Insights into the June 2020 Aniangzhai landslide in Danba County, China: A remote sensing analysis using satellite radar and optical data and corner reflectors

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Abstract

On 17 June 2020, an ancient landslide was partially reactivated close to the Aniangzhai village of Danba County in Sichuan Province of Southwest China. It was initiated by the erosion of the slope toe from the overflow of a dammed lake that was created due to heavy rainfall and the resulting debris flows coming from Meilonggou Gully to the Xiaojinchuan River. In this study, we report investigations on precursory and post-failure slope stability analysis exploiting optical and radar satellite remote sensing data. Using sub-pixel cross-correlation of optical data from Planet and Sentinel-2, we first derive the direction and magnitude of the main landslide failure. Advanced multi-temporal InSAR (MT-InSAR) analysis using Sentinel-1 and TerraSAR-X SAR data are then exploited to investigate the landslide kinematics before and after the big failure. Moreover, we report our experience on using a newly designed artificial corner reflector (CR), which is a half-round dihedral corner reflector (hr-DCR), for monitoring slope inability in this region using both ascending and descending SAR data. The CRs are quite useful auxiliaries for InSAR analysis as they could be recognized as stable targets during radar acquisitions, especially in the vegetated, semi-vegetated, or agricultural areas, where the widespread loss of coherence between consecutive image acquisitions could happen. Using MT-InSAR analysis, we observe precursory deformation amounting to approximately 50 mm/year in the year 2018-2020, reaching to a maximum of 270 mm/year for the post-failure period from Nov 2020 to June 2021. Before the main landslide failure in June 2020, the average deformation rate was approximately 14% higher in 2018-2020, dominated by above-average precipitation in summer, in comparison to the rate in 2014-2017. Interestingly, MTI analysis also detects a clear signal for the new instability and slow creep in the adjacent slope of the Aniangzhai ancient landslide, previously unrecognised in landslide inventory maps. Besides, the performance of newly designed DCRs is qualified and quantified in the experiments based on intensity time series (in dB), Signal-to-Cluster Ratio (SCR), and results from MTI time series.

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Background

- A large, deep-seated ancient landslide was partially reactivated on 17 June 2020 close to the Aniangzhai village of Danba County in Sichuan Province of Southwest China
- It was initiated by undercutting of the toe of this landslide resulting from increased discharge of the Xiaojinchuan River caused by the failure of a landslide dam, which had been created by the debris flow originating from the Meilong valley
- 12 townships in the downstream area were endangered leading to the evacuation of more than 20000 people
- This study investigated the Aniangzhai landslide area by optical and radar satellite remote sensing techniques

