AER/AGS Open File Report 2023-03

Turtle Mountain Field Laboratory, Alberta (NTS 82G): 2021 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, 2021. 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. Since that time, Turtle Mountain has been the site of ongoing monitoring and research focused on understanding the structure and kinematics of movements on the unstable eastern slopes. As this site provides a rich dataset and optimal conditions for the application of new and evolving warning characterization technologies, the site has been termed the 'Turtle Mountain Field Laboratory'.

As part of this responsibility, 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 2021. This includes a summary of system performance and reliability.
- The second section provides analysis and interpretation of data 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 2021.

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, to 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 2021.

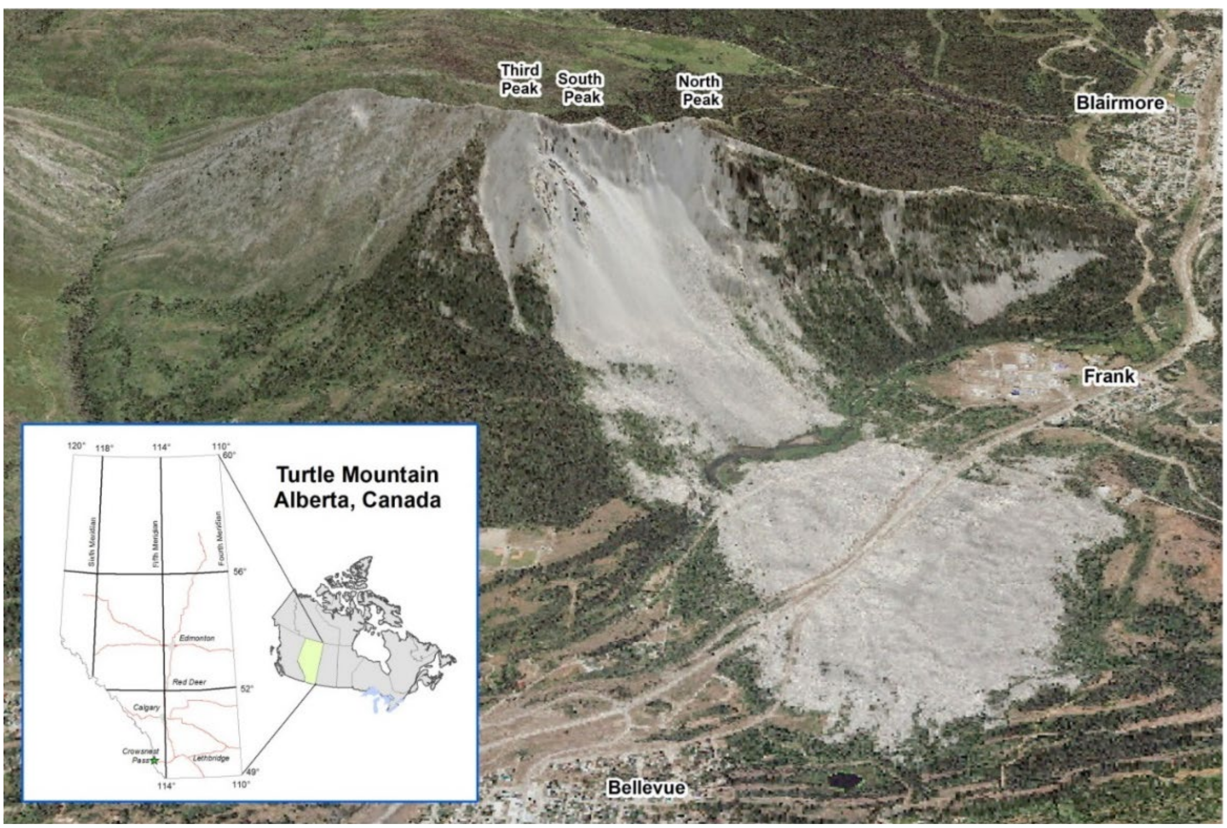

Figure 1. Location of Turtle Mountain in southwestern Alberta and full-extent aerial view of the Frank Slide.

The AGS leases a 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 (Figure 2). In addition, the AGS supports secondary monitoring campaigns periodically. 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. In 2021, an airborne LiDAR survey was selected for supporting studies and research (Section 4).

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 license from Industry Canada that allows them to operate the TMMS network link without interference from other frequencies in the surrounding Crowsnest Pass area.

2.1 Repairs and Maintenance

Ellegi was unable to conduct regular annual maintenance in 2021 due to international border closures and travel restrictions during the COVID-19 outbreak. However, the mechanical components of LiSAmobile were examined and fully tested in Italy by Ellegi following the repair of the equipment in April 2020. For additional information, refer to Chao (2022).

