

Investigating potential long-term geotechnical risks with slow movement analysis

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Abstract

Slopes with very low movement rates are unlikely to be visible under a standard normal slope radar processing approach, as the long-term data will likely indicate no active movement is occurring along the wall being monitored. Depending on the structural geology and other geotechnical conditions behind the wall, slow progressive movement could potentially lead to an instability event in the future. This paper presents an overview of a slow movement analysis using IBIS slope radar monitoring data and some examples of the analysis completed at one Rio Tinto Iron Ore site in the Pilbara region of Western Australia.

Keywords: *slope radar, slow movement analysis, subsampling analysis*

1 Introduction

Slow movement analysis (SMA) is a process used to detect instability in its early stages when the displacement rate is still very small. Usually the movement in the early stages cannot be captured by a ground-based radar because the normal processing system of the radar has a minimum detectable movement velocity (IDS GeoRadar 2021). This limitation is common to the technologies of both real aperture and synthetic aperture radars.

Movements that initially fall under the radar's sensitivity threshold between two consecutive interferograms might mimic phase variations that resemble atmospheric events, so they are usually filtered out by the system's standard processing algorithm. However, over time, these seemingly insignificant movements can accumulate and surpass the 0.1-mm accuracy, becoming detectable by the system (Leoni et al. 2015).

SMA, otherwise known as subsampling, is a procedure that was designed to overcome this limitation by reducing the minimum velocity that the radar can effectively track (IDS GeoRadar 2021). By monitoring these gradual movements on the slope, SMA augments the radar system's surveillance capacity, adding an extra layer of safety and ensuring a comprehensive analysis of potential risks.

This paper utilises some data captured from a Rio Tinto Iron Ore mine in the Pilbara region of Western Australia to demonstrate the application of SMA in investigating potential long-term geotechnical hazards. The analysed data originates from the ArcSAR radar, a product of IDS GeoRadar.

2 Slow movement analysis

The functionality of the ground stability radar is rooted in its ability to emit a series of microwave signals towards a targeted slope. The signals then rebound and return to the radar. Using an interferometry method, the radar compares the signal phase between interferogram images to calculate slope movements (Antonello et al. 2004). This allows geotechnical engineers to continuously monitor the stability of the slope, enabling the detection of slope instabilities and allowing for the implementation of pre-emptive safety measures (Coli

et al. 2018). This data proves invaluable in mitigating slope failure hazards within mining operations (Farina et al. 2011).

Figure 1 illustrates the process by which the radar measures displacement between scans. The phase difference between one scan and the next is compared to determine the displacement. However, when the microwave signal is transmitted between the radar and the slope being monitored, the phase captured by the radar is not solely due to movement. The influence of atmospheric disturbances such as humidity, temperature, air pressure, wind and rain are also factors.

