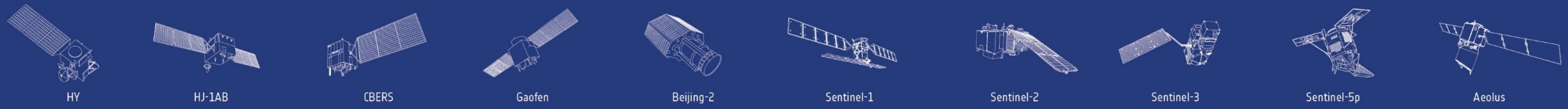

2023 DRAGON 5 SYMPOSIUM

3rd YEAR RESULTS REPORTING

Hohhot, China 11-15 SEPTEMBER 2023

PROJECT ID. 58029

COLLABORATIVE MONITORING OF DIFFERENT HAZARDS AND ENVIRONMENTAL IMPACT DUE TO HEAVY INDUSTRIAL ACTIVITY AND NATURAL PHENOMENA WITH MULTI-SOURCE REMOTE SENSING DATA

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ID. 58029

PROJECT TITLE:
COLLABORATIVE MONITORING OF DIFFERENT HAZARDS AND ENVIRONMENTAL IMPACT DUE TO HEAVY INDUSTRIAL ACTIVITY AND NATURAL PHENOMENA WITH MULTI-SOURCE REMOTE SENSING DATA

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PRESENTED BY:
CRISTIANO TOLOMEI & LIANHUAN WEI

Project Objectives

The industrial district of Shenyang and Fushun plays an important role in the economic and social development of Northeast China. The mining activities strongly impact local environment due to ground excavations of coal and iron extraction. The aforementioned areas are subjected to multi-hazard including subsidence, landslides, and building damages. Moreover, the Changbaishan volcano at the border with North Korea was also investigated due to its activity interesting thousands of people living in the surroundings.

Main goals of the project are to take advantage of the availability of a large variety of remote sensing data to:

1) monitor and analyze the different hazards and environmental impact due to heavy industrial activity at Shenyang areas (Fushun and Dagushan) and at the Changbaishan volcano complex;

2) identification and modeling of single and multiple hazards, identifying the cross-related influence and causing factors;

3) forecast when and how hazards might happen, generate hazard scenarios, and provide support for disaster prevention and damage reduction.

The applied methodologies to achieve the above objectives consists on the joint analysis of multi-source EO data, by means of InSAR time-series, VNIR optical data series, seismic, geochemical, laser scanning data and modeling.

Data used (first 3 yrs)

To reach the proposed objectives the following data were used:

- Sentinel1 (C-Band) and COSMO-SkyMed (X-Band) data along both the ascending and descending orbit (Shenyang, and Fushun area);
- ALOS-2 (L-Band) data for the ascending orbit (Changbaishan volcano), the first processed dataset has been extended up to 2022;
- Envisat and S1 (C-Band) data along the descending orbit (Changbaishan volcano);
- Landsat8 images for the Fushun and Changbaishan area.

In-situ Monitoring network of Changbaishan volcano

12 real-time transmission seismic stations;

12 real-time transmission GPS stations;

Strain meter:100 samples/s;

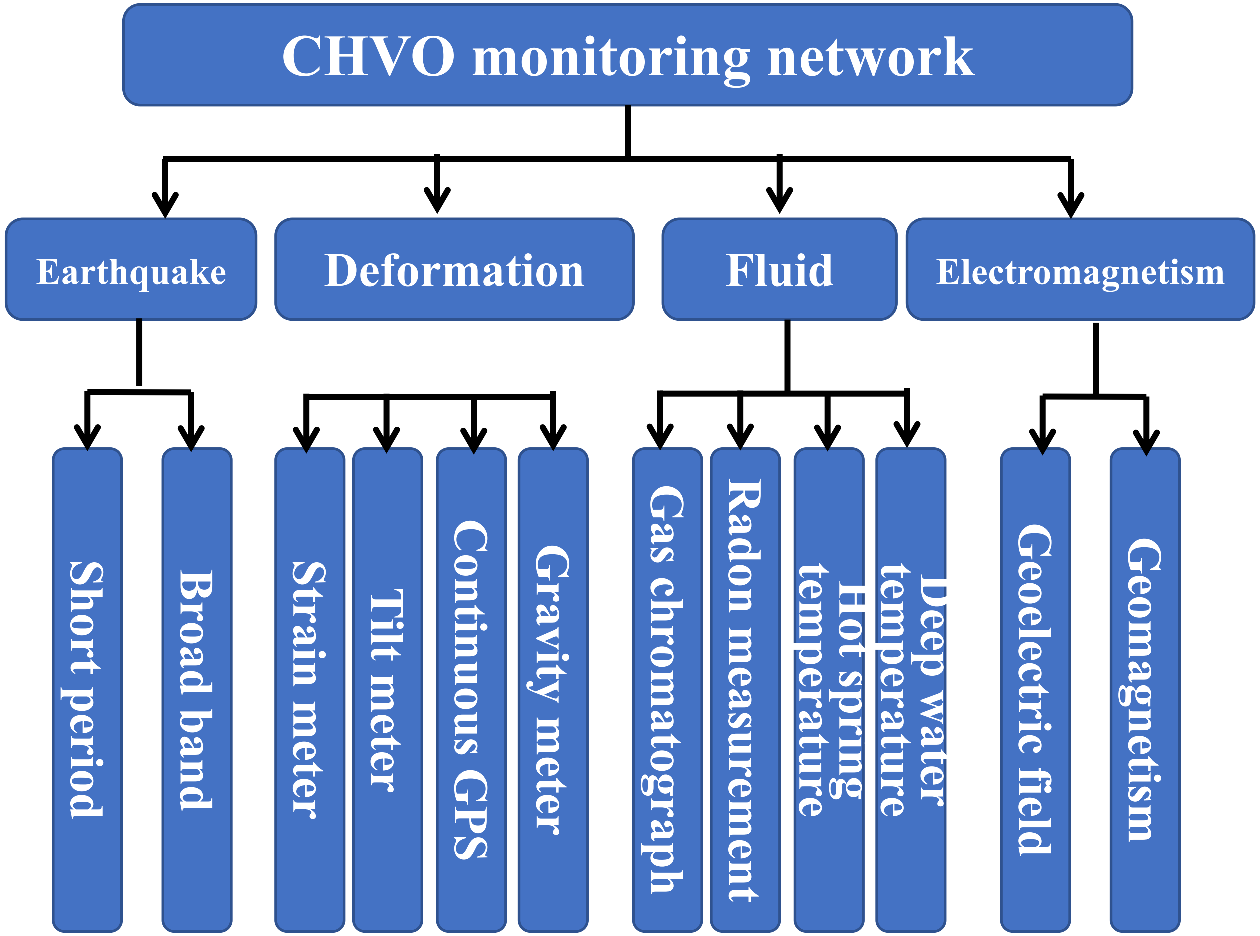
Tilt meter:100 samples/s;

Gravity meter:100 samples/s;

Gases, Radon and Temperatures:2-3 samples/month;

Geoelectric: 100 samples/s;

Geomagnetism: 4 samples/day



Retrieved results

In the framework of the project the European and Chinese team have jointly performed:

- A deep investigation of the Changbaishan volcano by means of InSAR techniques (both SBAS and PS) using S1 (Jan. 2015- Sept. 2020), Envisat (May. 2004- Jun. 2010) and **ALOS-2 data (Nov. 2018-Jul. 2022)**;
- The source modelling of the Changbaishan volcano;
- Update of the Fushun and Shenyang analysis using InSAR techniques up to 2022 through S1 data;
- Completion of the Fushun pit mine study covering a new temporal interval (2018-2020, descending track) using CSK data provided by the Italian Space Agency, also using **the multi-temporal Offset Tracking approach**;

Report on the training of young scientists

- One post-doc Chinese young researcher (Dr. Meng Ao) has been working on hazard monitoring in NEU since 2021.07.
- One post-doc Chinese young researcher (Dr. Zhitao Xu) has been conducting joint research in INGV since 2022.10 under the support of CSC.
- 5 postgraduate students have completed their master's theses.
  - Yun Zhang, Subsidence Monitoring along Shenyang SubwayLines withHigh-resolution Time-series SAR images
  - Jiayu Li, Research on Fusion Method of Multi-sensor Time Series SAR Data
  - Qiuyue Feng, Deformation Monitoring of High and Steep Slopes in Open Pit Mines using LiDAR DEM and Time Series SAR
  - Jiaqi Zhang, Inversion of the volcanic activity in Changbai Mountain on time-series InSAR
  - Xiaotian Wang, Fine Bridge Deformation Analysis by Integrating High Resolution Ascending-Descending Time Series InSAR and Finite Element Analysis
- 6 postgraduate students are conducting their research on geoharzard remote sensing in NEU.

Online meeting & public lectures

1. Online team meeting

2. Public Lectures / courses

2022-12-11
Lecture on MT-InSAR processing given by Dr. Cristiano Tolomei

2022-12-11
Lecture on volcanic hazards given by Dr. Guido Ventura

2022-12-12/13
Short course (8 hrs) on source modelling given by Dr. Elisa Trasatti

Schedule for the Next Year

In the last year of the project we plan to:

- Complete the study on the Changbaishan volcanic complex through new InSAR results retrieved by a new MT-InSAR approach improving the previous source modelling;
- Write a new paper on the Changbaishan volcanic complex;
- Processing for the Shenyang and Fushun areas using CSK data by means of the new Enhanced-PS algorithm;
- Modelling of the larger landslide affecting the Fushun open pit mine using as input the SAR data outcomes;
- Generate hazard scenarios, and provide support for disaster prevention and damage mitigation to Local Authorities (i.e. Civil Protection Dept.).

Published papers

- Paper publication for the Changbaishan study:
  - Trasatti E., et al., *Upward Magma Migration Within the Multi-Level Plumbing System of the Changbaishan Volcano (China/North Korea) Revealed by the Modeling of 2018–2020 SAR Data*. Frontiers in Earth Science 2021, 9, 1302, **https://doi.org/10.3389/feart.2021.741287**;
  - Wei L. et al., Analysis on The Volcanic Activity of Changbaishan Tianchi Volcano with Time Series SAR Data, Chinese Journal of Geophysics, accepted in 2022. (in Chinese)
- A third paper on the Changbaishan volcano complex is in preparation.
- Paper publication for the Fushun and Shenyang study:
  - L. Wei, F. Wang, C. Tolomei, S. Liu, C. Bignami, B. Li, D. Lv, E. Trasatti, Y. Cui, G. Ventura, M. Ao, S. Salvi, S. Wang & X. Pan (2023): *Displacements of Fushun west opencast coal mine revealed by multi-temporal InSAR technology*, Geo-spatial Information Science, DOI: 10.1080/10095020.2023.2239285
  - Ao M., et al., *Surface Deformation Monitoring and Mining Parameters Inversion of Puhe Coal Mine Based on DS-InSAR*, Journal of Northeastern University (Natural Science), accepted in 2023. (in Chinese)

Data used

ESA /Copernicus Missions	No. Scenes
1.Sentinel-1	205
2.	
3.	
4.	
5.	
6.	
Total:	205

Issues:
S1 data were downloaded through the ASF Vertex site

ESA Third Party Missions	No. Scenes
1.ALOS-2	32
2.COSMO-SkyMed	100
3.S1	205
4.SRTM-1 DEM	
5.ALOS DEM	
6. TERRASAR-X	30
Total:	162

Issues:
Both ALOS-2 and CSK data were downloaded via ftp from the related National Space Agencies' dedicated links.
DEMs were downloaded via ftp by the related online sites.

