U.S. Department of Transportation
Federal Railroad Administration

RESEARCH RESULTS
FRA OFFICE OF RESEARCH, DEVELOPMENT & TECHNOLOGY

RR 24-12 | **September** 2024

DETECTION OF ROCKFALL-PRONE AREAS THROUGH INSAR-SBAS ANALYSIS

SUMMARY

Identifying and monitoring rockfall- and landslide-prone areas is crucial for effective risk mitigation. Slope instabilities resulting in rockfalls and landslides along the railroad right of way (ROW) present significant challenges and hazards to railway operations and safety. Geohazard event prediction models combine data collected from monitoring systems with information from other heterogeneous sources (Figure 1) and provide an overall assessment of the risk. However, such models do not identify specific areas where an event could initiate under certain conditions with a triggering event.

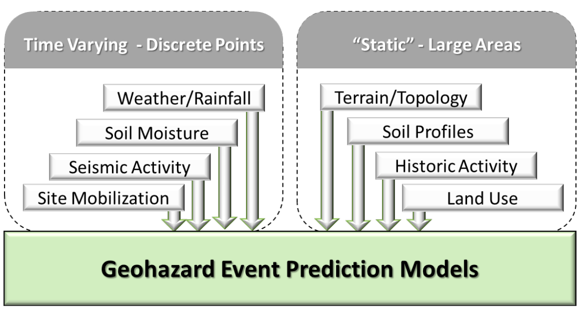

Figure 1. Geohazards event prediction models combine information from heterogeneous sources.

In contrast, Interferometric Synthetic Aperture Radar (InSAR) techniques, such as the Persistent Scatterer InSAR (PSInSAR), have shown great promise in monitoring these events [1]. Yet, PSInSAR requires a constant presence of Persistent Scatterers (PS) or high-coherent points in the area being monitored throughout the observation period, making it less universally applicable [2]. Small Baseline Subset (SBAS) analysis is an alternative to the PSInSAR technique that alleviates the PSInSAR shortcomings and can effectively measure soil surface mobilization in the absence of PS [3].

This work employs the SBAS analysis to identify areas along the railroad ROW that exhibit increased geohazard risk. SBAS is implemented within the framework of "threshold stacking" as an efficient method of filtering SBAS data for rockfall risk localization.

The research team implemented the proposed technique in two incidents involving rockfalls that resulted in train derailments: the first incident site is in Sandstone, West Virginia and the second site is in Maupin, Oregon. These two cases validate the proposed approach and demonstrate its effectiveness in identifying high risk areas prone to failure. Furthermore, the case studies underscore how satellite-based monitoring can enhance early warning systems for geohazards and assist disaster mitigation and preparedness efforts.

BACKGROUND

While performing InSAR analysis on slope failure events in Ingenheim, France and the Big Sur in California, researchers noted that a direct loss of coherence and slow site mobilization preceded the failure of the slope [4]. This observation led to this FRA-sponsored research project to develop an effective monitoring system that uses satellite radar images. Based on previous studies [5], [6], the researchers proposed a method to detect precursors to events that lead to ground hazards in the railway ROW by quantifying and monitoring soil moisture content changes and slow rate ground surface mobilization.

OBJECTIVES

This study aims to address the challenges presented by identifying and fine-tuning geohazard prediction models for railway systems. Specifically, the research sought to integrate InSAR techniques with available geohazard detection tools to efficiently increase railway safety.

METHODS

The proposed SBAS threshold stacking is a post-processing filtering technique that uses multiple SBAS analyses to identify regions with increasing mobilization activity. SBAS analysis can measure displacement in regions with low coherence, such as rural areas and densely vegetated terrain. The SBAS threshold stacking method harnesses the displacement data derived from a sequence of SBAS analyses, employing a timeline approach with 25 images per analysis and cycling in fresh data while retiring the oldest image in the stack [7]. The displacement information from each SBAS analysis undergoes filtering to remove displacements based on a predetermined threshold value.

