Dynamic process inversion using DInSAR of surface deformation in mining subsidence bowl by LT-1 satellite: a case study of Datong, China

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ABSTRACT

The subsidence bowl results derived from LT-1 show good agreement with the results derived from Sentinel-1 between March and April 2022. Furthermore, we projected continuous 3D GNSS to LOS direction to validate the DInSAR results derived from LT-1 and Sentinel-1, respectively. Finally, we observed the dynamic process associated to mining activities in this area by using four DInSAR results from different dates. InSAR results revealed obvious directional changes of the spatial location of ground surface displacements, with maximum horizontal displacement of the subsidence bowl of about 1.4294 km during the observation time lag.

INTRODUCTION

Datong coalfield has heavy mining activities in the Carboniferous-Permian and Jurassic coal seams. Mining activities have caused serious impacts of ecological and geological environment in mined-out (goaf) areas. Therefore, it is really urgent to dynamically monitor migration of the ongoing coal mining, and thus curb illegal coal mining.

As an important part of the medium- and long-term development plan for China's civil space infrastructure, LuTan-1 (LT-1, i.e., TwinSAR-L) mission is an innovative spaceborne bistatic SAR (Synthetic Aperture Radar) mission, which were formally established in 2016.

In previous studies, mining-induced displacement prediction using Synthetic Aperture Radar Interferometry (InSAR) mainly focus on the probability integral method (PIM), which is really complex. Therefore, we proposed a method using the centroid of subsidence bowl processed by differential interferometric synthetic aperture radar (DInSAR) in several time periods to dynamically and quantitatively monitor the direction and progress of the ongoing mining activities.

OBJECTIVE

- Dynamic inversion and monitoring of direction and length of underground mining activities without a priori knowledge.
- The uncertainty of the dynamic monitoring method were analyzed.
- The comparison of LT-1 and Sentinel-1 satellites was summarized.

