AER/AGS Open File Report 2018-12

Turtle Mountain Field Laboratory, Alberta (NTS 82G): 2017 Data and Activity Summary

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Contents

Tables

Figures

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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, 2017. 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, interpretation of data, and notification to 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 2017. This includes a review of the main repair and maintenance activities, a synopsis of abandoned stations, and a summary of system performance and reliability.

The second section provides data analysis and interpretation for the primary monitoring equipment, known as LiSAmobile.

The third section reviews supporting studies and research conducted during 2017 and includes a RADARSAT-2 imagery analysis.

The fourth section contains information on the final steps of the Turtle Mountain transition and information on the Turtle Mountain Decommission Project.

The last section features information on three videos produced by the AER to highlight work completed on Turtle Mountain in 2017.

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, 2018).

The first priority of the TMMP is to provide monitoring of Turtle Mountain; to review site characterization, hazard assessment, 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, research on the mountain, and changes to the monitoring program.

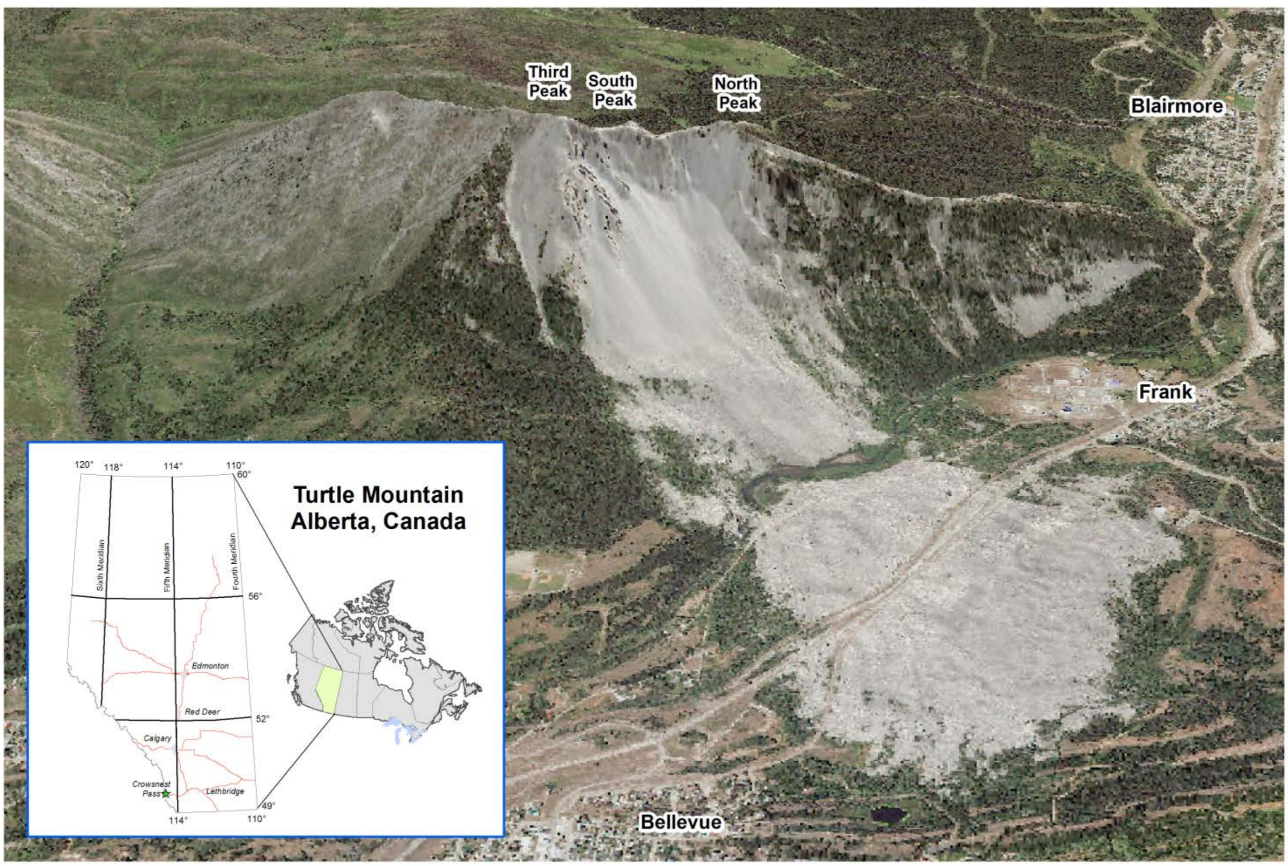

Figure 1. Location of Turtle Mountain in southwestern Alberta and full-extent aerial view of the Frank Slide.

2 Sensor Network Activity

This section provides an overview of the significant upgrades, repair, maintenance activities, and performance of the sensor network of the monitoring system during 2017.

The main activities undertaken concerning the sensor network during 2017 included

- decommissioning of the non-operational equipment on Turtle Mountain; 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. 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. 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 2017, the monitoring campaign included a RADARSAT-2 InSAR analysis for supporting studies and research (Section 4.1).

The AGS also receives and reviews monitoring reports on a quarterly basis from Ellegi srl. Ellegi also provides *Quick Reports* if an area has displacement values outside of the defined thresholds determined by Ellegi technicians. During this period, LiSAmobile and Ellegi have proven to be optimal for monitoring surface displacements and will continue to be the primary sensor into 2018.

