# Collaborative Monitoring of Slope Displacements in Open-pit Mines with LiDAR DEM and Sentinel-1 Data

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## Abstract

Surface displacement monitoring of open-pit mines is of vital importance for the safety of field operators and mine production. With the Development of Synthetic Aperture Radar (SAR) remote sensing technology, Time series Interferometric SAR (TS-InSAR) has been widely used in wide-area displacement monitoring in recent decades. However, limited by the side-looking geometry, the estimated displacements in TS-InSAR are only in the satellite's line-of-sight (LOS) direction, which are completely different from real displacements in areas with large topographic inequality, since displacements may occur in the three dimensional space in such areas. In translational landslide monitoring, an assumption that displacements generally happen parallel to the largest slope gradient is made. In order to resolve slope displacements of landslides, an accurate digital elevation model (DEM) aided slope displacement inversion method is proposed[1,2]. The accurate DEM is generated by Light Detection and Ranging (LiDAR) scanning, used to minimize the topographic residual TS-InSAR analysis, and then in inversion of slope displacements from those in LOS.

In this paper, three stacks of Setinel-1 images (186 scenes) acquired from both ascending and descending orbits are used for SBAS analysis over Qidashan and Anqian open-pit mines, with temporal coverage from December 2016 to May 2019. In the SBAS processing, LiDAR DEM of the mining pits and TanDEM-X DEM with 3 arc second spatial resolution are used to remove the topographic phase[3,4] . Accurate slope angles and aspects derived from the LiDAR DEM are used to estimate the slope displacements. In order to ensure high temporal sampling rate and high point density, a multi-master interferometry mode is adopted in the small baseline subsets (SBAS) method, with reduced spatio-temporal decorrelation problems. In SBAS, firstly, all the slave images are registered with the super master image, and small baseline differential interferograms are generated[5]. Then, a minimum cost flow algorithm is used to unwrap the differential interferograms. After that, singular value decomposition method is adopted to combine the unwrapped differential interferograms and generate a time series which includes atmosphere, residual terrain and deformation signal. After that, the residual topography and atmosphere signals are eliminated by a second-order unwrapping and filtering, and finally the deformation rates and the cumulative deformation are retrieved. With the assistance of high-resolution LiDAR DEM, the deformation parameters in LOS are converted to slope direction using the radar incidence angle, heading angle, azimuth angle, slope aspects and angles.

The derived results are highly consistent with on-site GPS measurements and precipitation data. Based on the analysis of local precipitation changes, it is found that there is a correlation between deformation and precipitation. The results show that the stability of open-pit mines is mainly affected by rock mass structure, lithology and precipitation. SBAS method can be used as a routine tool to monitor the stability of open-pit mines, and provide technical support for disaster prevention and safe production.


## Study area

Anqian open-pit mine is one of the large - scale open - pit mines in Anshan. It is located in the east of Anshan City, Liaoning Province. The general elevation is 100-200m and the ore beds are thickly bedded. The mixed rock occurring in the mining area belongs to the rock mass with block fracture structure, which leads to the low stability of the edge of the mining area and easy to be deformed.

Qidashan Iron Mine covers an area of 14.6 square kilometers, 4 kilometers from the north to the south of the stope, with a surface elevation of 42 meters. It is the first metallurgical mine in Asia.