Chinese EO data	No. Scenes
1.GF-1/2/6	15
2.	
3.	
4.	
5.	
6.	
Total:	15

Issues:

European Young scientists contributions in Dragon 5

Name	Institution	Poster title	Contribution including period of research
Camilo Ariza	INGV		2023.10-2024.07
Fang Wang	NEU	Displacements of Fushun West Opencast Coal Mine Revealed by Multi-temporal InSAR Technology	2021.09-2024.07
Ying Sun	NEU	Recent Unrest of the Changbaishan Tianchi Volcano Revealed by Time-series InSAR and Geophysical Modeling	2021.09-2024.07
Yi Cui	NEU	Pre-earthquake MBT Anomalies in the Central and Eastern Qinghai-Tibet Plateau Detected by a Wavelet-based Two-step Difference Method	2021.09-2024.07

Recent activity of Changbaishan Volcano Complex

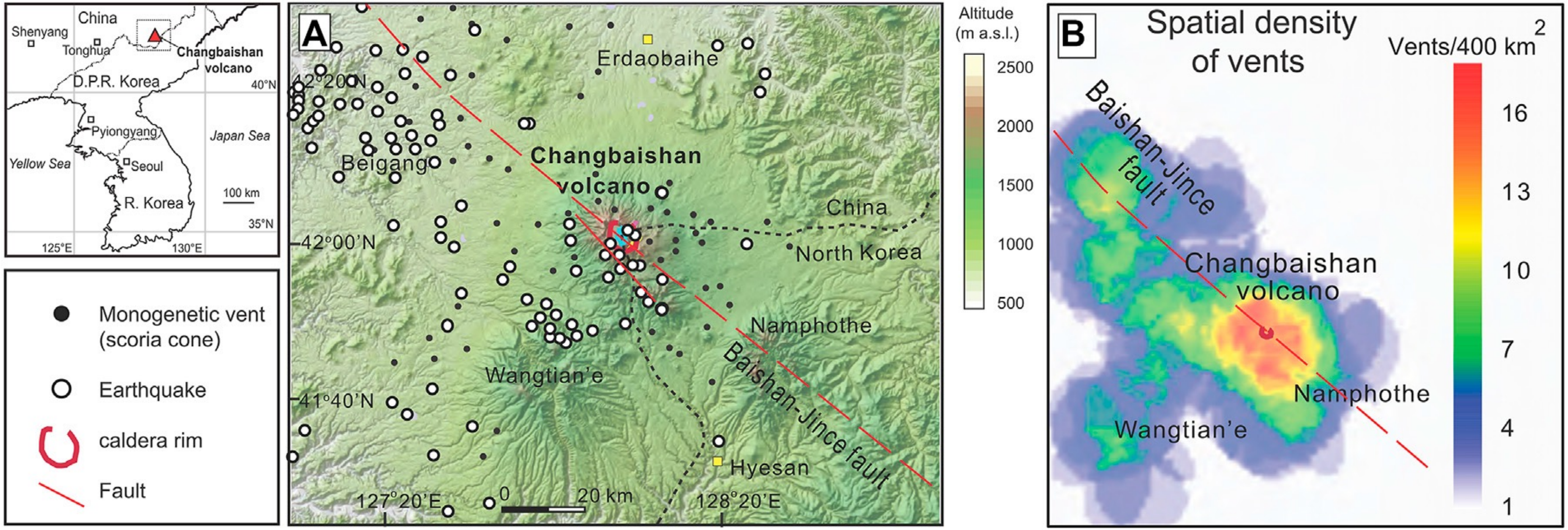
Study area

Changbaishan Tianchi volcano is the most complete Cenozoic composite volcano preserved in China. There is an annual uplift of about 4 mm close to the crater.

- 2002-2005: Volcanic disturbance
- 2011.3.11: Impact of The 2011 Tōhoku earthquake
- 2020.12.22: Volcanic earthquake swarms
- 2021.3.5: Large volcanic-tectonic event (M_L3.5)

From 2002 to 2005, the Tianchi volcano has obvious magma disturbance events. On December 22, 2020, a volcanic earthquake swarms suddenly appeared on Tianchi Volcano. An earthquake of magnitude ML3.1 occurred on March 5, 2021, which was the largest structural volcanic earthquake event after the end of the volcanic disturbance period. There are 135000 Chinese and 31000 North Korean residents living within 50km of the volcano, and about 2 million tourists visit Changbaishan Volcano National Nature Reserve every year. Therefore, the dynamic monitoring of Tianchi volcano is very important to ensure the safety of these people's lives and properties.

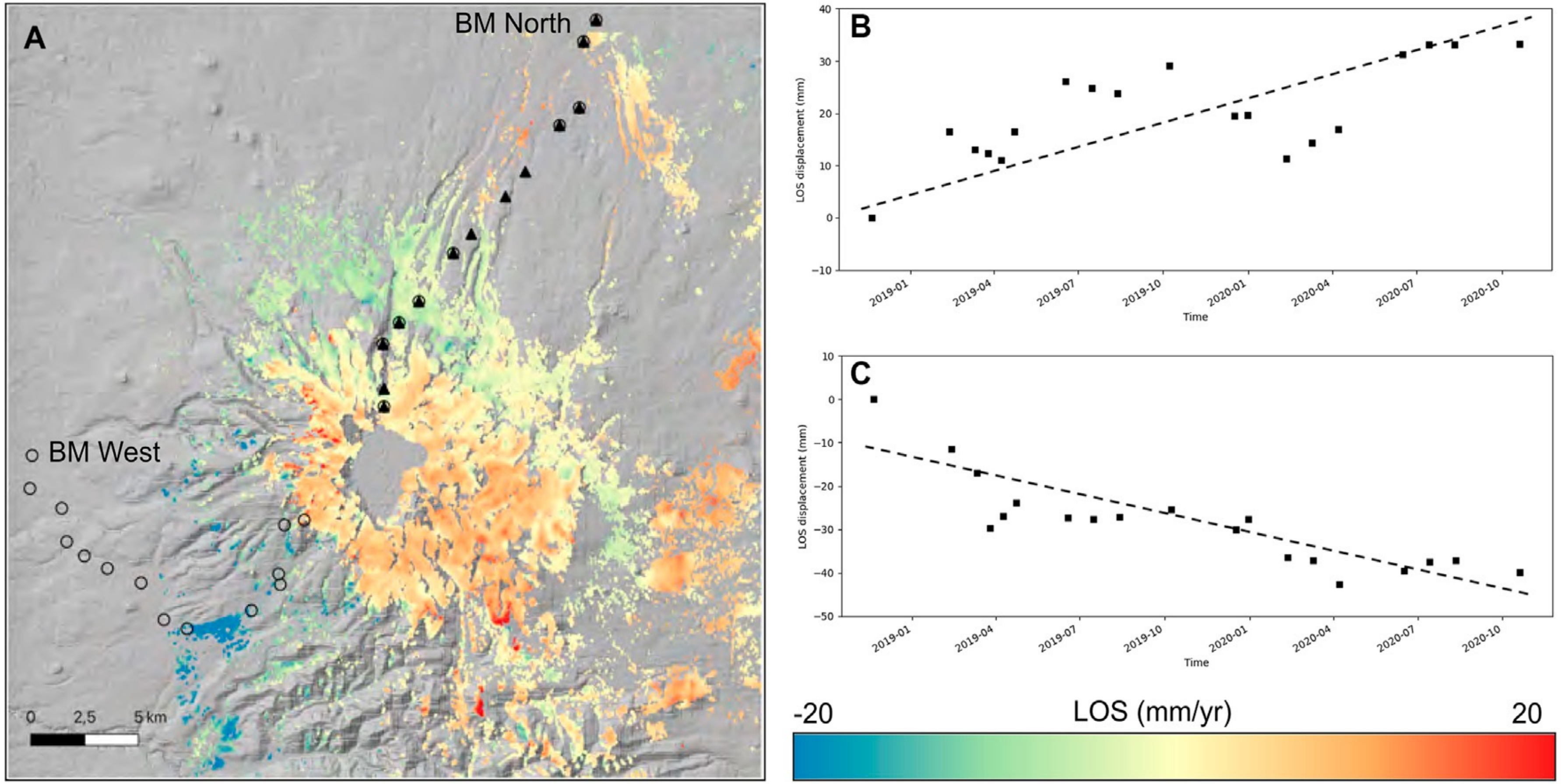
Changbaishan volcano analisys



A) Main tectonic structures; B) Vents density on CBS volcano

ALOS-2 data

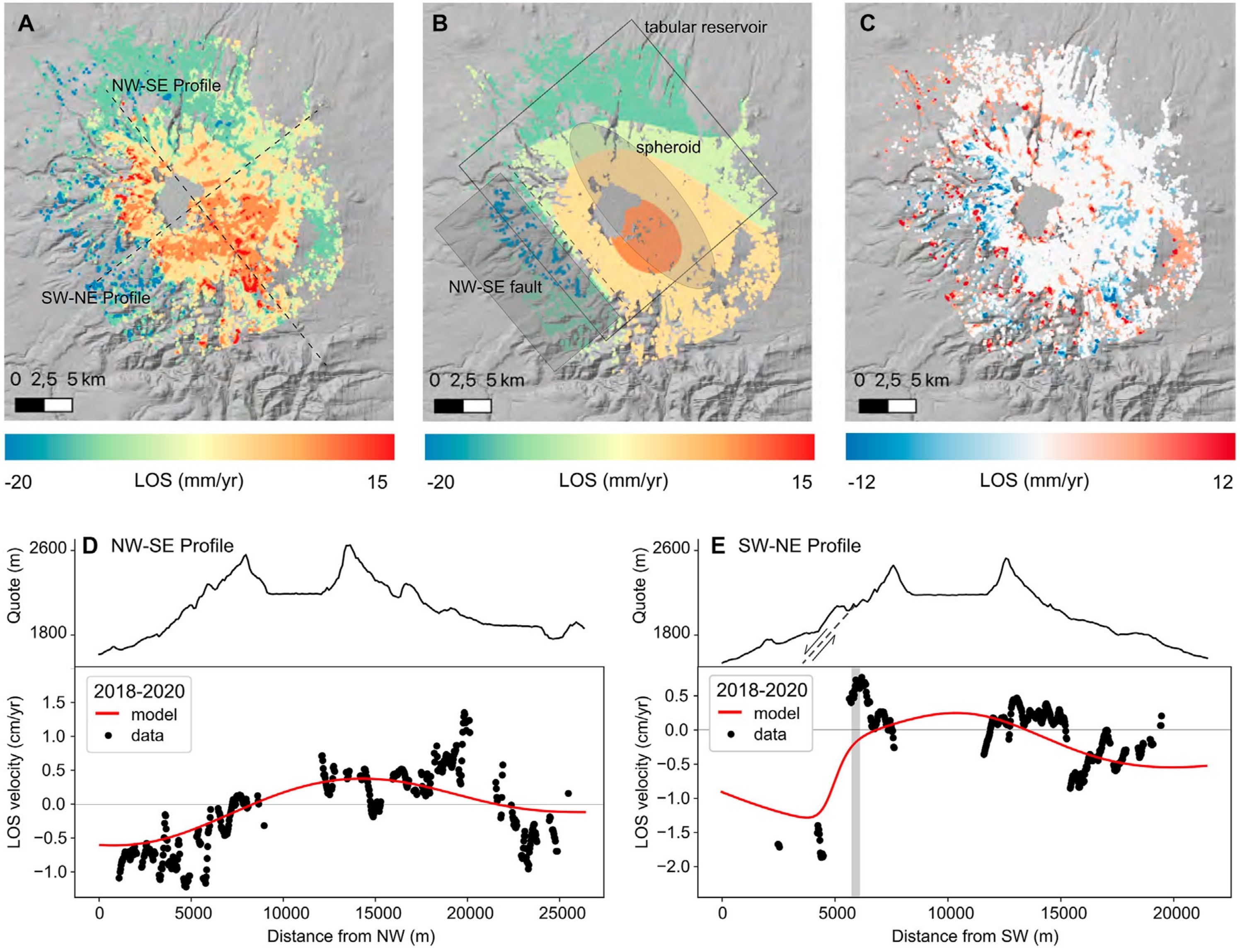
21 L-band ALOS-2 images (ascending orbit) covering the study area from November 2018 to November 2020 were processed using both the SBAS and PSI techniques. The latter was then selected as input for the source modelling due to its higher confidence.