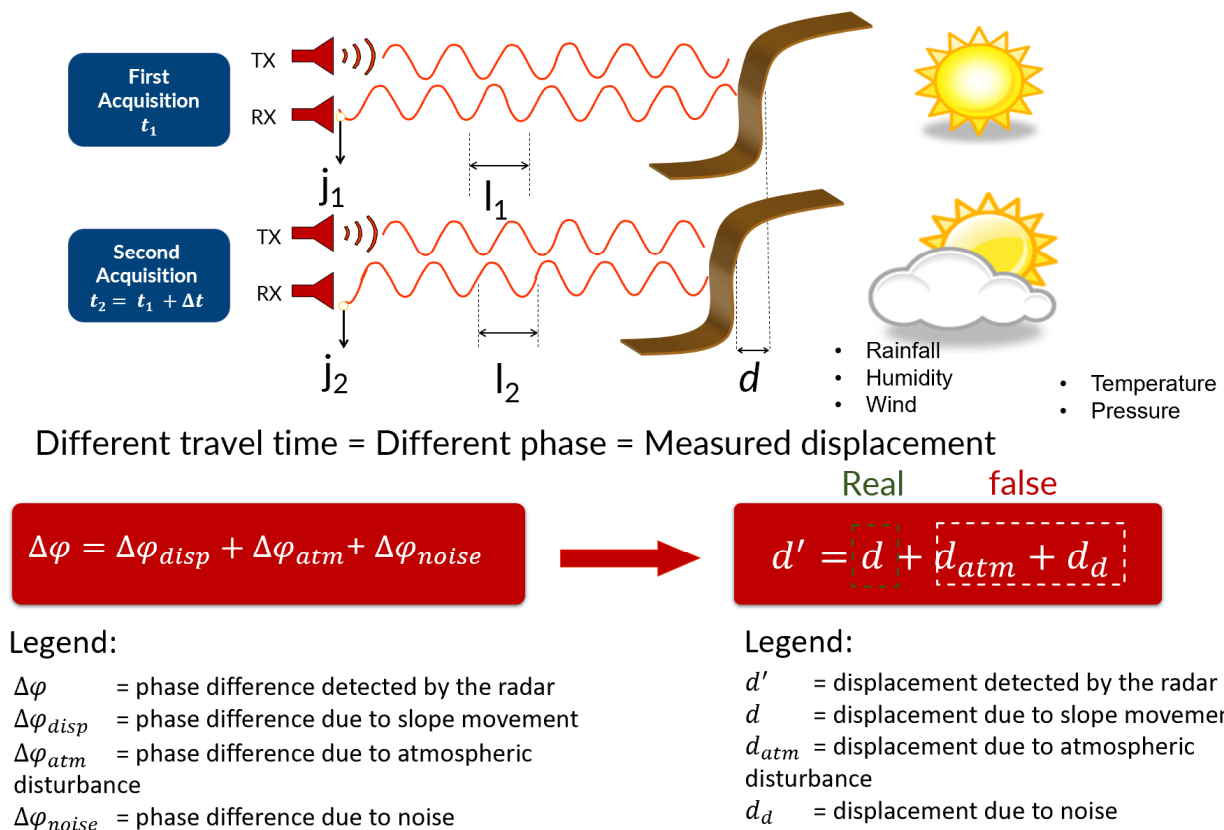


Figure 1 The radar process in detecting slope movement (IDS GeoRadar 2021)

To account for this atmospheric disturbance, the processing software integrates an atmospheric correction algorithm that cancels out the atmospheric disturbance (see Figure 2).

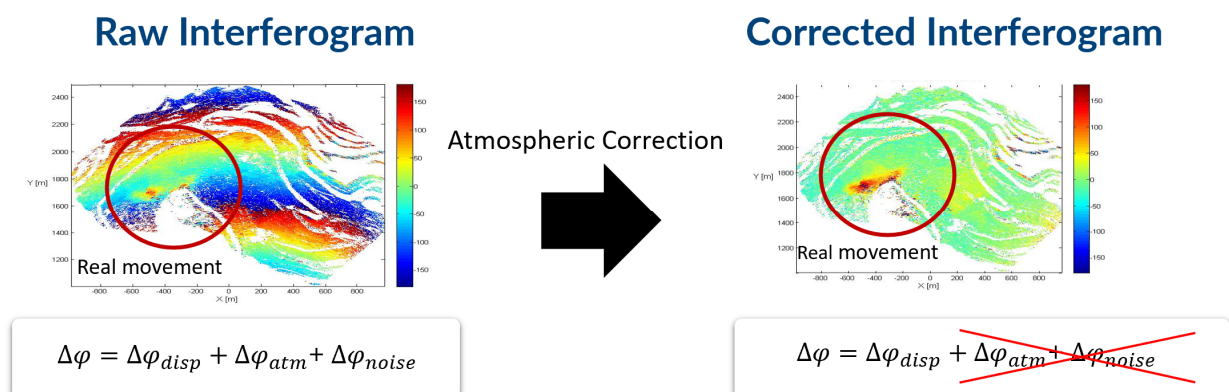


Figure 2 Atmospheric correction, before and after (IDS GeoRadar2021)

However, even with state-of-the-art of ground-based radar atmospheric correction algorithms, there is still a limitation in trying to differentiate displacement caused by actual movement and that due to atmospheric disturbance. This differentiation becomes especially challenging if the displacement between two scans is less than the radar's accuracy threshold of 0.1 mm. Therefore, the radar will neglect the movement that is less than 0.1 mm between the data of two scans.