3 Data Collection and Analysis

3.1 LiSAmobile Ground-Based InSAR Collection

LiSAmobile was installed at the Bellevue pump house in June 2014 to monitor small displacements on the eastern face of Turtle Mountain. The LiSAmobile GB-InSAR (Figure 3) uses the 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, which range from positive to negative values (Figure 4). Positive values (blue colours) indicate displacement away from the sensor, whereas negative values (red colours) indicate displacement towards the sensor.

3.2 Discussion and Interpretation of Monitoring Data from LiSAmobile

The displacement map displayed in Figure 4 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 2021 and are provided by Ellegi to the AGS in quarterly reports (quarterly reporting period [Q] 27 to Q30 for 2021). Each report contains the cumulative data starting from June 20, 2014, to the end of the respective quarterly reporting period.

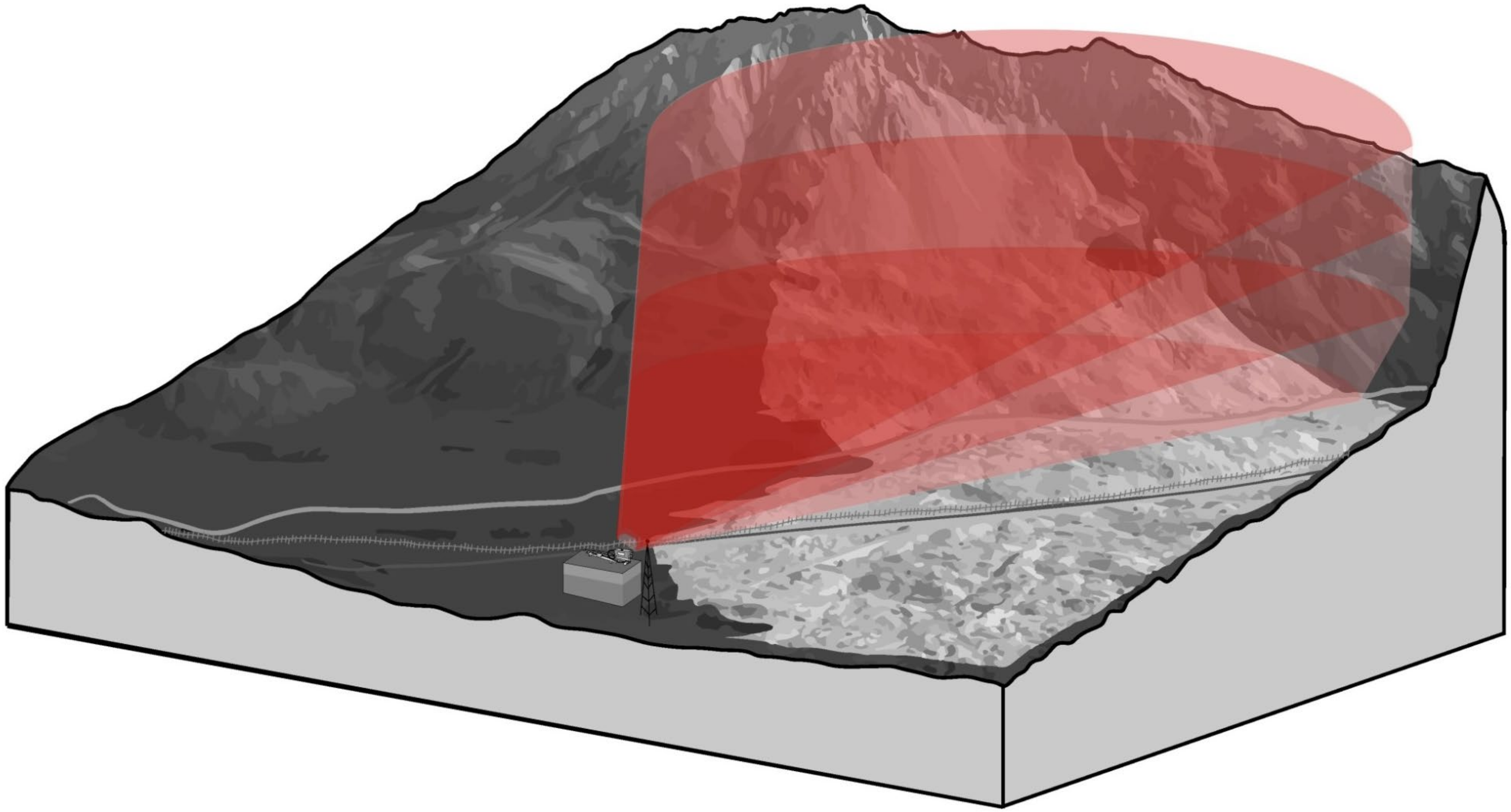

Figure 2. Overview, as of December 2021, of the primary monitoring equipment at Turtle Mountain, southwestern Alberta. The drawing marks the location of the LiSAmobile system, and the red beam depicts the scanning of the mountain. The light grey area represents the extent of the original 1903 slide. The image is not drawn to scale, and its purpose is to highlight the area LiSAmobile scans.