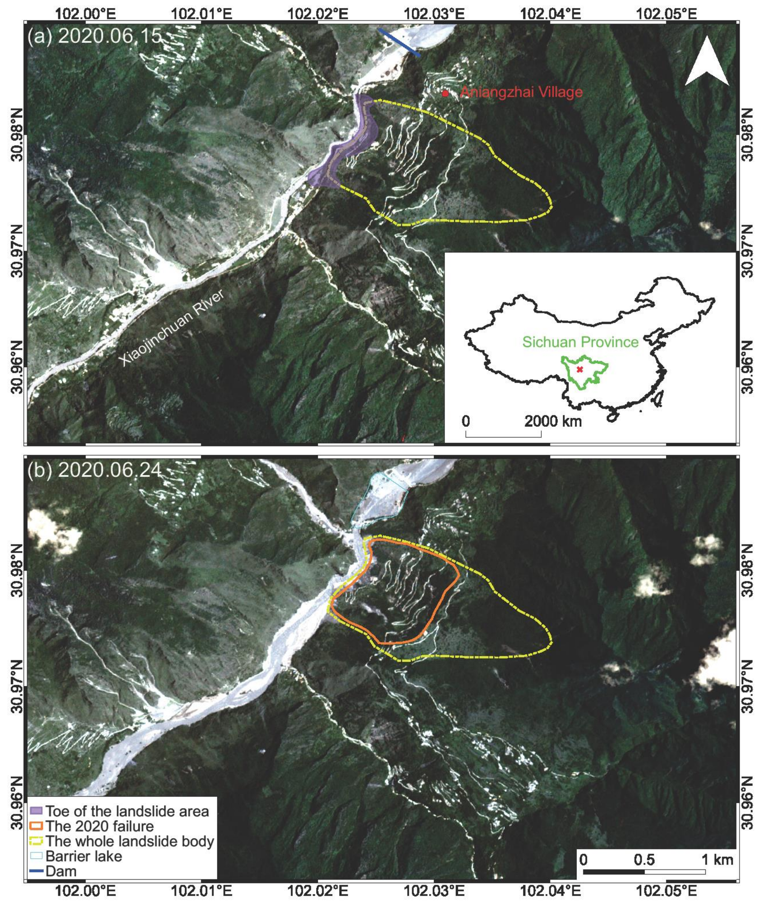

Fig. 1 Location of the study area. Location of the study area. Backgrounds are Planet high-resolution remote sensing optical images (RGB bands), which are acquired **(a)** before the failure on 15 June 2020, and **(b)** after the failure on 24 June 2020.

Multiple satellite dataset

- Deformation before and after the failure of landslide → satellite remote sensing optical images, i.e., Sentinel-2 & Planet & Skysat optical images (resolution of 10m, 3m and 1m respectively)
- Precursory analysis (6 years before the failure) → Sentinel-1 SAR images
- Post-failure analysis → Planet optical images + Sentinel-1 SAR images + TSX SAR images
- Investigating precipitation configuration of more than 20 years and NDVI values → CHIRPS + MODIS + Landsat-8 + Sentinel-2 data (in Google Earth Engine)
- Testing of the new dihedral corner reflectors (DCRs) → Sentinel-1 SAR images + TSX SAR images

Methodology

- Applying sub-pixel cross-correlation method of satellite optical images, to estimate the 2D horizontal displacement of the failure, as well as the time-series after the failure
- Using advanced multi-temporal InSAR (MTI) methods, e.g., persistent scatterer interferometry (PSI) and small baseline subsets (SBAS) techniques, to evaluate the changes in landslide creep rates in response to the external triggering factors before the failure, e.g., rainfall, NDVI values and soil moisture; as well as using MIT methods to monitor the displacement rates after the failure
- Applying inverse-velocity (INV) method to anticipate the time of failure and to analyze slope surface kinematics in different parts of the ancient landslide area
- Exploiting multiple techniques to testing the new DCRs, including MTI methods, split-band interferometry and amplitude analysis of time-series for the DCRs

Results

2D results of horizontal displacement

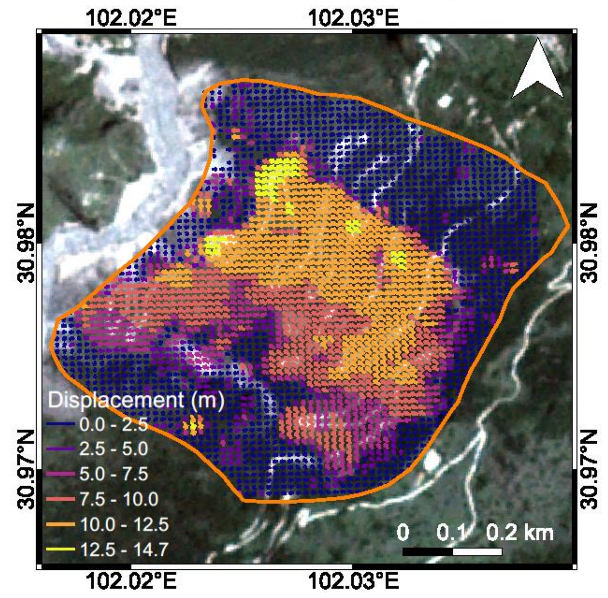

Fig. 2 2D results of horizontal displacement (Duration: 15 June 2020 and 24 June 2020) generated using Planet optical images. The lengths and directions of the arrows represent the magnitudes and the moving directions of motion. The orange line represents the failure area.

