AER/AGS Open File Report 2024-03

Turtle Mountain Field Laboratory, Alberta (NTS 82G): 2022 Data and Activity Summary

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Alberta Energy Regulator
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Abstract

This report provides a summary of both the lessons learned from the Turtle Mountain monitoring system (TMMS), and from studies undertaken by the Alberta Geological Survey (AGS) and collaborators between January 1 and December 31, 2022. The TMMS is a near–real-time remote monitoring system that provides data from a network of sensors and monitoring systems on Turtle Mountain, located in the Crowsnest Pass of southwestern Alberta.

As of April 1, 2005, the AGS took ownership of this system, and the responsibility for long-term monitoring, interpreting data, and notifying the Alberta Emergency Management Agency should significant movements occur.

The AGS performs an annual detailed review of the data stream from the TMMS. To help in this interpretation, the AGS initiated specific studies to better understand the structure of the mountain and its relationship to the style and rate of movement seen in recent and historical deformations of South Peak. These studies also better define the unstable volumes of rock from the South, North, and Third Peak areas.

This report comprises four main sections:

- The first section contains information about the significant changes to the TMMS's network during 2022. This includes a summary of system performance and reliability.
- The second section provides data analysis and interpretation from the primary monitoring equipment, known as LiSAmobile.
- The third section discusses supporting studies and research.
- The last section features information on two videos produced by the Alberta Energy Regulator to highlight the changes on Turtle Mountain in 2022.

1 Introduction

In 2005, the Alberta Geological Survey (AGS), a branch of the Alberta Energy Regulator (AER), assumed responsibility for the long-term monitoring of Turtle Mountain, the site of the 1903 Frank Slide in southwestern Alberta (Figure 1). In July 2016, the Turtle Mountain Monitoring Program (TMMP) transitioned from a near–real-time early warning monitoring system to a near–real-time remote monitoring network. This transition encompassed monitoring advancements due to improved displacement measurement technologies and a review of over a decade of monitoring data and techniques. For more information, refer to Wood et al. (2017a, b, 2018a, b).

The first priority of the TMMP is to provide monitoring of Turtle Mountain, review site characterization, review monitoring practices, and make recommendations for the future of the monitoring program. The second priority is to provide an opportunity for the research community to test and develop instrumentation and monitoring technologies to better understand the mechanics of slow-moving rock masses. This ongoing research will aid in understanding the rock movements on Turtle Mountain.

This annual report provides the public and researchers with a synthesized update on data trends, monitoring on the mountain, and changes to the monitoring program.

2 Sensor Network Activity

This section provides an overview of the major upgrades, repair, maintenance activities, and performance of the sensor network of the monitoring system during 2022.

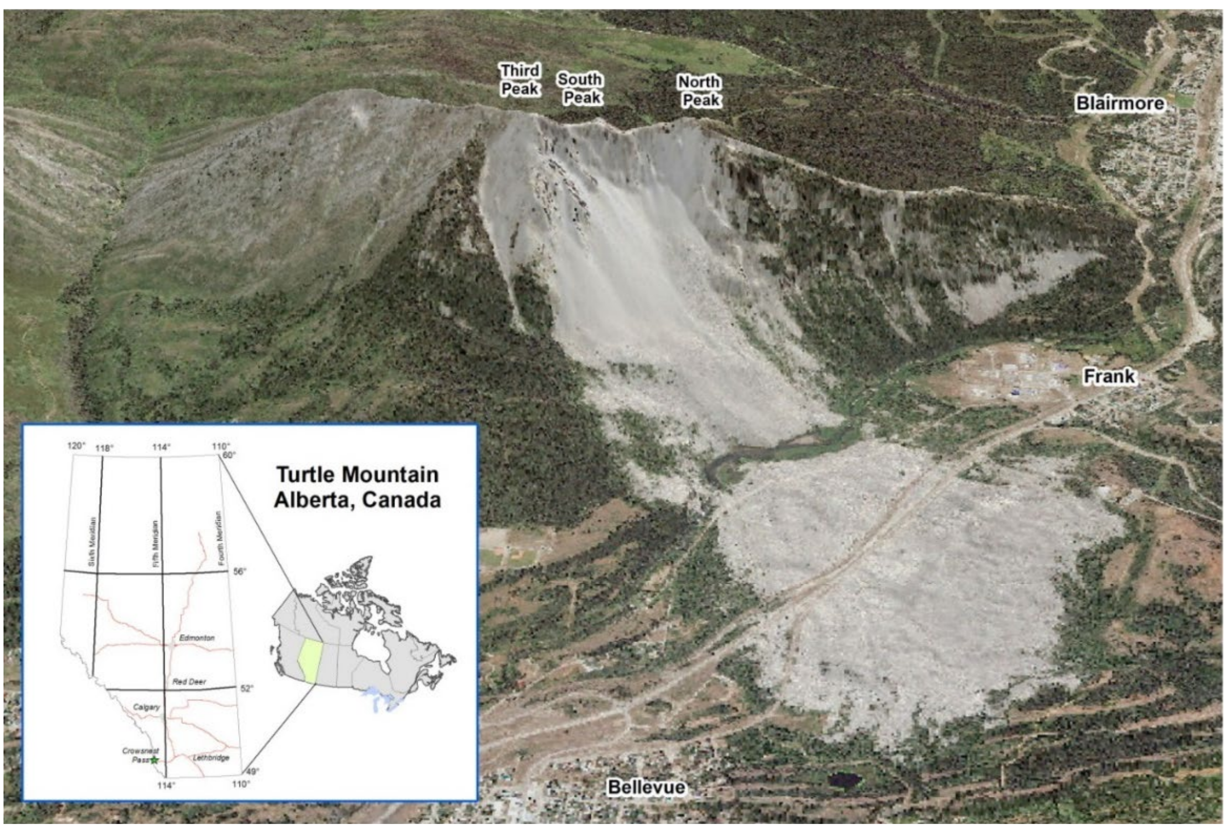

Figure 1. Location of Turtle Mountain in southwestern Alberta and full-extent aerial view of the Frank Slide.