Fig.1 Study Area

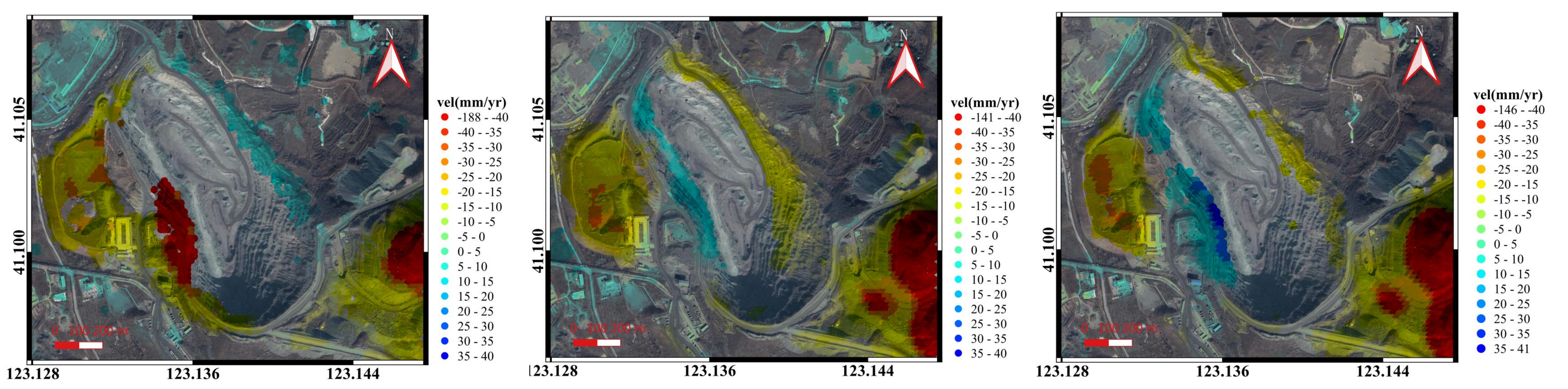
## Dataset

Table1 Image data information

| Sensor Name | Track number | Images number | Temporal span | Orbit type | Heading angle | Incidence angle |
|---|---|---|---|---|---|---|
| Sentinel-1A | P25 | 50 | 20170605-20190420 | Ascending | -13.539 | 33.726 |
| Sentinel-1B | P105 | 68 | 20170111-20190419 | Descending | -166.421 | 43.890 |
| Sentinel-1B | P3 | 68 | 20161211-20190424 | Descending | -166.376 | 33.981 |

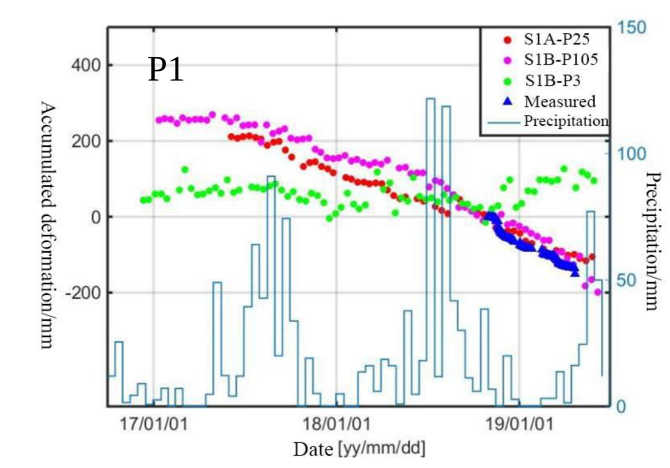
In this study, three stacks of Setinel-1 images (186 scenes) acquired from both ascending and descending orbits are used for SBAS analysis over Qidashan and Anqian open-pit mines, with temporal coverage from December 2016 to May 2019. The detailed parameters are summarized in Table 1.

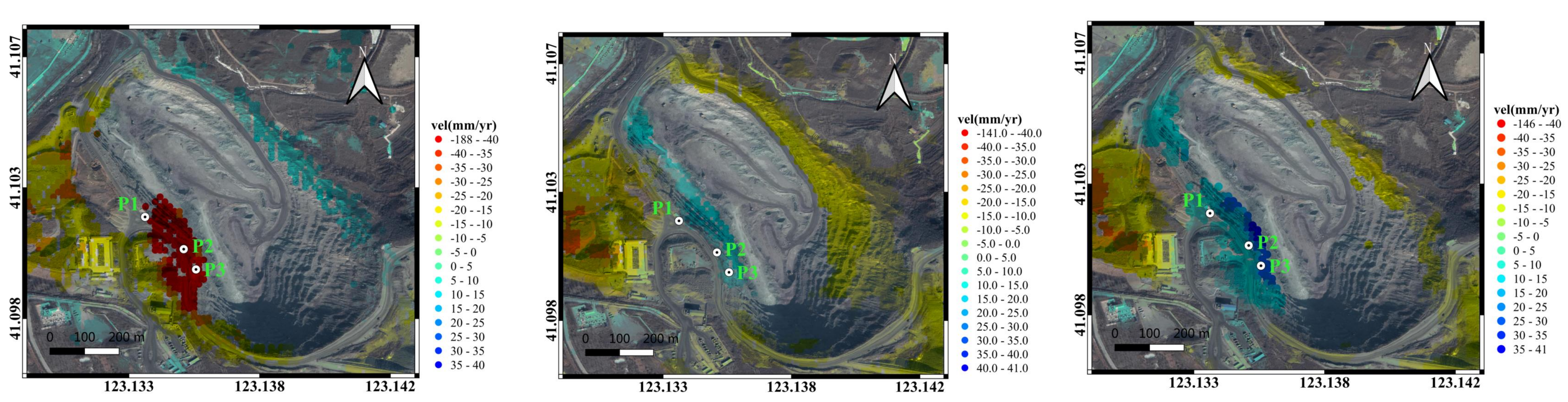
## Results(Anqian open-pit mine )