The threshold value in the present studies ranges from -10mm to 10mm, resulting in a refined dataset highlighting regions with large activity. The displacement maps are then divided into subsets and stacked progressively. For every new map added to the stack the accumulation rate of active points is computed in each subset and monitored for identifying the regions experiencing increasing activity.

RESULTS

This section presents the results obtained for both implementation studies.

Sandstone, WV

The Sandstone WV incident occurred on March 8, 2023, when a train enroute to Sandstone collided with a sizable rock on the railway, leading to a derailment [8]. This incident took place approximately one mile from Sandstone, nestled between a densely vegetated cliff and the New River. The derailment site is shown in Figure 2(a).

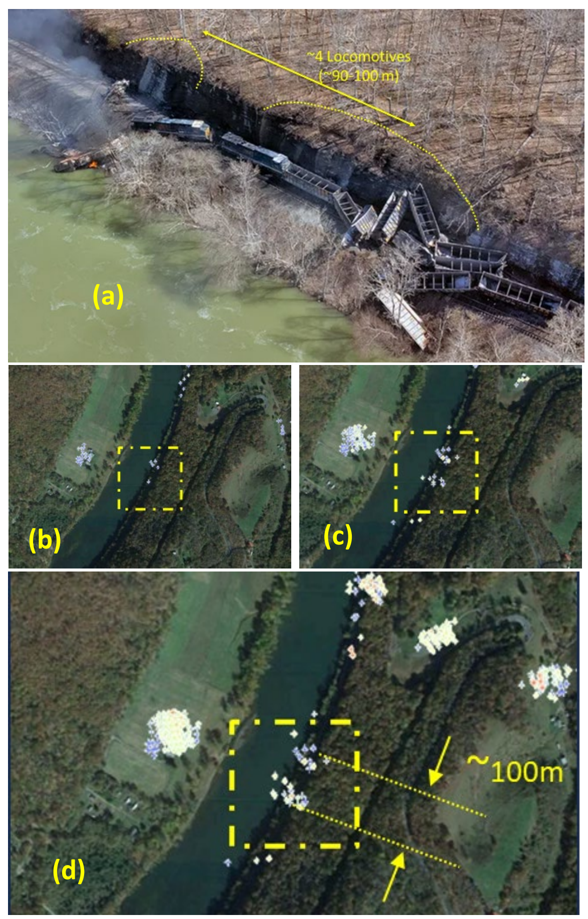

Figure 2. Sandstone WV: (a) Derailment site with two evident failure areas [8], (b) SBAS with threshold stacking up to 6 months before the

event, (c) SBAS with threshold stacking up to 3 months before the event, (d) SBAS with threshold stacking up to 7 days before the event

The image shows two distinct surface areas approximately 100 meters apart. Seven SBAS analyses were conducted to compute the ground surface deformation in the satellite's line of sight. Data acquired by satellite “Sentinel-1A” were used in the analysis. Each analysis uses 25 images. The first analysis uses data from October 14, 2021 to September 3, 2022, representing activity six months before the event. The yellow dotted boxes represent the location of the rockfall event.

Figure 2(b) shows the displacement activity from the first phase of SBAS threshold stacking and uses only the data from October 14, 2021 to September 3, 2022. Some activity in the region of rockfall is noted, even 6 months before the event. Figure 2(c) shows the results using data from October 14, 2021 to December 18, 2022, up to 3 months before the event. The region in the yellow box shows increasing activity as additional points are visible, since their displacement exceeds the threshold value.

Finally, Figure 2(d) shows the complete SBAS threshold stacking from October 14, 2021 to March 3, 2023, up to 7 days before the rockfall with significant activity in the highlighted region. The two clusters in the yellow highlighted region are 100 m apart, the same distance as the unstable region noted in the optical image in Figure 2(a). Nearby regions also show increasing activity, but these regions do not have terrain conditions that would lead to rockfalls.

Maupin, OR

The research team also applied the proposed SBAS threshold stacking approach to a rockfall incident in Maupin, OR, which caused a train derailment on May 7, 2020.