The AGS leases a ground-based interferometric synthetic aperture radar (GB-InSAR) monitoring system known as LiSAmobile from Ellegi srl (Ellegi), Milan, Italy. LiSAmobile was installed in June 2014 and has been in continuous operation, except during annual repair and maintenance, as well as a short outage in 2020. The AGS's lease with Ellegi provides customer service and technical support in case of an emergency or equipment changes.

In 2016, LiSAmobile was transitioned from being the secondary monitoring system to the primary monitoring system. In addition, the AGS supports secondary monitoring campaigns. These secondary monitoring campaigns, such as airborne light detection and ranging (LiDAR) scanning, photogrammetry, terrestrial laser scanning (TLS), etc., are selected by the AGS based on monitoring frequency and an airborne LiDAR survey completed in 2021 (Chao, 2023).

The AGS receives and reviews monitoring reports on a quarterly basis from Ellegi. Ellegi also provides *Quick Reports* if an area has displacement values outside of the defined thresholds determined by Ellegi technicians. Ellegi continues to provide a premium level of technical support, innovative shelter technology, and timely detailed reporting. The AGS will continue to use LiSAmobile as the primary monitoring sensor.

The AGS has a radio licence from Innovation, Science and Economic Development Canada that allows them to operate the Turtle Mountain monitoring system (TMMS) network link without interference from other frequencies in the surrounding Crowsnest Pass area.

2.1 Repairs and Maintenance

2.1.1 LiSAmobile Annual Maintenance

In 2022, an annual maintenance campaign was conducted in early July by a joint team from Ellegi and the AGS. The field maintenance objectives included

- visual examination of the system, wiring, and power box,
- inspection of the radome (housing structure) for any structural or waterproofing issues,
- inspection of the air conditioning system and replacement of its filters,
- mechanical maintenance on the system, which included cleaning, inspecting, and lubricating the horizontal positioning system (rail) and belt,
- examination of the radar including the functionalities, inclination, and performance of its measuring head,
- replacement of two uninterruptible power supply (UPS) batteries for the internal computer unit and validation on the functionality and performance of the processing boards, and
- reboot to test for normal data acquisition.

During the site maintenance, the LiSAmobile radome was inspected for signs of physical damage, structural deterioration, and water leak exposure. The radome protects LiSAmobile from significant fluctuations in precipitation and temperatures, which are typical throughout the year in the Crowsnest Pass. Environmental conditions at the site include high and low temperatures during summer and winter, high wind gusts, and heavy precipitation events. The inspection revealed the radome had continued to withstand all the environmental factors and protected the LiSAmobile system efficiently as designed.

The horizontal positioning system, belt, and motor that drives LiSAmobile were cleaned, lubricated, and inspected for signs of deterioration.

The original UPS batteries for the internal computer unit were replaced after eight years of continual operation. The system was rebooted to confirm data was acquired, processed, and transmitted as expected.

2.1.2 TMMS Radio Network Repair

The radio network at Turtle Mountain failed on May 16 and interrupted the live webcam feeds to the AER and data transmission to Ellegi in Italy. As a result, AGS and AER staff planned a site visit for a detailed diagnosis and repair. Ellegi was immediately instructed to switch the data transmission to a cellular network, but the live webcam feed remained unavailable during the network outage.

Staff from the AGS and AER's Information Management and Technology (IMT) branch travelled to the site on May 30. They inspected the computer network and equipment, including the communication ports, power supplies, PoE injectors, and radio network, which included the transmitting/receiving devices at the Provincial Building (Figure 2), pumphouse, and Frank Slide Interpretative Centre (FSIC). It appeared that the radio network at the Provincial Building and FSIC had also failed. After extensive and exhausting trouble shooting, the problem was finally identified to be a faulty power adaptor (Figure 3a) for the PoE injector at the Provincial Building (Figure 3b). It was providing inconsistent or low voltage at the Provincial Building and creating a cascading effect to the radio network in the other two locations causing them to stop transmitting and receiving data. The communication port(s) on the supernet gateway/firewall did not light up because data was not being received. The staff replaced the faulty power adaptor and the radio network and communication to AER and Ellegi were restored.

Figure 2. Radio receivers at the Provincial Building in Blairmore, southwestern Alberta.