Mean velocity map from InSAR (PS approach) processing of ALOS-2 data. Circles are the benchmarks from the western and northern leveling measured during the 2009–2011 surveys;

Full triangles are the northern leveling benchmarks measured during the 2002–2005 campaigns.

(B,C) Displacement time series in the areas of maximum deformation.



Source modeling at Changbaishan volcanic complex

(A) InSAR ALOS-2 data and (B) LOS displacements generated by the mean model obtained by non-linear inversion.

(B) Modelled sources (synthetic data):

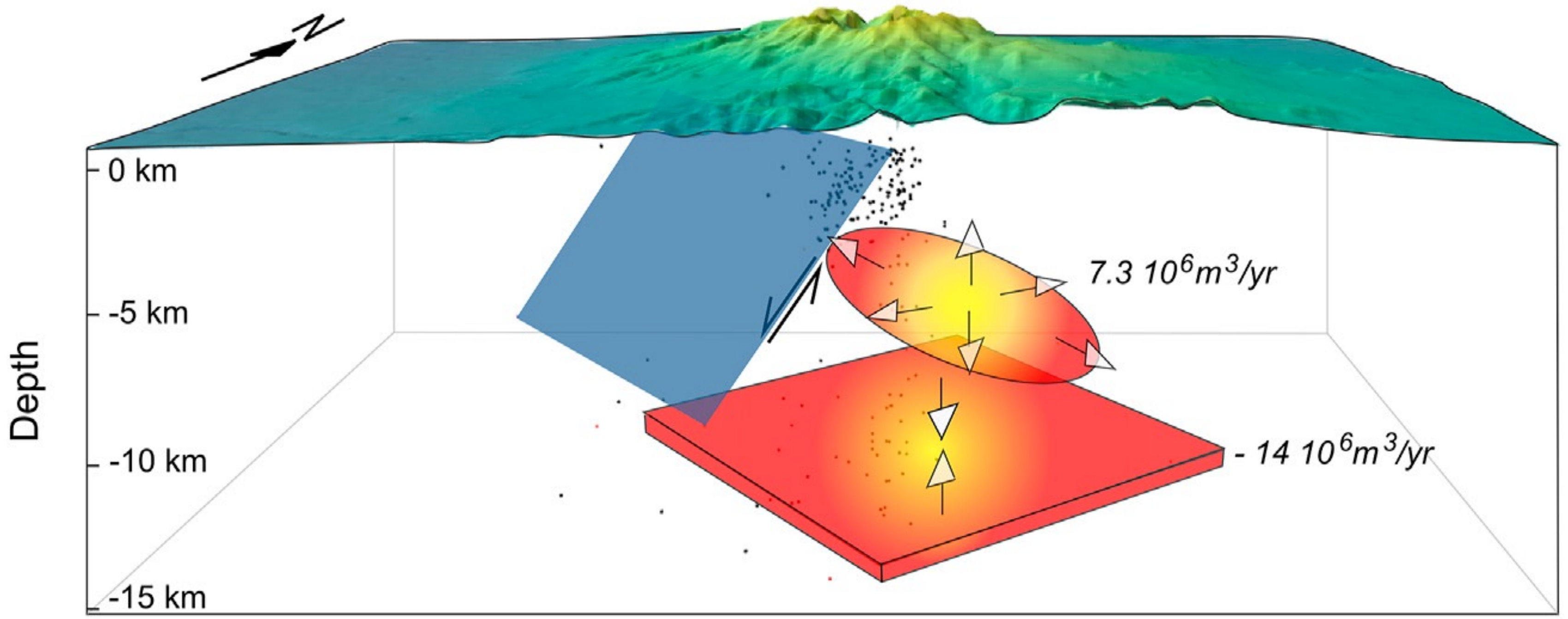
- spheroid
- tabular reservoir
- NW-SE fault

(C) Residuals

(D) Profiles (black dots) and model (red line).

Dashed line is the NW-SE fault (section across the volcano edifice).

Source modeling at Changbaishan volcanic complex



- The main source consists on a NW-SE elongated horizontal spheroid.
- A square tabular reservoir with a negative volume variation at 14 km b.s.l.
- NW-SE dip-slip fault located on the western flank.

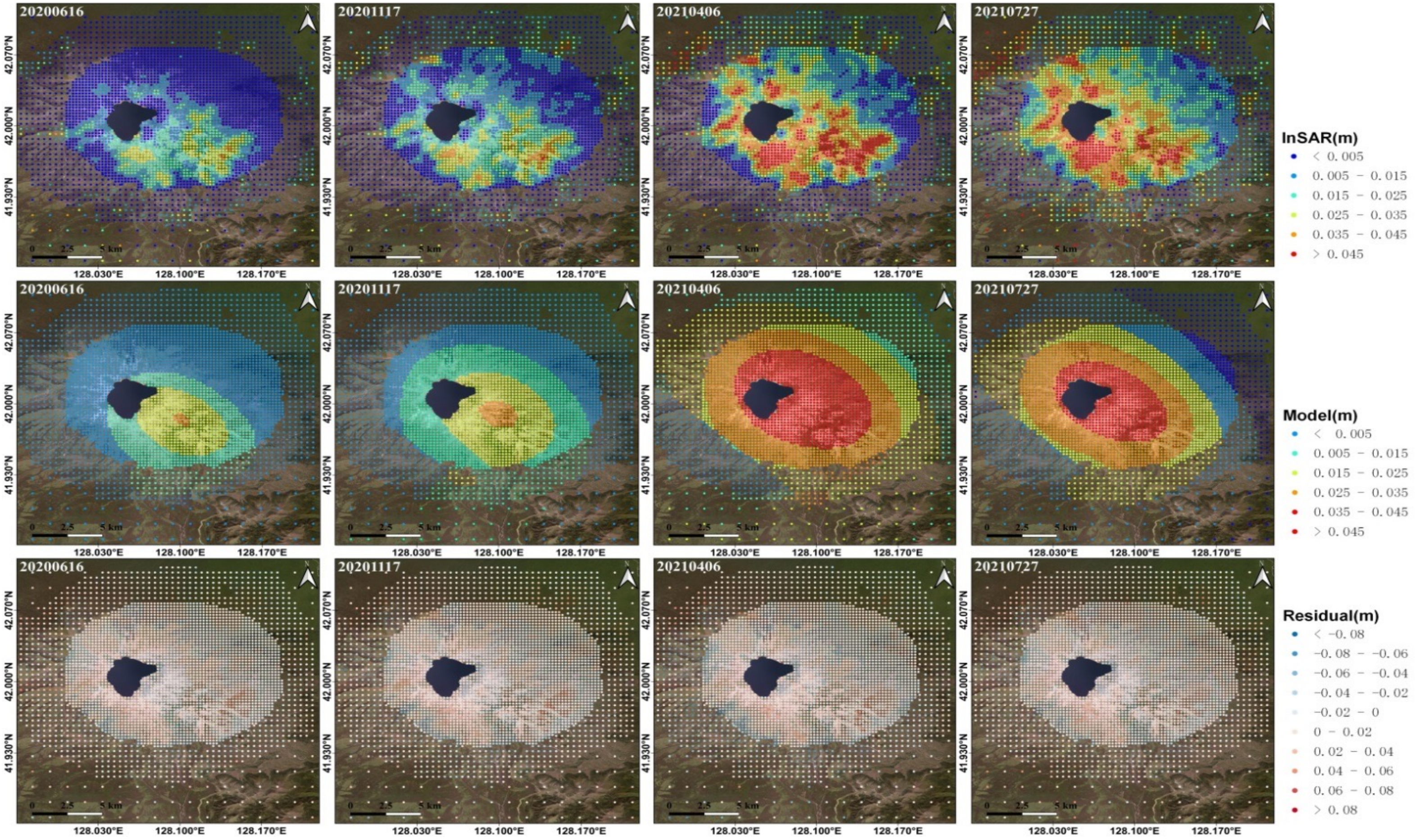
ALOS-2 data updated

	20200616	20201117	20210406	20210727

InSAR

Model

Residual error

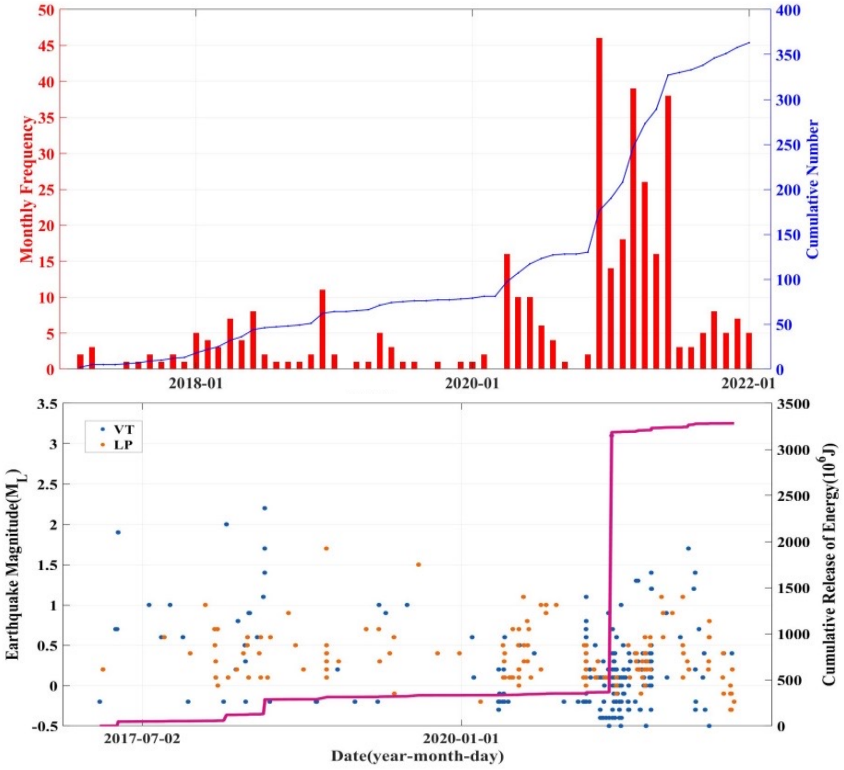


ALOS-2 data updated

Inversion using a combined volcanic deformation model

The volume change of the shallow ellipsoid source and the energy released by earthquakes during the inverted period.