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 2017, an annual maintenance campaign was conducted in mid-July that included a joint-team from Ellegi and the AGS. The field maintenance objectives included

- inspection of the radome for any structural or waterproofing issues,
- examination of all power and communication cables,
- replacement of a temperature control unit,
- mechanical maintenance on the radar head with lubrication of moving parts,
- internal radome cover and gasket checks,
- power box inspection,
- dust and lubrication of drive belt and instrument components,
- replacement of various filters,
- radio frequency evaluation, 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 that 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 percipitation 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. Inspection of the belt system showed little sign of wear, and the motor was in good operating condition. The temperature controller was replaced during the site visit with an updated model for preventative maintenance (Figure 2). Since its replacement, the unit has been performing optimally with no issues. The annual field maintenance for LiSAmobile found no problems with the system and only preventative maintenance was completed.

Figure 2. Replacement of temperature control unit during annual LiSAmobile maintenance conducted by an Ellegi engineer.

2.2 Non-operational Instruments

After review of the monitoring equipment in 2015, we decided that the use of specific instruments would be discontinued in the 2016 field season due to varying underlying issues (Wood et al., 2016 , 2017a, and 2018) and decommissioned in 2017. The term 'non-operational instrument' refers to an instrument that has been abandoned due to poor quality or inadequate data. Historical information on these instruments can be found in previous reports (Moreno and Froese, 2006, 2008a, 2008b, 2009a, 2009b, 2011, 2012; Moreno et al., 2013; and Warren et al., 2014, 2016).

2.3 Performance

Continuous slope monitoring is challenging in the harsh and highly variable weather conditions on Turtle Mountain. However, the effects of these adverse conditions on the normal operation of the monitoring system are minimized by a series of preventative measures, including frequent inspections, replacement of aging equipment, and system modifications and upgrades. This section provides detailed information on sensor performance in 2017.

The TMMS has been operational for over a decade. This has enabled us to understand not only the challenges of maintaining a reliable and continuously running system, but also to identify the factors that affect the normal operation of the monitoring network. These observations over the previous decade have led to a continually developing monitoring network.

2.3.1 Continuous-Reading dGPS Monitoring Network

In July 2013, the AGS convened an independent international expert panel to provide a review of the current management of the slope hazards on Turtle Mountain. A report by the panel was submitted to AGS in October 2014 (Wood et al., 2016, Appendix 3). This report examined the current practices and made future recommendations for the TMMP.

Based on the report's recommendation, AGS decided that the dGPS stations would be decommissioned due to the aging stations and changing technologies better suited to monitor Turtle Mountain. The dGPS stations were decommissioned by NavStar and AGS in June 2017. Further information on this decommission can be found in Yusifbayov et al. (2018).

2.3.2 LiSAmobile Ground-based InSAR

The LiSAmobile system was leased to AGS and installed in June 2014 (Figure 3). Additional documentation on the feasibility study, service contract, fabrication of supporting materials, LiSAmobile installation, and initial system calibration is included in Wood et al. (2016).

LiSAmobile continued to provide high-quality data throughout 2017 with little to no interruption. The innovative radome structure (Figure 3) continued to perform as expected and protected the equipment from harsh environmental factors. The internet service provider lost the connection between LiSAmobile and its network communication a couple of times during the year. Data collected during these disruptions was temporarily stored on local storage and transmitted once the internet connection was re-established; therefore, no displacement data were lost. The internet service plan was updated in 2017.

Ellegi provides a premium level of technical support, innovative shelter technology, and timely detailed reporting. AGS will continue to utilize LiSAmobile as the primary monitoring sensor.

(a)

(b)

Figure 3. (a) LiSAmobile system without radome and temperature regulation unit; (b) LiSAmobile system completely assembled (Photo courtesy of Ellegi).

3 Data Analysis and Collection

3.1 LiSAmobile Ground-based InSAR Data Collection

LiSAmobile was installed at the Bellevue pump house (Figure 4) in June 2014 to monitor small displacements on the eastern face of Turtle Mountain. The LiSAmobile uses the interferometric synthetic aperture radar technique to measure small displacements at each point on the surface of the mountain (Figure 5).

Figure 4. LiSAmobile system at the Bellevue pump house station.