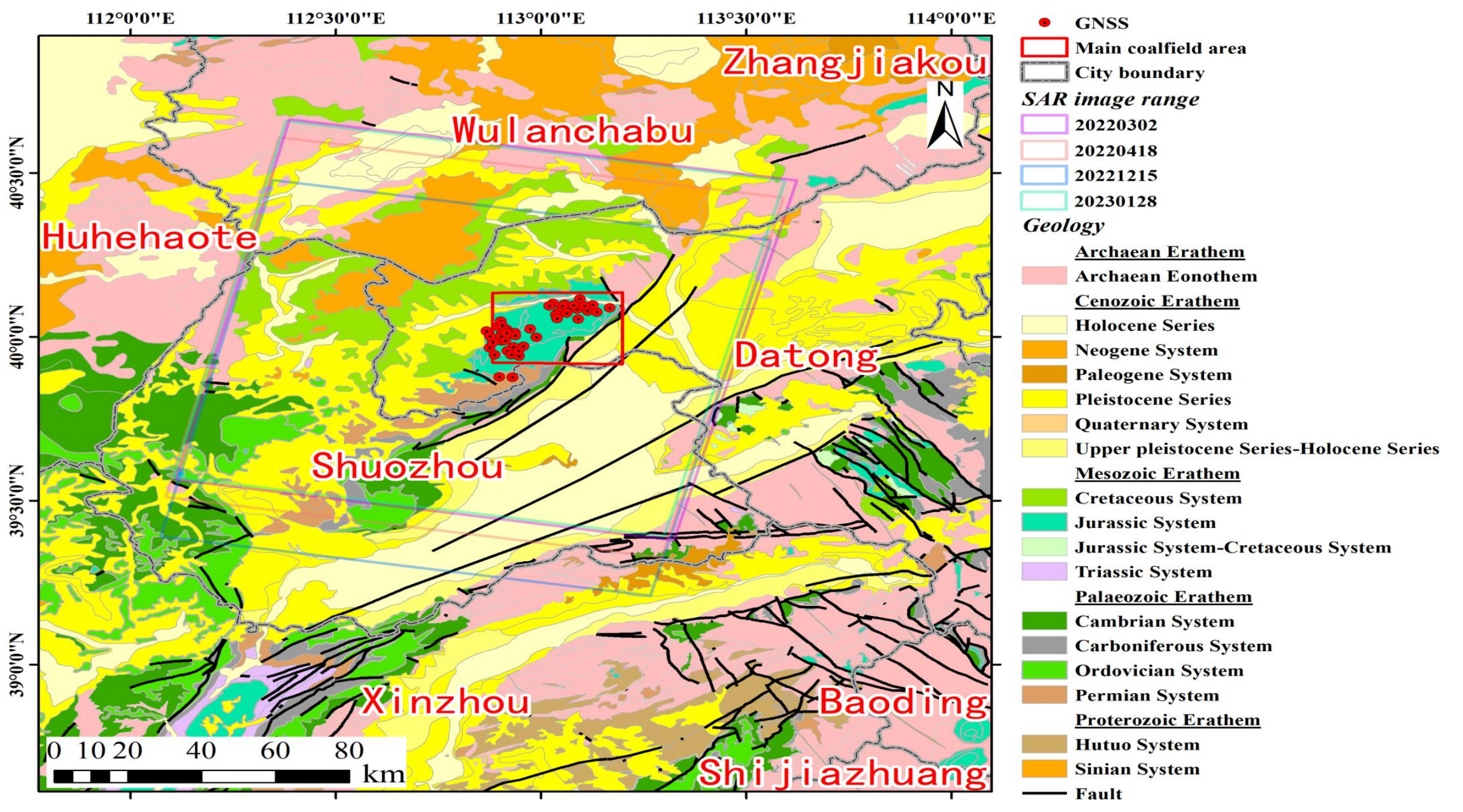

Fig. 1. Geological map of study area.

METHODS

In accordance with previous studies of InSAR-PIM, the ground surface displacement caused by a potential mining is symmetric if the dip angle is zero. For the sake of simplicity, we assumed the subsidence is symmetrical. Therefore, we extracted the centroid of the subsidence bowl using the first three time periods. To indicate the direction and process of mining according to their slow migration, we connected centroid points to form a directional line. The centroid point of the first time period was taken as the starting point to look for the centroid point of the second time period at the nearest distance within 2 km. Subsequently, the same method was used to find the direction from the second time period to the third time period. It should be noticed that the angle between the two directions should be greater than 90°. Finally, the directional line from the first centroid points to the third centroid points indicated the direction of mining, and the length of the directional line was an approximate representation of the depth of the excavation.

RESULTS

The comparison between GNSS and InSAR data demonstrates the high accuracy of the LT-1 datasets. Furthermore, the parameters gradually stabilize, resulting in improved quality and accuracy of LT-1 dataset.

Additionally, there are 29 overlapping subsidence bowls between Sentinel-1 and LT-1 with an area of 5.9681 km², confirming good spatial coherence. Furthermore, the corresponding rates are 60.4167% and 44.7256% for Sentinel-1, and 76.3158% and 49.1695% for LT-1.

A total number of 13 directional lines were identified. Furthermore, the longest directional line measures 1.4294 km, which is approximately equivalent to the mining excavation length.

