AER/AGS Open File Report 2020-07

Turtle Mountain Field Laboratory, Alberta (NTS 82G): 2019 Data and Activity Summary

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A special thanks to Ellegi srl who provided the scientific review of the LiSAmobile section.

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, 2019. The TMMS is a near–real-time remote monitoring system that provides data from a network of sensors and monitoring campaigns on Turtle Mountain, located in the Crowsnest Pass of southern 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 five main sections:

- The first section contains information about the significant changes to the TMMS’s network during 2019. This includes a review of the main repair and maintenance activities and a summary of system performance and reliability.
- The second section provides the analysis and interpretation of data from the primary monitoring equipment, known as LiSAmobile.
- The third section discusses supporting studies and research.
- The fourth section contains information on the emergency preparedness documentation and collaborations with external government agencies on the Turtle Mountain Monitoring Program. In addition, the Alberta Energy Regulator (AER) hosted an internal workshop on emergency response principles and best practices.
- The last section features information on two videos produced by the AER to highlight work completed on Turtle Mountain in 2019.

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 (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, the reader may 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 slowly 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.

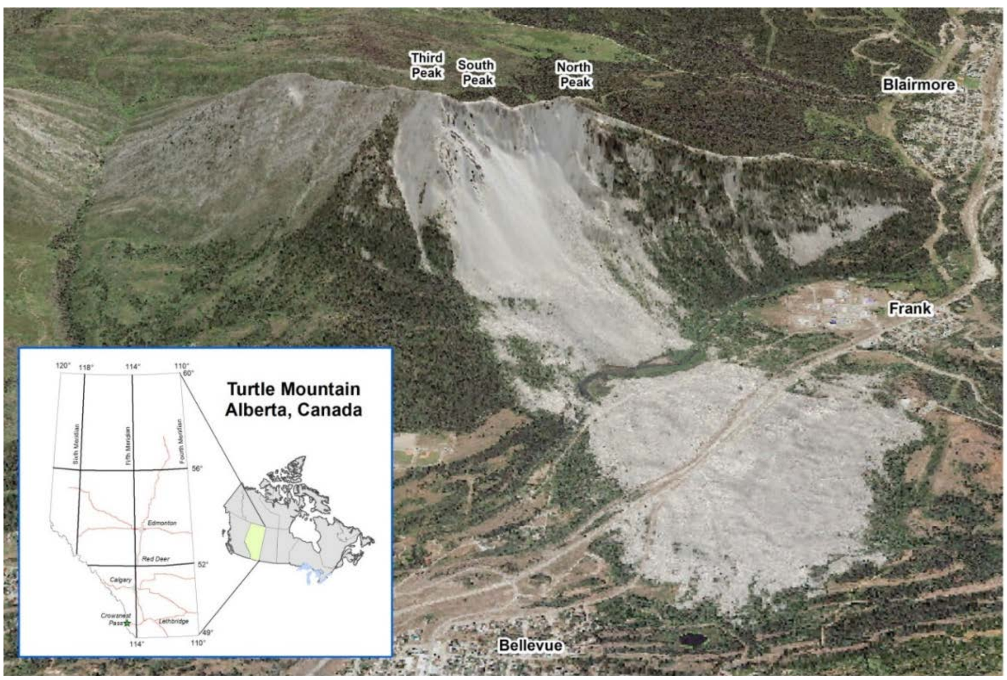

Figure 1. Location of Turtle Mountain in southwestern Alberta and full-extent aerial view of the Frank Slide.

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 2019.

The main activities undertaken concerning the sensor network during 2019 included

- annual maintenance of the wireless radio network, and
- annual LiSAmobile ground-based interferometric synthetic aperture radar (GB-InSAR) equipment maintenance.

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 since then. The AGS's lease with Ellegi provides customer service and technical support in case of emergency or equipment changes.

In 2016, LiSAmobile was transitioned from being the secondary monitoring system to the primary monitoring system (Figure 2). In addition, AGS also uses secondary monitoring campaigns. These secondary monitoring campaigns, such as aerial light detection and ranging (LiDAR) scanning, photogrammetry, terrestrial laser scanning (TLS), etc. are selected by the AGS based on monitoring frequency. In 2019, no secondary monitoring campaign 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. During 2019, LiSAmobile continued to provide high-quality data with little to no interruption. Ellegi continues to provide a premium level of technical support, innovative shelter technology, and timely detailed reporting. AGS will continue to utilize LiSAmobile as the primary monitoring sensor.