20 years of regional precipitation

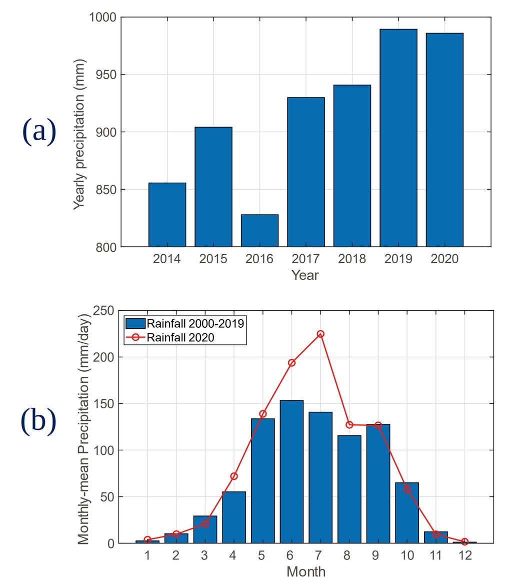

Fig. 3 (**a**) Annual precipitation within Danba County for period of 2014 to 2020. (**b**) Comparison of monthly-mean precipitation for period of the last 20 years with precipitation in 2020.

MTI results for precursory analysis (2014-2020)

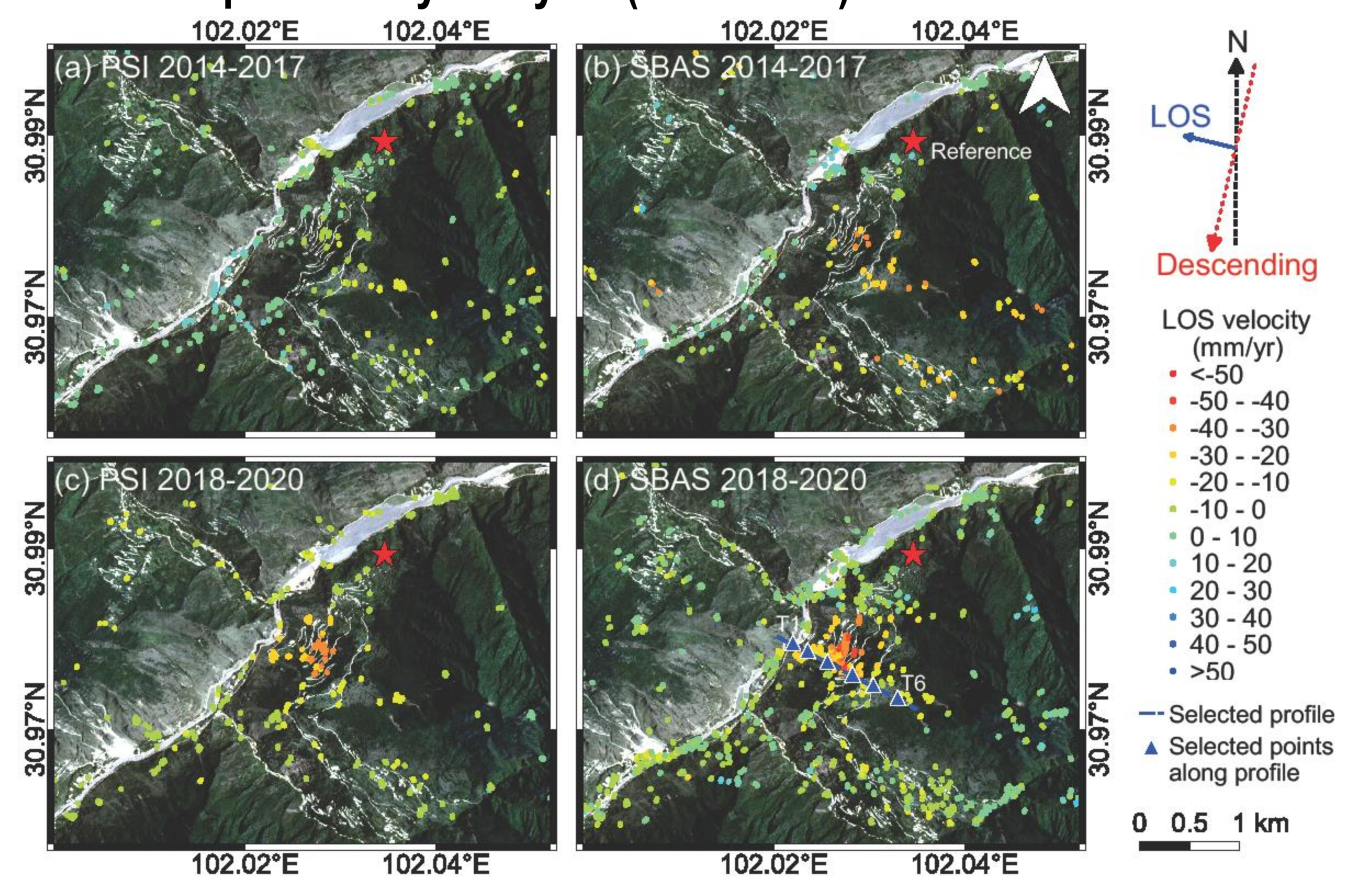

Fig. 4 Comparison of MTI results for (**a**) PSI in period of 2014–2017, (**b**) SBAS in 2014–2017, (**c**) PSI in 2018–2020 and (**d**) SBAS in 2018–2020. Image background is comprised of the Planet optical image acquired on 15 June 2020.

Comparison of LOS displacement in different parts