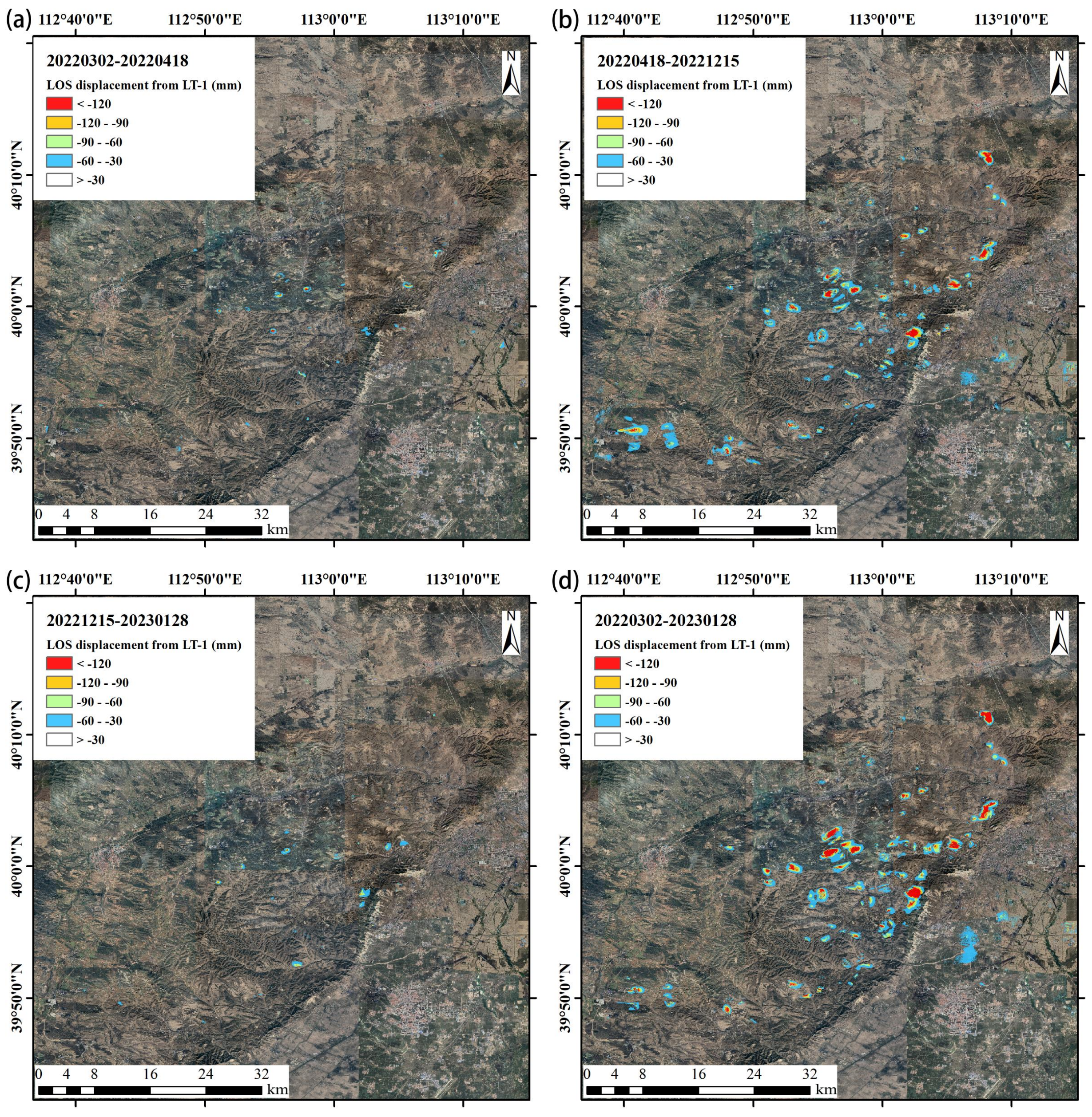

Fig. 2. Displacement along the LOS direction derived from LT-1 for the time periods: (a) 2 March 2022 to 18 April 2022, (b) 18 April 2022 to 15 December 2022, (c) 15 December 2022 to 28 January 2023, and (d) 2 March 2022 to 28 January 2023.