Figure 3. LiSAmobile system without radome (housing structure), Turtle Mountain, southwestern Alberta.

The data are divided into nine regions of interest (A–I; Figure 4), which are further subdivided into 17 points of interest (POIs, labelled P_1 through P_12, P_18, and P_20 through P_23 in Figure 4). Regions H and I, and POIs P_18 and P_20 belong to the morphologically connected channels that extend to the valley bottom below region D (below South Peak). They were added to the data collection in February 2020 after displacements were observed in December 2019. Additional documentation of the LiSAmobile parameters can be found in Wood et al. (2016). Points of interest P_21 to P_23 were added to region D in June 2021 after displacements were observed in the previous month.

The high displacement rates detected in the vegetation zone (region F, Figure 4) are considered to be measurement errors introduced by atmospheric moisture, snow cover, or vegetation within the line of sight and for this reason they have been excluded.

The results from the Q27 to Q30 reporting periods provided to the AGS by Ellegi are shown in Tables 1 through 8. Generalized displacement in the regions of interest for the period from June 20, 2014, to the end of the respective quarterly reporting period (i.e., Q27, Q28, Q29, Q30) is 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 4, 7, and 8), 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 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). The AGS monitors all displacement movements (blue, red, and green) reported by Ellegi.

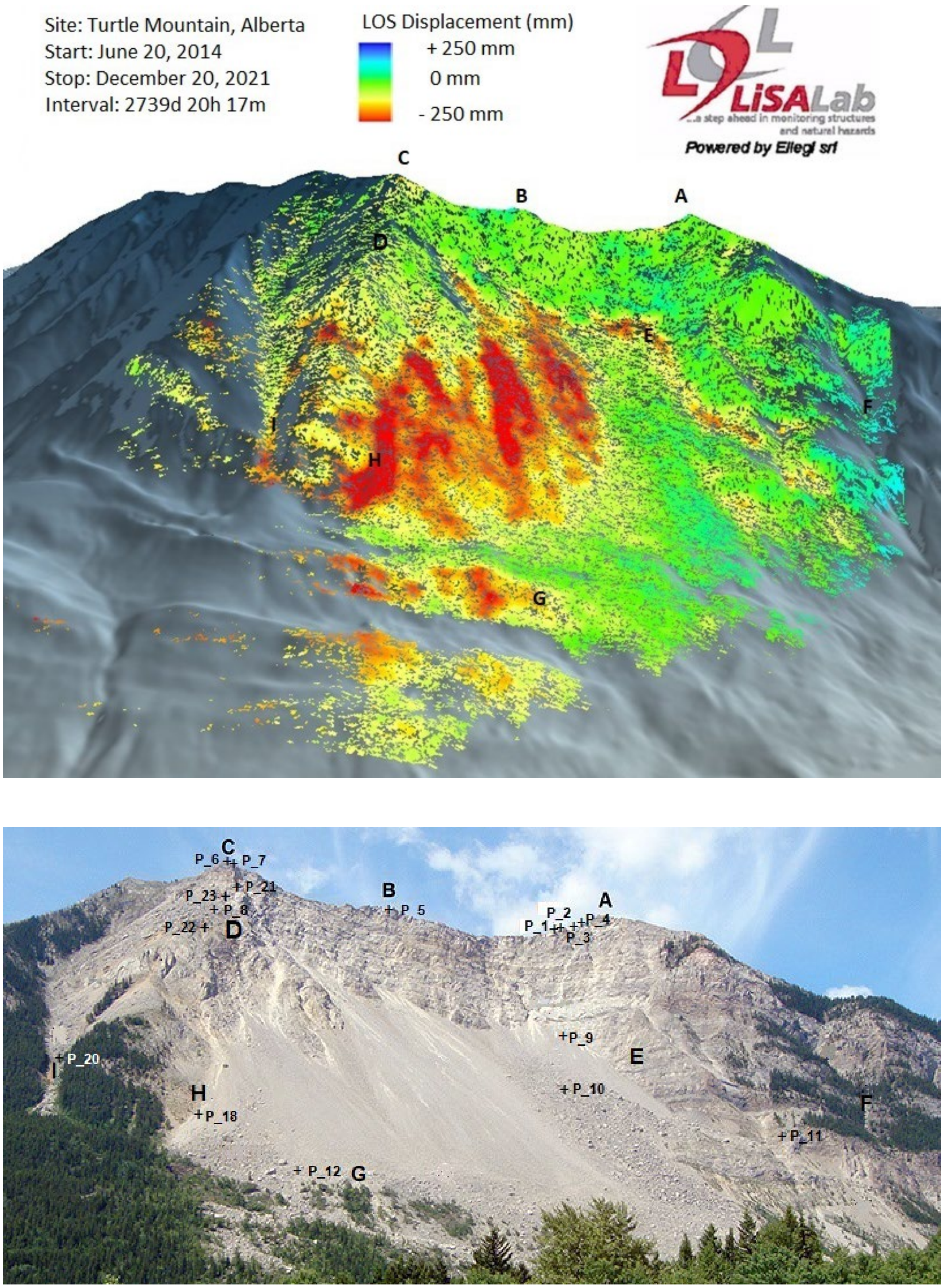

Figure 4. Three-dimensional (3D) displacement map (top) measured from June 20, 2014, to December 20, 2021, and view of the eastern face of Turtle Mountain, southwestern Alberta (bottom). Letters A to I denote the locations of regions of interest. Letters P_1 through P_12, P_18, and P_20 through P_23 denote points of interest. Abbreviations: d, day; h, hour; LOS, line of sight; m, minute.

3.2.1 Report to the End of Q27

Generalized displacement in Q27 for regions A to I was relatively unchanged compared to Q26. Slight displacements were observed throughout Q27 for most of the POIs, most likely due to dynamic snowpack in the regions. The Crowsnest Pass area is subject to large amounts of snow accumulation during winter months that can affect the data.

Table 1. LiSAmobile generalized displacement in regions of interest for quarterly reporting period (Q) 27, from June 20, 2014, to March 31, 2021 (2476 days).

Region	Location Description	Displacement (mm)	Approximate Region Area (m^2)