The AGS has a radio license from Industry Canada that allows us to operate the 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 2019, an annual maintenance campaign was conducted in mid-June that included a joint team from Ellegi and the AGS. The field maintenance objectives included

- inspection of the radome (housing structure) for any structural or waterproofing issues,
- examination of all power and communication cables,
- mechanical maintenance on the radar head with lubrication of moving parts,
- internal radome cover and gasket checks,
- replacement of damaged chain cable,
- replacement of stepper motor controller and serial-to-lan converter,
- inspection of the power box,
- removal of dust and lubrication of the drive belt and instrument components,
- replacement of various filters,
- upgrade the 'stop&go' to 'continuous' images acquisition mode,
- evaluation of the radio frequency, and
- mechanical shut-down and restart testing.

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, Alberta. These exposures 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 belt and motor that drives LiSAmobile were cleaned, lubricated, and inspected for signs of deterioration, as it has been in continuous motion since 2014.

One week before site maintenance, LiSAmobile had stopped transmitting data to Milan, Italy. Upon inspection during the maintenance, it was determined that the chain cable, a flexible plastic conduit for the data cable connected to the radar, was damaged due to continuous motion (Figure 3). The conduit had cut into the data cable and prevented data from communicating with the internal computer. The entire

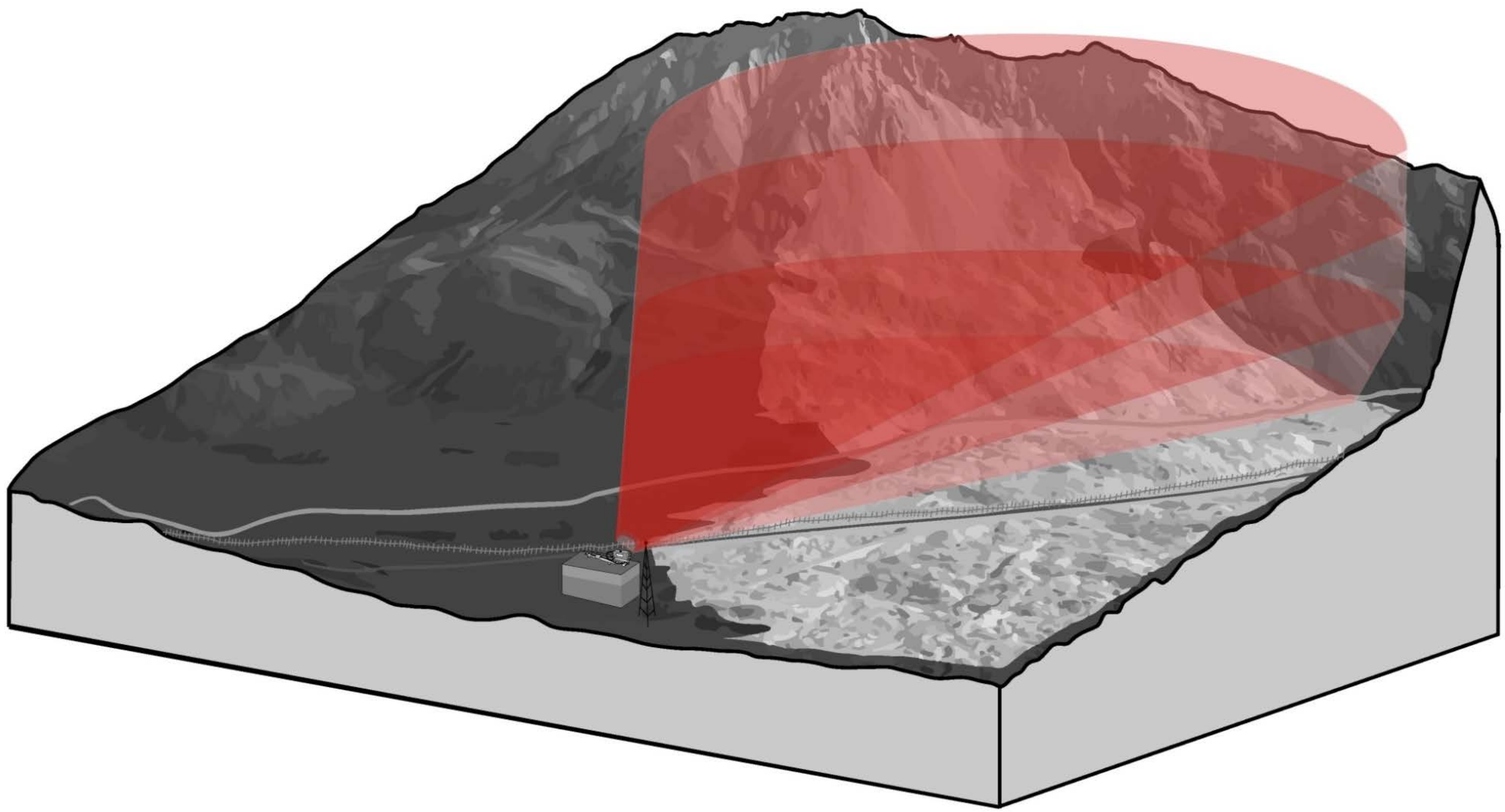

Figure 2. Overview, as of December 2019, of the primary monitoring equipment. The drawing marks the location of the LiSAmobile system, and the red beam depicts the scanning of the mountain. The light grey area represents the extent of the original 1903 slide. The image is not drawn to scale, and its purpose is to highlight the area LiSAmobile scans.

damaged cable was replaced, and new stepper motor controller and serial-to-lan converter were installed. In addition, a system upgrade was performed to improve the ‘stop&go’ with ‘continuous’ images acquisition mode. The new acquisition mode will enhance data capturing capability and improve overall measurement accuracy.

Figure 3. Damaged chain cable had cut into the data cable causing it to fail.

2.1.2 TMMS Radio Network Maintenance

In March 2019, there was a network outage caused by aging hardware located at the Blairmore Provincial Building. Upon investigation it was determined that the firewall hardware had failed and would need to be replaced. An external local contractor was hired to pull and replace the CAT6 cabling at the Blairmore Provincial Building and the new equipment was installed. Once the network was rebooted and returned online, we found the Bellevue web camera remained impacted by this outage and would require an on-site power cycle and update. Staff travelled to the Bellevue pump house and power cycled the camera. The camera returned online and staff were able to collect the image data from the disruption period and upload it to the network. During this time no data was lost.