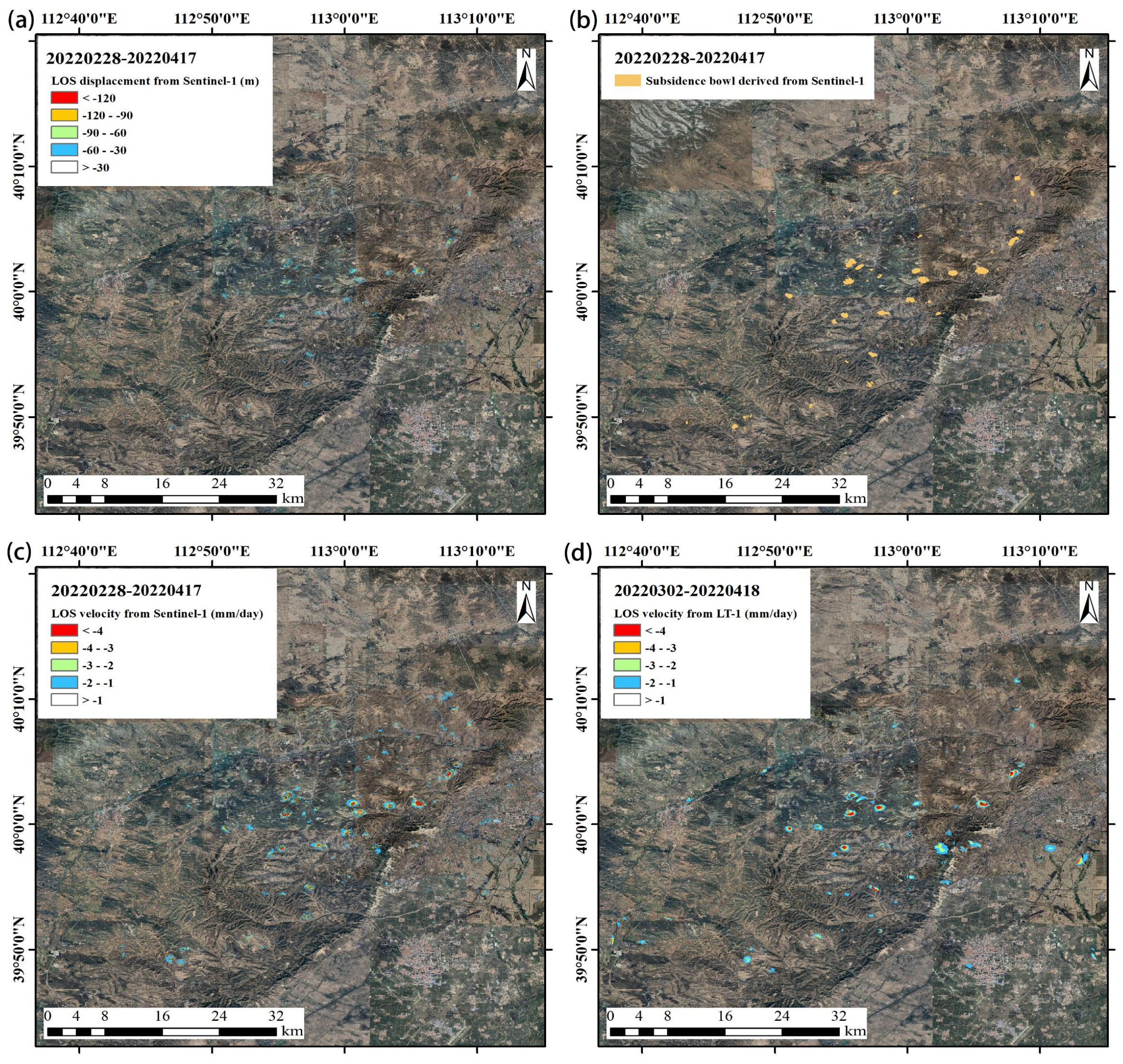

Fig. 3. LOS displacement (a) and subsidence bowls (b) derived from Sentinel-1 between 28 February 2022 to 17 April 2022. LOS deformation rate derived from Sentinel-1 between 28 February 2022 to 17 April 2022 (c) and derived from LT-1 between 2 March 2022 to 18 April 2022 (d).