A	Close to North Peak	≤47.7	3405
B	Between North and South peaks	≤0.0	3034
C	Close to South Peak	≤61.3	8031
D	Below South Peak	≤48.3	10030
E	Debris area toe of North Peak rock wall	≤0.8	12928
F	Mid to lower vegetated rock wall	-	2865
G	Debris zone runout area	≤112.4	11494
H	Elongated channel (right) to the valley	≤233.7	17718
I	Elongated channel (left) to the valley	≤168.5	8684

Table 2. LiSAmobile measured displacement at points of interest (POI) for the period from June 20, 2014, to March 31, 2021 (2476 days), with observations specific to quarterly reporting period (Q) 27.

Region	Point of Interest (POI)	Displacement (mm)	Displacement Descriptions Specific to Q27
A	P_1 to P_4	28.4 to 203.7	Negative displacements in Q27, subject to errors due to snow cover.
B	P_5	≤10.0	Small fluctuations throughout Q27, subject to errors due to snow cover.
C	P_6 and P_7	10.0 to 119.3	Stablization observed in Q26 and continued throughout Q27.
D	P_8	40.6 to 50.7	No remarkable displacement throughout Q27.
E	P_9 and P_10	≤166.8	No remarkable displacement in Q27.
F	P_11	-	Data are excluded due to errors introduced by atmospheric moisture, snow cover, or vegetation in the instrument's line of sight.
G	P_12	≤109.9	Stabilization observed in Q27.
H	P_18	≤319.1	Accelerated negative displacement possibly caused by snow gliding and debris creep.
I	P_20	≤168.5	Accelerated negative displacement possibly caused by snow gliding.

3.2.2 Report to the End of Q28

Generalized displacement for all regions was minor in Q28. Measured displacements at some POIs were subject to errors due to snow cover and atmospheric moisture, such as heavy rainfall or fog. The Q28 report marks the end of seven years since installation of the LiSAmobile system in 2014.

Table 3. LiSAmobile generalized displacement in regions of interest for quarterly reporting period (Q) 28, from June 20, 2014, to June 20, 2021 (2557 days).

Region	Location Description	Displacement (mm)	Approximate Region Area (m^2)
A	Close to North Peak	≤53.0	3405
B	Between North and South peaks	≤3.6	3034
C	Close to South Peak	≤62.9	8031
D	Below South Peak	≤54.5	10030
E	Debris area toe of North Peak rock wall	≤2.4	12928
F	Mid to lower vegetated rock wall	-	2865
G	Debris zone runout area	≤115.2	11494
H	Elongated channel (right) to the valley	≤246.7	17718
I	Elongated channel (left) to the valley	≤177.4	8684

Table 4. LiSAmobile measured displacement at points of interest (POI) for the period from June 20, 2014, to June 20, 2021 (2557 days), with observations specific to quarterly reporting period (Q) 28.