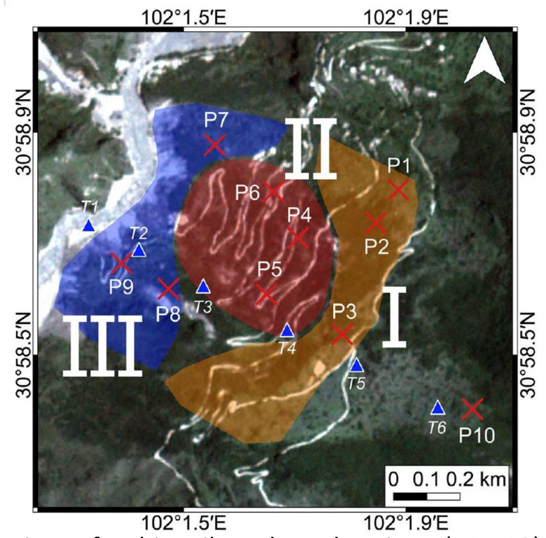

Fig. 5 Location of arbitrarily selected points (P1-P10) over the landslide body. The region is classified according to the behavior of these points from spring 2020 until the failure; P1-P9 are within the failure region while P10 from the landslide body is located outside of the 2020 failure. The background image is from Planet optical image.

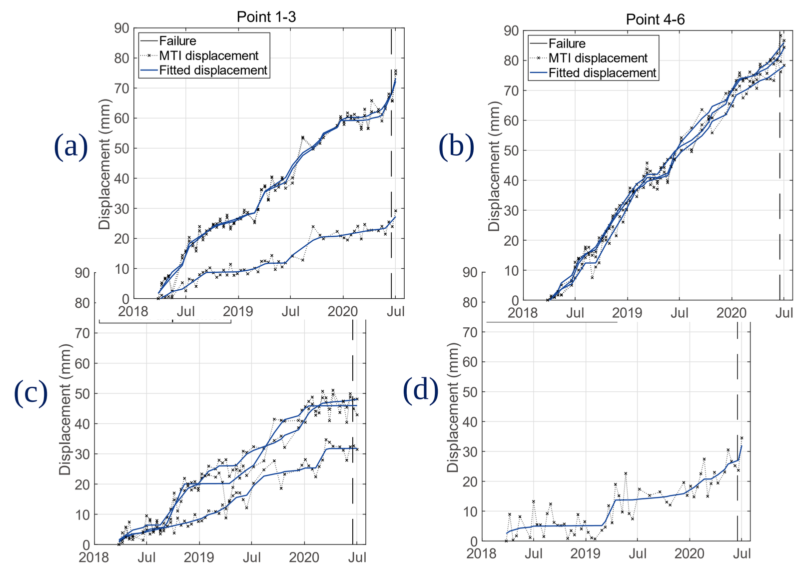

Fig. 6 LOS displacement for period of 2018–2020 for SBAS result and the corresponding fittings of points (**a**) P1-P3, (**b**) P4-P6, (**c**) P7-P9 and (**d**) P10. The locations of points have shown in Fig. 5.