In June 2019, staff returned to the Crowsnest Pass to complete preventative maintenance on communication equipment at the Frank Slide Interpretive Centre (FSIC). In 2018, staff discovered the battery charge controller and batteries had begun to show signs of low voltage and the backup power supply would need to be replaced. In the event of a power failure at the FSIC, the communication equipment would be unable to remain online with aging equipment. The battery charge controller and batteries were replaced in the attic space in the FSIC and the network was brought back online.

During the annual meeting with the council members in 2019, AGS informed them over the last decade of monitoring, the trees between the pump house and FSIC have grown and could potentially impact future communication transmissions. In the upcoming years, it would be beneficial to trim the tops of these trees to maintain a strong transmission between the Bellevue pump house and FSIC.

3 Data Analysis and Collection

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 4) uses the interferometric synthetic aperture radar technique to measure small displacements at each point on the surface of the mountain. For additional information, the reader may refer to Wood et al. (2016).

Figure 4. LiSAmobile system without radome.

The LiSAmobile system is connected via the Internet through a Wi-Fi connection that allows virtual private network (VPN) access. The data are processed onsite, and the results are transferred to Ellegi via VPN to be evaluated. The LiSAmobile system obtains raw data of measurements from the radar head. These data are processed by LiSAmobile, evaluated for data quality by Ellegi and used to create displacement maps showing a pixelated image of ground displacements that range from positive to negative values (Figure 5). 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 5 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 a 91-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 2019 and are provided by Ellegi to the AGS in quarterly reports (Q19 to Q22 for 2019). 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 seven regions (A–G, Figure 5), which are further subdivided into twelve points of interest (POIs; labelled P_1 through P_12 in Figure 5). 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 5) are considered to be measurement errors introduced by atmospheric moisture within the line of sight.

The results from report Q19 to Q22 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., Q19, Q20, Q21, Q22) is shown in Tables 1, 3, 5, and 7, respectively. Measured displacements at POIs for the same period are presented in Tables 2, 4, 6, and 8.

On the displacement maps (Figures 5 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 indicate displacement towards the sensor (negative value), such as rocks falling and accumulating in the debris zones (regions D, E, and G). Green colours depict a neutral range of displacement with minimal movements towards or away from the sensor.

For simplicity, 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.