Ascending,P25 Descending,P3 Descending,P105

Fig2 Anqian open-pit Mine SBAS results





Ascending,P25 Descending,P3 Descending,P105

Fig3 Anqian open-pit Mine Slope deformation results

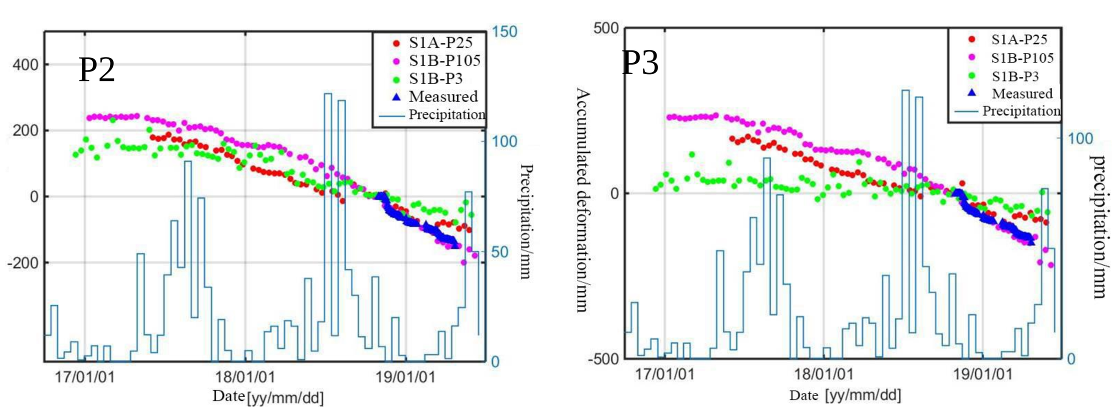
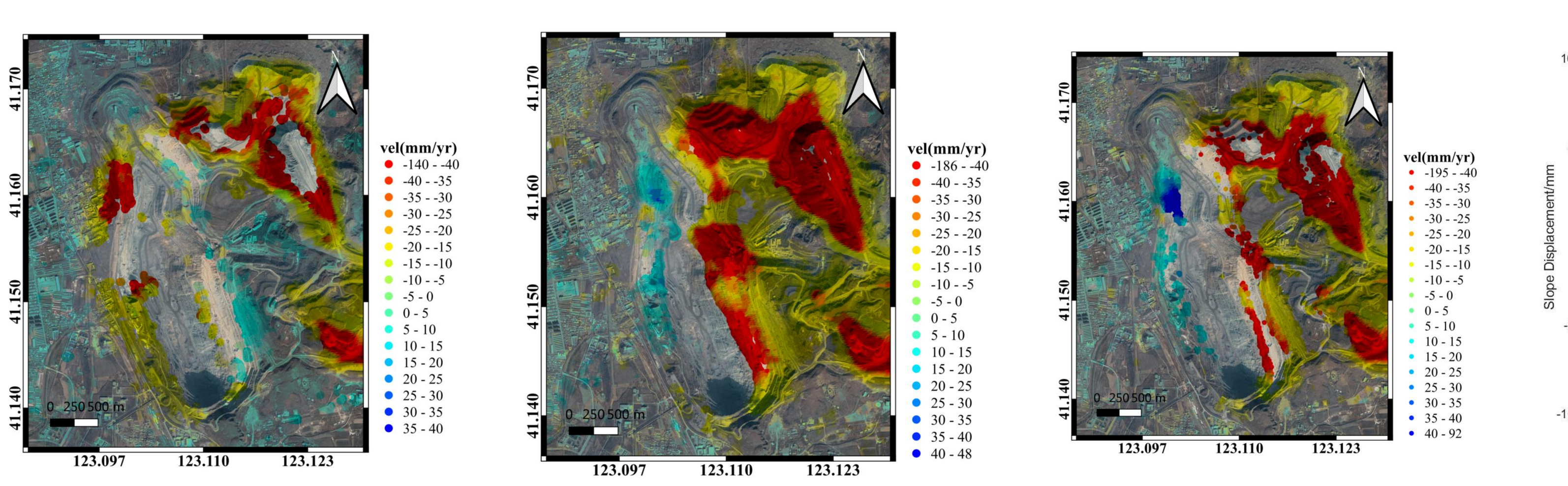