In standard processing, the Guardian software will process all scans collected directly in the field. This process, which typically takes between 1 to 4 minutes per data acquisition cycle, provides near real-time insights into slope stability. This efficient approach ensures any sudden or significant displacements are promptly detected, enabling rapid responsive action. However, since the data is received in less than four minutes, the slope has only that amount of time to reach a 0.1 mm displacement, as shown in Figure 3.

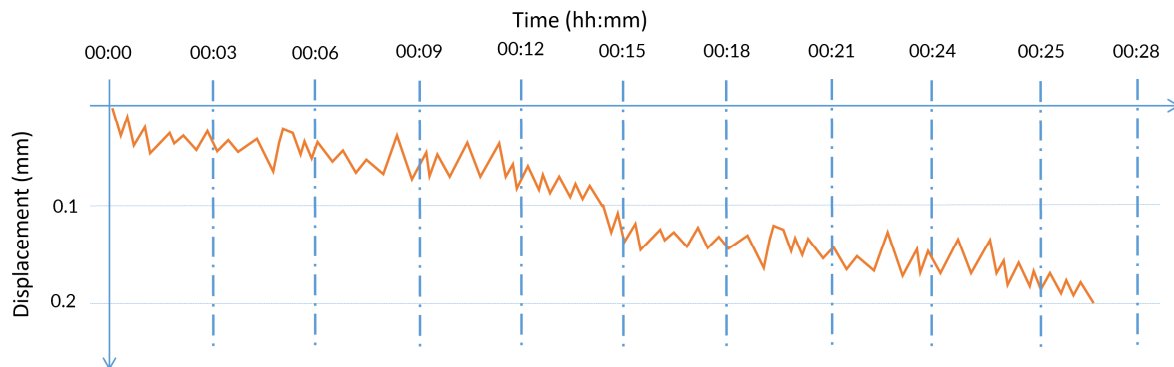


Figure 3 Example of movement that will be neglected due to the movement of less than 0.1 mm between scan (IDS GeoRadar 2021)

SMA involves calculating the displacement for each radar image over an extended duration defined by the user. It allows for the accumulation of subtle slope displacement over time, revealing slower, more gradual displacement that may go undetected during real-time processing. Typically, SMA uses a longer time period between the scan data, such as 24 hours, three days etc., providing a longer time for slope changes to reach 0.1 mm, as depicted in Figure 4. This extended duration allows slow movement to accumulate and surpass the detection threshold, making IT 'visible' to the system. SMA serves as a complementary approach to real-time processing, offering a more holistic understanding of both rapid and slow movement in ground stability over time (IDS GeoRadar 2021).