Region	Point of Interest (POI)	Displacement (mm)	Displacement Descriptions Specific to Q28
A	P_1 to P_4	33.6 to 206.8	Stabilized with only minor negative displacements and no significant acceleration observed in Q28.
B	P_5	≤10.6	Fluctuations continued throughout Q28, likely due to snow cover changes.
C	P_6 and P_7	12.1 to 128.5	Trend of stabilization continued throughout Q28.
D	P_8, P_21 to P_23	44.9 to 53.7	No remarkable displacement throughout Q28.
E	P_9 and P_10	≤184.2	P_9 experienced minor fluctuations from dynamic snowpack and P_10 continued to be stable throughout Q28.
F	P_11	-	Data are excluded due to errors introduced by atmospheric moisture, snow cover, or vegetation in the instrument’s line of sight.
G	P_12	≤111.5	Trend of stabilization continued throughout Q28.
H	P_18	≤327.3	Slower rate of displacement in Q28 compared to Q27.
I	P_20	≤170.6	Slower rate of displacement in Q28 compared to Q27.

Region D has been exhibiting slow rates of displacement since 2014 (Chao, 2022). Three new additional POIs (P_21, P_22, and P_23) were added to this area in Q28. Together with the original P_8, they form a straight line from region D along the upper part of the crest towards regions H and I (Figure 5). Measurements from these POIs will provide a better understanding of this area. Ellegi reported that the displacements at P_21 to P_23 started to stabilize at the beginning of May. This stabilization may indicate the disappearance of snow and reflect the stable behaviour of largely static rock instead of a more dynamic snowpack.

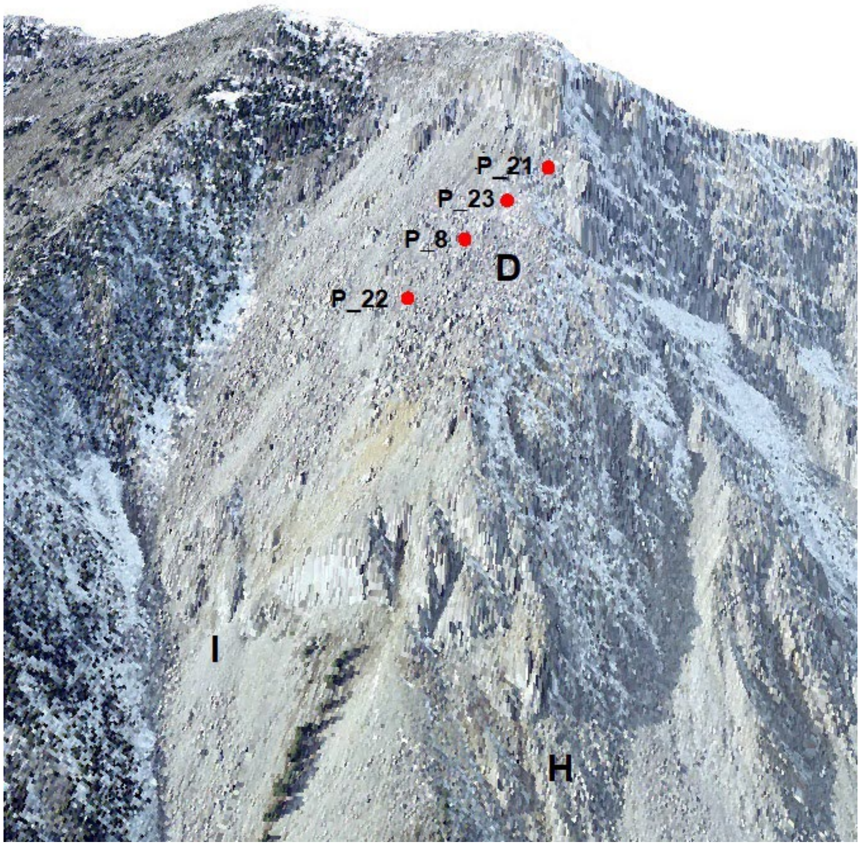

Figure 5. In region D, points of interest P_8 and P_21 to P_23 form a straight line along the upper part of a crest towards regions H and I below, Turtle Mountain, southwestern Alberta. Data collected will provide a better understanding of this area.

3.2.3 Report to the End of Q29

In Q29, generalized displacement for all regions and measured placements at POIs were stable or slowing down. Ellegi noted that the slowing down at P_18 and P_20 since Q28 is likely related to debris creep. Ellegi also noticed that strong atmospheric effects reflected in the data might be linked to forest fires. The effected data were removed from the dataset before measurements were calculated.

Table 5. LiSAmobile generalized displacement in regions of interest for quarterly reporting period (Q) 29, from June 20, 2014, to September 20, 2021 (2649 days).