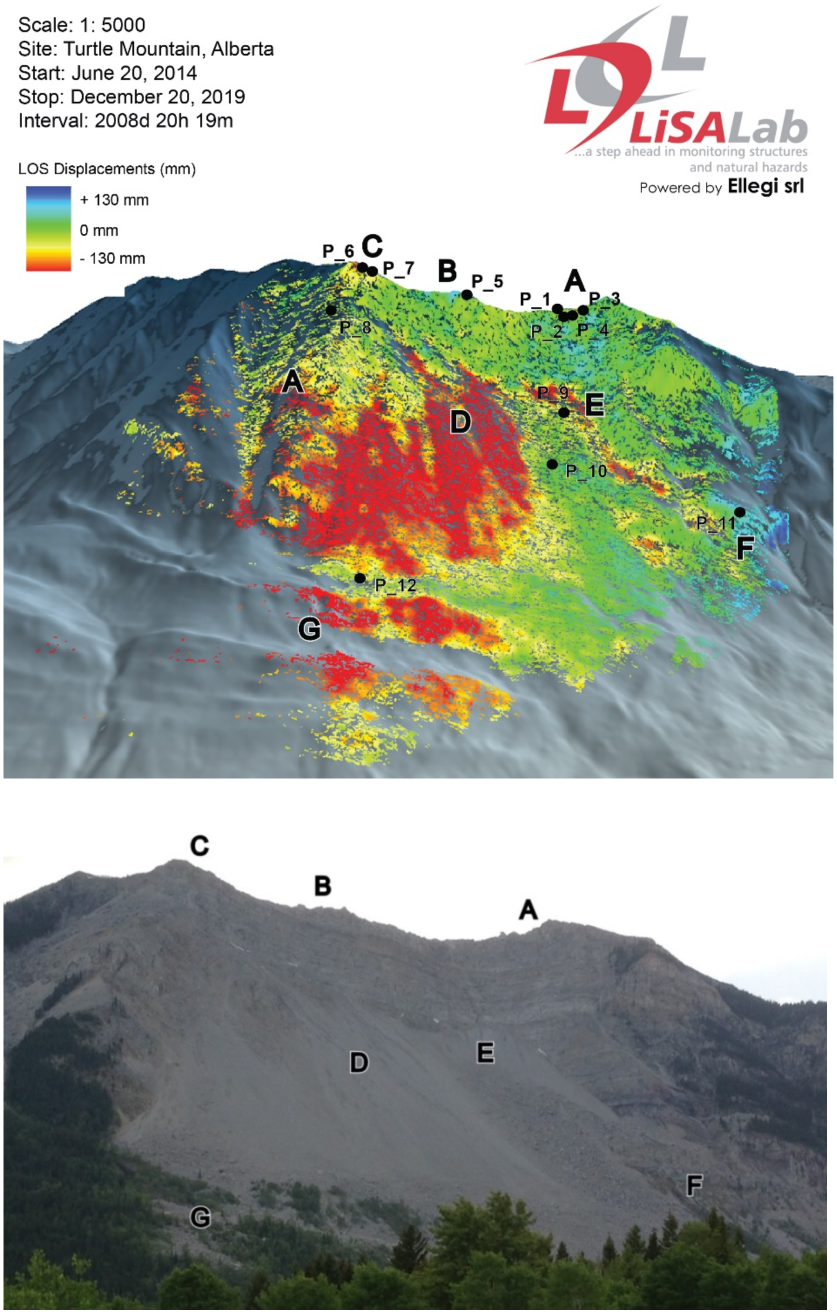

Figure 5. Three-dimensional (3D) displacement map (top) measured from June 20, 2014, to December 20, 2019, and view of the eastern face of Turtle Mountain (bottom). Letters A to G denotes the location of regions described in Tables 1 to 8. Abbreviations: d, day; h, hour; LOS, line of sight; m, minute.

Table 1. LiSAmobile generalized displacement in regions of interest for the period from June 20, 2014, to March 20, 2019 (1733 days).

Region	Location Description	Displacement (mm)	Approximate Region Area (m^2)
A	Close to North Peak	25.5 to 179.7	4600
B	Between North and South peaks	≤7.0	600
C	Close to South Peak	≤46.5	1200
D	Debris area toe of South Peak rock wall	-	-
E	Debris area toe of North Peak rock wall	≤52.5	-
F	Mid to lower vegetative rock wall	-	-
G	Debris zone run-out area	≤72.7	-

Table 2. LiSAmobile measured displacement at points of interest (POI) for the period from June 20, 2014, to March 20, 2019 (1733 days) with observations specific to quarterly reporting period (Q) 19.

Region	Point of Interest (POI)	Displacement (mm)	Displacement Descriptions Specific to Q19
A	P_1	25.5 to 179.7	Positive trend observed in Q19, subject to errors due to snow cover.
	P_2		
	P_3		
	P_4		
B	P_5	≤7.0	Fluctuations in Q19, subject to errors due to snow cover.
C	P_6	-	Fluctuations in Q19, subject to errors due to snow cover.
	P_7		
D	P_8	≤46.6	Rate of displacement maintained prior to Q19, followed by minor fluctuations during this quarter.
E	P_9	≤52.5	A positive displacement from Q18 to 19, subject to errors due to snow cover.
	P_10	-	Data is omitted due to error introduced by snow cover.
F	P_11	-	Data is omitted due to error introduced by snow cover.
G	P_12	-	Fluctuations in Q19, subject to errors due to snow cover.