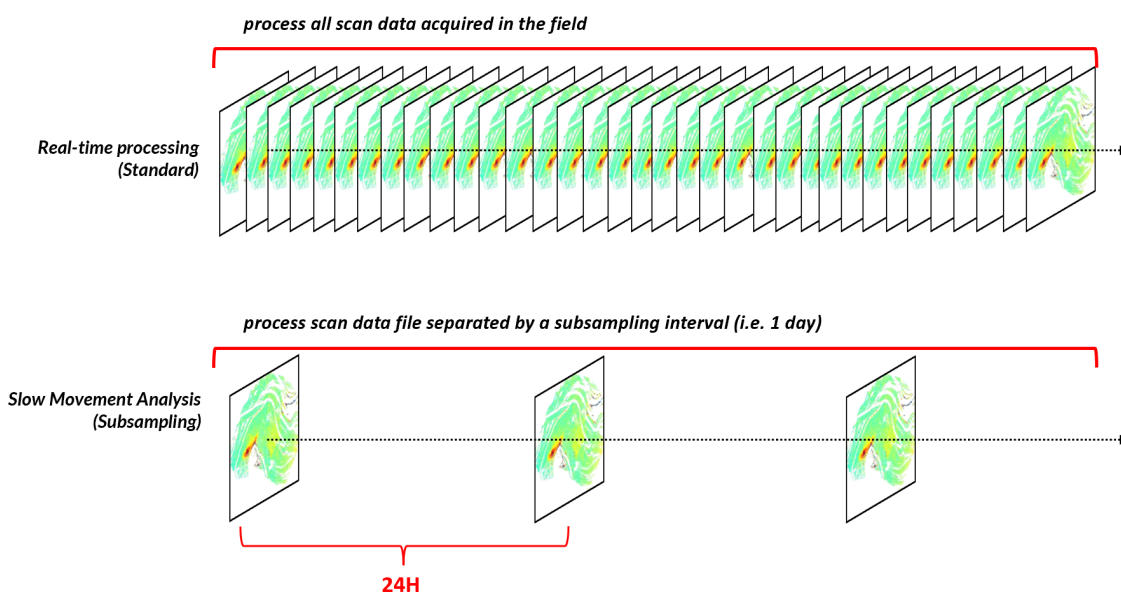


Figure 4 Real-time processing versus slow movement analysis (IDS GeoRadar 2021)

By combining both methods, a comprehensive and dynamic understanding of an area's slope conditions can be attained, facilitating informed decision-making and enhancing safety measures. Table 1 compares the standard real-time processing with SMA.

Table 1 Standard real-time processing versus slow movement analysis

Standard real-time processing	Slow movement analysis
Data is processed as soon as it is received from the field, ensuring the latest information is always available.	This approach involves processing and analysing already collected radar data.
The displacement data is continually updated to reflect the most recent, providing near real-time insights.	Displacement data is updated based on the latest information for the specific project, providing a detailed historical view of changes over time.
This technique is crucial for critical monitoring applications and promptly triggers hazard alarms when potential instability is detected.	SMA is valuable for analysing slow deformation rates (measured in mm per month) or conducting back-analysis of a previous event.
It excels at capturing quick movements, making it ideal for monitoring rapidly changing environments.	It excels at capturing slower movements, offering a comprehensive picture of gradual movement in ground stability over extended periods.

The subsampling time interval plays a pivotal role in determining the capacity to pinpoint specific rates of deformation. This interval essentially acts as a lens, allowing the user to focus on different scales of motion that can vary from swift to gradual shifts.

For illustrative purposes (IDS GeoRadar 2022):

- With a finer subsampling time interval set at one hour, the detection capabilities allow the user to observe a minimum displacement nearing 0.1 mm over a span of 60 minutes. This rate translates to a velocity of 2.4 mm/day.
- Alternatively, if the subsampling time interval was stretched to one day, the system would still identify a minimal displacement of approximately 0.1 mm but this would be over an extended period of 1,440 minutes. As a result, the derived velocity is significantly slower at 0.1 mm/day.

Therefore, selecting an appropriate subsampling time interval is not arbitrary; it is fundamentally tied to the specific velocity range an analyst or user wishes to scrutinise. Making the right choice ensures that the data collected is relevant and useful for the intended analysis. This is highlighted in Table 2.

Table 2 The slowest detectable movement with different subsampling periods (IDS GeoRadar 2022)

Processing algorithm	Interval of data	The slowest detectable movement		
		(mm/hour)	(mm/day)	(mm/month)
SMA (subsampling)	12 hours	0.008	0.2	6
	1 day	0.004	0.1	3
	3 days	0.001	0.03	1

3 Data processing

Initiating the SMA requires careful data selection. It is vital to choose data that exhibits minimal interference from atmospheric disturbances. To discern the most appropriate data time, one can refer to the data quality graph. This (see Figure 5) graph delineates the congruence between the atmospheric model and the actual data. The depicted value ranges between one and zero.

A value close to zero indicates that the atmospheric model significantly diverges from real-time data, leading to a decline in data quality. Conversely, when the atmospheric model aligns closely with the processed data, the data quality value is close to one. It's worth noting that data quality typically demonstrates a cyclical pattern. Fluctuations in data quality are more pronounced during transitions from night today and vice versa, and are associated with temperature and air pressure variations attributed to the sun's movements. For SMA, data is generally sourced from midnight periods as atmospheric conditions tend to be most stable at that time. Nonetheless, the optimal data collection point can vary based on the specific site and the patterns observed in the data quality graph.