Discussion and conclusion

In general, this study aims to provide an example of how full exploitation of optical and radar satellite remote sensing data can be used for a comprehensive analysis of destabilization and reactivation of an ancient landslide in response to a complex cascading event chain.

Co-failure

- The maximum deformation could reach around 15 meters towards northwest direction between June 15th and June 24th 2020 (the failure took place on June 17th)
- The undercutting effects on the toe of the landslide, as well as the sediments from the debris flows are clearly revealed by exploiting high-resolution optical data

Pre-disaster

- The landslide has long been active before the failure
- In 2014-2017, the LOS displacement could reach around 20-30 mm per year
- In 2018-2020, the LOS displacement has significantly increased, with the largest annual deformation rate of more than 50 mm/year
- The 3-year wet period that followed a relative drought year in 2016 resulted in a 14% higher average velocity in 2018–2020, in comparison to the rate in 2014–2017
- The temporal changes in precipitation are mainly correlated with kinematics of motion at the head part of the failure body

Post-failure

- Reactivation of the landslide body, and continuing deformation with much larger displacement rates compared to pre-event (over 300 mm/year)
- Another concomitant slide has been discovered in the southern hillslope
- The new DCRs are not recognizable for Sentinel-1 data, but they could be identified and implemented in InSAR processing using TSX dataset
- The DCRs have smaller scale, but signals are still higher than the surrounding areas (55-65 dB); and it could be applied for both ascending and descending orbits

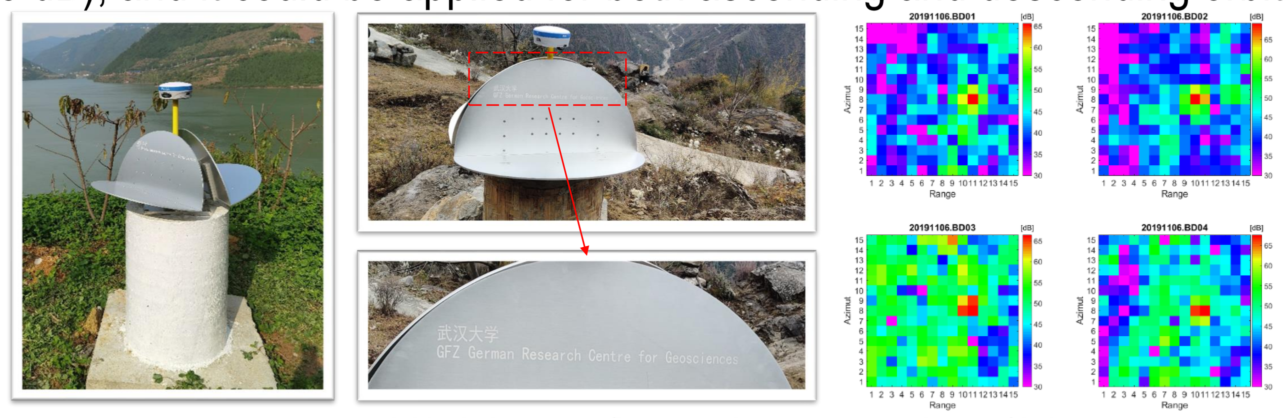

Fig. 7 Tested dihedral corner reflectors and its intensity in the test filed.

Reference, acknowledgements and contact

- Zhuge, X., Mahdi, M., Tao, L. & Sigrid, R. (2021) The June 2020 Aniangzhai landslide in Sichuan Province, Southwest China: slope instability analysis from radar and optical satellite remote sensing data. *Landslides, DOI: 10.1007/s10346-021-01777-4 (accepted).*
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- If you have any questions or any interests for more discussion, please contact using the email: *zhuge.xia@gfz-potsdam.de* .

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