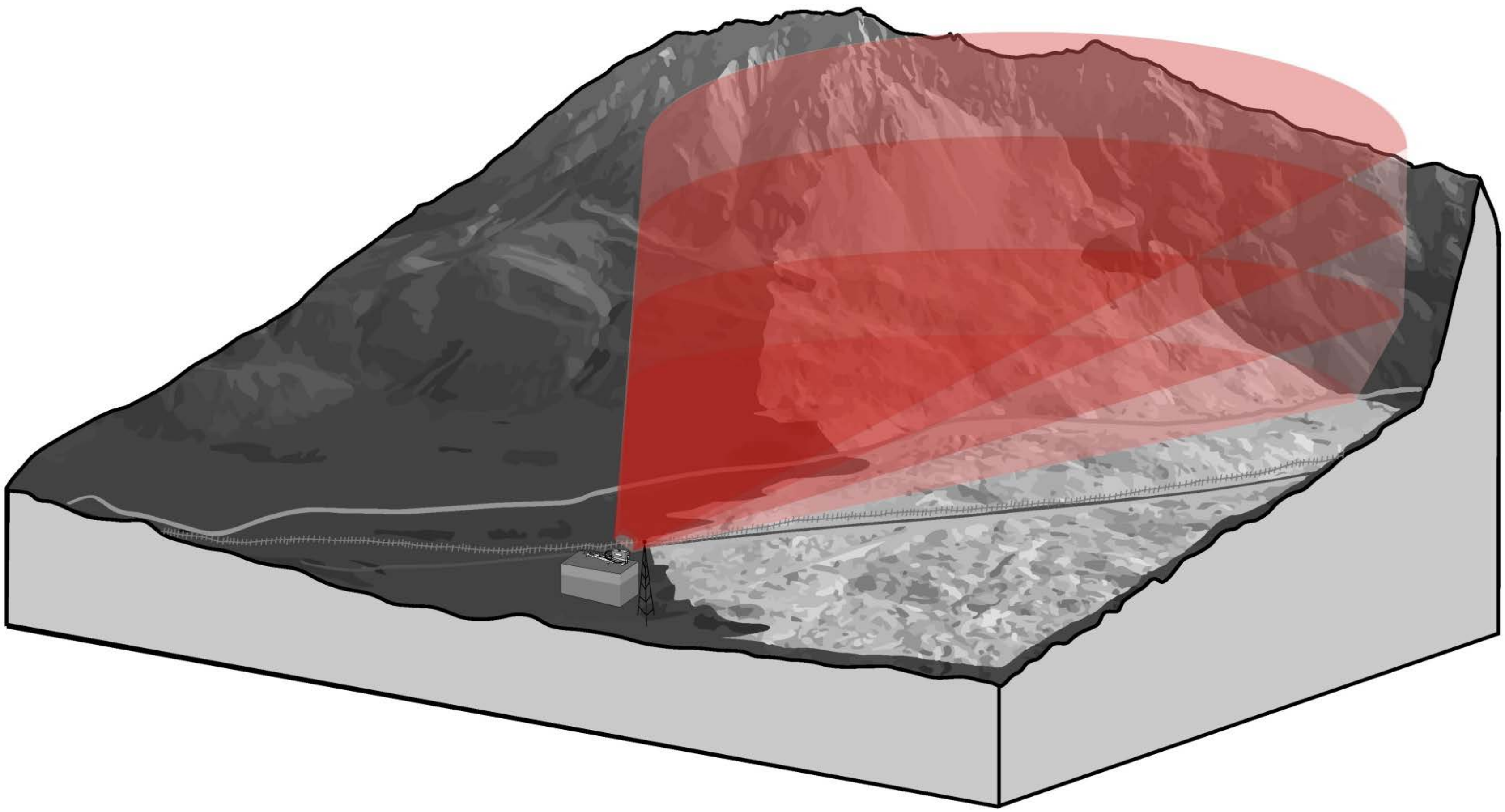

Figure 5. Overview, as of December 2017, of the primary monitoring equipment. The drawing marks the location of the LiSAmobile system, and the red beam depicts the scanning of the mountain. The light gray area represents the extent of the original 1903 slide. The image is not drawn to scale, and its purpose is to highlight the area LiSAmobile scans.

The LiSAmobile system is connected via the Internet through a WiFi connection that allows 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 from measurements from the radar head. This data is processed by LiSAmobile and is 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. Positive values are depicted as blue colours indicating displacement away from the sensor, while red colours illustrate displacement towards the sensor (Figure 6).

3.2 Discussion and Interpretation of Monitoring Data from LiSAmobile

The displacement map displayed in Figure 6 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 2017 and are provided by Ellegi to the AGS in quarterly reports (Q11 to Q14 for 2017). 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 6), which are further subdivided into twelve points of interest (POIs, labelled P_1 through P_12, in Figure 6). 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 6) are considered to be measurement errors introduced by atmospheric moisture within the line of sight.

The results from report Q11 to Q14 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., Q11, Q12, Q13, Q14) is shown in Tables 1, 3, 5, and 7, respectively. Measured displacements at points of interest (POI) for the same period are presented in Tables 2, 4, 6, and 8.

On the displacement maps (Figures 6 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 (region D, E, and G). Green colour depicts 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).