Region	Location Description	Displacement (mm)	Approximate Region Area (m^2)
A	Close to North Peak	≤53.7	3405
B	Between North and South peaks	≤3.1	3034
C	Close to South Peak	≤64.8	8031
D	Below South Peak	≤53.8	10030
E	Debris area toe of North Peak rock	≤2.2	12928
F	Mid to lower vegetated rock wall	-	2865
G	Debris zone runout area	≤116.2	11494
H	Elongated channel (right) to the valley	≤249.2	17718
I	Elongated channel (left) to the valley	≤179.9	8684

Table 6. LiSAmobile measured displacement at points of interest (POI) for the period from June 20, 2014, to September 20, 2021 (2649 days), with observations specific to quarterly reporting period (Q) 29.

Region	Point of Interest (POI)	Displacement (mm)	Displacement Descriptions Specific to Q29
A	P_1 to P_4	35.1 to 208.7	Stabilized with only minor negative displacements and no significant acceleration observed in Q29.
B	P_5	≤12.2	No remarkable movement throughout Q29.
C	P_6 and P_7	9.1 to 127.2	No remarkable movement throughout Q29.
D	P_8, P_21 to P_23	44.0 to 53.0	No remarkable movement throughout Q29.
E	P_9 and P_10	≤187.4	No remarkable movement throughout Q29.
F	P_11	-	Data are excluded due to errors introduced by atmospheric moisture, snow cover, or vegetation in the instrument's line of sight.
G	P_12	≤110.8	No remarkable movement throughout Q29.
H	P_18	≤328.5	Visible slowing down of movement throughout Q29.
I	P_20	≤170.9	Continued slowing of rate of displacement throughout Q29.

Annual analyses collected since 2014 identified an area with a very slow rate of displacement near region C, between South and Third peaks. In 2016, Ellegi determined this block was in fact two different blocks moving with similar behaviours (Figure 6). 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 this region, 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, while 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 one year to the previous. Ellegi states results are influenced by the size of the area chosen (large versus small) and whether pixel values are precisely measured or averaged and, therefore, are subjective. The lower block below region C had peaked at around –1.5 mm in 2019–2020 and displayed a very similar displacement pattern as 2018–2019. The upper block in region C and smaller block near region A exhibited an annual average displacement of –3.0 mm with peaks around –5.0 mm in 2019–2020.

In 2021, an analysis of the same areas was completed for September 19, 2020, to September 19, 2021. Both upper and lower blocks near region C continued to display a very slow rate of displacement that peaked at around –3.5 mm (Figure 6). Together, regions A and C had an average displacement of about –3 mm with peaks at around –16 mm (Figure 7).

This study confirms the belief that overall large block movements are extremely small. This 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. This data will be compared to that of the previous year to monitor and investigate large block movements.

Figure 6. The upper and lower blocks (outlined in blue) near region C continued to display a slow rate of displacement, Turtle Mountain, southwestern Alberta.

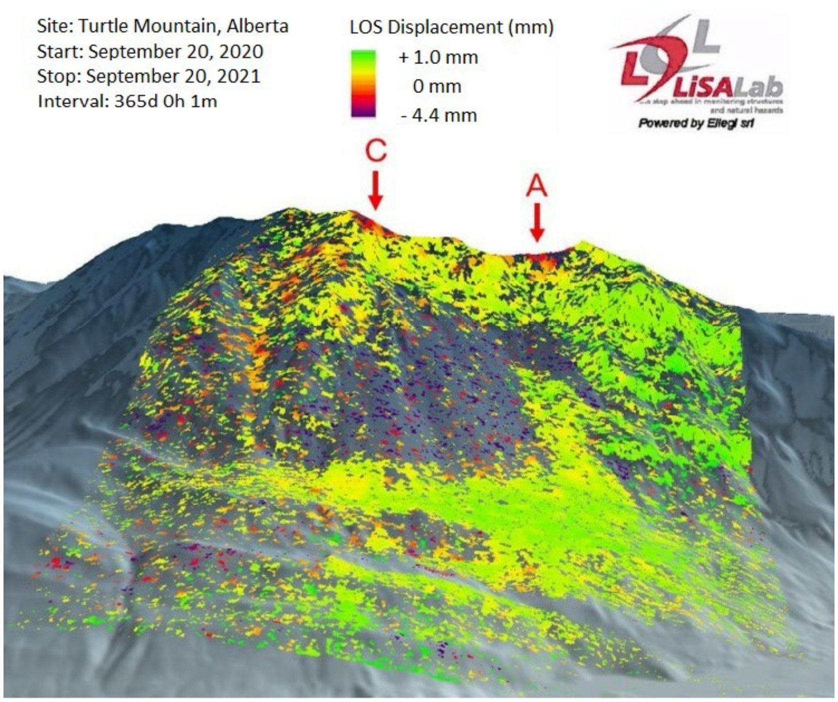

Figure 7. The line-of-sight (LOS) three-dimensional (3D) displacement map of Turtle Mountain, southwestern Alberta, shows the annual analysis of large block movements near regions A and C, from September 20, 2020, to September 20, 2021 (365 days, 0 hours, 1 minute).