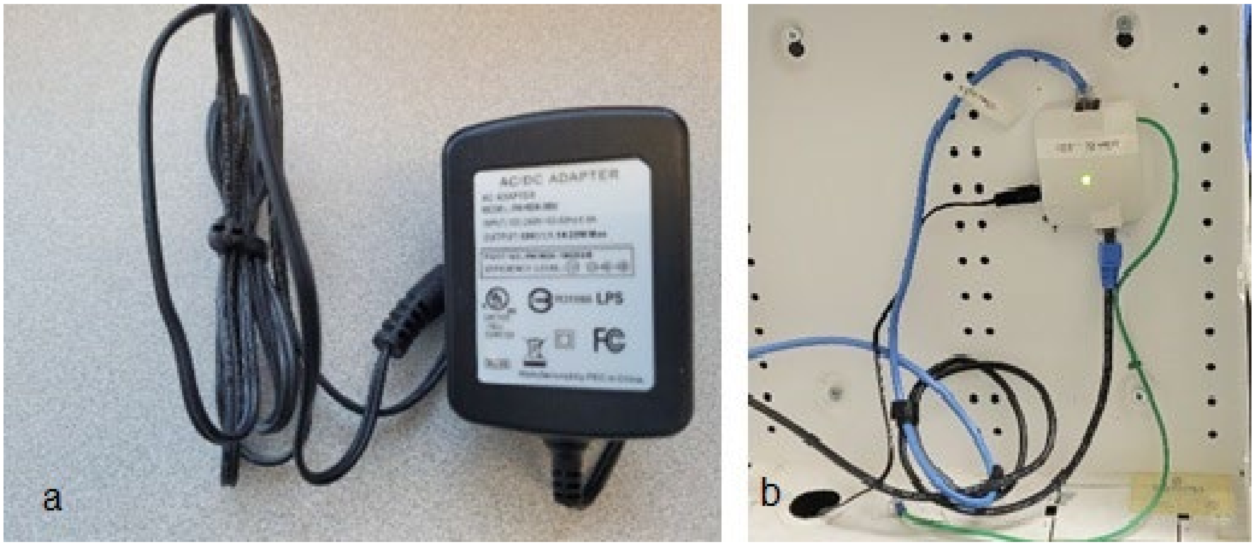

Figure 3. Faulty power adaptor (a) that caused malfunction of the Power over Ethernet (PoE) injector (b) at the Provincial Building in Blairmore, southwestern Alberta.

2.1.3 UPS Unit Replacement

There are two UPS units in the Provincial Building for the radio and computer network equipment in case of a power outage. The UPS units supply emergency power during an outage and will automatically re-engage the power supply to the equipment after the power is restored.

There had been a couple of incidents in 2022 where the UPS unit for the supernet gateway/firewall had failed to re-engage and required a manual restart. After the second outage in November, AGS staff noticed that the units were either not charging or not holding their charge. Both units were replaced in late November.

3 Data Collection and Analysis

3.1 LiSAmobile Ground-Based InSAR Data Collection

LiSAmobile was installed at the Bellevue pumphouse in June 2014 to monitor small displacements on the eastern face of Turtle Mountain. The LiSAmobile (Figure 4) uses the ground-based InSAR technique to measure small displacements at each point on the surface of the mountain. For additional information, refer to Wood et al. (2016).

The LiSAmobile system is connected via the Internet through a Wi-Fi connection that allows virtual private network (VPN) access. The LiSAmobile system obtains raw measurement data from the radar head. These data are processed onsite by LiSAmobile, the results are transferred, and the data quality is evaluated by Ellegi and used to create displacement maps showing a pixelated image of ground displacements that range from positive to negative values (Figure 5a). Positive values (blue colours) indicate displacement away from the sensor, whereas negative values (red colours) indicate displacement towards the sensor.

Figure 4. LiSAmobile system without radome (housing structure), Turtle Mountain, southwestern Alberta.

3.2 Discussion and Interpretation of Monitoring Data from LiSAmobile

The displacement map displayed in Figure 5a depicts how the slopes on the east face of the mountain are affected by slow and small movements, measured in the millimetre range. Displacement maps are created through a collection of data from the LiSAmobile system over an approximately 90-day period (per quarter), with approximately 15-day increments. The displacement maps were produced from data collected from the start of LiSAmobile operation in June 2014 to the end of December 2022 and are provided by Ellegi to the AGS in quarterly reports (quarterly reporting period [Q]31 to Q34 for 2022). Each report contains the cumulative data starting from June 20, 2014, to the end of the respective quarterly reporting period.

The data are divided into nine regions of interest (A–I, Figure 5a and b), which are further subdivided into 18 points of interest (POIs; labelled P_1 through P_12, P_17, P_18, and P_20 through P_23 in Figure 5b). Regions H and I, and POIs P_18 and P_20 belong to the morphologically connected channels extending to the valley bottom below region D (South Peak). They were added to the data collection in February 2020 after displacements were observed in December 2019. Points of interest P_21 to P_23 were added to region D in June 2021 after displacements were observed in the previous month. In January 2022, P_17 was added to region E, above P_9 and P_10, to enhance the characterization of the region. Additional documentation of the LiSAmobile parameters can be found in Wood et al. (2016).

The high displacement rates detected in the vegetation zone (region F, Figure 5a and b) are considered to be measurement errors introduced by atmospheric moisture within the line of sight and the presence of vegetation.