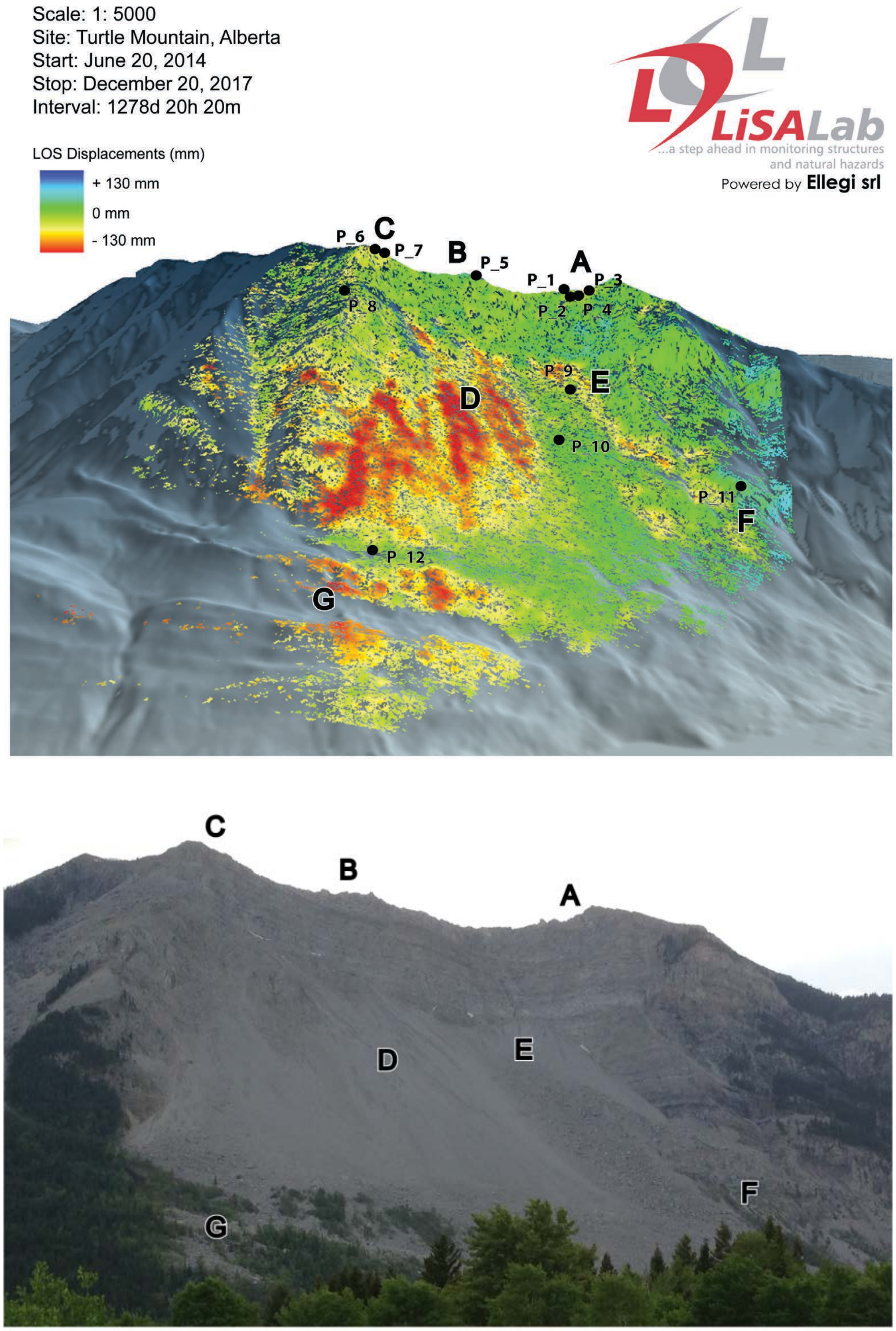

Figure 6. 3D displacement map (top) measure from June 20, 2014, to December 20, 2017, and view of the eastern face of Turtle Mountain (bottom). Letters A to G and P_1 to P_12 denote locations of regions and points of interest described in Tables 1–8.

Table 1. LiSAmobile generalized displacement in regions of interest for the period from June 20, 2014, to March 20, 2017 (1003 days).

Region	Location Description	Displacement (mm)	Approximate Region Area (m^2)
A	Close to North Peak	26.0 to 152.0	4600
B	Between North and South Peak	≤6.0	600
C	Close to South Peak	≤41.6	1200
D	Debris area toe of South Peak rock wall	≥18.0	-
E	Debris area toe of North Peak rock wall	≤23.0	-
F	Mid to lower vegetative rock wall	-	-
G	Debris zone run out area	23.8 to 31.8	-

Table 2. LiSAmobile measured displacement at points of interest (POI) for the period from June 20, 2014, to March 20, 2017 (1003 days) with observations specific to quarter Q11.

Region	Point of Interest (POI)	Displacement (mm)	Displacement Descriptions Specific to Q11
A	P_1	26.0 to 152.0	Continuous movement, rate of displacement unchanged
	P_2		
	P_3		
	P_4		Small fluctuations in movement, subject to errors due to snow cover.
B	P_5	≤21.4	Small fluctuations throughout Q11, subject to errors due to snow cover.
C	P_6	-	Fluctuations throughout Q11, subject to errors due to snow cover.
	P_7		
D	P_8	≤21.0	Debris zone exhibited a slight acceleration throughout Q11.
E	P_9	-	Data is omitted due to error introduced by 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	-	Small fluctuations throughout Q11, subject to errors due to snow cover.

Generalized displacement in Q11 for all seven regions was relatively unchanged compared to Q10. Measured displacements at most POI were subject to errors due to snow cover and atmospheric moisture (e.g., fog, snowfall, rain). Ellegi reported that snow cover trends are apparent in the data and concentrated during mid to end of Q11. The Crowsnest Pass area is subject to errors due to large amounts of snow accumulation during winter months. Ellegi noted that region A during Q9 and Q10 (Wood et al., 2017a), had increased in acceleration. However, data during Q11 shows this area has since decelerated, and no relative movements were captured.

The Q11 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, 2017 (1095 days).

Region	Location Description	Displacement (mm)	Approximate Region Area (m^2)
A	Close to North Peak	24.0 to 162.0	4600
B	Between North and South Peak	≤ 15.0	600
C	Close to South Peak	≤ 54.8	1200
D	Debris area toe of South Peak rock wall	-	-
E	Debris area toe of North Peak rock wall	≤ 38.7	-
F	Mid to lower vegetative rock wall	-	-
G	Debris zone run out area	25.7 to 30.7	-

Table 4. LiSAmobile measured displacement at points of interest (POI) for the period from June 20, 2014, to June 20, 2017 (1095 days) with observations specific to Q12.