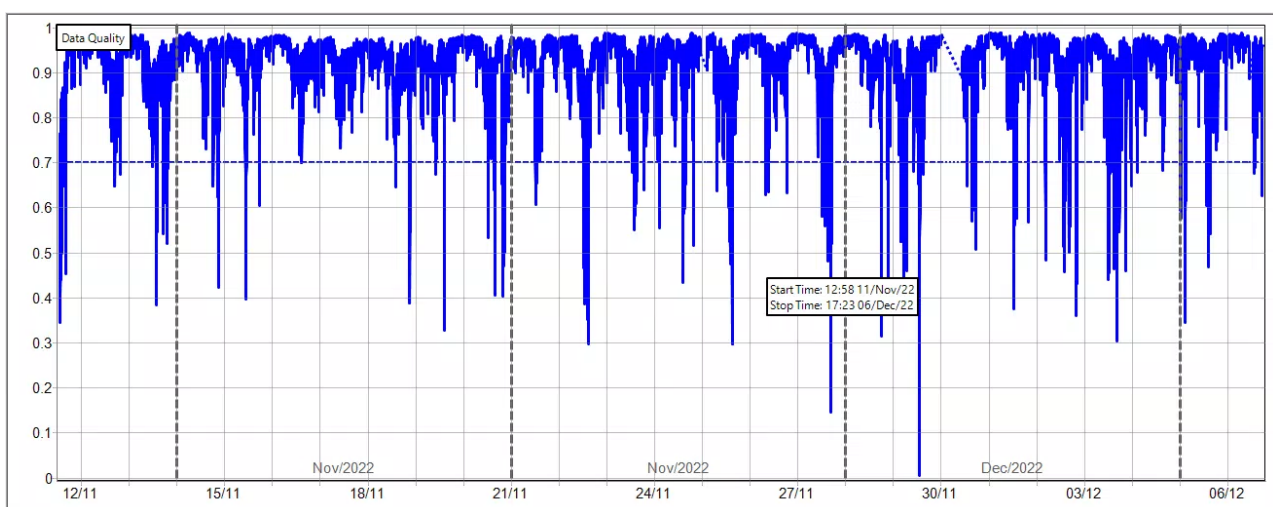


Figure 5 Data quality graph

Once the desired time frame is identified, configurations related to the time and interval can be adjusted within the IDS GeoRadar IBIS Guardian software, specifically within the 'Project Options' feature. This software allows for customisation, where users can determine the starting date and time. Within the advanced settings, one can specify both the subsampling process and its corresponding interval. For instance, selecting a start time of 02:00 AM with a 24-hour interval instructs the Guardian software to incorporate scan data from approximately 02:00 AM daily into the analysis process.

4 Case study of slow movement analysis

In this case study for one of Rio Tinto's open pit iron ore mines, subsampling was conducted for both the south and north walls of an iron ore pit. Each of these walls has its own distinct challenges and concerns. It is essential to analyse them individually to understand the unique geotechnical factors and potential risks associated with each wall.

4.1 South wall area of interest

A pre-existing instability event had occurred along the southern wall of the pit. The nature of this instability was a planar failure, predominantly involving the Mount Newman Member of the Marra Mamba Iron Formation. Notably, this instability resulted from a slippage that occurred along the N2L shale band (Lascelles 2000). Figure 6 shows a picture of the instability event over an area of 30 by 400 m.

