West Open Pit Coal Mine(FWOCM), located in the southwest of Fushun City, Liaoning Province, which started open pit mining in 1914, has since formed the largest open pit in Asia with an east-west length of 6.6km, a north-south width of 2.2km, a depth of 418m and an area of about 10.86km^2. The Fushun West Open Pit is located in the Hun River Fracture Zone, which is a complex tectonic area with many longitudinal and transverse faults, including the east-west F1A and F1 faults and several secondary faults distributed near the north slope of the coal mine, as shown by the red solid lines in the Fig 1. On the south slope of the coal mine, there is a typical cascade landslide named Qiantai Shan, with gneiss, basalt, tuff, etc., and a small amount of thin coal seams interspersed from bottom to top.

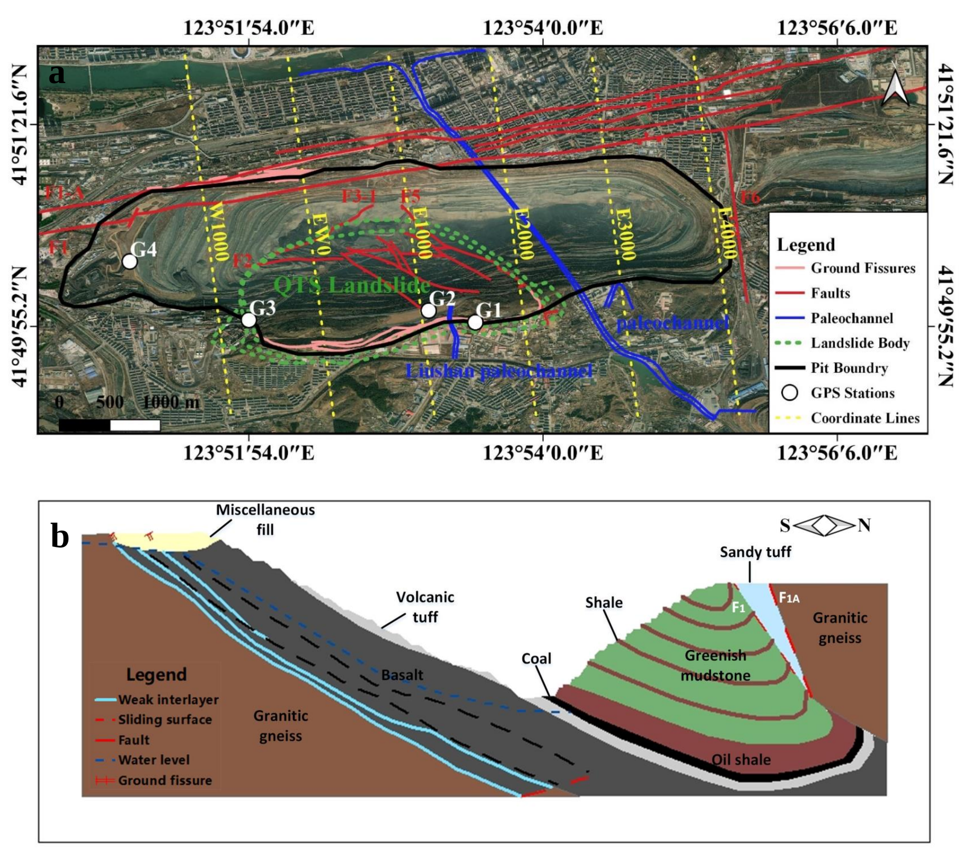

Fig 1. The study area of Fushun west opencast coal mine (FWOCM): (a) geological structures in the FWOCM; (b) The rock stratum of FWOCM.

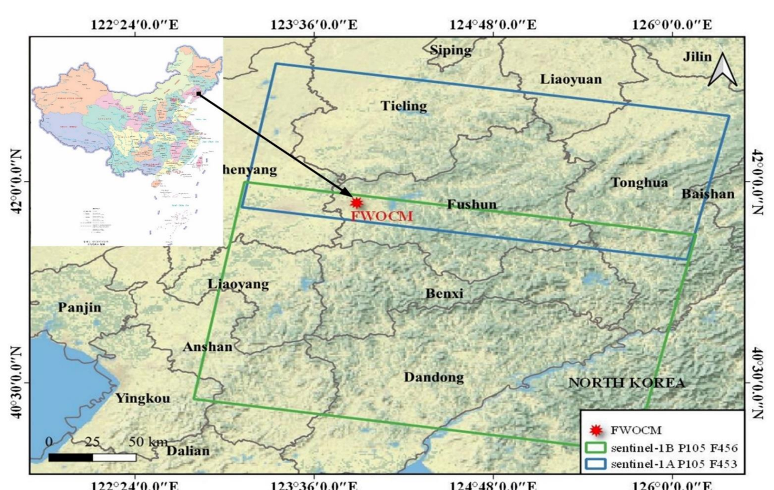

Fig 2. Location of FWOCM and spatial coverage of the SAR datasets.