This location (Figure 3[a]) featured rocky terrain with sloping topography [9]. The research team conducted seven SBAS analyses to obtain the deformation in the satellite's line of sight. Data from satellite “Sentinel-1B” were used for the analysis (25 images for each).

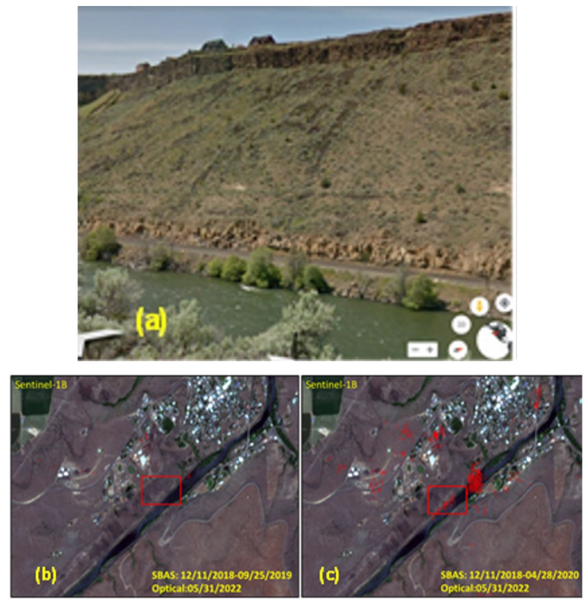

Figure 3. Maupin, OR Case: (a) Derailment site (b) The first phase of SBAS threshold stacking analysis shows no activity in the rockfall event's region. (c) The final phase of SBAS threshold stacking with significant activity taking place near the area of interest.

The first analysis used data from December 11, 2018 to September 25, 2019. Figure 3(b) shows the displacement activity from the first analysis of SBAS threshold stacking and uses only the data from December 11, 2018 to September 25, 2019. The rockfall region rockfall exhibits low activity, and the limited activity in the surrounding regions is unrelated to the rockfall event. Figure 3(c) shows the complete SBAS threshold stacking using 25 image SBAS analysis from December 11, 2018 to April 28, 2020, which covers the period to up to 5 days before the rockfall. Notably, large clusters of activity were consistently identified at the location of the rockfall, even 6 months before the event. The activity significantly increased within the last month before the event. In addition to the region of the derailment, a cluster of ground surface points formed adjacent to the upper right corner of the area of interest also on the ROW of the track. Anecdotal evidence indicated that a rockfall event may have taken place, but the track was cleared before the blockage disrupted any train traffic or caused derailments.

CONCLUSIONS

The research successfully applied the SBAS threshold stacking method in regions characterized by high and low coherence to detect specific areas within large observation regions that show changes in mobilization activity over time along the railroad track. When coupled with terrain and topographic data, the proposed method was capable of identifying specific locations where failures would initiate first when a triggering event occurred. The method highlighted areas experiencing increasing activity and that were most susceptible to landslides as a result.

The threshold limit in the current implementation case was taken as constant for all signal coherence. Threshold limits can be better identified when associated with the quality characteristics of the signals through training based on future datasets. Although SBAS threshold stacking identifies the high-risk areas, it must be integrated with other information to be used as a predictive tool.

FUTURE ACTION

This methodology will be tested in additional cases using archived satellite data to improve the data filtering and pre-processing process. This task is expected to increase computational efficiency and to demonstrate the robustness of the proposed approach. The proposed approach can be fully automated and implemented in active monitoring of the ROW in areas with a history of events within the framework of an early warning system for rockfall and slope failures. Furthermore, integrating the proposed technique with data from other heterogeneous data sources, such volumetric water content, weather, terrain, soil profile, and land use, will form the basis of the development of failure predictive tools.

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KEYWORDS

InSAR, Rockfall, SBAS, High Risk Area Detection, Satellite, Infrastructure

CONTRACT NUMBER

693JJ621C000013