Generalized displacement in Q19 for all seven regions was relatively unchanged compared to Q18. Positive cumulative displacements are observed throughout Q19 for most of the POIs at the end of Q19, most likely due to persistent snow cover in the region. Ellegi reported that snow cover trends are apparent in the data for Q19. The Crowsnest Pass area is subject to large amounts of snow accumulation during winter months, which can affect the data.

The Q19 summary report from Ellegi noted that the system was operational from the installation date in June 2014, with minimal interruptions.

Table 3. LiSAmobile generalized displacement in regions of interest for the period from June 20, 2014, to June 20, 2019 (1825 days).

Region	Location Description	Displacement (mm)	Approximate Region Area (m^2)
A	Close to North Peak	21.0 to 178.7	4600
B	Between North and South peaks	≤0.4	600
C	Close to South Peak	≤72.4	1200
D	Debris area toe of South Peak rock wall	-	-
E	Debris area toe of North Peak rock wall	≤67.1	-
F	Mid to lower vegetative rock wall	-	-
G	Debris zone run-out area	≤71.9	-

Table 4. LiSAmobile measured displacement at points of interest (POI) for the period from June 20, 2014, to June 20, 2019 (1825 days) with observations specific to quarterly reporting period (Q) 20.

Region	Point of Interest (POI)	Displacement (mm)	Displacement Descriptions Specific to Q20
A	P_1	21.0 to 178.7	Fluctuations from December onwards with positive trends throughout Q20.
	P_2		
	P_3		
	P_4		
B	P_5	≤0.4	Fluctuations throughout Q20.
C	P_6	≤72.4	Minor fluctuations observed throughout Q20.
	P_7		
D	P_8	≤49.2	Debris zone previously exhibited a stabilized trend with a small acceleration during Q20.
E	P_9	≤67.1	Exhibited continuous movement with small fluctuations until the end of Q20.
	P_10	-	Rate of displacement unchanged, displaying stable behaviour until the end of Q20.
F	P_11	-	Data is omitted due to errors introduced by snow cover or vegetation in the instrument's line of sight.
G	P_12	≤69.0	Minor fluctuations observed for the remaining of Q20.

Generalized displacement in Q20 for all seven regions were relatively the same from Q19 to Q20 Measured displacements at some POIs were subject to errors due to snow cover and atmospheric moisture, such as heavy rainfall or fog. The Q20 report marks the end of five years since installation of the LiSAmobile system in 2014.

The Q20 summary report from Ellegi noted that the system was operational from the installation date in June 2014, with the exception of a hardware issue detailed in Section 2.1.1. LiSAmobile collected data during this disruption, which were temporarily stored on local storage and transmitted once the Internet and radio connections were re-established; therefore, no displacement data were lost.

Table 5. LiSAmobile generalized displacement in regions of interest for the period from June 20, 2014, to September 20, 2019 (1917 days).

Region	Location Description	Displacement (mm)	Approximate Region Area (m^2)
A	Close to North Peak	24.2 to 183.7	4600
B	Between North and South peaks	≤4.4	600
C	Close to South Peak	≤76.1	1200
D	Debris area toe of South Peak rock wall	-	-
E	Debris area toe of North Peak rock wall	≤69.9	-
F	Mid to lower vegetative rock wall	-	-
G	Debris zone run-out area	≤72.6	-

Table 6. LiSAmobile measured displacement at points of interest (POI) for the period from June 20, 2014, to September 20, 2019 (1917 days) with observations specific to quarterly reporting period (Q) 21.

Region	Point of Interest (POI)	Displacement (mm)	Displacement Descriptions Specific to Q21
A	P_1	24.2.0 to 183.7	Small acceleration from June 2019.
	P_2		
	P_3		
	P_4		
B	P_5	≤4.4	Fluctuations throughout Q21.
C	P_6	≤76.1	Continuous movement with fluctuations until the end of Q21.
	P_7		
D	P_8	≤51.2	Debris zone exhibited a constant trend with minor fluctuations throughout Q21.
E	P_9	≤69.9	Minor fluctuations throughout Q21.
	P_10		Rate of displacement unchanged, displaying stable behaviour until the end of Q21.
F	P_11	-	Data is omitted due to errors introduced by vegetation in the instrument's line of sight.
G	P_12	≤69.0	Minor fluctuations throughout Q21.