Table 1. The SAR datasets in FWOCM.

Sensor	Number of images	Time period	Orbit Type	Path and Frame	Incidence angle (°)
Sentinel-1B	89	2018/12/08-2021/12/16	descending	P105 F456	43.81°
Sentinel-1A	19	2022/03/16-2022/10/18	descending	P105 F453	43.86°

Data Processing and Results

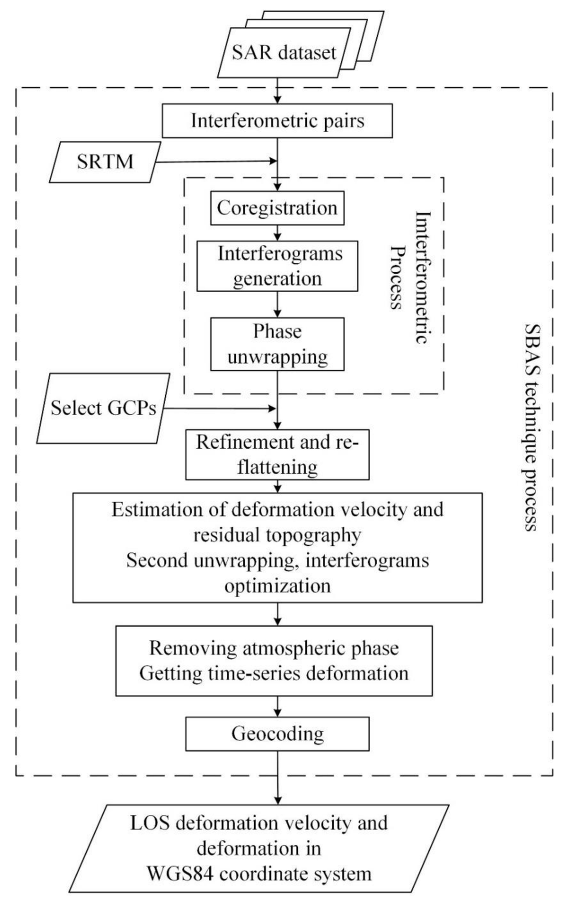

Fig 3. Key steps of SBAS algorithm.

Table 2. Displacement velocities of P1-P10 during the three monitoring periods.

ID	Location	2018.12.08-2020.12.21 LOS velocities (mm per year)	2021.01.02-2021.12.16 LOS velocities (mm per year)	2022.03.016-2022.10.18 LOS velocities (mm per year)
P1	QTS landslide	68.45	68.82	85.39
P2	QTS landslide	133.2041（max）	131.38（max）	132.15
P3	Fushun city	42.82	25.32	20.85
P4	north slope	41.35	30.44	23.53
P5	north slope	37.82	48.62	45.79
P6	north slope	10.49	41.13	17.13
P7	north slope	21.73	39.49	39.54
P8	former power plant	1.88	12.29	21.92
P9	west slope	124.09	97.24	42.33
P10	east slope	121.24	155.55	90.85

The displacement rate of P9 has been consistently decreasing, indicating gradual stabilization of the west slope. P4 and P3 also experienced gradual decrease of the displacement rates. P6 and P5 located on the north slope have all experienced acceleration first and then deceleration during the three monitoring periods, this means stability of the north slope has been reinforced. Displacement rates of P2 and P1 located at QTS landslide on the south slope both remain higher than the other points, and there is even some slight acceleration on P1 (in vicinity of fault F5) in 2022.