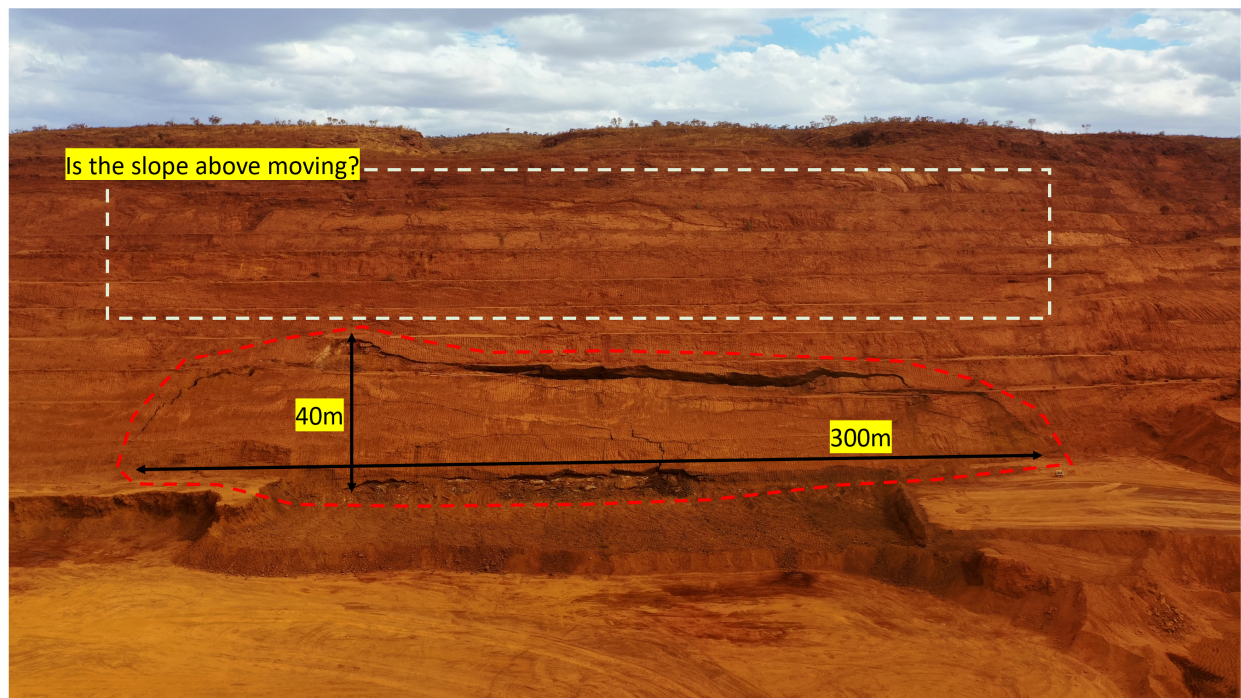


Figure 6 South wall area of analysis

The geotechnical condition of the toe of the slope prompts inquiries regarding the impact on the overall stability of the slope: specifically, the concern about whether this condition could induce further instability or movement in the part of the slope above the failure. Any such movement could significantly disrupt the operational activities within the mine operation. SMA was used in this example to resolve this concern.

SMA is based on the principles of physics: the initiation of slope instability is marked by gradual, low-rate motion. This creeping stage might go unnoticed with standard real-time processing methods. Hence, SMA becomes crucial for detecting such early signs of instability. For the analysis, scan data from around 02:00 was employed as it consistently delivers the highest quality data for this operation over time. A 24-hour interval is set as the standard for this analysis to capture the slow-moving changes effectively. The overall displacement of the wall is shown on the left of Figure 7, with the chart on the right of Figure 7 showing the displacement graph.

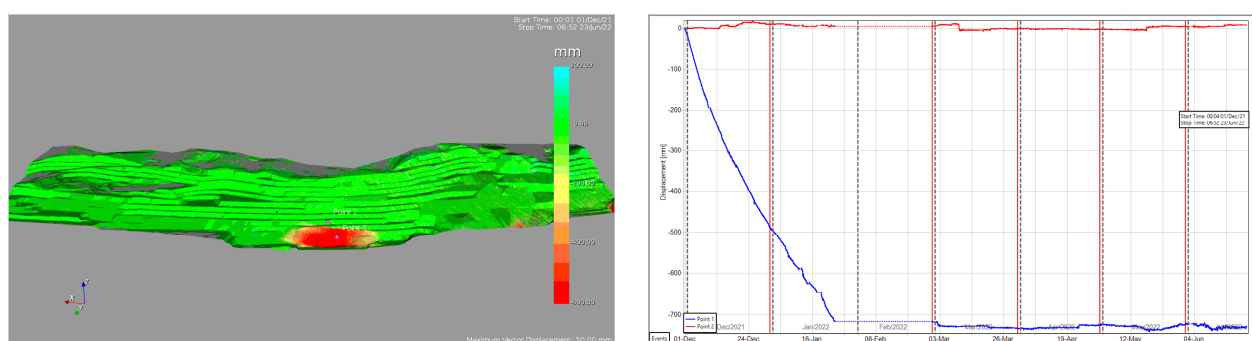


Figure 7 Real-time processing result

In Figure 7, the instability area at the toe of the slope displayed continuous movement until 24 January 2022, as indicated by the real-time processing data. However, a noticeable gap in the data exists between 24 January and 1 March. Post 1 March, observations suggest that the movement within the failure zone had stabilised and remained consistent. The insights derived from real-time processing indicated that the region situated above the area of failure remained largely static, as indicated by the green colour. No substantial

movements were detected, which would suggest that the instability was confined to the failure area and had not influenced the adjoining upper slope.