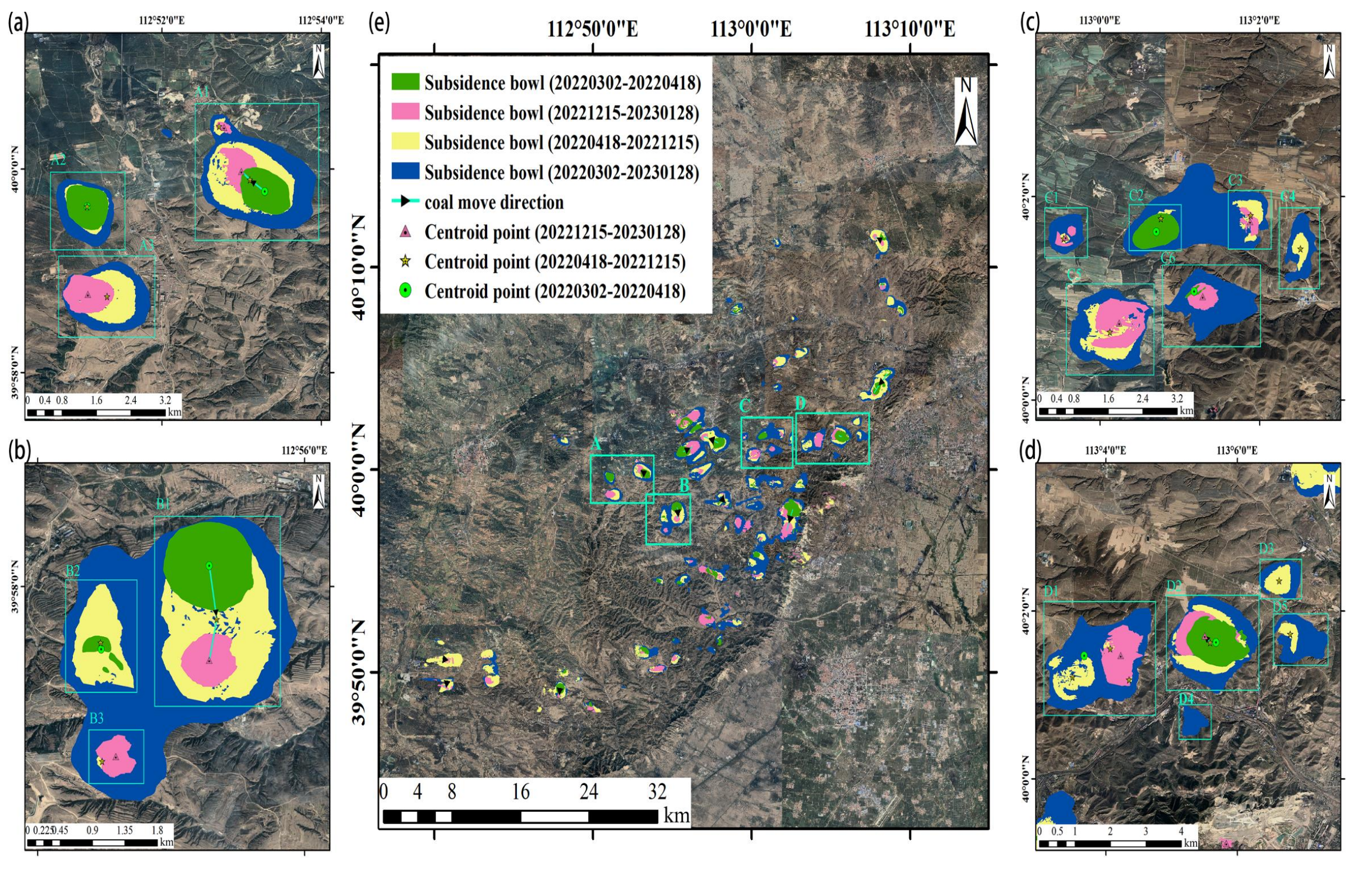

Fig. 4. Distribution of subsidence bowls mapped during different time period.

Table 1. Statistic regarding the number and area of subsidence bowls obtained from DInSAR results, including the value of maximum displacement.

	Maximum displacement (mm)	Number of subsidence bowl	Area of subsidence bowls (km²)
20220228-20220417 (Sentinel-1)	-126.8791	48	13.3438
20220302-20220418 (LT-1)	-179.5473	38	12.1378
20220418-20221215 (LT-1)	-373.1613	88	45.0541
20221215-20230128 (LT-1)	-206.2706	82	17.9120
20220302-20230128 (LT-1)	-385.0004	66	101.0827

Table 2. Statistical results of the comparison between DInSAR and GNSS.

	Maximum (mm/day)	Minimum (mm/day)	Mean (mm/day)	RMSE (mm/day)
20220228-20220417 (Sentinel-1)	0.5260	-0.2286	0.0203	0.1231
20220302-20220418 (LT-1)	0.4010	-0.3340	0.1088	0.1860
20220418-20221215 (LT-1)	0.6972	-0.1168	0.0202	0.1492
20221215-20230128 (LT-1)	0.4436	-0.2282	0.0389	0.1160
20220302-20230128 (LT-1)	0.6919	-0.0999	0.0190	0.1157

Table 3. Statistical results derived to analyze the number and area of overlapping with each other.

	Number of overlapping with another		Area of overlapping with another	
	Number	Rate (%)	Area (km²)	Rate (%)
20220228-20220417 (Sentinel-1)	29	60.4167	5.9681	44.7256
20220302-20220418 (LT-1)	29	76.3158	5.9681	49.1695

DISCUSSION

Firstly, due to the decorrelation of DInSAR and data voids due to the unwrapping method of MCF, the subsidence bowls are incomplete. Therefore, the centroid of the subsidence bowl may be inaccurate due to the absence of DInSAR results. Secondly, some subsidence bowls are enlarged, but not moving. Furthermore, due to several centroid points in 2 km and false extraction of centroid points, it is possible to connect subsidence bowls originated by different mining galleries.

In the other hand, DInSAR results is only LOS direction, but not 3D displacements, which also caused uncertainty. The centroid method is under the assumption of horizontal dig surfaces, which maybe not true in some coal mines. Moreover, the beginning of mining is not the centroid of the subsidence bowl, resulting in an error of the length of the excavation. Consequently, it should be taken into account that the mining parameters inverted from DInSAR results are just a reference for field verification to monitor illegal mining due to the lack of field material.

CONCLUSIONS

In terms of accuracy assessment using GNSS data in different time periods, the results from LT-1 demonstrate gradually stable parameters during the in-orbit performance test. Additionally, in the comparisons between LT-1 and Sentinel-1, the results show a good agreement in the location of subsidence bowls, indicating that both two datasets possess excellent precision. It is worth noting that the SAR satellites developed by China are expected to play an increasingly important role in international research and applications in the future.

Finally, the inversion approach utilizing the centroid points of subsidence bowls in multiple time periods allows for the semi-automatic speculation and reproduction of underground mining pathways, which is particularly important for monitoring illegal mining activities.

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