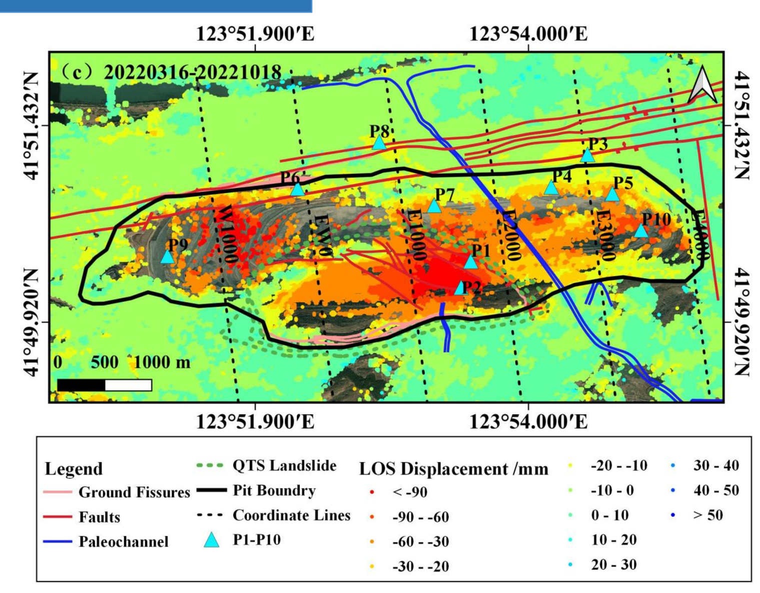

Fig 4. The LOS displacements of FWOCM.

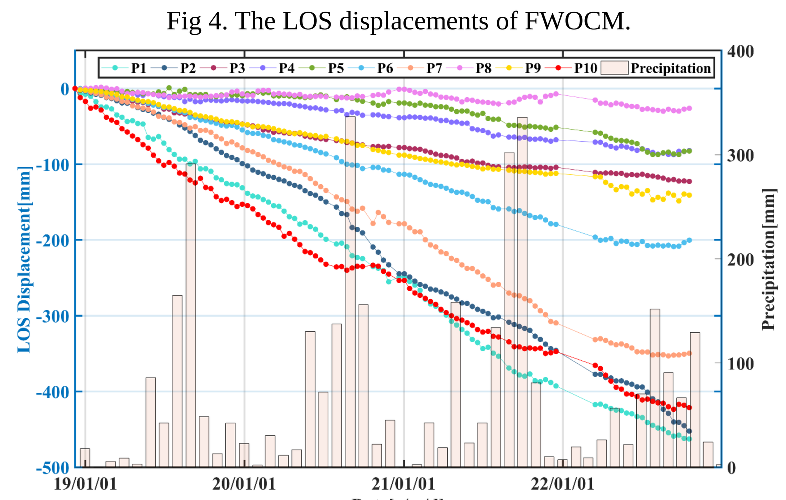

Fig 5. Time series displacements of the 10 points in FWOCM.