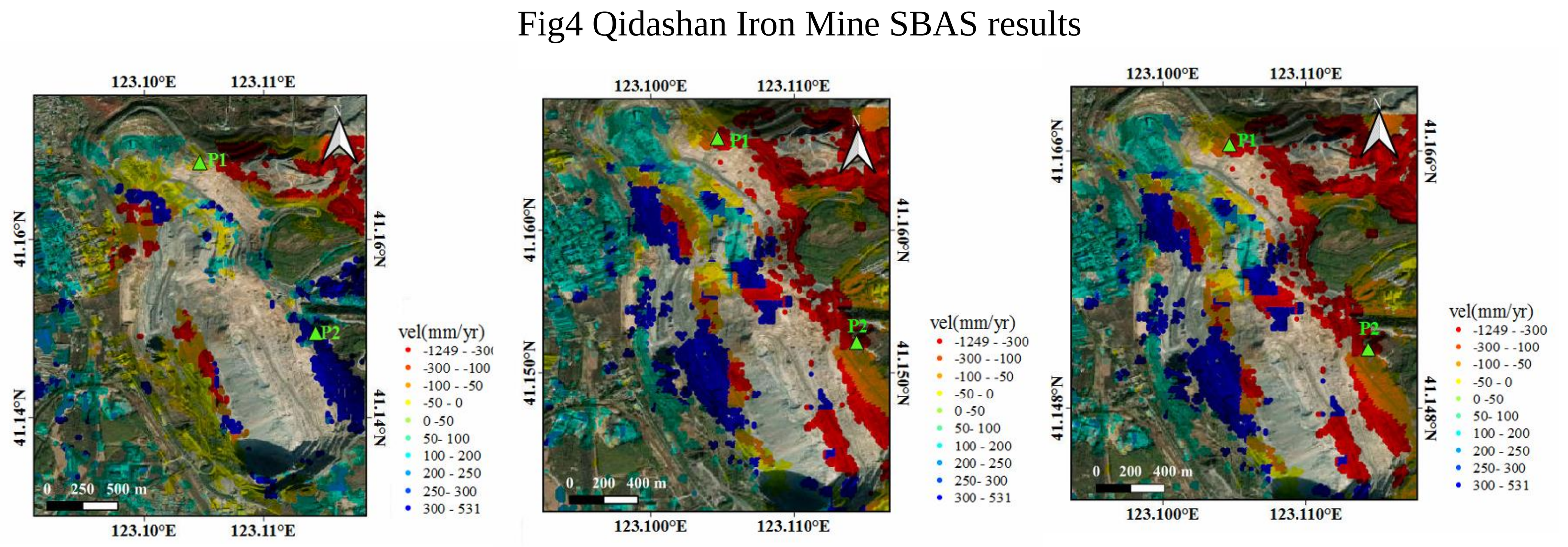
Fig3 Comparison of actual deformation with precipitation