3.2.4 Report to the End of Q30

Generalized displacements in Q30 for all regions accelerated minimally from Q29, but otherwise generally showed stable (unchanged) rates of displacement during Q30. Measured displacements at some POIs were subject to errors due to atmospheric moisture, such as heavy rainfall, fog, and accumulating snow cover. The Crowsnest Pass area is known for large amounts of snow accumulation during the winter months. Since the beginning of monitoring in 2014, the debris zones and the channel on the right that leads to the valley (i.e., regions E, G, and H) have experienced the highest generalized displacement from snow cover changes amongst all the regions (Figure 8).

Table 7. LiSAmobile generalized displacement in regions of interest for quarterly reporting period (Q) 30, from June 20, 2014, to December 20, 2021 (2740 days).

Region	Location Description	Displacement (mm)	Approximate Region Area (m^2)
A	Close to North Peak	≤56.2	3405
B	Between North and South peaks	≤6.9	3034
C	Close to South Peak	≤64.8	8031
D	Below South Peak	≤60.9	10030
E	Debris area toe of North Peak rock	≤1.6	12928
F	Mid to lower vegetated rock wall	-	2865
G	Debris zone runout area	≤120.9	11494
H	Elongated channel (right) to the valley	≤257.4	17718
I	Elongated channel (left) to the valley	≤180.3	8684

Table 8. LiSAmobile measured displacement at points of interest (POI) for the period from June 20, 2014, to December 20, 2021 (2740 days), with observations specific to quarterly reporting period (Q) 30.

Region	Point of Interest (POI)	Displacement (mm)	Displacement Descriptions Specific to Q30
A	P_1 to P_4	41.8 to 212.3	Some positive displacements with one acceleration at P_4 at the end of October caused by snowpack.
B	P_5	≤7.4	Some positive displacement with one acceleration at the end of October caused by snowpack.
C	P_6 and P_7	12.5 to 133.3	Acceleration at the end of October caused by snowpack.
D	P_8, P_21 to P_23	47.4 to 57.0	No significant displacements throughout Q30 with one acceleration at the end of October caused by snowpack.
E	P_9 and P_10	≤198.1	Small displacements at P_9 and stabilization at P_10 in Q30.
F	P_11	-	Data are excluded due to errors introduced by atmospheric moisture, snow cover, or vegetation in the instrument's line of sight.
G	P_12	≤119.6	Stable throughout Q30.
H	P_18	≤335.8	Acceleration in December caused by snowpack.
I	P_20	≤174.3	Very slow and constant rate of movement throughout Q30.