Date	X/m	Y/m	Depth/m	Cumulative volume change of the ellipsoidal source/10^6m^3	Volume change of the ellipsoidal source with reference to the previous date/10^6m^3	Energy released by earthquakes with reference to the previous date/10^6J
20200616	426458.11	4649421.65	5040.71	5.91	5.91	49.75
20201117	426713.54	4649833.56	6815.70	8.30	2.39	13.49
20210406	426237.01	4651849.88	9010.06	25.96	17.66	2839.73
20210727	425850.96	4651191.30	7496.66	16.67	-9.29	43.44



The peak cumulative volume change of 25.96*10^6 m^3 and energy release of 2839.73*10^6 J were observed on April 6, 2021, coinciding with the ML3.1 earthquake on March 5, 2021. From April 6, 2021 to July 27, 2021, the volume of the shallow magma chamber decreased by -9.29 * 10^6 m^3, and the energy release decreased to 43.44 * 10^6 J, indicating that the activity of Tianchi volcano has returned to the background level.

The 2018–2020/22 deformation analysis: conclusions

- 2018–2020 Changbaishan has been characterized by an uplift phase with maximum velocity of 15–20 mm/yr. The uplifted area is NW-SE elongated and mainly affects the North Korea side of the volcano.
- The inversion of the ALOS-2 data identifies sources of deformation related to magma dynamics. The constrained active plumbing system consists of a deeper (14 km b.s.l.), deflating and tabular source, and a shallower (7.7 km b.s.L.), spheroidal and NW-SE elongated inflating source.
- A NW-SE striking fault affecting the western flank slipped aseismically by creep and accounts for the down to −20 mm/yr subsidence observed in the western plain surrounding the edifice.
- The deformation characteristics extracted in this study are consistent with the seismic monitoring records, and jointly reveal a low-level disturbance event from December 22,2020 to June 27,2021.
- **The plumbing system of the Changbaishan volcano is still active, vertically extended and affected by magma recharging processes at different depths.**
- **A monitoring system including massive analysis of satellite data will ensure a full spatial coverage of the deformation field at the China/North Korea border associated with possible pre-eruptive unrests.**

Fushun open pit mine areas (NE China)

Fushun west open pit mine

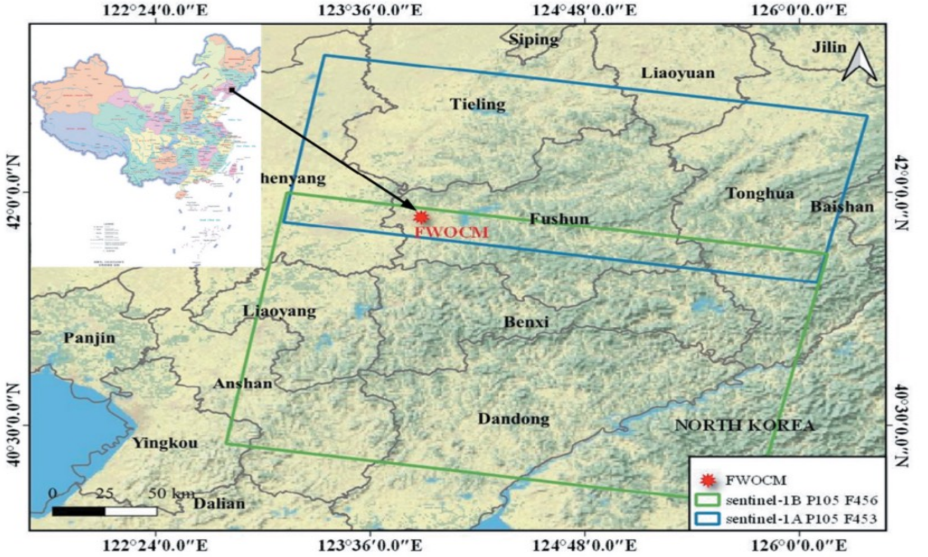
Landslide-induced surface phenomena

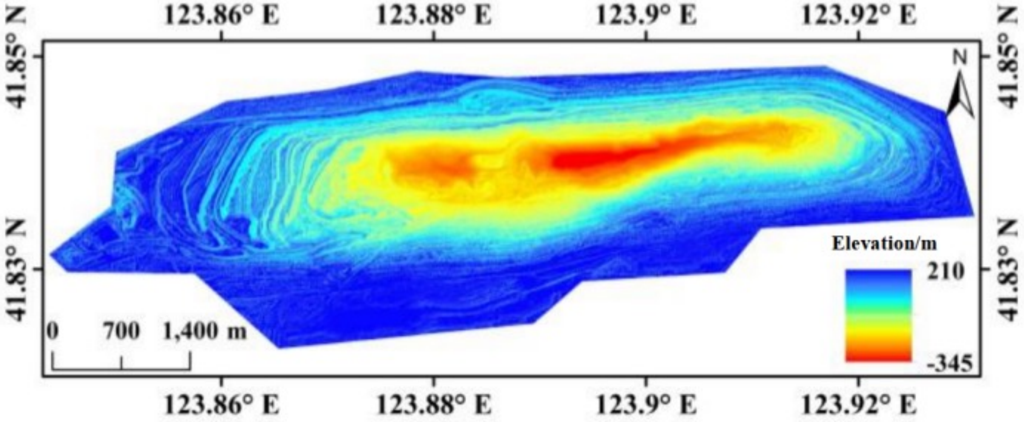
Fushun West Opencast Coal Mine (FWOCM), located in the southwest of Fushun city, is the largest opencast coal mine in Asia. Due to the long-term intensive mining activities, over 100 landslides and severe urban subsidence have been reported in Fushun West Opencast Coal Mine (FWOCM), directly threatening the safety of neighboring residents, factories and other infrastructures.

Landslide Monitoring in Fushun West Open Pit Mine

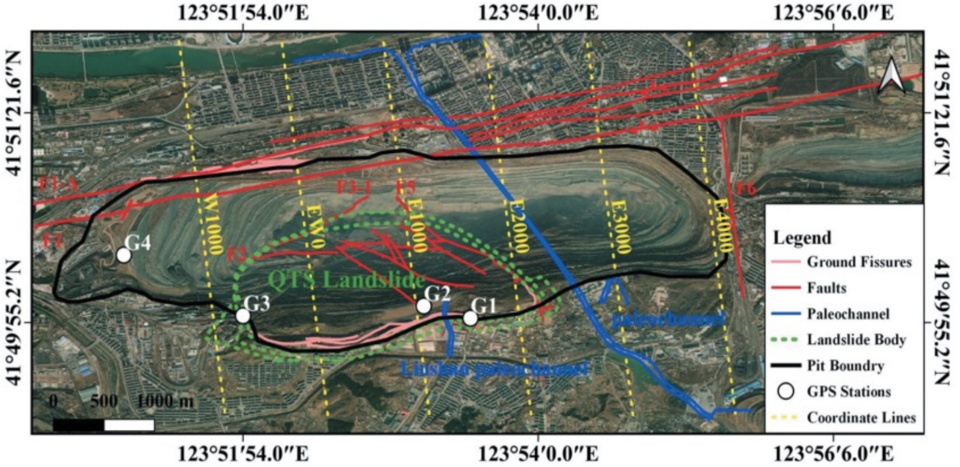
Study area and datasets

Sensor	Number of images	Temporal Coverage	Orbit Direction	Path and Frame	Incidence Angle (°)
Sentinel-1B	89	2018/12/08-2021/12/16	Desc	P105 F456	43.81
Sentinel-1A	19	2022/03/16-2022/10/18	Desc	P105 F453	43.86
COSMO-SkyMed	7	2014/03/16-2016/12/18	Desc	-	25.09





LiDAR DEM

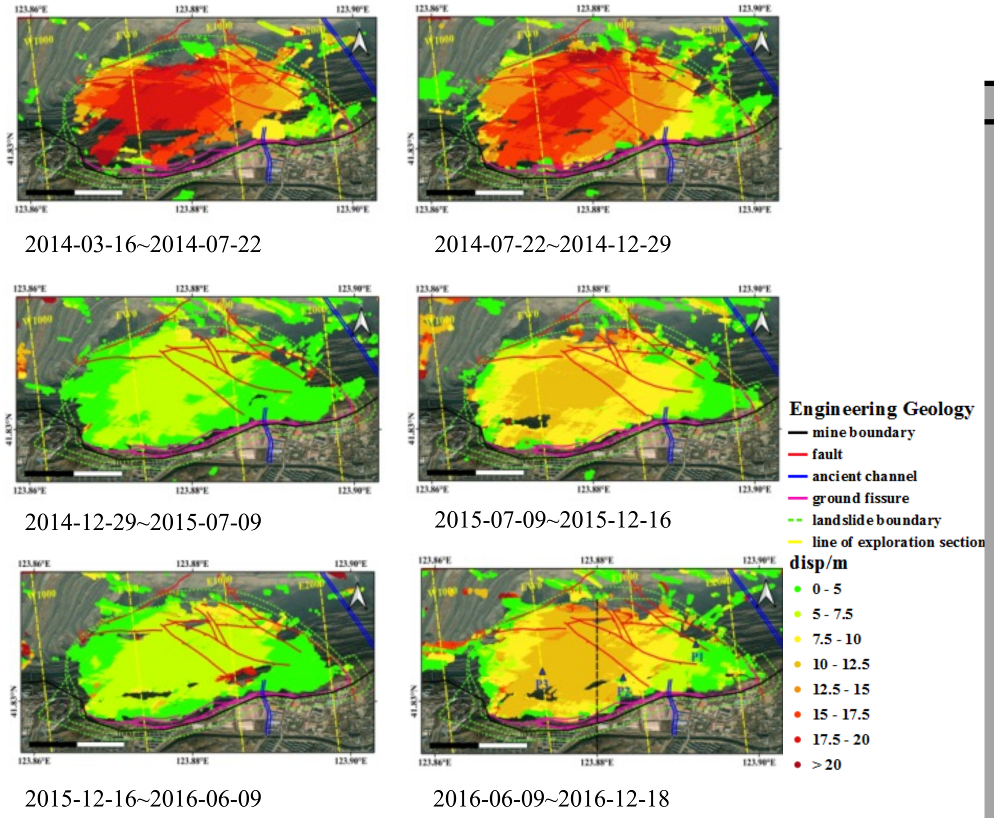


The study area of Fushun west opencast coal mine (FWOCM)

Landslide Monitoring in Fushun West Open Pit Mine

Down-slope displacements retrieved by POT

Amplitude-based POT is conducted with image pairs acquired approximately every half year. Then, the line-of-sight displacements is converted to downslope displacements with assistance of the LiDAR DEM.