## Results(Qidashan open-pit mine )



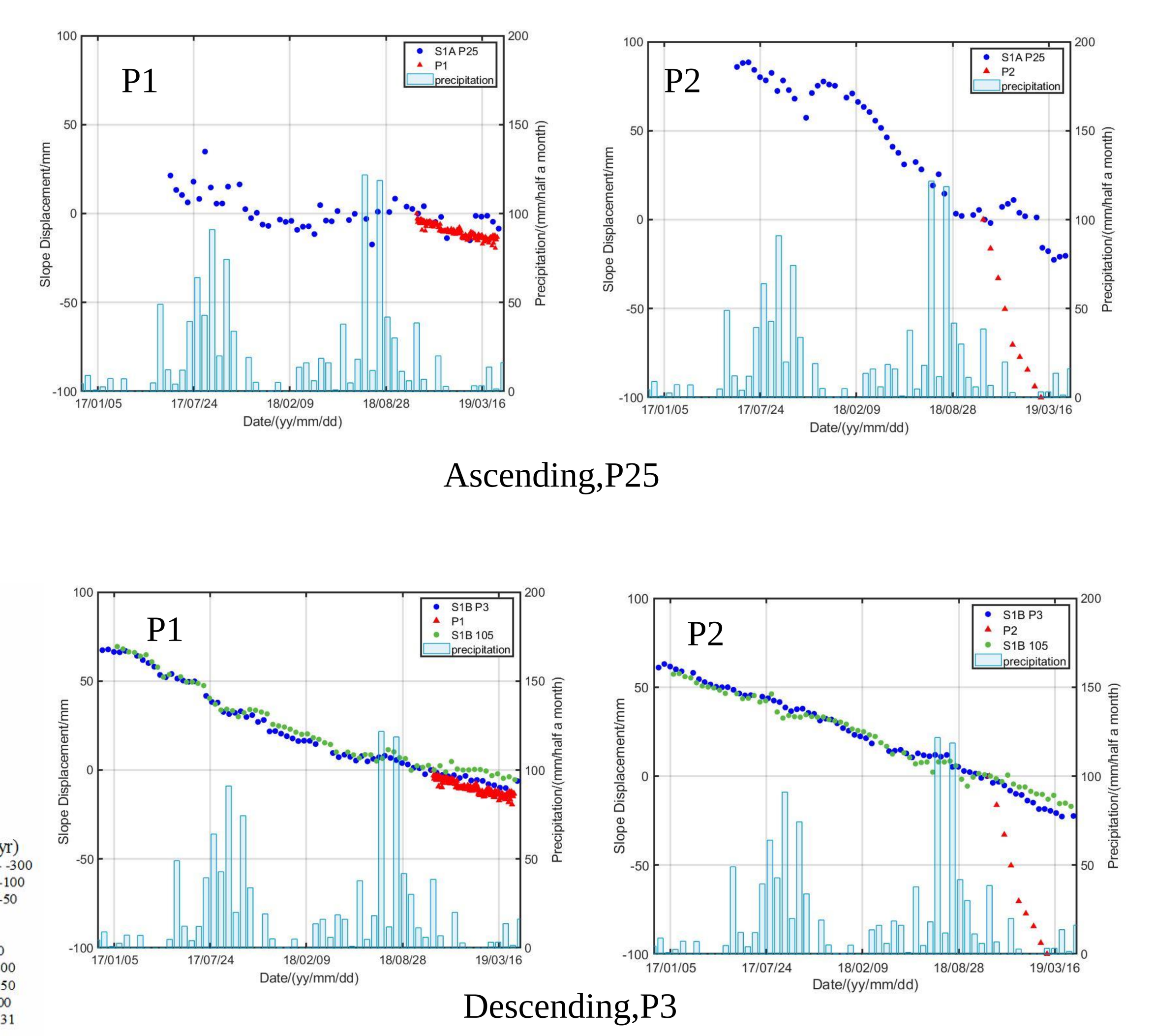
Ascending,P25 Descending,P3 Descending,P105

Fig4 Qidashan Iron Mine SBAS results



Ascending,P25 Descending,P3 Descending,P105

Fig5 Qidashan Iron Mine Slope deformation results



Ascending,P25

Descending,P3

Fig6 comparison of actual deformation with precipitation in Qidashan Iron Mine

## Conclusion

The slope deformation of Anqian and Qidashan open-pit mines before the landslide was monitored by SBAS method, and the monitoring results in the satellite LOS direction were obtained. By using the slope deformation solution method, the shape variables along the direction of the maximum slope are inverted. By comparing the displacement time series with precipitation, it is found that precipitation accelerates the deformation, and there is a seasonal correlation between the deformation and precipitation. The results show that the stability of open-pit mine is mainly affected by rock mass structure, lithology and precipitation.

## Major references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