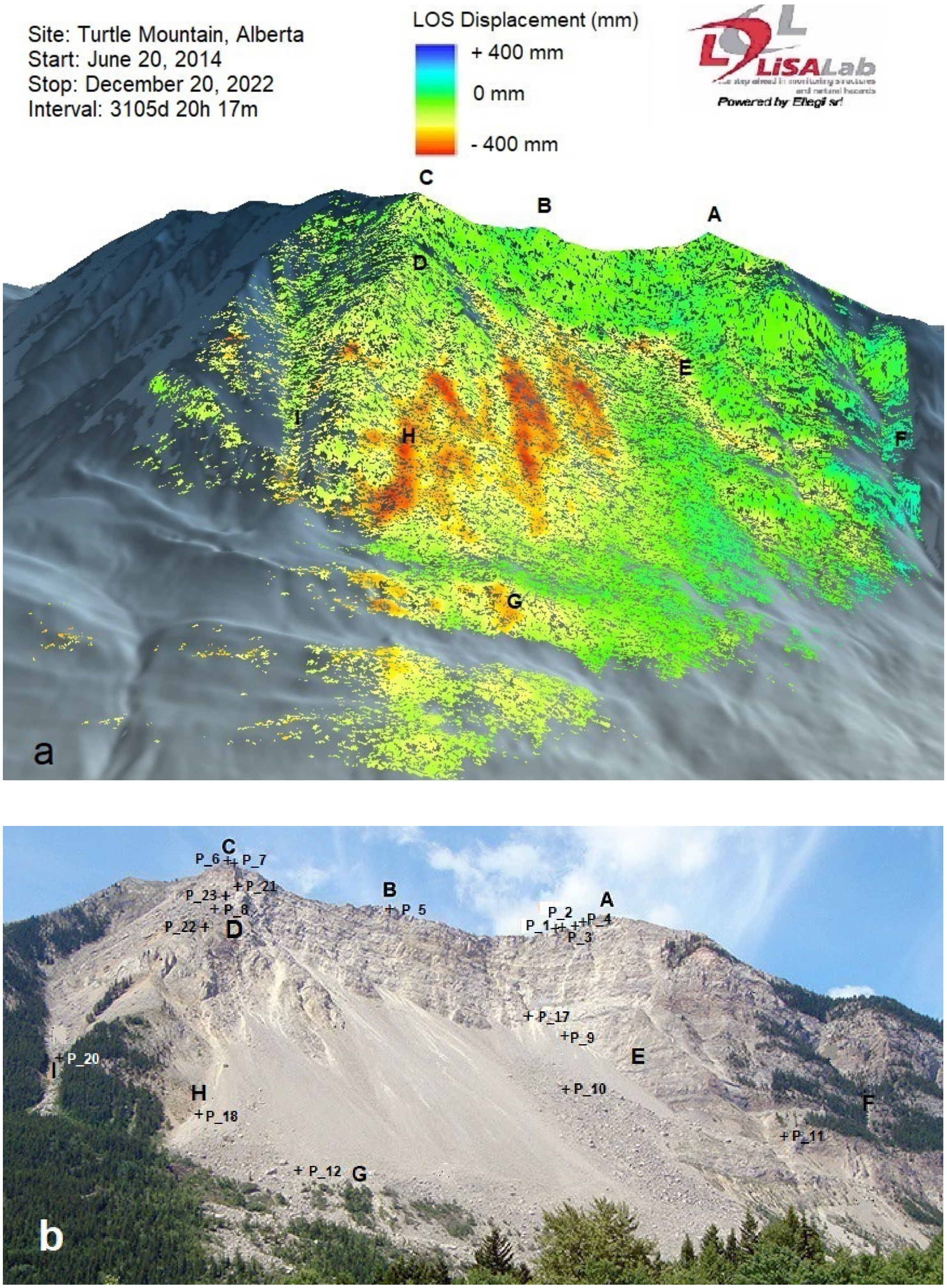

Figure 5. Three-dimensional (3D) displacement map (a), measured from June 20, 2014, to December 20, 2022 (3105 days [d], 20 hours [h], 17 minutes [m]), and view (b) of the eastern face of Turtle Mountain, southwestern Alberta. Letters A to I denote the locations of the regions of interest. Letters P_1 through P_12, P_17, P_18, and P_20 through P_23 denote points of interests. Abbreviation: LOS, line of sight.

The quarterly reports Q31 to Q34 submitted to AGS by Ellegi contained erroneous displacement data. Ellegi provided AGS with updated displacement data and descriptions and confirmed that the displacement maps in the original report were not affected by these errors. The updated displacement data and descriptions are presented in Tables 1 through 8. Generalized displacements in the regions of interest for the period from June 20, 2014, to the end of the respective quarterly reporting period (i.e., Q31, Q32, Q33, Q34) are shown in Tables 1, 3, 5, and 7, respectively. Measured displacements at POIs for the same periods are presented in Tables 2, 4, 6, and 8.

On the displacement maps (Figures 5a, b, and 7), both positive and negative displacement values are depicted using colours. Blue colours indicate displacement away from a sensor (positive value), for example, rocks calving off and exposing new rock surfaces from behind. Red colours (and purple colours on Figure 7) indicate displacement towards the sensor (negative value), such as rocks falling and accumulating in the debris zones (regions E and G). Green colours depict a neutral range of displacement with minimal movements towards or away from the sensor.

For simplicity, the AGS has removed the negative sign from the reported displacement tables (Tables 1 to 8) and is reporting the cumulative movements towards the sensor (i.e., only the red colours on Figure 5a). The AGS monitors all displacement movements (blue, red, and green) reported by Ellegi.

3.2.1 Report to the End of Q31

Generalized displacement in Q31 for regions A to I was relatively small compared to Q30 (Table 1). There was no evidence of generalized deformation of the rock walls, and displacement in the debris zone (regions E, G and H) was influenced by the presence of snow throughout Q31 (Table 2). The Crowsnest Pass area is subject to large amounts of snow accumulation during winter months that can affect the data.