Generalized displacement in Q21 for all seven regions accelerated minimally, similar to Q20 and otherwise generally showed stable (unchanged) rates of displacement during summer 2019. The Q21 summary report from Ellegi noted that the system was operational from the installation date in June 2014, with minimal interruptions. The system was temporarily stopped in June for annual maintenance and system checks.

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 identified that 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 the region, identifying small-scale movements over a larger area (large block movements). These analyses are conducted over a one-year time frame and are compared to the results from the year prior. Ellegi states results are influenced by the size of an area chosen (large versus small) and whether pixel values are precisely measured or averaged; and therefore are subjective.

In 2019, the same study was completed between September 15, 2018, and September 15, 2019. This analysis determined the upper block near region C (Figure 6) displayed movements of about 1.4 mm on average, with some peaks displaying a maximum displacement of more than 4.0 mm. The lower block, near region C (Figure 6) moved similarly and displayed movement of about 1.5 mm on average, with some peaks displaying a maximum displacement of more than 8.0 mm.

In addition, Ellegi also identified a third area with a very slow rate of displacement over a larger area near region A, close to North Peak. Over the one year, an area of about 5500 m^2 displayed movements of about 2.7 mm on average in the larger block, with some peaks displaying maximum displacement of more than 8.5 mm (Figure 6). The annual analyses on this block displays the rate of displacement measured in this area is lower than the rate measured from September 2017 to 2018.

This study confirms our 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.

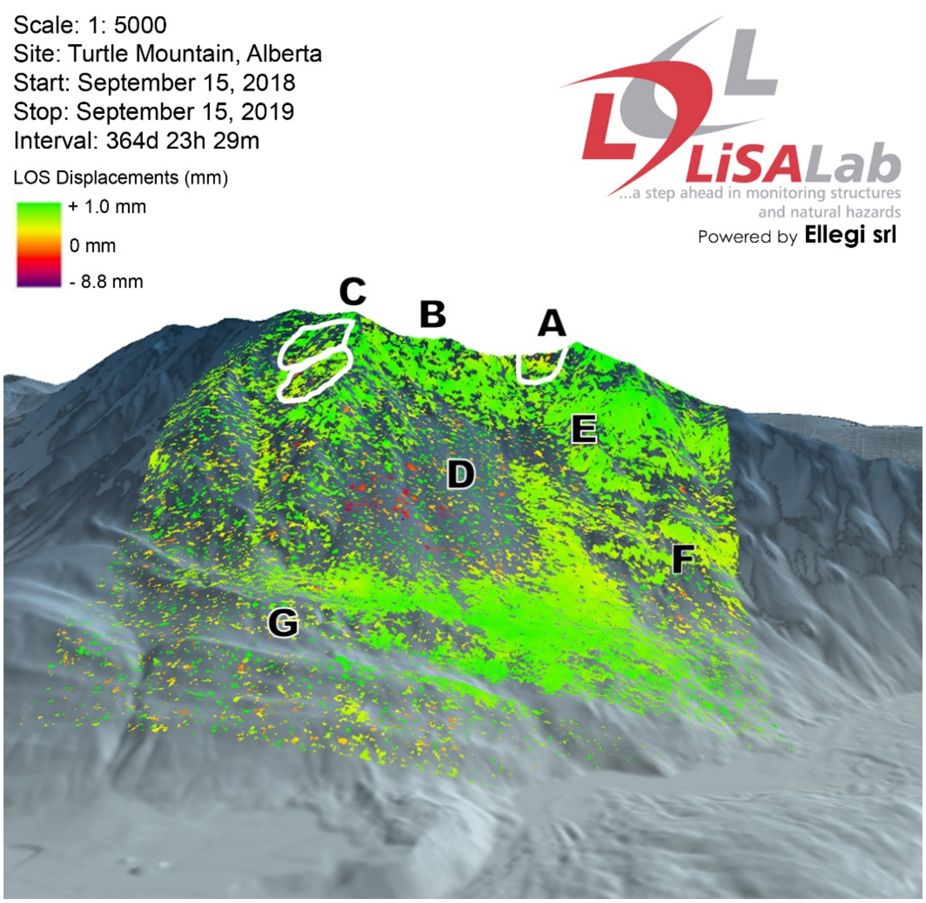

Figure 6. Annual analysis of large block movements near regions A and C, from September 15, 2018, to September 15, 2019 (364 days, 23 hours, 29 minutes). Abbreviation: LOS, line of sight.

Table 7. LiSAmobile generalized displacement in regions of interest for the period from June 20, 2014, to December 20, 2019 (2008 days).