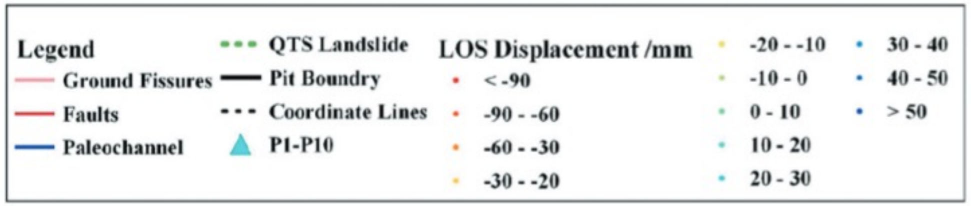
Down-slope displacements

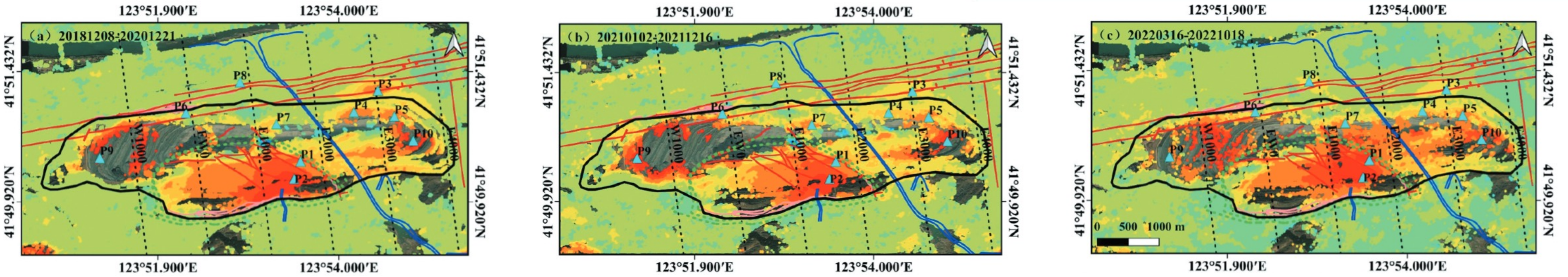
Accuracy assessment of three GPS points

Point ID	P1			P2			P3		
period	GPS	POT	error	GPS	POT	error	GPS	POT	error
14-03-16~14-07-22	10.402	11.372	0.97	14.039	14.779	0.74	19.780	19.119	-0.661
14-07-22~14-12-29	8.888	8.596	-0.292	17.798	15.018	-2.78	17.990	17.632	-0.358
14-12-29~15-07-09	3.181	3.251	0.07	5.410	5.184	-0.226	5.820	6.304	0.484
15-07-09~15-12-16	5.994	5.890	-0.104	10.342	9.274	-1.068	11.066	11.013	-0.053
15-12-16~16-06-09	3.982	3.990	0.008	6.452	6.477	0.025	6.488	6.742	0.254
Mean Error	-	-	0.130	-	-	-0.662	-	-	-0.067
RMSE	-	-	0.489	-	-	1.349	-	-	0.459
Cumulative displacement	32.447	33.099	0.652	54.041	50.732	-3.309	61.144	60.810	-0.334
Relative precision		98%			93.9%			99.5%	

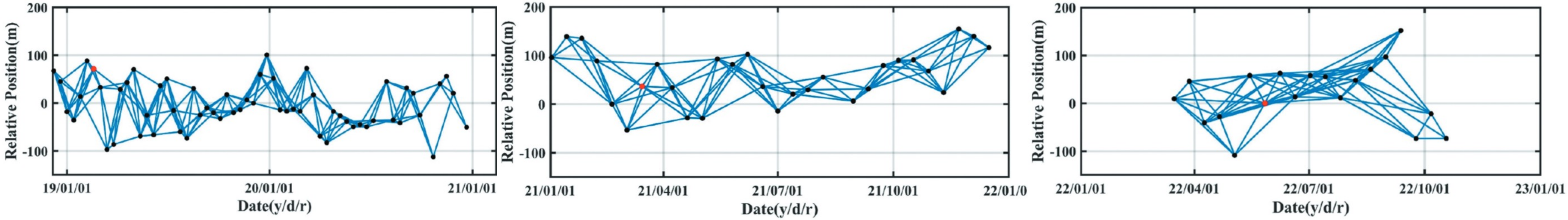
Landslide Monitoring in Fushun West Open Pit Mine

The LOS displacements of FWOCM





The LOS displacements of FWOCM were obtained by MT-InSAR in three different monitoring periods.



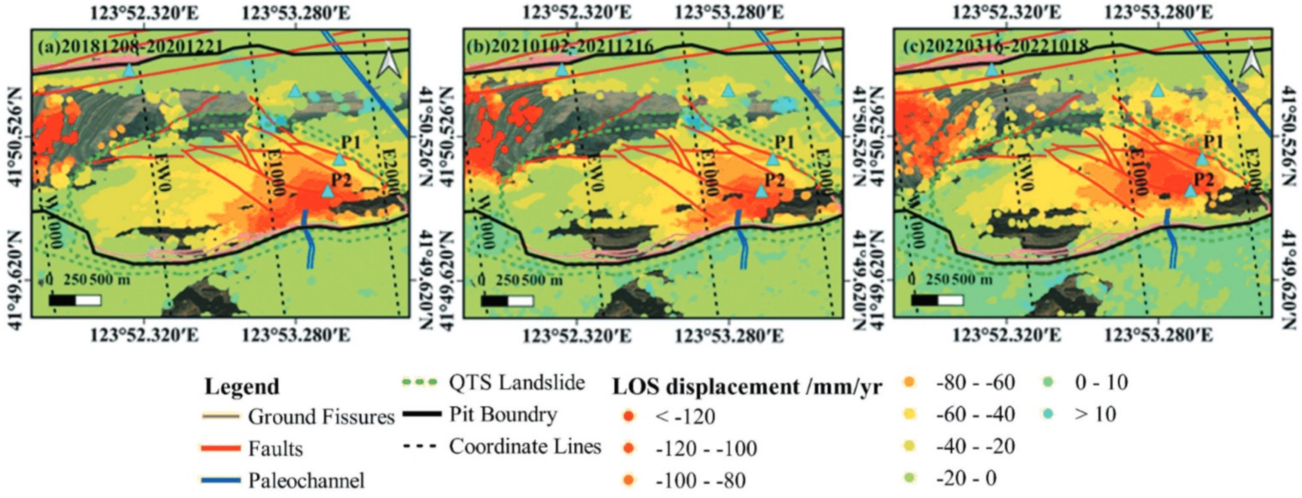
(a) 2018.12.08 - 2020.12.21.

(b) 2021.01.02-2021.12.16.

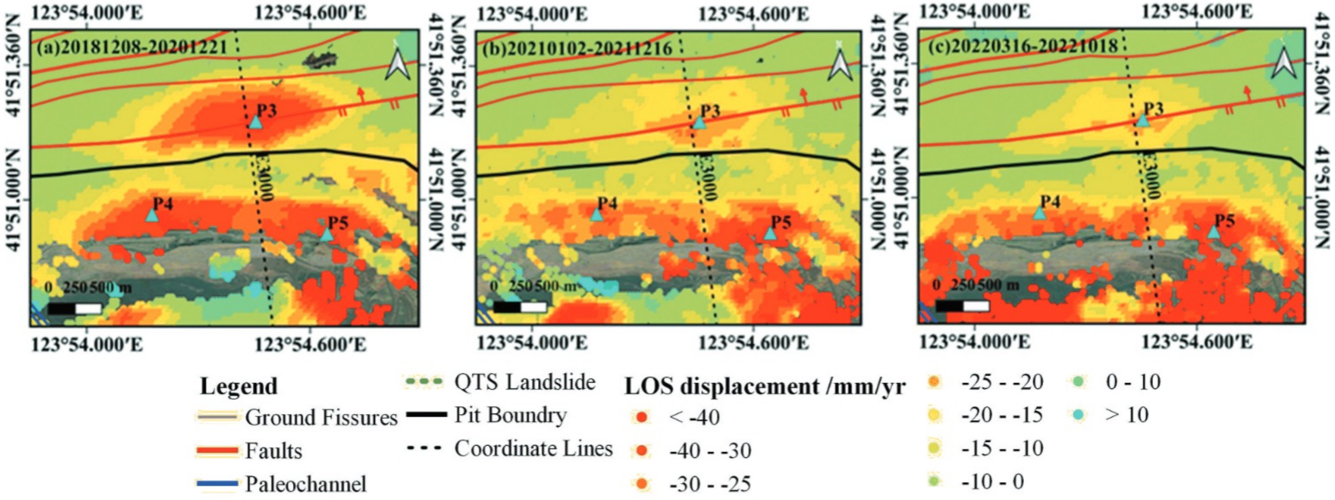
(c) 2022.03.16-2022.10.18.

The spatial-temporal baseline distributions of the during MT-InSAR processing.

Landslide Monitoring in Fushun West Open Pit Mine



Qian Tai Shan (QTS) landslide

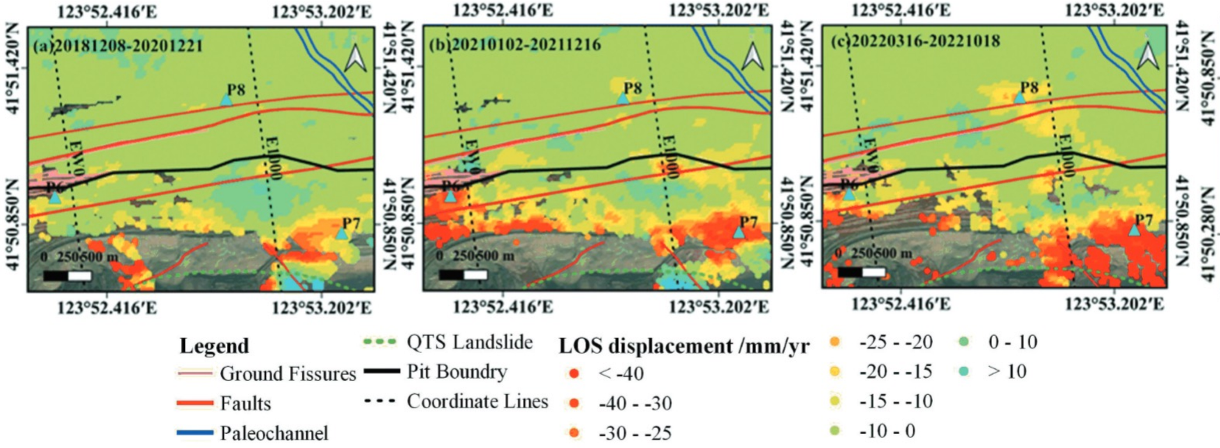


eastern part of the north slope

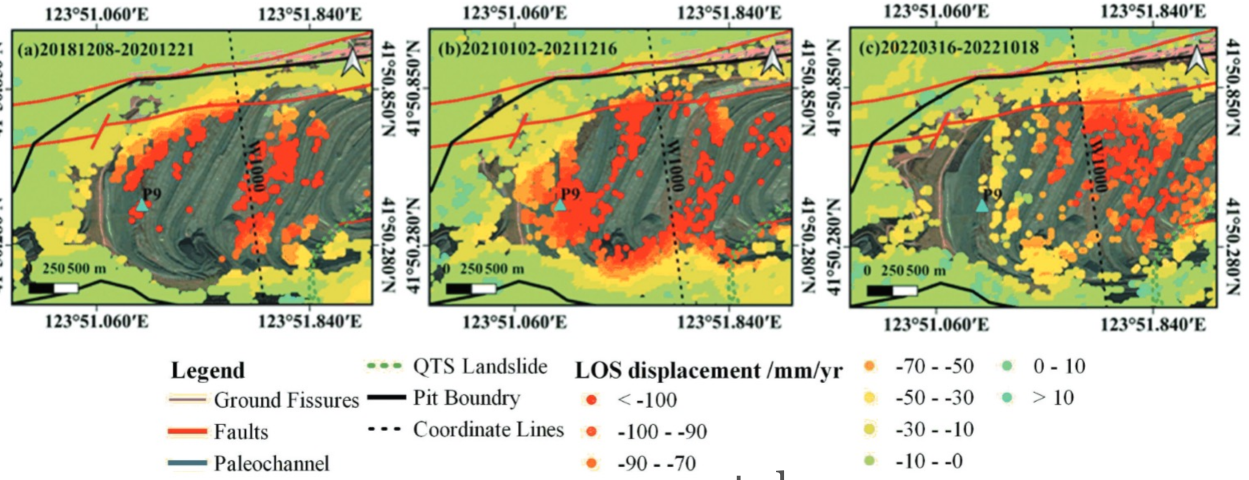
Deformation areas:

- **Qiantai Mountain Landslide on the south slope:** Compared with 2018-2020, the main displacement area of QTS landslide in 2022 moves downward as a whole, and the overall displacement rate of the western half is smaller than that of the eastern half. The area with the highest displacement rate of QTS landslide is located near the ancient river channel of Liushan.
- **The northeastern part of the mining pit:** elliptical subsidence area (centered on the intersection of E3000 and F1 Fault) has decelerated in 2021 and 2022 compared to 2018~2020.