The application of SMA revealed that there were no instances of gradual or ‘creeping’ movement in the areas directly above the area of concern. This suggests that the movement was primarily limited to the instability zone, without causing or prompting any significant alterations to the slope situated above the affected region. By examining both the displacement map and its accompanying graphical representation in Figure 8, it becomes evident that from December 2021 to June 2022, the slope remained predominantly stable. The lack of discernible or substantial movement in these regions aligns with the results from the standard processing. These findings provided the site’s geotechnical engineer with the added assurance that the instability in the lower part of the slope did not adversely impact the stability of the slope above.

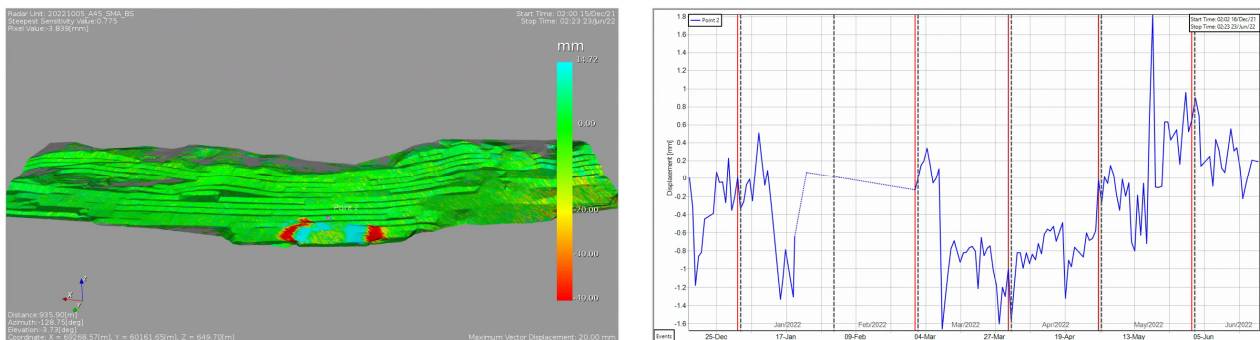


Figure 8 Slow movement analysis result

4.2 North wall area of interest

The northern wall of the same pit displayed signs of instability due to the presence of Wittenoom Formation of the West Angela shale member (Lascelles 2000). Data gathered from inclinometers installed in the wall indicated that a potential deep-seated movement was taking place in close proximity to the West Angela bedded unit. However, the velocity of this movement was so low that it would have been undetected by standard radar processing. To validate this subtle indication, an SMA was applied.

Initially, when the SMA was undertaken using a one-day interval, no significant movement was observed below the 640 mRL elevation. However, upon comparison with the inclinometer data, it became evident that the non-detection was attributable to the small rate of movement, which was as low as 0.002 mm/hr. To better capture this, a subsequent SMA with longer time intervals was conducted, this time over a span of three days. This extended interval proved effective as the movement of the particular area in the north wall became detectable.

From the analysis of slow movement over three-day intervals, the radar detected some movement between elevations of 670 mRL and 610 mRL covering an area of approximately 22,000 m². The displacement graph displayed a movement rate of 0.002 mm/hr from December 2022 to March 2023. This rate then exhibited a slight increase, reaching 0.004 mm/hr between April and June 2023. This is shown in Figure 9.

At present the slope’s movement remains in its early stages as the displacement rate is still quite low. Since the displacements are minimal it does not imply a significant failure is likely to occur soon. However, recognising this early indication of instability provides the geotechnical team advanced insight for preparing mitigation strategies to minimise the adverse consequences to personnel, equipment and infrastructure, and business disruption.