Point of interest P_17 was added to region E, above P_9 and P_10, in Q31 to enhance the characterization of the region.

Table 1. LiSAmobile generalized displacement in regions of interest from June 20, 2014, to the end of the quarterly reporting period (Q) 31 on March 20, 2022 (2830 days).

Region	Location Description	Displacement (mm)	Approximate Region Area (m^2)
A	Close to North Peak	≤47.4	3405
B	Between North and South peaks	-	3034
C	Close to South Peak	≤68.8	8031
D	Below South Peak	≤61.3	10030
E	Debris area toe of North Peak rock wall	≤4.9	12928
F	Mid to lower vegetated rock wall	-	2865
G	Debris zone runout area	≤122.9	11494
H	Elongated channel (right) to the valley	≤270.5	17718
I	Elongated channel (left) to the valley	≤188.8	8684

Table 2. LiSAmobile measured displacement at points of interest (POI) from June 20, 2014, to March 20, 2022 (2830 days), with observations specific to quarterly reporting period (Q) 31.

Region	Point of Interest (POI)	Displacement (mm)	Displacement Description Specific to Q31
A	P_1 to P_4	36.2 to 212.2	Generalized stability and only minor fluctuations in Q31.
B	P_5	≤7.3	Generalized stability and only minor fluctuations in Q31.
C	P_6 and P_7	5.3 to 126.3	Generalized stability and only minor fluctuations (displacement influenced by snow cover) in Q31.
D	P_8, P_21 to P_23	48.6 to 62.8	Generalized stability and only minor fluctuations (minor acceleration at P_8 likely influenced by snow cover) in Q31.
E	P_9, P_10, and P_17	≤203.5	Generalized stability and only minor fluctuations in Q31.
F	P_11	-	Data is omitted due to errors introduced by atmospheric moisture within the line of sight or presence of vegetation.
G	P_12	≤124.6	Negative displacement, up to 7 mm, likely caused by snow cover in Q31.
H	P_18	≤344.3	Negative displacement, up to 8 mm, likely caused by snow cover in Q31.
I	P_20	≤172.6	Generalized stability and only minor fluctuations in Q31.

3.2.2 Report to the End of Q32

Generalized displacement for most regions were stable or minor in Q32 (Table 3). Rock walls remained stable with no evidence of deformation. Measured displacements at some POIs were subject to errors due to snow cover and atmospheric moisture, such as heavy rainfall or fog (Table 4). Furthermore, displacement of POIs belonging to regions E, F, and G are often related to the movement of loose debris. The Q32 report marks the end of eight years since installation of the LiSAmobile system in 2014.

Region D has been exhibiting slow rates of displacement since 2014 (Chao, 2023). In 2021, three additional POIs (P_21, P_22, and P_23) were added to this region. Together with P_8, they provide a better understanding of the area (Figure 6). After detailed analysis of radar images from two periods of snow-free conditions, Ellegi reported that displacements in the area were small. Similarly, time-series displacements at P_21 to P_23, created using daily interferograms, also showed relatively small displacements. Most of these time-series displacements were heavily affected by snow cover during the winter months. The snow cover in the Crowsnest Pass area persisted until late spring 2022.

Table 3. LiSAmobile generalized displacement in regions of interest from June 20, 2014, to the end of the quarterly reporting period (Q) 32 on June 20, 2022 (2922 days).

Region	Location Description	Displacement (mm)	Approximate Region Area (m^2)
A	Close to North Peak	≤54.3	3405
B	Between North and South peaks	≤3.7	3034
C	Close to South Peak	≤72.5	8031
D	Below South Peak	≤71.3	10030
E	Debris area toe of North Peak rock wall	≤7.8	12928
F	Mid to lower vegetated rock wall	-	2865
G	Debris zone runout area	≤124.0	11494
H	Elongated channel (right) to the valley	≤282.1	17718
I	Elongated channel (left) to the valley	≤194.0	8684

Table 4. LiSAmobile measured displacement at points of interest (POI) from June 20, 2014, to June 20, 2022 (2922 days), with observations specific to quarterly reporting period (Q) 32.

Region	Point of Interest (POI)	Displacement (mm)	Displacement Description Specific to Q32
A	P_1 to P_4	40.7 to 222.9	Generalized stability with displacement at P_4 affected by snow cover in Q32.
B	P_5	≤13.3	Negative displacement, up to 7 mm, affected by snow cover in Q32.
C	P_6 and P_7	6.9 to 127.7	Generalized stability with only minor fluctuations in Q32.
D	P_8, P_21 to P_23	52.7 to 67.4	Minor fluctuations in Q32. Slight negative displacements in early March at P_8 affected by snow cover.
E	P_9, P_10, and P_17	≤206.9	Generalized stability at P_10 in Q32. Displacement in the first part of the quarter at P_9 influenced by snow and debris.
F	P_11	-	Data is omitted due to errors introduced by atmospheric moisture within the line of sight or presence of vegetation.
G	P_12	≤123.4	Generalized stability in Q32.
H	P_18	≤363.7	Negative displacement, up to 20 mm, caused by snow movement in Q32.
I	P_20	≤182.9	Negative displacement, up to 12 mm, caused by snow movement in Q32.

3.2.3 Report to the End of Q33

There were no significant generalized displacements from the rock walls and only some incremental displacements in the debris zone (regions E, G, and H) throughout Q33 (Tables 5 and 6).