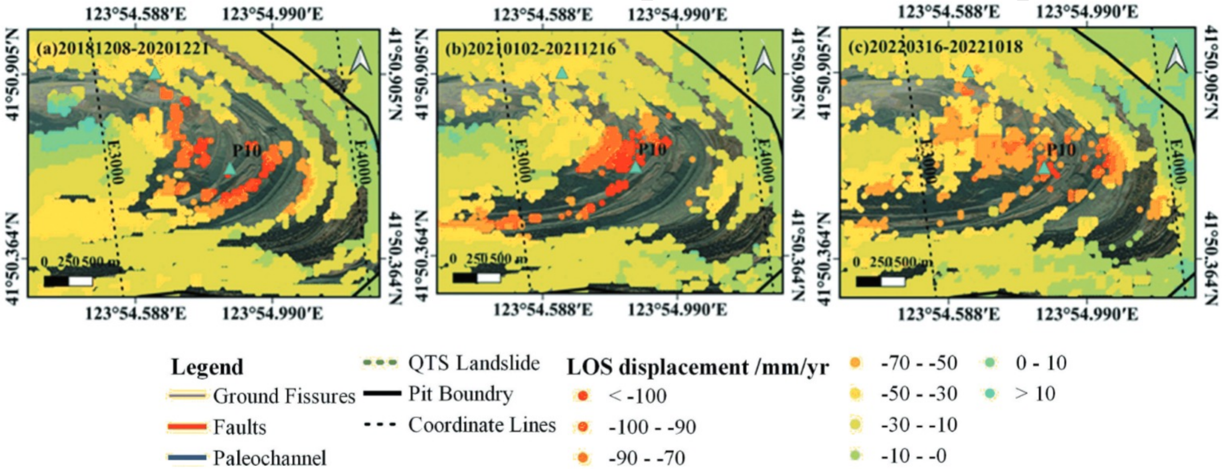
Landslide Monitoring in Fushun West Open Pit Mine



the central and western part of the north slope



west slope

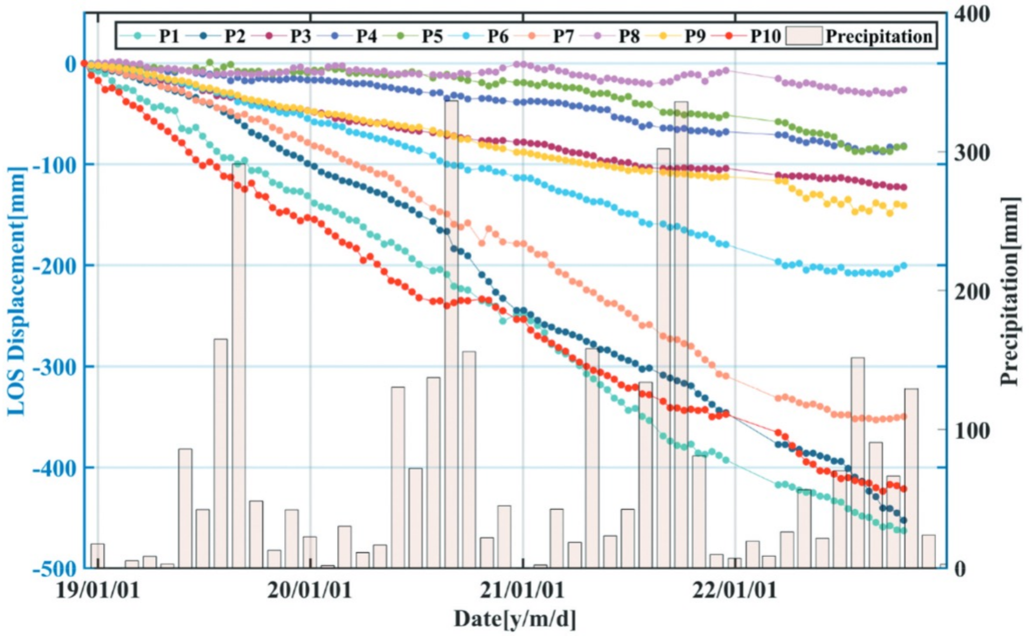


east slope

Deformation areas:

- **The historical landslide area on the central and western part of the north slope:** the historical landslide area was stable from 2018 to 2020, while some local deformation occurred in 2021 (near EW0).
- **The west slope of FWOCM:** reclaimed, with gentle slope angles, consolidation settlement of the backfill continuously occurs. In 2022, the displacement velocity in the west of W1000 decreases. In 2021, a small settlement funnel appeared in the original Fushun Power Plant, and continued to increase in 2022.
- **The east slope of FWOCM:** steep slope, large deformation, vehicles passing by frequently, should be continuously monitored. The QTS landslide (especially the east part) is still the most dangerous landslide in FWOCM.

Landslide Monitoring in Fushun West Open Pit Mine



Time series displacements of the 10 points in FWOCM.

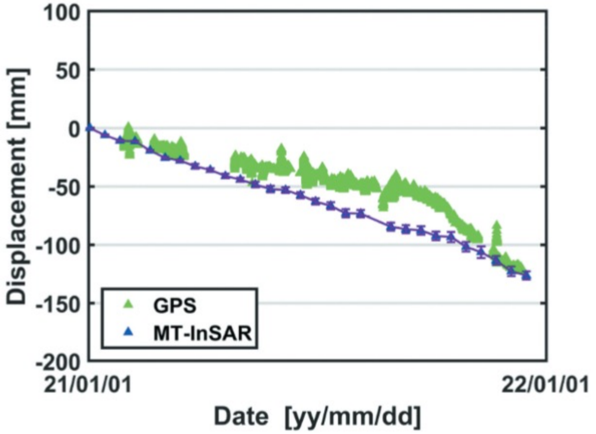
Point ID.	Location	2018.12.08 ~ 2020.12.21 Vel. In LOS（mm/yr)	2021.01.02 ~ 2021.12.16 Vel. In LOS（mm/yr)	2022.03.16 ~ 2022.10.18 Vel. In LOS（mm/yr)
P1	QTS landslide	68.45	68.82	85.39
P2	QTS landslide	133.2041(max)	131.38(max)	132.15
P3	Fushun city	42.82	25.32	2.85
P4	North slope	41.35	3.44	23.53
P5	North slope	37.82	48.62	45.79
P6	North slope	1.49	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	9.85

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

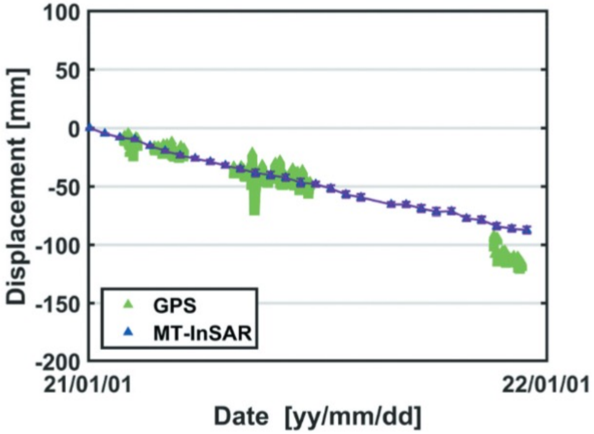
Landslide Monitoring in Fushun West Open Pit Mine

Accuracy assessment and displacement influence factors

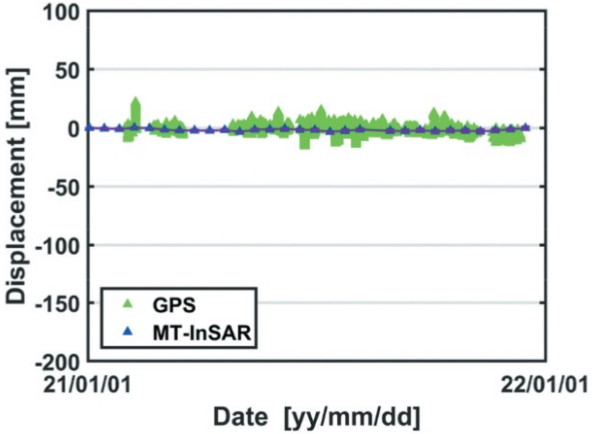
The cross-comparison of GMT-InSAR processing results with GNSS measurements (G1 ~ G4).