Region	Location Description	Displacement (mm)	Approximate Region Area (m^2)
A	Close to North Peak	21.0 to 183.0	4600
B	Between North and South peaks	≤3.8	600
C	Close to South Peak	≤83.0	1200
D	Debris area toe of South Peak rock wall	-	-
E	Debris area toe of North Peak rock wall	≤78.0	-
F	Mid to lower vegetative rock wall	-	-
G	Debris zone run-out area	≤75.0	-

Table 8. LiSAmobile measured displacement for the period from June 20, 2014, to December 20, 2019 (2008 days) with observations specific to quarterly reporting period (Q) 22.

Region	Point of Interest (POI)	Displacement (mm)	Displacement Descriptions Specific to Q22
A	P_1	21.0 to 183.0	Minor acceleration between June and November in Q22.
	P_2		
	P_3		
	P_4		
B	P_5	≤3.8	Small fluctuations throughout Q22, subject to errors due to snow cover.
C	P_6	≤83.0	Continuous movement with positive displacement observed until the end of Q22, subject to errors due to snow cover.
	P_7		
D	P_8	≤43.7	Acceleration at the beginning of October 2019 followed by small fluctuations in Q22, subject to errors due to snow cover.
E	P_9	≤78.0	An acceleration at the beginning of October 2019 followed by a positive trend at the end of Q22, subject to errors due to snow cover.
	P_10		
F	P_11	-	Algorithm to improve data at P_11 is underway.
G	P_12	≤69.0	Small fluctuations throughout Q22, subject to errors due to snow cover.

Generalized displacements in Q22 for all seven regions accelerated minimally from Q21, but otherwise generally showed stable (unchanged) rates of displacement during Q22. A positive cumulative displacement is observed for the POIs throughout Q22, most likely due to persistent snow cover in the region. 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. Newly added to the report is measurements of P_11 in Q22. Ellegi is working on an algorithm to improve the data collected in this area. Up until Q22, no data has been reliable and consistent in this area (P_11) and was omitted from previous reports.

The Q22 summary report from Ellegi noted that the system was operational from the installation date in June 2014, with minimal interruptions.

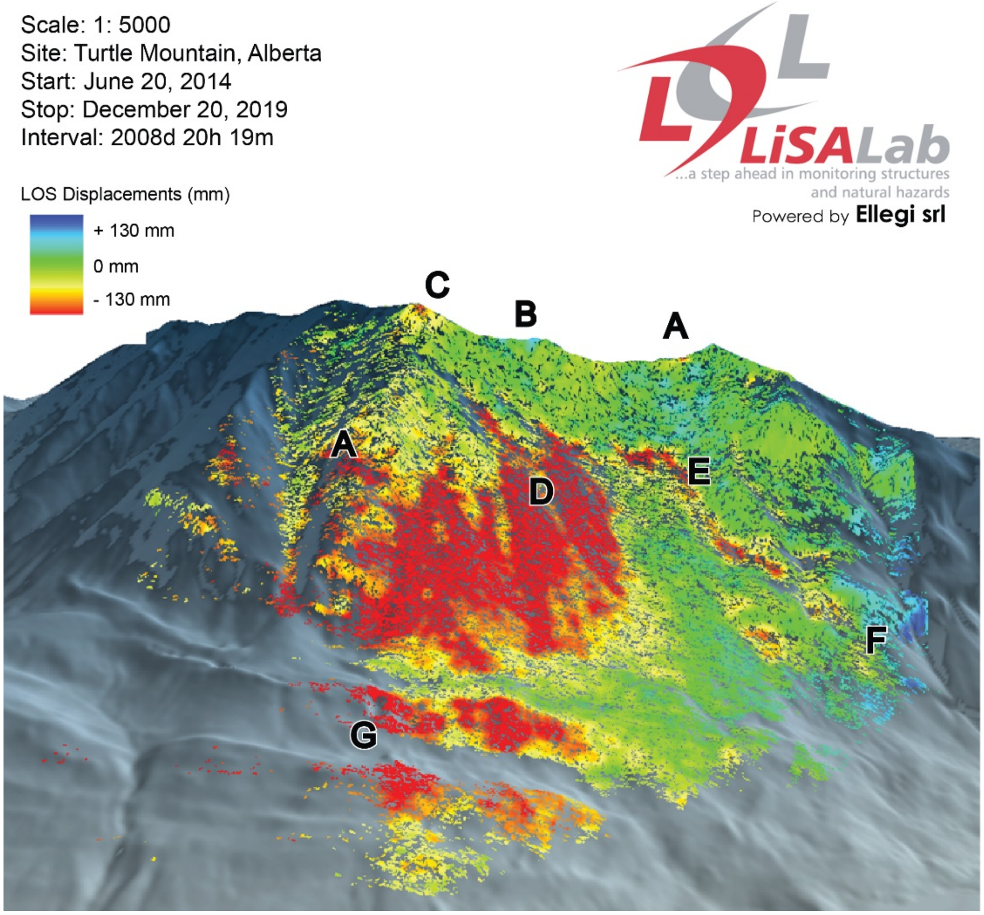

Figure 7. The line-of-sight three-dimensional (3D) displacement map of Turtle Mountain measured from June 20, 2014, through December 20, 2019 (2008 days, 20 hours, 19 minutes). Abbreviation: LOS, line of sight.