Region	Point of Interest (POI)	Displacement (mm)	Displacement Descriptions Specific to Q12
A	P_1	24.0 to 162.0	Small acceleration from April until the end of Q12.
	P_2		
	P_3		
	P_4		Increased acceleration observed during June until the end of Q12. P_4 monitored daily by Ellegi for increased rate of displacement.
B	P_5	≤14.6	Minimal acceleration observed until the end of Q12. Area subject to errors introduced by snow cover in early to late Spring.
C	P_6	≤54.3	Minimal acceleration observed throughout Q12. Area subject to errors introduced by snow cover in early to late Spring.
	P_7		
D	P_8	≤26.7	Debris zone exhibited acceleration in Q12.
E	P_9	≤ 38.7	Minimal acceleration observed throughout Q12. Area subject to errors introduced by snow cover in early to late Spring.
	P_10	-	Data is omitted due to errors introduced by snow cover.
F	P_11	-	Data is omitted due to errors introduced by snow cover.
G	P_12	-	Rate of displacement maintained throughout Q12 with minor fluctuations.

Generalized displacements in Q12 for all seven regions were slightly larger than those measured in Q11, which is expected during the spring. In particular, P_4 showed an increased rate of displacements in June. P_4 will continue to be monitored daily for increased acceleration in the region and at individual POI. Ellegi will notify AGS of any significant movements observed in region A via *Quick Reports*. Measured displacements at some POI were subject to errors due to snow cover and atmospheric moisture, such as heavy rainfall or fog. The Q12 report marks the end of three years since installation in 2014.

The Q12 summary report from Ellegi noted that the system was operational from the installation date in June 2014, with minimal interruptions.

Table 5. LiSAmobile generalized displacement in regions of interest for the period from June 20, 2014, to September 20, 2017 (1187 days).

Region	Location Description	Displacement (mm)	Approximate Region Area (m^2)
A	Close to North Peak	24.0 to 167.0	4600
B	Between North and South Peak	≤ 15.5	600
C	Close to South Peak	≤ 56.0	1200
D	Debris area toe of South Peak rock wall	-	-
E	Debris area toe of North Peak rock wall	≤ 43.5	-
F	Mid to lower vegetative rock wall	-	-
G	Debris zone run out area	29.6 to 32.4	-

Table 6. LiSAmobile measured displacement at points of interest (POI) for the period from June 20, 2014, to September 20, 2017 (1187 days) with observations specific to Q13.

Region	Point of Interest (POI)	Displacement (mm)	Displacement Descriptions Specific to Q13
A	P_1	27.0 to 168.0	Deceleration and stabilization until the end of Q13.
	P_2		
	P_3		
	P_4		Decelerated rate of displacement observed throughout Q13.
B	P_5	≤17.3	No significant movement.
C	P_6	≤55.5	No significant movement.
	P_7		
D	P_8	≤26.6	No significant displacement observed with minor fluctuations in Q13.
E	P_9	≤44.6	Small accelerated rate of displacement observed in Q13.
	P_10	-	No significant movement throughout Q13.
F	P_11	-	Data is omitted due to errors introduced by vegetation in the instrument's line of sight.
G	P_12	-	No significant movement observed with minor fluctuations in Q13.

Generalized displacement in Q13 for all seven regions accelerated minimally, but otherwise generally showed stable (unchanged) rates of displacement during summer 2017. The Q13 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 July for annual maintenance and system checks.

Analyses from Q1 to Q5 and Q6 to Q9 identified an area with a very slow rate of displacement near region C, between South and Third Peak. Ellegi was able to evaluate the displacement rates within the region, identifying small-scale movements over a larger area.

In 2015, Ellegi measured this area to have a surface area of 45,000 m^2 and measured a displacement value of -2.4 mm over 457 days. A similar study was conducted in 2016, with a total period of 365 days from June 20, 2015, to June 20, 2016. In comparison to the analysis in 2015, it appears the area observed in 2015 had divided into two separate moving blocks. Each block exhibited displacements of about 4 mm over the entire period.

In 2017, a similar annual study was completed between September 17, 2016, to September 17, 2017. This analysis identified two areas of approximately 10,600 m^2 and 12,000 m^2 displaying movements of about 3.5 mm on average in both blocks (Figure 7), with some peaks displaying a maximum displacement of 8.0 mm. Ellegi states results are influenced by the size of the area chosen (large vs. small) and whether pixel values are precisely measured or averaged; and therefore are subjective.

This study confirms our belief that overall large block movements are extremely small. This provides assurance that the LiSAmobile system has the capacity to identify and record data points for both large block movement and smaller natural rockfalls. Ellegi will complete another investigative study in this area 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.