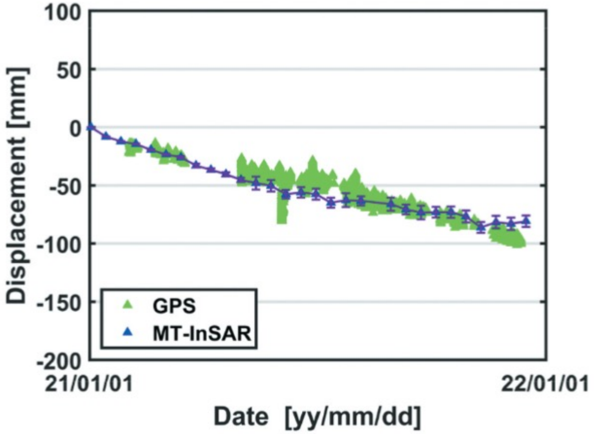
(a) G1



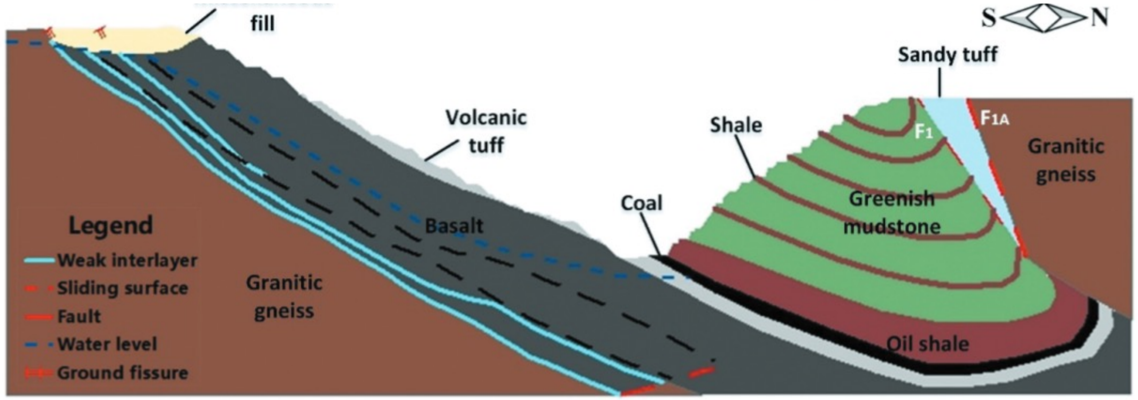
(b) G2



(c) G3



(d) G4



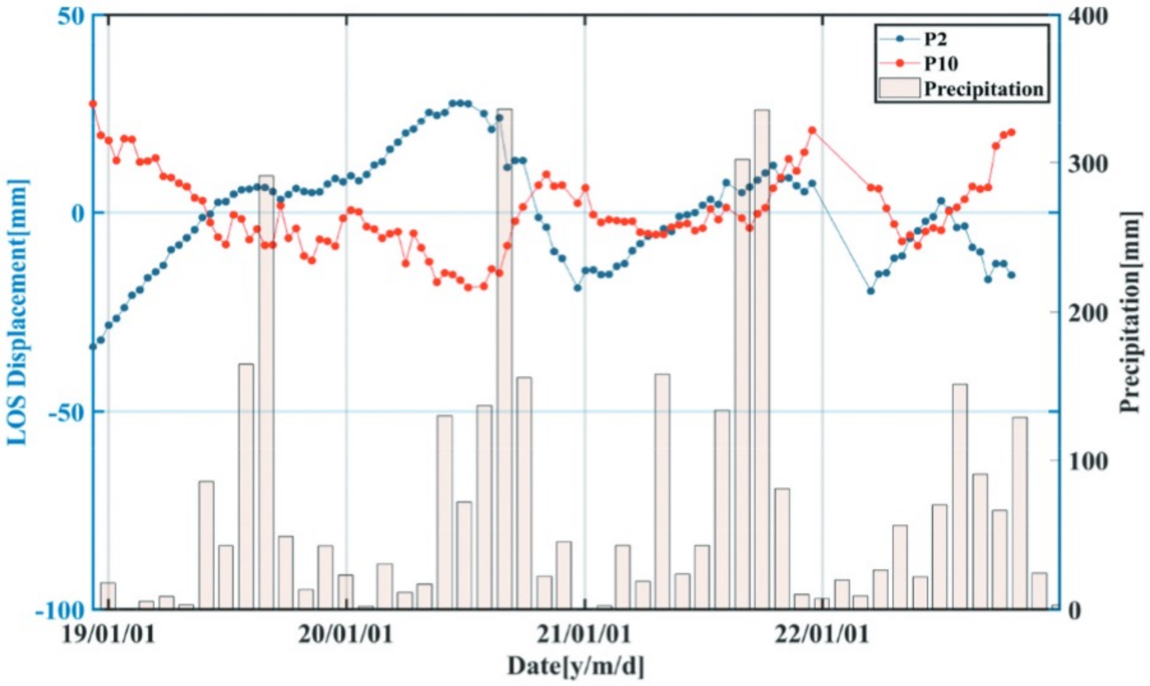
The rock stratum of FWOCM.

The engineering geological conditions of the FWOCM are very complicated, with many faults developed, which influence the stability of the mining pit. The QTS landslide in FWOCM is initiated by instability of the upper part of the landslide body, and followed by shearing of the slope toe, which belongs to a high slope bedding rock landslide with pushing slip.

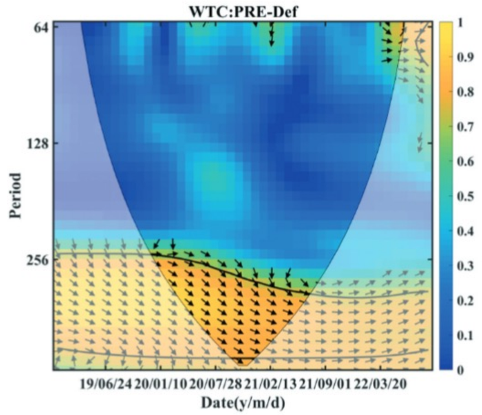
Landslide Monitoring in Fushun West Open Pit Mine

Accuracy assessment and displacement influence factors

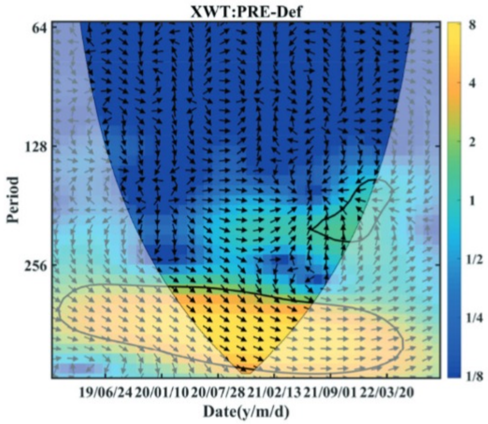
Wavelet spectra between the time series displacements and precipitation for P2 and P10.



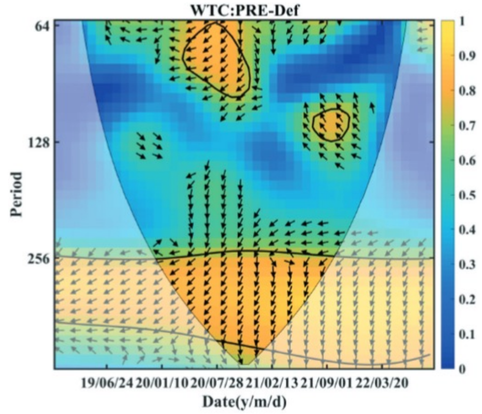
(a) Seasonal displacement time series of P2 and P10.



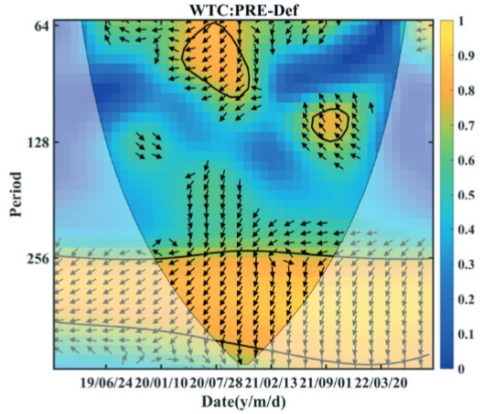
(b) WTC map of P2.



(c) XWT map of P2.



(d) WTC map of P10.



(d) WTC map of P10.

Landslide Monitoring in Fushun West Open Pit Mine

Conclusion

1. The MT-InSAR results show that displacements of FWOCM are mainly distributed in five areas due to different causative factors.
2. 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.
3. The results of this study fully consider the complex characteristics of surface displacement in open-pit mining areas. By combining MT-InSAR with engineering geological information and other data, the long-term displacement mechanism of open-pit mines is comprehensively interpreted, which is of great significance for geological disaster prevention in the investigated mining area.

Surface Deformation Monitoring and Mining Parameters Inversion of Puhe Coal Mine

Field investigation photos of Puhe

Puhe Coal Mine is located in the east of Shenbei Coalfield. In recent years, with the increase of mining depth in Puhe Coal Mine, many deformation phenomena have occurred in the mining and mining process of deep roadway, which seriously affects the safe production of the mine. At present, the area has been classified as a geological disaster prone area. Affected by the surface subsidence disaster, the housing structure in the area has been destroyed.

Surface Deformation Monitoring and Mining Parameters Inversion of Puhe Coal Mine

Study area and datasets

Datasets	TerraSAR-X
Orbital direction	ascending
Pattern	SM
Temporal Coverage	20150825-20170421
Number of images	27
Wavelength (m)	0.031
Incidence angle(°)	23.9
Azimuth(°)	348.71
Polarization mode	HH
Resolution / m (range / azimuth)	2.89/3.30

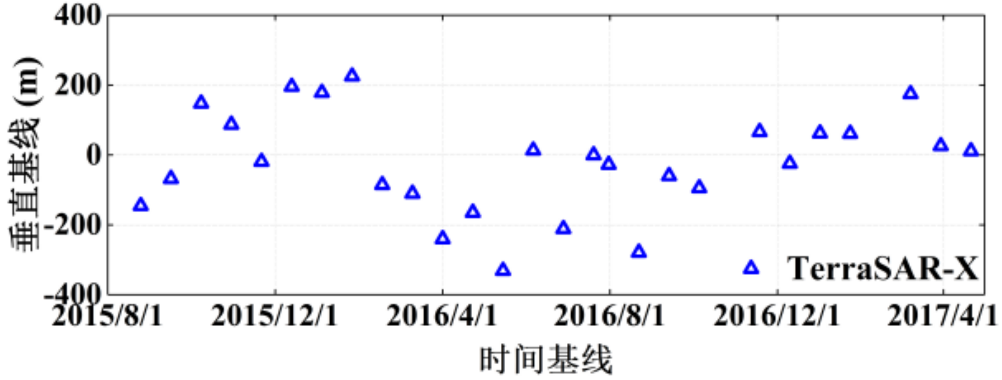
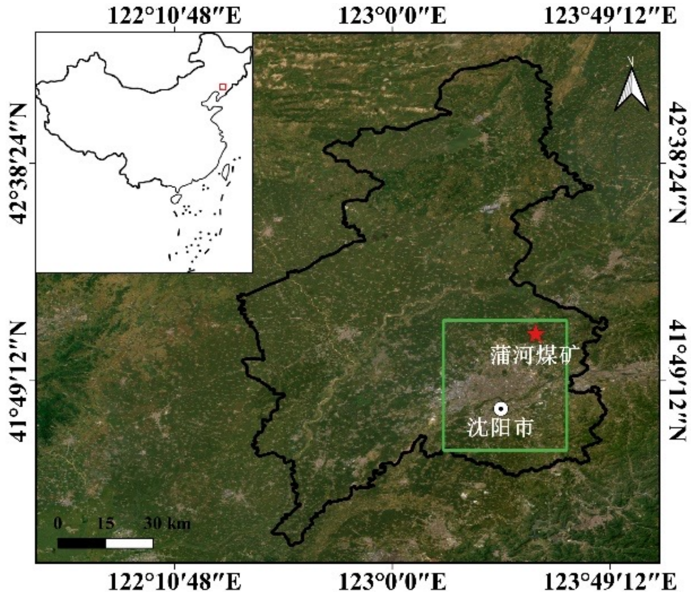