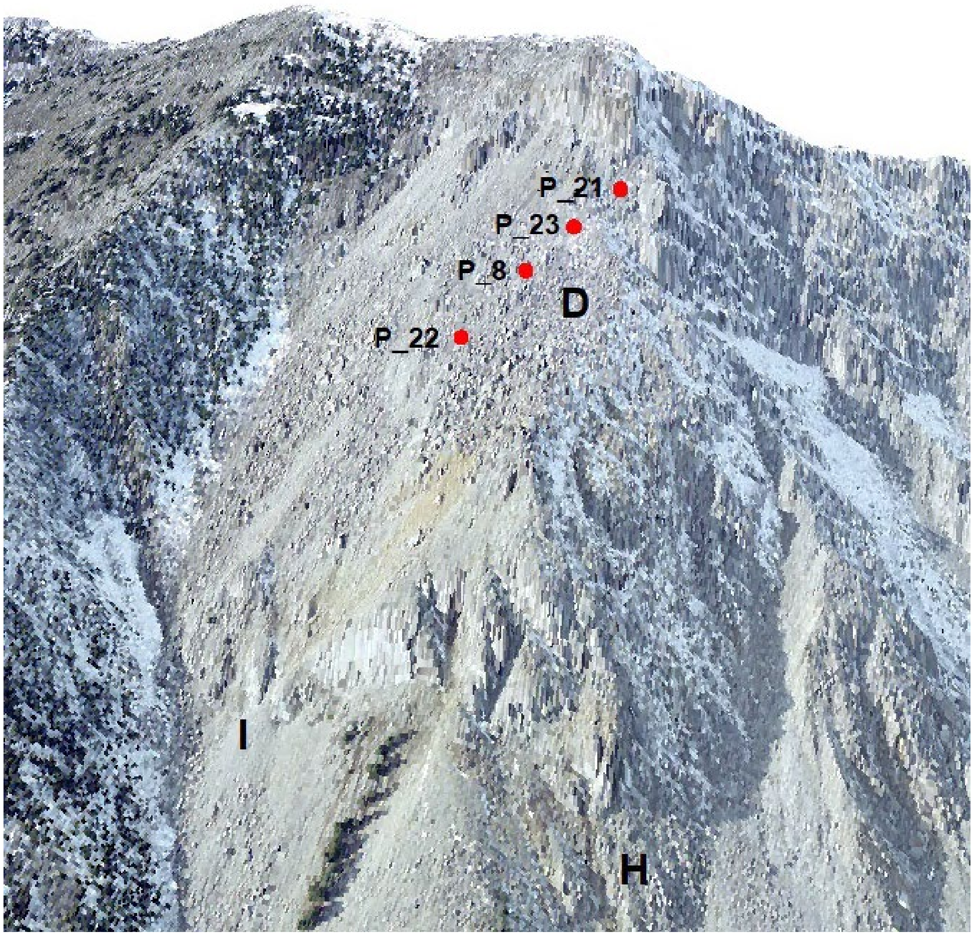

Figure 6. In region D, data from points of interest P_8 and P_21 to P_23 provide a better understanding of displacements in the area, Turtle Mountain, southwestern Alberta.

Table 5. LiSAmobile generalized displacement in regions of interest from June 20, 2014, to the end of the quarterly reporting period (Q) 33 on September 20, 2022 (3014 days).

Region	Location Description	Displacement (mm)	Approximate Region Area (m^2)
A	Close to North Peak	≤56.0	3405
B	Between North and South peaks	≤3.3	3034
C	Close to South Peak	≤70.6	8031
D	Below South Peak	≤76.0	10030
E	Debris area toe of North Peak rock wall	≤6.7	12928
F	Mid to lower vegetated rock wall	-	2865
G	Debris zone runout area	≤122.6	11494
H	Elongated channel (right) to the valley	≤284.0	17718
I	Elongated channel (left) to the valley	≤192.2	8684

Table 6. LiSAmobile measured displacement at points of interest (POI) from June 20, 2014, to September 20, 2022 (3014 days), with observations specific to quarterly reporting period (Q) 33.

Region	Point of Interest (POI)	Displacement (mm)	Displacement Description Specific to Q33
A	P_1 to P_4	42.7 to 225.8	Generalized stability in Q33.
B	P_5	≤15.9	Generalized stability and only minor fluctuations in Q33.
C	P_6 and P_7	8.9 to 128.7	Generalized stability and only minor fluctuations in Q33.
D	P_8, P_21 to P_23	55.7 to 74.4	Generalized stability for P_21 to P_23 and slight negative displacement at P_8, up to 7 mm, likely influenced by debris in Q33.
E	P_9, P_10, and P_17	≤209.9	Generalized stability in Q33.
F	P_11	-	Data is omitted due to errors introduced by atmospheric moisture within the line of sight or presence of vegetation.
G	P_12	≤123.8	Generalized stability with minor negative displacement in Q33.
H	P_18	≤363.8	Generalized stability in Q33.
I	P_20	≤185.1	Generalized stability in Q33. Small displacements likely associated with debris movement in the quarter.

Annual analyses since 2014 have identified an area with a very slow rate of displacement below region C, between South and Third peaks. In 2016, Ellegi determined this block was in fact two different blocks moving with similar behaviours. In 2018, Ellegi identified an additional third area with a very slow rate of displacement over a larger area near region A, close to North Peak. Ellegi was able to evaluate the displacement rates within region A, identifying small-scale movements over a larger area (large block movements). In 2019, both upper and lower blocks near region C continued to exhibit a slow rate of displacement, whereas the third area near region A was moving slower than in 2017–2018.