4 Supporting Studies and Research

During 2019, no secondary monitoring campaign was selected for supporting studies and research, based on the fact that multiple secondary campaigns were conducted in 2016 and 2017. 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 TMMP Emergency Preparedness

In 2017, the *AER/AGS Roles and Responsibilities Manual for the Turtle Mountain Monitoring Program, Alberta* (Wood et al., 2017a) was updated and published. This report provides information about the AGS's ownership of the TMMS and the specific roles and responsibilities of the AER/AGS staff during normal operations and escalation of an event.

All internal roles and responsibilities pertaining to the TMMS are referenced to the four-stage alert system to maintain consistency for all parties involved. This four-stage alert system is based on a review of the sensor thresholds (green, yellow, orange, and red) developed by AMEC Earth and Environmental (2005) and subsequently incorporated into the Alberta Emergency Management Agency's (AEMA) emergency response protocol for Turtle Mountain. This protocol establishes that the AER, through the AGS, is responsible for determining the appropriate alert level for a potential emergency at Turtle

Mountain based on analyses received from Ellegi. Further information on these documents is available in Wood et al. (2017a) and Alberta Emergency Management Agency (2017).

The AGS's internal emergency response protocol (ERP) was reviewed and updated in 2019. This ERP is revised as often as required to ensure that the current version reflects best practices and is fit for its purpose. At a minimum, a review is done annually.

The AER's Emergency Management and Incident Management teams conducted a one-day workshop for AGS management in November. It was based on the internal roles and responsibilities outlined in Wood et al. (2017a). The workshop was divided into three sections: Incident Command System (ICS), Emergency Coordination Centre (ECC), and scenario exercises. Prior to taking the workshop, participants completed the ICS 100 prerequisite certification from the AEMA.

During the first section of the workshop, participants developed a better understanding of ICS command structure, primary management functions, and principles and features. Attendees learnt the concept of unified command (UC) for multi-agencies, best-practices for stakeholders cooperation, and set objectives using P.P.O.S.T. (priority, problems, objectives, strategies, and tactics), and S.M.A.R.T. (specific, measurable, achievable, realistic, and time) principles.

Next, participants reviewed the concept of an ECC and its applications to the AER. Participants reviewed the differences between ICS and ECC, roles and responsibilities in both structures, interactions between the ECC, AER, and ICS structure during an emergency, such as a potential rock slide.

Lastly, attendees reviewed scenario exercises specific to Turtle Mountain. Participants were asked to apply both concepts of ICS and ECC principles to environmental factors leading to the failure scenario of an incident on Turtle Mountain. They were asked to identify and rank the importance of contributing facts, and apply them to the four-stage alert system. Participants developed S.M.A.R.T. objectives; created tactics and strategies; and assigned AER/AGS staff to the ECC structure. The exercise was concluded with a group discussion of different options and alternatives to the failure scenario.

This workshop provided AER/AGS invaluable training and knowledge on applying ICS and ECC principles to the AGS's roles and responsibilities during an event at Turtle Mountain.

6 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 (web cameras), and to illustrate the daily changes on Turtle Mountain throughout the year. Links to the 2019 annual videos are available for download on the AGS website (https://ags.aer.ca/activities/turtle-mountain-monitoring-program). In addition, both videos are available for streaming on YouTube: Bellevue at https://youtu.be/004bBkw1AIs and South Peak at https://youtu.be/BxASTAixghY.

7 Conclusions

Recent application of monitoring and modelling technologies has greatly increased our 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 review of LiSAmobile performance and data at the end of 2019 allowed us to assess the program's monitoring needs and plan field activities for 2020. The Alberta Geological Survey will continue to work with Ellegi srl for maintenance and upgrades to LiSAmobile. We will also continue to investigate different forms of monitoring systems.

Communication of the risks associated with the hazards at Turtle Mountain to the affected population is also ongoing. We publish the most recent results annually (Warren et al., 2014, 2016; Wood et al., 2016, 2017b, 2018a, b; Yusifbayov et al., 2018; Wood and Chao, 2019) and present them 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/activities/turtle-mountain-monitoring-program).

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