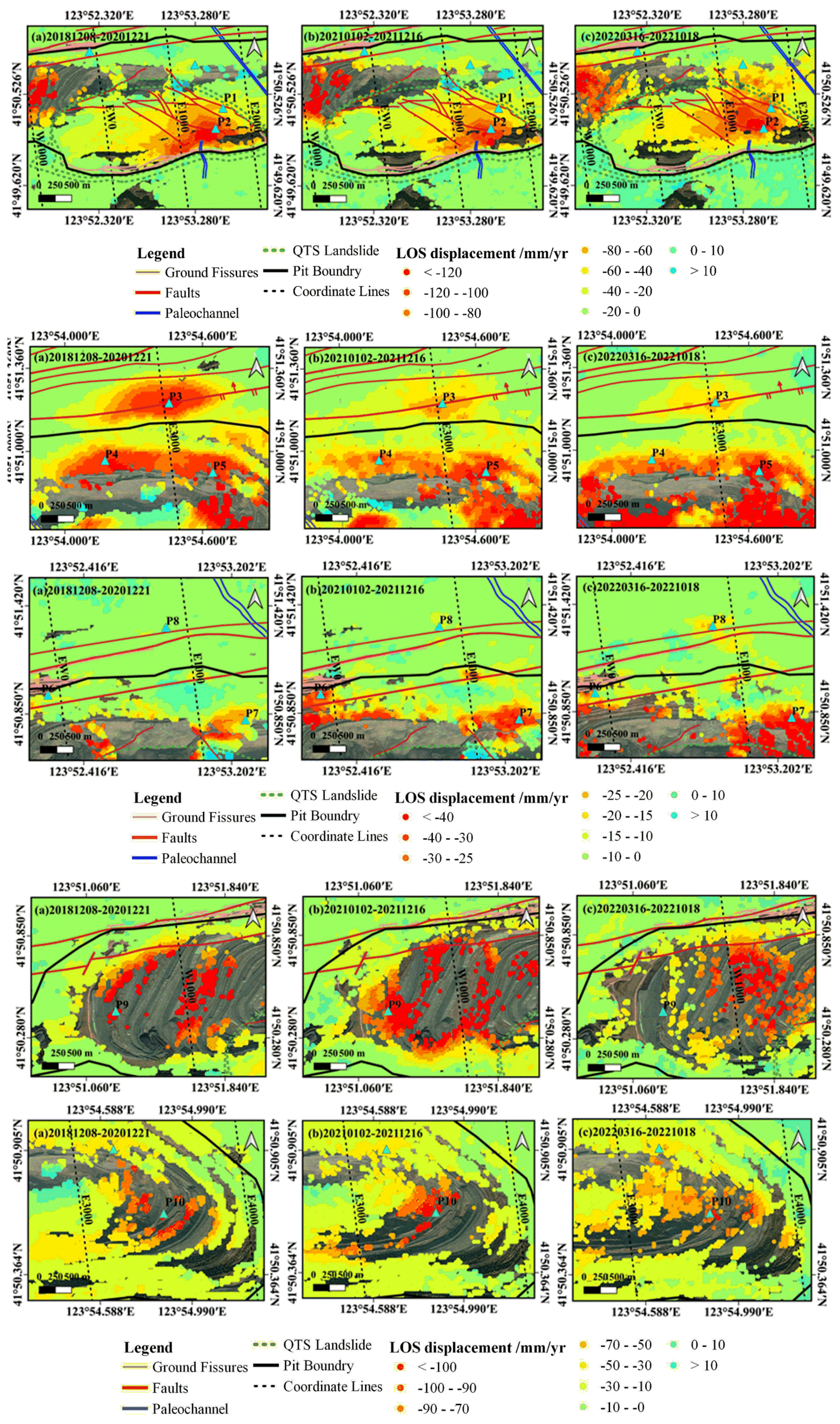

Fig 6. The displacements of FWOCM located at five different areas, area 1 is the Qian Tai Shan (QTS) landslide area on the south slope (highlighted by green dashed lines), area 2 is located at the northeastern part of the mining pit, area 3 is the historical landslide area located at the central and western part of the north slope, area 4 is on the west slope and area 5 is on the east slope of the mining pit.

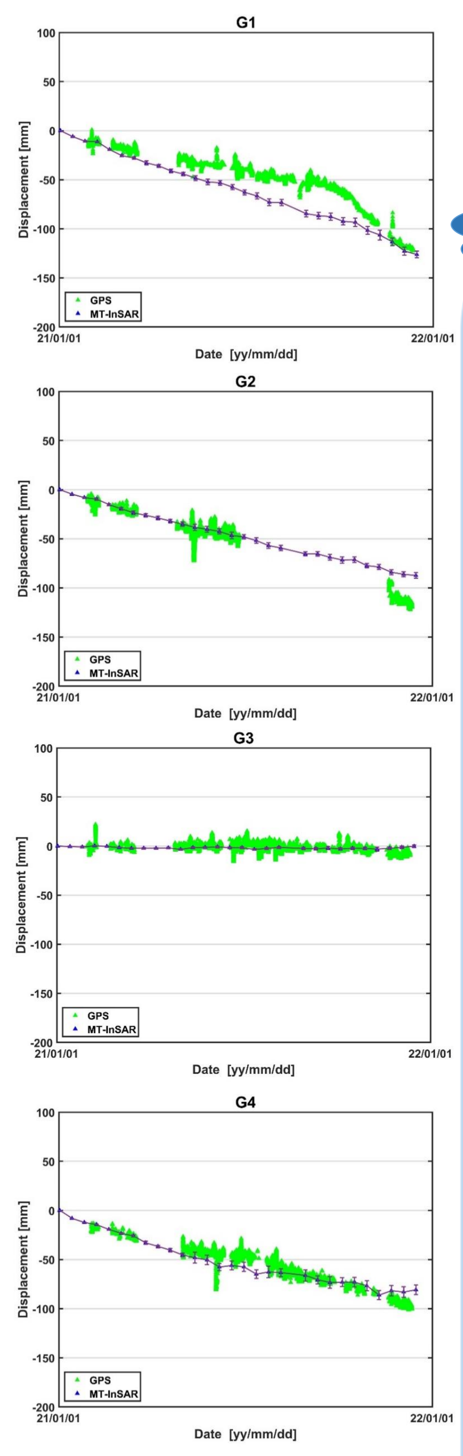

Fig 7. Cross comparison with GNSS measurements, G1-G4 marked in Fig 1. time series displacements estimated by MT-InSAR shows an obvious linear trend, and in very good agreement with the GNSS measurements.