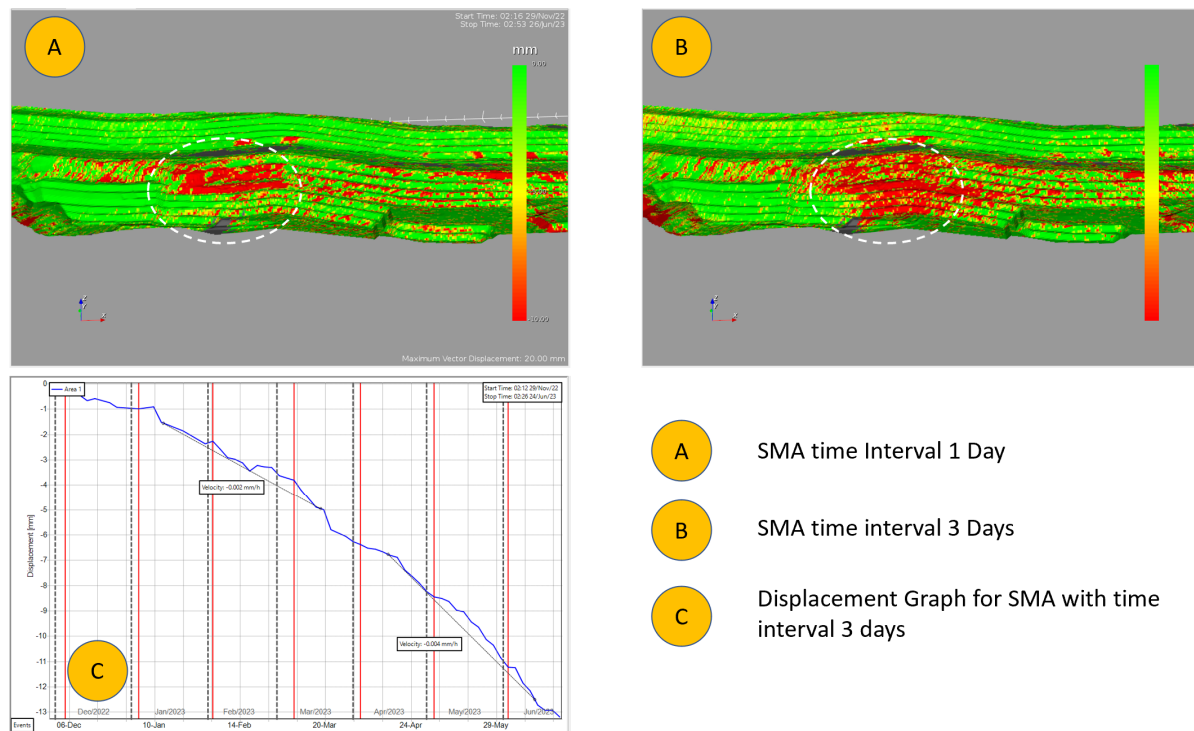


Figure 9 Slow movement analysis result

Part of this anticipatory process includes setting alarm thresholds based on instability data collection and retrospective analysis. This ensures alarms remain effective and can warn the site team well in advance of any impending instability events. Simultaneously, it is vital to calibrate these alarms above site-specific noise levels, minimising any undue disruptions from false alerts which could disrupt mining operations.

5 Conclusion

The potential of SMA using subsampling is a promising tool for accessing the potential for slope instability. At the heart of its capability lies its ability to identify slow displacement rates which would otherwise not have been detected using standard ground-based radar real-time processing capabilities. This translates into the ability to identify an anomalous deformation shortly after its initiation, though processing with several different time intervals is still needed.

The benefit of SMA is the lead time in the identification of long-term low creep. Sullivan (2007) demonstrates that creep is one of the five stages of pit movement. This knowledge provides site stakeholders with the opportunity to implement proactive mitigation plans, reducing the risk to personnel from instability and minimising business disruption.

In addition, understanding the total moving area becomes vital for effective decision-making. A geotechnical engineer armed with the knowledge of the entire affected zone can devise more informed strategies, be they remediation activities or back-analysis of the dynamics of the impacted instability area. Such insights also lend a greater degree of certainty to engineers, enabling them to determine with confidence whether a particular region is indeed moving.

SMA, through subsampling processing, offers a reliable tool from which actionable insights can be gleaned by allowing for the early detection and effective remediation of potential slope instability, which ensures the safety and efficiency of operations.

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