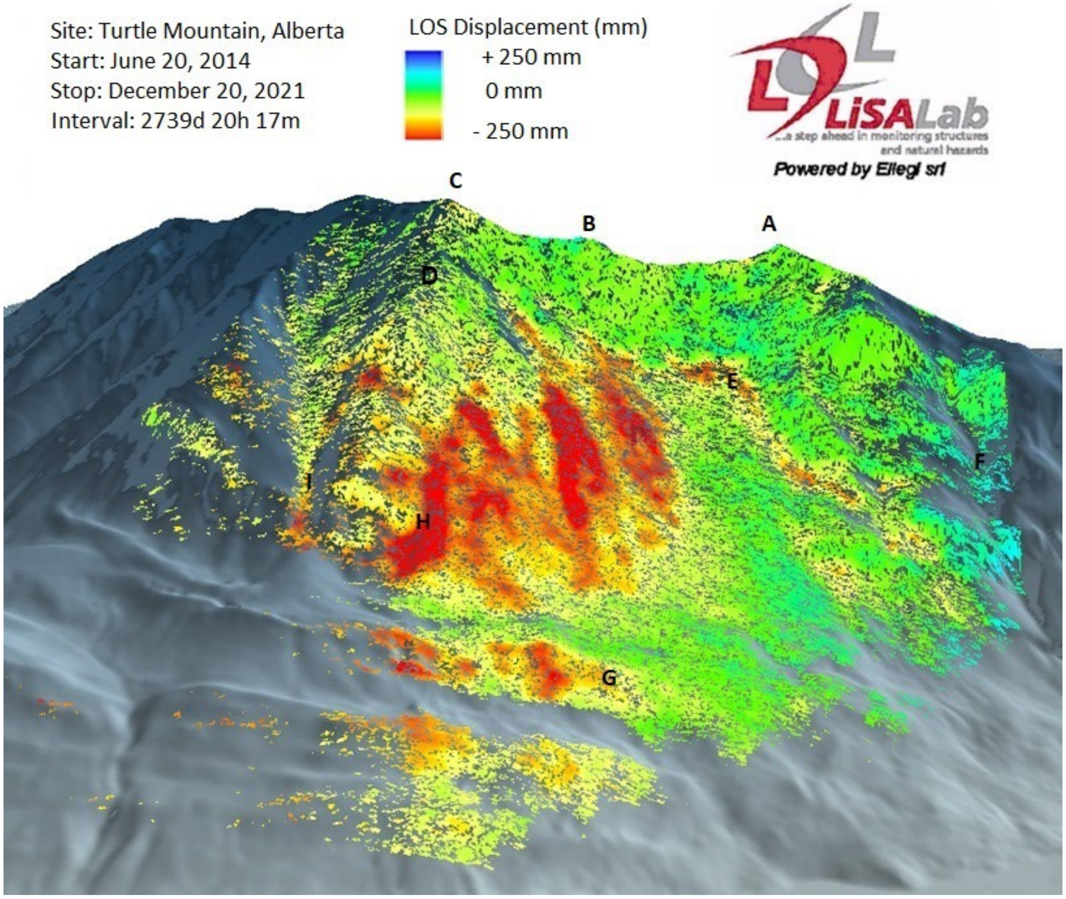

Figure 8. The line-of-sight (LOS) three-dimensional (3D) displacement map of Turtle Mountain, southwestern Alberta, measured from June 20, 2014, to December 20, 2021 (2739 days, 20 hours, 17 minutes). Letters indicate regions of interest.

4 Supporting Studies and Research

The AGS conducted an airborne LiDAR survey in July 2021 as a secondary monitoring campaign. The areal extent of the survey covers 7.32 km^2 including both eastern and western slopes of the Turtle Mountain, part of Frank Industrial Park to the north, and south of South Peak (Figure 9). This very high resolution image with a 50 by 50 cm cell size will be used as baseline data when calculating rock displacements from similar LiDAR surveys in the future. The data will complement LiSAmobile data analysis as it will cover areas that are out of LiSAmobile monitoring range. The AGS plans to repeat a similar survey every two to three years depending on funding.

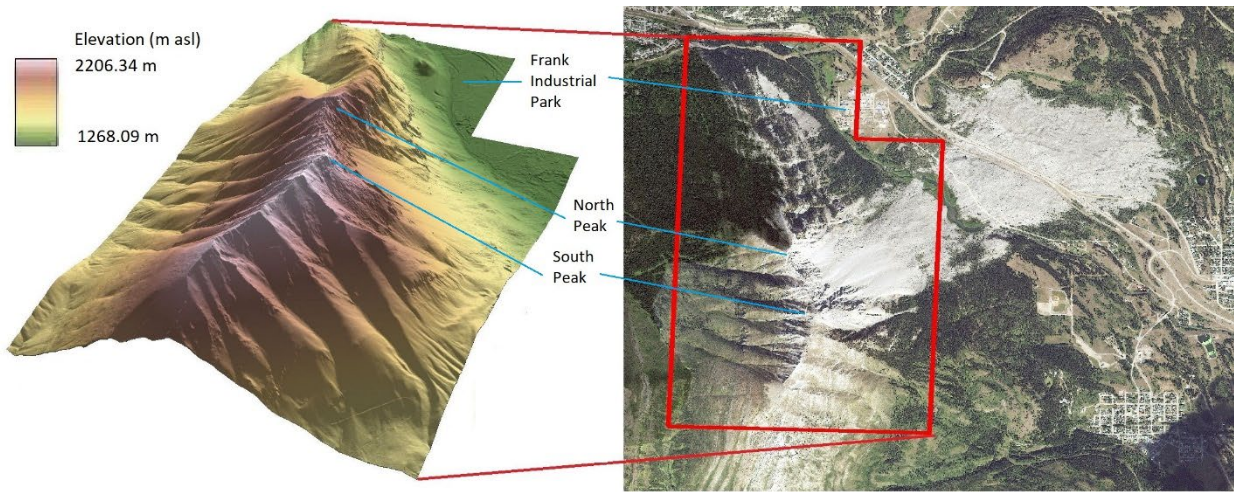

Figure 9. The right image shows the areal coverage of the airborne light detection and ranging (LiDAR) survey conducted in July 2021 at Turtle Mountain, southwestern Alberta (SPOT 7 image © 2022 Planet Labs PBC). The left image shows the digital elevation model of the area derived from the LiDAR data.

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 2021 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=alG3FcY88es and South Peak at https://www.youtube.com/watch?v=aXuxCwSQ91U.

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 risks associated with these hazards to the affected population is also ongoing. The most recent results are published annually (Warren et al., 2014, 2016; Wood et al., 2016, 2017a, b, 2018a, b; Yusifbayov et al., 2018; Wood and Chao, 2019, 2020; Chao, 2022) and presented in public meetings. 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).

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