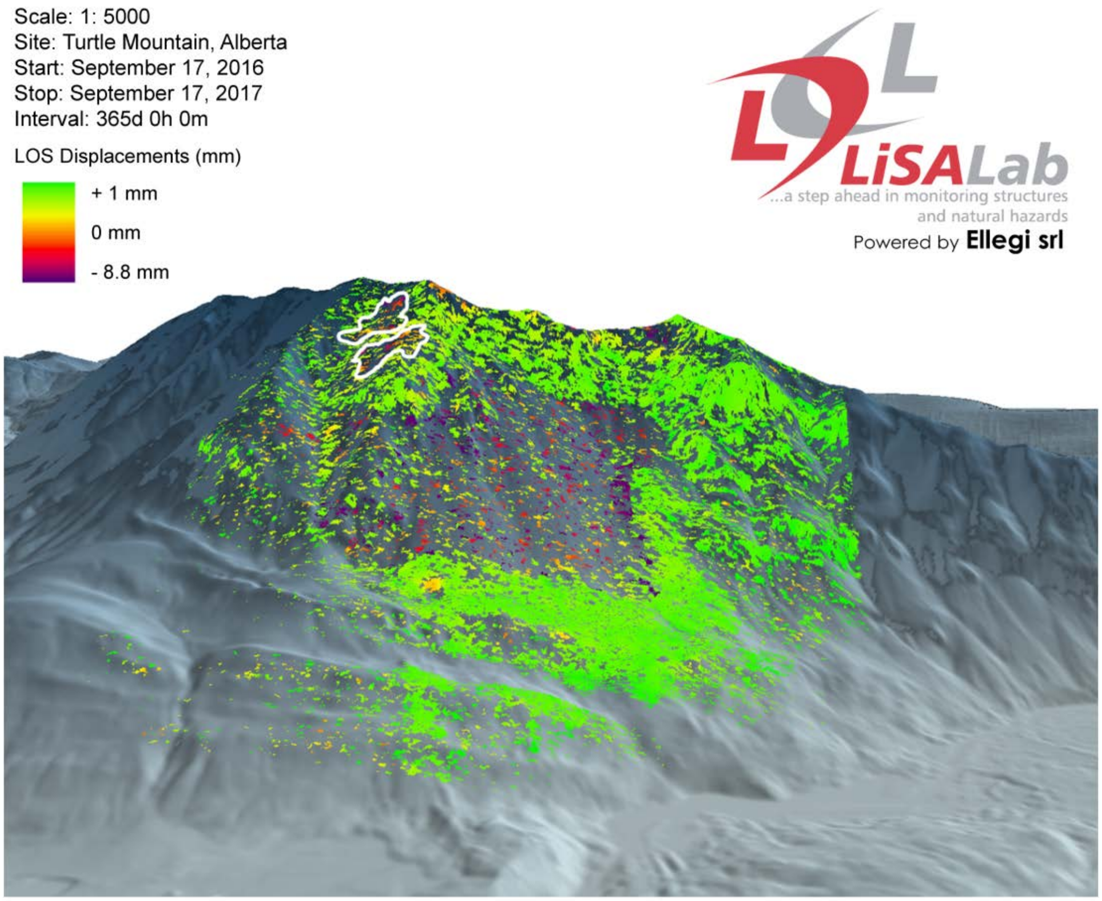

Figure 7. Annual analysis of large block movements near region C, from September 17, 2016, to September 17, 2017 (365 days).

Table 7. LiSAmobile generalized displacement in regions of interest for the period from June 20, 2014, to December 20, 2017 (1278 days).

Region	Location Description	Displacement (mm)	Approximate Region Area (m^2)
A	Close to North Peak	33.0 to 174.0	4600
B	Between North and South Peak	≤ 26.0	600
C	Close to South Peak	≤ 65.0	1200
D	Debris area toe of South Peak rock wall	-	-
E	Debris area toe of North Peak rock wall	≤ 56.0	-
F	Mid to lower vegetative rock wall	-	-
G	Debris zone run out area	31.6 to 35.6	-

Table 8. LiSAmobile measured displacement for the period from June 20, 2014, to December 20, 2017 (1278 days) with observations specific to Q14.

Region	Point of Interest (POI)	Displacement (mm)	Displacement Descriptions Specific to Q14
A	P_1	33.0 to 174.0	Continued deceleration until the end of Q14.
	P_2		
	P_3		
	P_4		Continued deceleration until the end of Q14.
B	P_5	≤ 13.4	Small fluctuations throughout Q14, subject to errors due to snow cover in mid-December.
C	P_6	≤ 59.7	No significant movement throughout Q14.
	P_7		
D	P_8	-	No significant movement observed with minor fluctuations in Q14.
E	P_9	≤ 54.0	Small fluctuations throughout Q14, subject to errors due to snow cover.
	P_10	-	Rate of displacement unchanged until the end of Q14, subject to errors due to snow cover in mid-December.
F	P_11	-	POI data is omitted due to errors introduced by snow cover.
G	P_12	-	Rate of displacement is unchanged, similar to Q13.

Generalized displacement in Q14 for all seven regions increased minimally from Q13. During Q14, unchanged rates of displacement were noted with no large accelerations in region A, specifically P_4. A positive cumulative displacement is observed for all POI at the end of Q14, most likely due to persistent snow cover in the region.

Measured displacements at some POI were subject to errors due to atmospheric moisture, such as heavy rainfall, fog, and accumulating snow cover. The Q14 summary report from Ellegi noted that the system was operational from the installation date in June 2014, with minimal interruptions.