Analyses of these areas have a one-year time frame, comparing the results from September of one year to those from September of the previous year. Ellegi states results are highly influenced by local effects, the size of the area chosen (large versus small), and whether pixel values are precisely measured or averaged. In addition, snow accumulation from late fall to early spring introduces noise in the readings, producing fluctuations in the time series. Filtering algorithms are applied to reduce the noise but can not eliminate it completely.

The lower block below region C had peaked at a displacement value around −1.5 mm in 2019–2020 and displayed a very similar displacement pattern as in 2018–2019. The upper block in region C and the smaller block near region A exhibited an annual average displacement of −3.0 mm with peaks around −5.0 mm in 2019–2020. Both blocks continued to display a very slow rate of displacement that peaked at around −3.5 mm in 2020–2021.

In 2022, an analysis of the upper block below region C was completed for the period from September 19, 2021, to September 19, 2022. Its average displacement was approximately −0.9 mm with isolated peaks at around −3.0 mm. In addition, there were small displacements between −3 and −5 mm (Figure 7) at the ridge. These displacements were mostly concentrated in regions A (average of −1.5 mm and peak at −5 mm) and C (average of −1.1 mm and peak at −5 mm). The remaining portion of the mountain side, with the exception of the debris area that had experienced relative rapid movements, was stable. The results of this annual analysis are very similar to those for the 2020–2021 period.

This study confirms the belief that overall large block movements are extremely small. It provides assurance that the LiSAmobile system has the capability to identify and record data points for both large block movement and smaller natural rockfalls. Ellegi will complete another investigative study on these areas after collecting and compiling data for another year.

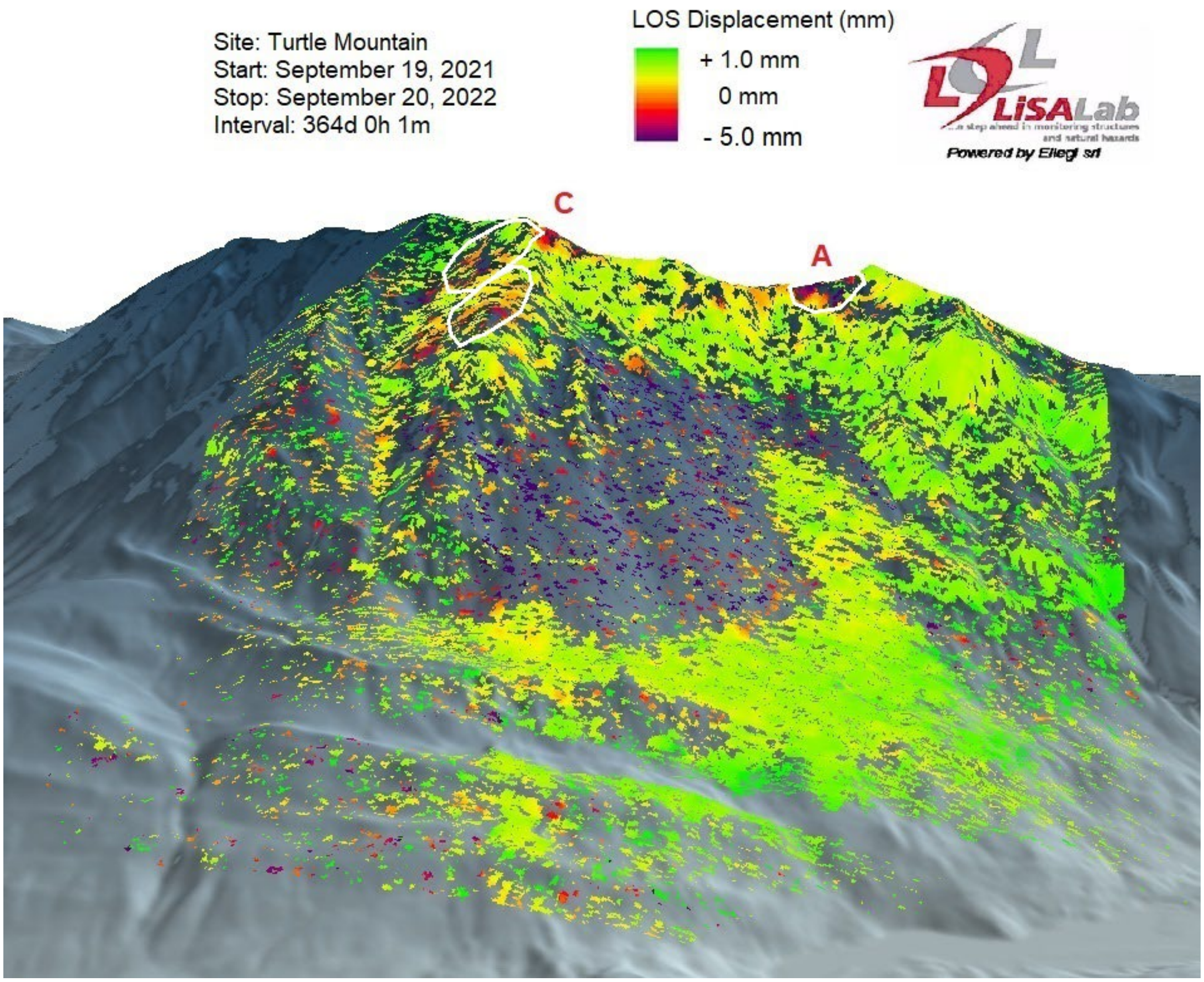

Figure 7. The line-of-sight (LOS) three-dimensional (3D) displacement map of Turtle Mountain, southwestern Alberta, shows the annual analysis of areas of large block movements (outlined in white) near regions A and C, from September 19, 2021, to September 20, 2022 (364 days [d], 0 hours [h], 1 minute [m]).