Discussion

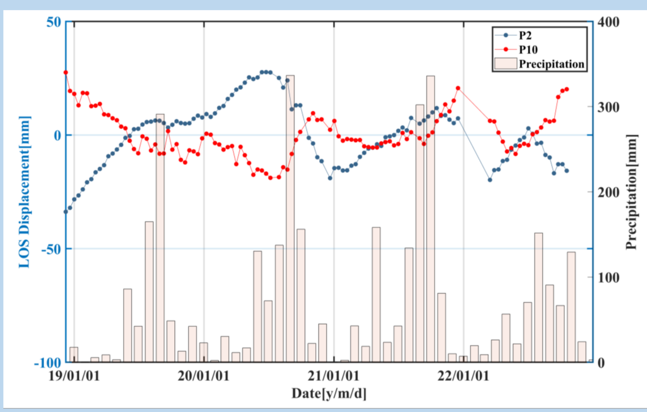

Fig 8. Seasonal displacement time series of P2 and P10. After the heavy precipitation in July and August each year, significant displacement changes are found for both P2 and P10.

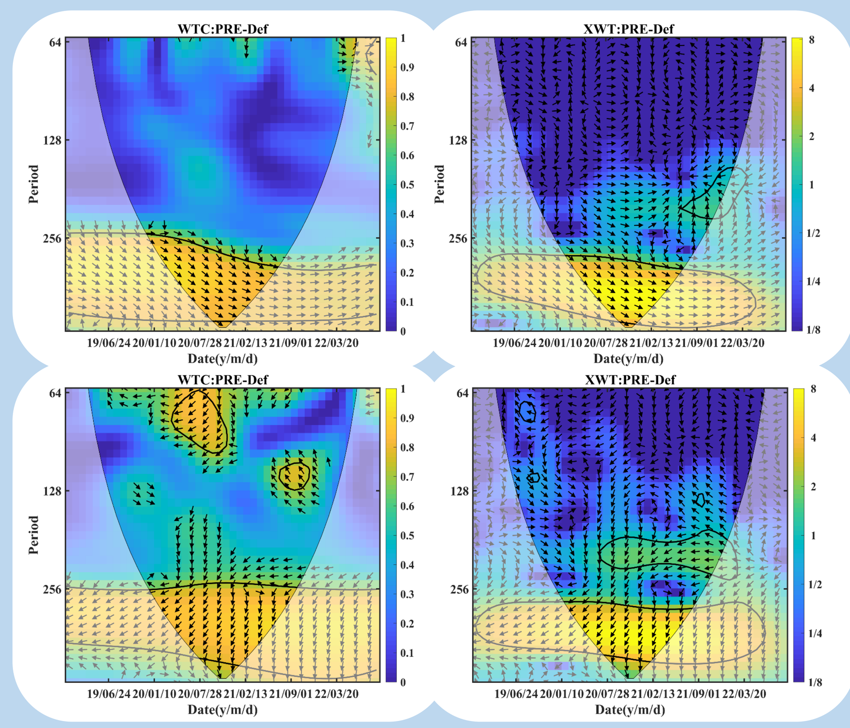

Fig 9. Wavelet spectra between the time series displacements and precipitation for P2 and P10. Coherence higher than 0.8 is detected between the displacement and precipitation for both points. The phase lag between displacements and precipitation is approximately 30° ~45° , indicating that displacements respond to precipitation after approximately 30 ~ 45 days.

Conclusions

In this paper, the Multi-Temporal Interferometric Synthetic Aperture Radar (MT-InSAR) technology in combination with cross-wavelet analysis is adopted to analyze the displacements of Fushun West Opencast Coal Mine (FWOCM) with Sentinel-1 SAR images acquired from 2018 to 2022. The MT-InSAR results show that displacements of FWOCM are mainly distributed in five areas due to different causative factors. Among the major displacement areas, the Qian Tai Shan (QTS) landslide on the south slope presents seasonal deceleration and acceleration associated to precipitation, with the maximum displacement in vicinity of the Liushan paleochannel. By combining MT-InSAR with engineering geological information and other data (e.g. precipitation), it is possible to comprehensively interpret the long-term displacement mechanism of opencast mines, which is of great significance for geological disaster prevention in the investigated mining area.

Major References

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