Illustration of temporal-spatial baseline



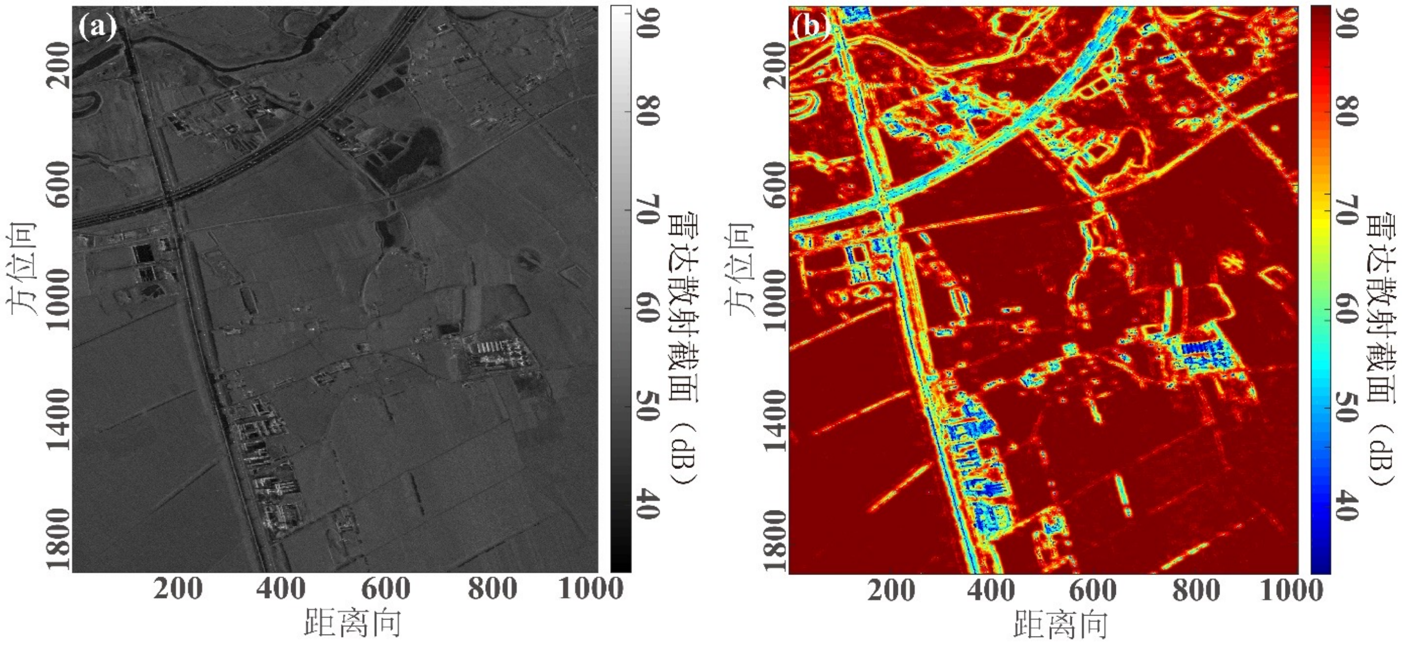
Distribution coverage of SAR dataset

Methodology:

In this study, the distributed scatterer InSAR analysis method is used to accurately describe the time evolution law and spatial distribution characteristics of mining area deformation. Based on the high-precision monitoring data of InSAR, the key underground mining parameters of the mining area are obtained by geophysical modeling inversion.

Surface Deformation Monitoring and Mining Parameters Inversion of Puhe Coal Mine

Mining deformation monitoring results

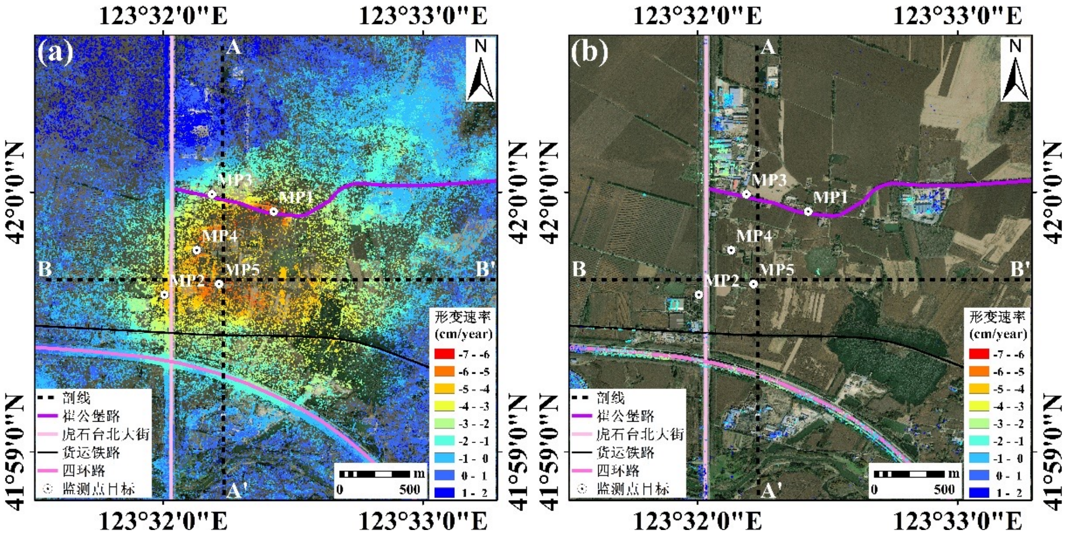


Multi-image mean intensity map (a) and number of SHP identified by KS test (b)

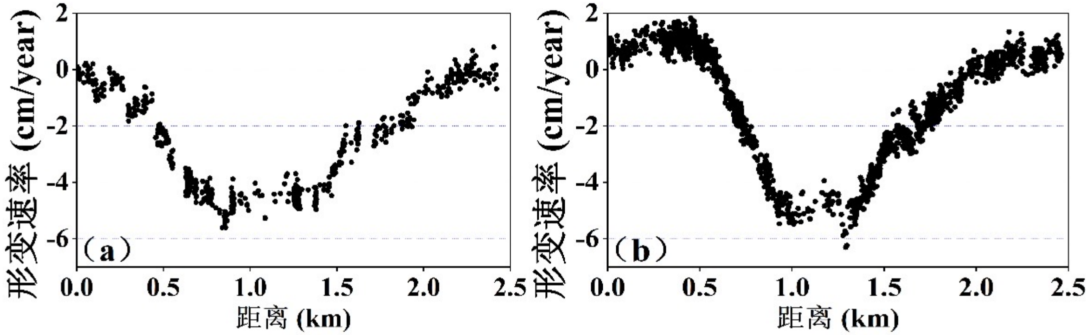
Based on 27 TerraSAR-X images, this paper identifies a large number of Statistically Homogeneous Pixels (SHP) by using the self-developed homogeneous pixel recognition algorithm on the basis of the average intensity map of the Puhe coal mining area. The results show that the number of SHPs is highly correlated with surface coverage.

Surface Deformation Monitoring and Mining Parameters Inversion of Puhe Coal Mine

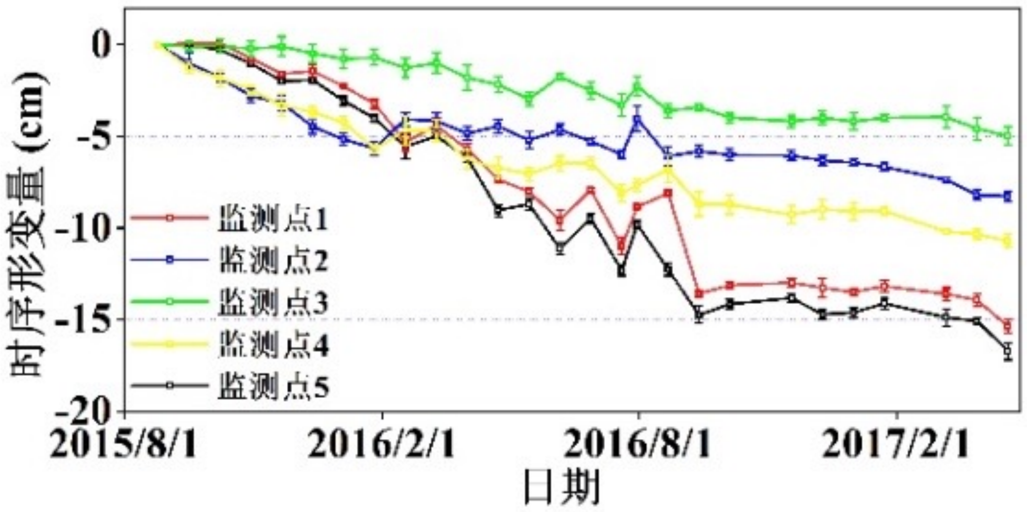
Mining deformation monitoring results



Annual deformation rate results of Puhe Coal Mine obtained by (a) DS-InSAR and (b) SBAS



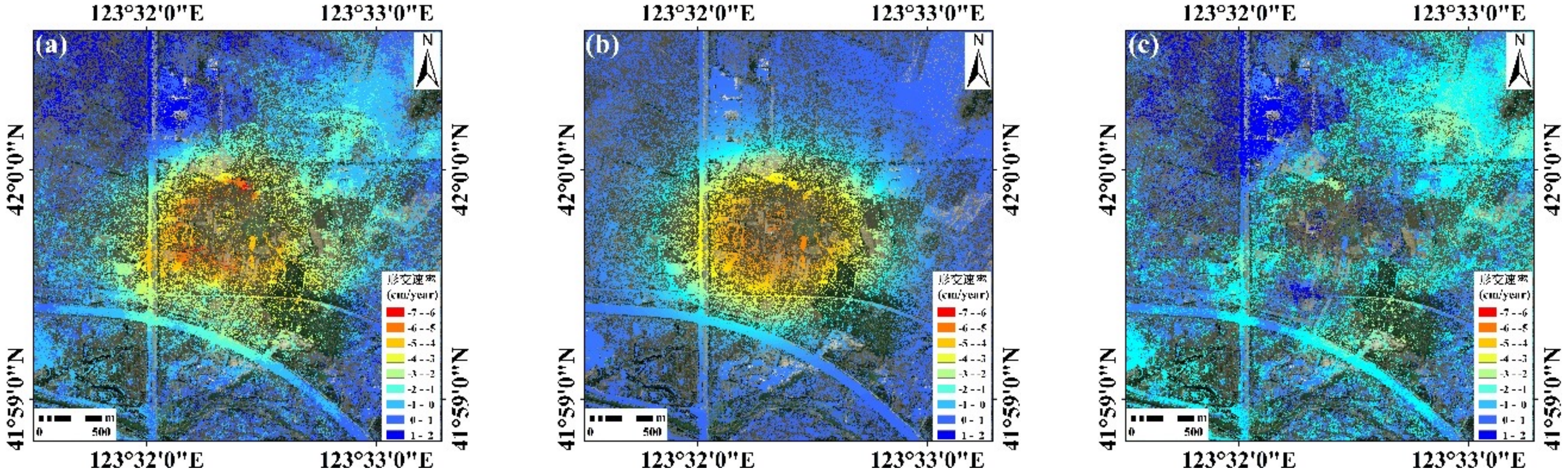
Deformation along profile of Puhe Coal Mine. (a) horizontal AA' (b) vertical BB'



Time series of different MPs.(The square connected by the solid line represents the cumulative deformation of the average time series of the measurement points, and the vertical error bar represents the standard deviation or uncertainty of the measurement.)

Surface Deformation Monitoring and Mining Parameters Inversion of Puhe Coal Mine

Inversion results of Okada model



(a) InSAR deformation monitoring results (b) Okada model simulation results (c) residual results

Optimal Parameters of Okada Inversion Model

Inversion parameters	Source-location X	Source-location Y	Length(m)	Width(m)	Depth(m)	Tensor(m)	Strike(°)
Optimal parameters	571	248	1092	1216	519	-0.07	31

Surface Deformation Monitoring and Mining Parameters Inversion of Puhe Coal Mine

Conclusion

1. Field investigation shows that Puhe is a prone area of geological disasters, and the surface buildings in the goaf are seriously damaged.
2. In this study, the distributed scatterer interferometry analysis method was used to successfully obtain the surface deformation rate and time series cumulative deformation of the goaf. The results show that the Puhe coal mine presents the characteristics of funnel-shaped ground deformation, and the deformation rate of the subsidence center exceeds – 6 cm / year. The deformation mainly shows a linear trend. The deformation rate is large from August 2015 to September 2016, and the deformation trend slows down after September 2016.
3. Based on the deformation monitoring results obtained by time-series DS-InSAR, the geophysical model-Okada model is used for parameter inversion. The coal seam mining length of Puhe Coal Mine is 1092 meters, the width is 1216 meters, the depth is 519 meters, and the strike of the coal seam is 31 ° clockwise from the north.

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Thanks for your attention!

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