3.2.4 Report to the End of Q34

The overall general displacements in Q34 were attributed to snow accumulation and there was no evidence for displacement on the rock walls (Table 7). At the beginning of September, the only significant displacement occurred in the debris area (Table 8). Snow began to accumulate on the mountain slope in mid-October causing the measured displacement data to be less representative of the overall behaviour of rock movement. In addition, measurements at most POIs in Q34 were also subject to errors due to atmospheric moisture, such as heavy rain, snowfall, and fog. The displacements at P_18 and P_20 were prominently associated with debris and snow movements in the channels towards the valley bottom. The Crowsnest Pass area is known for large amounts of snow accumulation during the winter months. The cumulative displacement map (2014 to 2022; Figure 5a) shows the largest part of the deformation occurred in the debris zone.

Table 7. LiSAmobile generalized displacement in regions of interest from June 20, 2014, to the end of the quarterly reporting period (Q) 34 on December 20, 2022 (3106 days).

Region	Location Description	Displacement (mm)	Approximate Region Area (m^2)
A	Close to North Peak	≤61.9	3405
B	Between North and South peaks	≤10.8	3034
C	Close to South Peak	≤78.3	8031
D	Below South Peak	≤75.3	10030
E	Debris area toe of North Peak rock wall	≤4.9	12928
F	Mid to lower vegetated rock wall	-	2865
G	Debris zone runout area	≤129.2	11494
H	Elongated channel (right) to the valley	≤288.4	17718
I	Elongated channel (left) to the valley	≤198.7	8684

Table 8. LiSAmobile measured displacement at points of interest (POI) from June 20, 2014, to December 20, 2022 (3106 days), with observations specific to quarterly reporting period (Q) 34.

Region	Point of Interest (POI)	Displacement (mm)	Displacement Description Specific to Q34
A	P_1 to P_4	49.7 to 232.7	Generalized stability until early November. After this date, fluctuations caused by snow cover in Q34.
B	P_5	≤24.6	Generalized stability until early November. After this date, fluctuations caused by snow cover in Q34.
C	P_6 and P_7	17.7 to 134.1	Generalized stability with only minor fluctuations in Q34.
D	P_8, P_21 to P_23	48.9 to 76.3	Generalized stability until early November. After this date, fluctuations caused by snow cover in Q34.
E	P_9, P_10, and P_17	≤209.3	Generalized stability with minor fluctuations in Q34.
F	P_11	-	Data is omitted due to errors introduced by atmospheric moisture within the line of sight or presence of vegetation.
G	P_12	≤118.6	Generalized stability in Q34.
H	P_18	≤370.6	Negative displacement associated with snow movement in Q34.
I	P_20	≤177.3	Positive displacement influenced by snow cover in Q34.

4 Supporting Studies and Research

During 2022, no secondary monitoring campaign was selected for supporting studies and research, because a LiDAR survey had been conducted in 2021 (Chao, 2023). The AGS selects secondary campaigns based on monitoring frequency and supplementary monitoring is predetermined on an annual basis. A summary of this type of selection system is defined in Wood et al. (2017a).

5 Turtle Mountain Year-in-Review

Two time-lapse videos were produced by the AER showing a 12-month cycle of video clips taken daily at noon from the Bellevue and South Peak webcam video streams. These videos were created for educational purposes, to display the data collected from the tertiary monitoring system (web cameras), and to illustrate the daily changes on Turtle Mountain throughout the year. Links to the 2022 annual videos are available for download on the AGS website (https://ags.aer.ca/research-initiatives/turtle-mountain-webcams). In addition, both videos are available for streaming on YouTube: Bellevue at https://www.youtube.com/watch?v=Wk0cGxxQ-m0 and South Peak at https://www.youtube.com/watch?v=lr5bht3K71s.

6 Conclusions

Recent application of monitoring and modelling technologies has greatly increased the understanding of the existing rock-slope hazard at Turtle Mountain. The rate of displacement for large blocks is low and has remained substantially constant over the last decade of monitoring.

The Alberta Geological Survey will continue to work with Ellegi srl for maintenance and upgrades to LiSAmobile. At the end of each year, an internal review of LiSAmobile and its data is conducted and the program's monitoring needs for the next year are assessed. This assessment will help with planning for the next year. Different forms of monitoring systems continue to be investigated.

Communication of the monitoring effort is also ongoing. The Alberta Geological Survey publishes the results in annual reports (e.g., Wood and Chao, 2019, 2020; Chao, 2022, 2023). The Alberta Geological Survey continues to collaborate with the Municipality of Crowsnest Pass council members and staff to provide information on the Turtle Mountain Monitoring Program. Updates are also available on the 'Turtle Mountain Monitoring Program' page of the Alberta Geological Survey website (https://ags.aer.ca/research-initiatives/turtle-mountain).

7 References

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