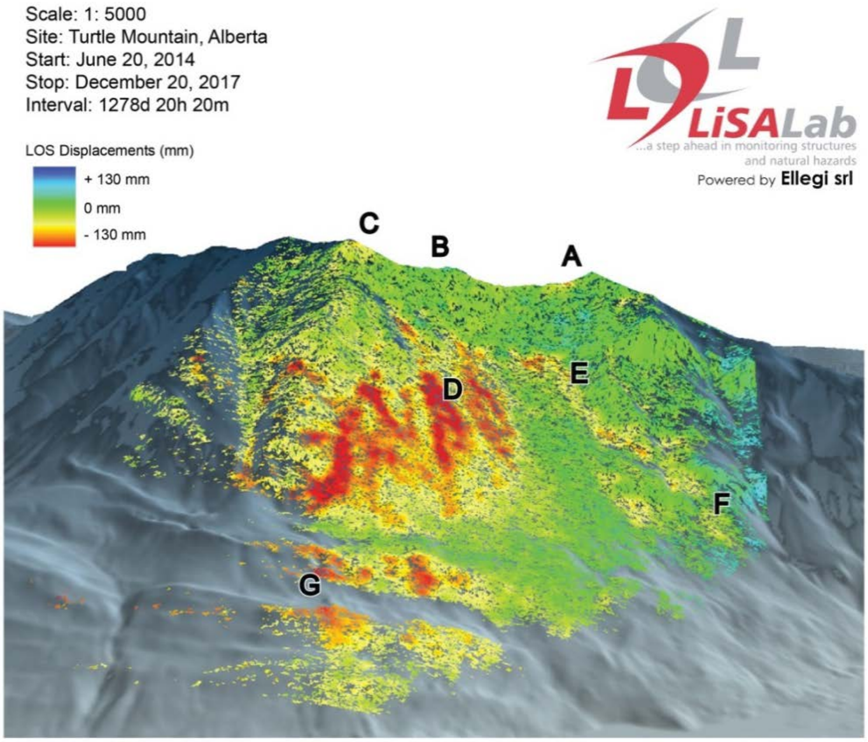

Figure 8. The line of sight 3D displacement map of Turtle Mountain measured from June 20, 2014, through December 20, 2017 (1278 days).

4 Supporting Studies and Research

During 2017, AGS preselected one secondary monitoring campaign, using RADARSAT-2 Synthetic Aperture Radar (SAR) imagery, to be run during the year. The AGS selects secondary campaigns based on monitoring frequency and supplementary monitoring is predetermined on an annual basis. This type of system summary is defined in Wood et al. (2017b).

4.1 RADARSAT-2

During 2017, five high-resolution spotlight RADARSAT-2 SAR images were collected between April 28 and Oct 13. The spotlight mode of RADARSAT-2 has the highest pixel resolution of 1m × 3m. To achieve stable coherence, each SAR image was pre-processed with 4 × 8 multilook averaging, which renders an effective resolution of 8m × 12m.

The SAR interferograms were processed using GAMMA InSAR processing software. The stacked deformation over time, and linear deformation rate were then computed using a linear least squares inversion technique (Samsonov et al., 2011). Figure 9 shows the observed surface deformation relative to the LiDAR DEM for 2016 and 2017. Through the InSAR, we do not observe anomalous deformation more than half a centimetre between each year. The computed linear deformation rate with the stacked 2015 and 2016 results was reported to be ~0.3cm/year (Wood et al., 2018).

The 2017 InSAR data analysis did not show any change in the deformation rate on the front side of Turtle Mountain. Due to the look angle of the satellite, InSAR does not provide deformation information for the back of the mountain. These SAR image analysis results agree with the displacement results measured by our ground-based InSAR, LiSAmobile, and show very slow deformation rates in 2017.

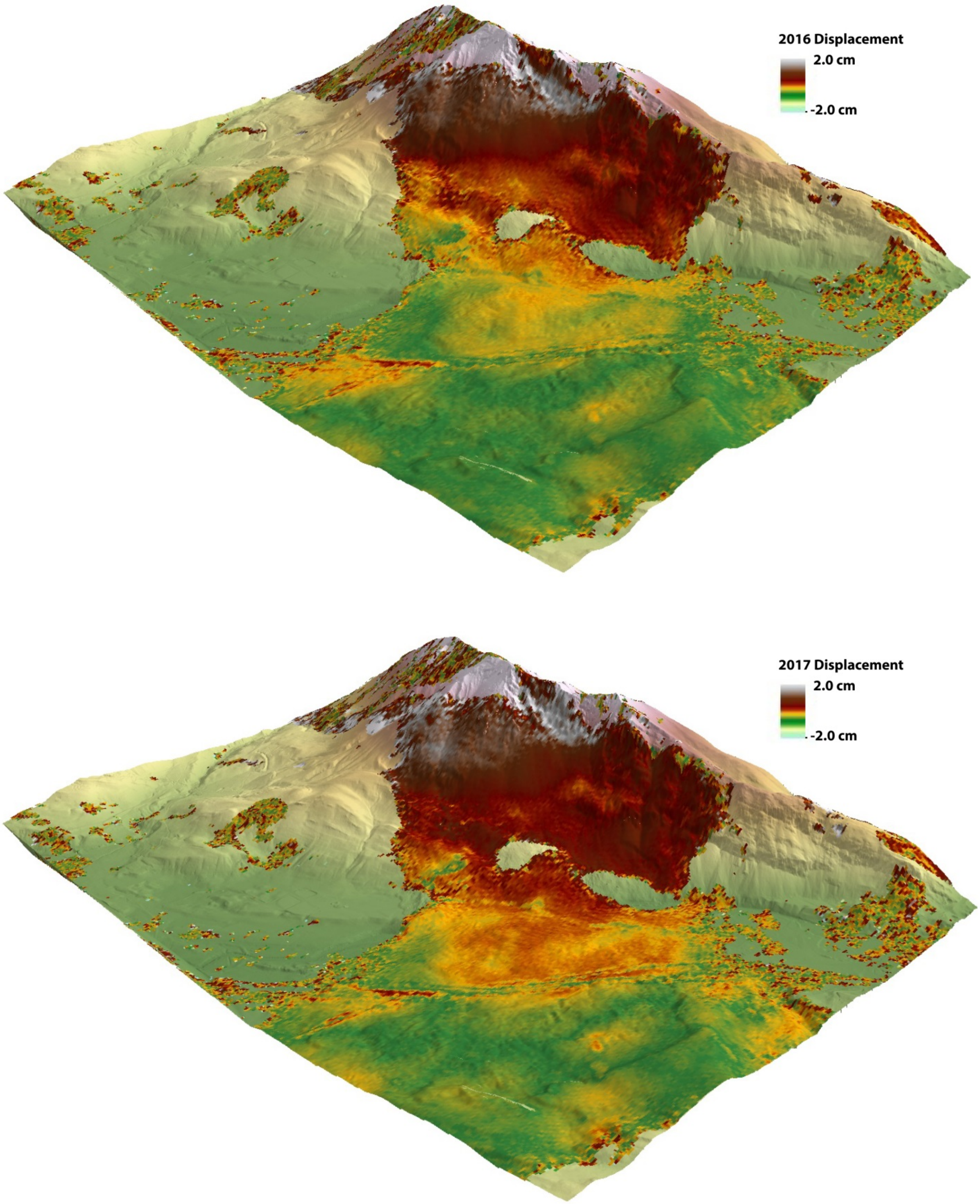

Figure 9. Processed SAR images from 2016 and 2017 depicting annual displacements on Turtle Mountain.

5 TMMP Transition and Decommission

In 2015, the TMMP began the transition to a near-real-time remote monitoring system, as recommended by the 2014 expert panel report (see Wood et al., 2016, 2017a, and 2018b, for additional details). This transition includes

- lowering the current level of response readiness (i.e., 24/7 continual on-call status) as it is not warranted by the hazard as observed and evaluated throughout the last decade of monitoring,
- making the GB-InSAR the primary monitoring sensor, and
- removing some of the non-operational equipment that is not considered vital to the long-term monitoring.

Additional information on this transition can be found in Wood et al. (2017a, b, and 2018) regarding the initial changes and information on the formal contributions from supporting agencies.

The AGS met with the Alberta Emergency Management Agency (AEMA) and Municipality of Crowsnest Pass (MCNP) throughout 2017 to ensure changes made to the program were reflected in the updated AER/AGS and AEMA's roles and responsibilities manuals. The AEMA's emergency response protocol was published in May 2017 and is available on their website (AEMA, 2017). AGS' *Roles and Responsibilities Manual for the Turtle Mountain Monitoring Program* (Wood et al., 2017b) was published in 2017 and supersedes the previous version published as ERCB/AGS Open File Report 2009-06. This report provides information about the AGS' 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 (2005) and subsequently incorporated into the AEMA's 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. Plans to convene a tabletop-exercise to reflect the change to a near-real-time remote monitoring system will be discussed in 2018 with supporting agencies and response groups.

The emergency response protocol 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. Further information on these documents is available in Wood et al. (2017b) and AEMA (2017).

During 2016, AGS identified non-operational instrumentation to be decommissioned in 2017 and work began on the mountain in June to remove the instrumentation. Historical signs were also installed on South Peak to provide public information and commemorate the historical monitoring of the TMMS from 2003-2015. Further information on the Turtle Mountain decommissioning project can be found in Yusifbayov et al. (2018).

6 Turtle Mountain Year-in Review

The successful decommissioning of the non-operational monitoring systems from Turtle Mountain marks a notable milestone of the TMMS. While it was complex and required lots of coordination and detailed planning, the decommissioning project was completed without incident, on time and budget. As part of the project's report, the AER documented and produced a YouTube video (https://www.youtube.com/watch?v=FnAHWyGAci8) showing the AGS's involvement on the TMMP and modernization of the equipment on the mountain to a near-real-time remote monitoring system. The video highlights work the AGS has completed over the last decade of monitoring and features new public outreach signs installed on South Peak in partnership with the Frank Slide Interpretive Centre.

In addition, 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 2017 annual videos are available on the AGS website (https://ags.aer.ca/turtle-mountain-monitoring-program).

7 Conclusions

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

The AGS will continue to work with Ellegi for maintenance and upgrades to LiSAmobile. We will complete an internal review of LiSAmobile and its data at the end of 2017 and assess the program's monitoring needs for 2018. This assessment will help us plan for the 2018 field season. We will also continue to investigate different forms of monitoring systems.

Communication of the risks associated with these hazards to the affected population is also ongoing. We publish the most recent results annually (Wood et al., 2016, 2017a, 2017b, and 2018) and present them in public meetings. The AGS continues to collaborate with the MCNP council members and staff to provide information on the TMMP. Updates are also available on the "Turtle Mountain Monitoring Program" page of the Alberta Geological Survey website (http://ags.aer.ca/turtle-mountain-monitoring-program).

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