AER/AGS Open File Report 2019-07

Alberta Energy Regulator

Turtle Mountain Field Laboratory, Alberta (NTS 82G): 2018 Data and Activity Summary

AGS
ALBERTA GEOLOGICAL SURVEY

AER/AGS Open File Report 2019-07

Turtle Mountain Field Laboratory, Alberta (NTS 82G): 2018 Data and Activity Summary

D.E. Wood and D.K. Chao

Alberta Energy Regulator
Alberta Geological Survey

September 2019

ISBN 978-1-4601-4497-8

If you use information from this publication in other publications or presentations, please acknowledge the AER/AGS. We recommend the following reference format:

Wood, D.E. and Chao, D.K. (2019): Turtle Mountain Field Laboratory, Alberta (NTS 82G): 2018 data and activity summary; Alberta Energy Regulator / Alberta Geological Survey, AER/AGS Open File Report 2019-07, 15 p.

Publications in this series have undergone only limited review and are released essentially as submitted by the author.

Published September 2019 by:
Alberta Energy Regulator
Alberta Geological Survey
4th Floor, Twin Atria Building
4999 – 98th Avenue
Edmonton, AB T6B 2X3
Canada

Tel: 780.638.4491
Fax: 780.422.1459
Email: AGS-Info@aer.ca
Website: www.ags.aer.ca

Contents

Tables

Figures

Acknowledgements

We acknowledge the following colleagues and collaborators who have contributed to the operation, maintenance, or studies of the Turtle Mountain monitoring system during 2018:

- J. Warren (Alberta Energy Regulator, Alberta Geological Survey, Edmonton, AB)
- J. Guo (Alberta Energy Regulator, Information Services Branch, Calgary, AB)
- T. Morrow (Alberta Energy Regulator, Information Services Branch, Calgary, AB)
- G. Bjorgan (NavStar Geomatics Ltd., Kelowna, BC)
- C. Rivolta (Ellegi srl, Milan, Italy)
- D. Leva (Ellegi srl, Milan, Italy)
- I. Binda Rossetti (Ellegi srl, Milan, Italy)
- G. Rogolino (Ellegi srl, Milan, Italy)
- P. Thomas (Municipality of Crowsnest Pass, Crowsnest Pass, AB)
- J. Ogertschnig (Municipality of Crowsnest Pass, Crowsnest Pass, AB)
- Municipality of Crowsnest Pass Council Members (Crowsnest Pass, AB)
- Frank Slide Interpretive Centre Staff (Crowsnest Pass, AB)
- Edon Management (Crowsnest Pass, AB)

The authors also wish to acknowledge the technical review and layout completed by editor M. Grobe. 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, 2018. 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 2018. This includes a review of the main repair and maintenance activities 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 discusses supporting studies and research conducted during 2018 and includes information on monitoring frequencies based on multiple secondary campaigns run in previous years.

The fourth section contains information on the emergency preparedness documentation and collaborations with external government agencies on the Turtle Mountain Monitoring Program.

The last section features information on two videos produced by the AER to highlight work completed on Turtle Mountain in 2018.

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, and b).

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, monitoring on the mountain, and changes to the monitoring program.

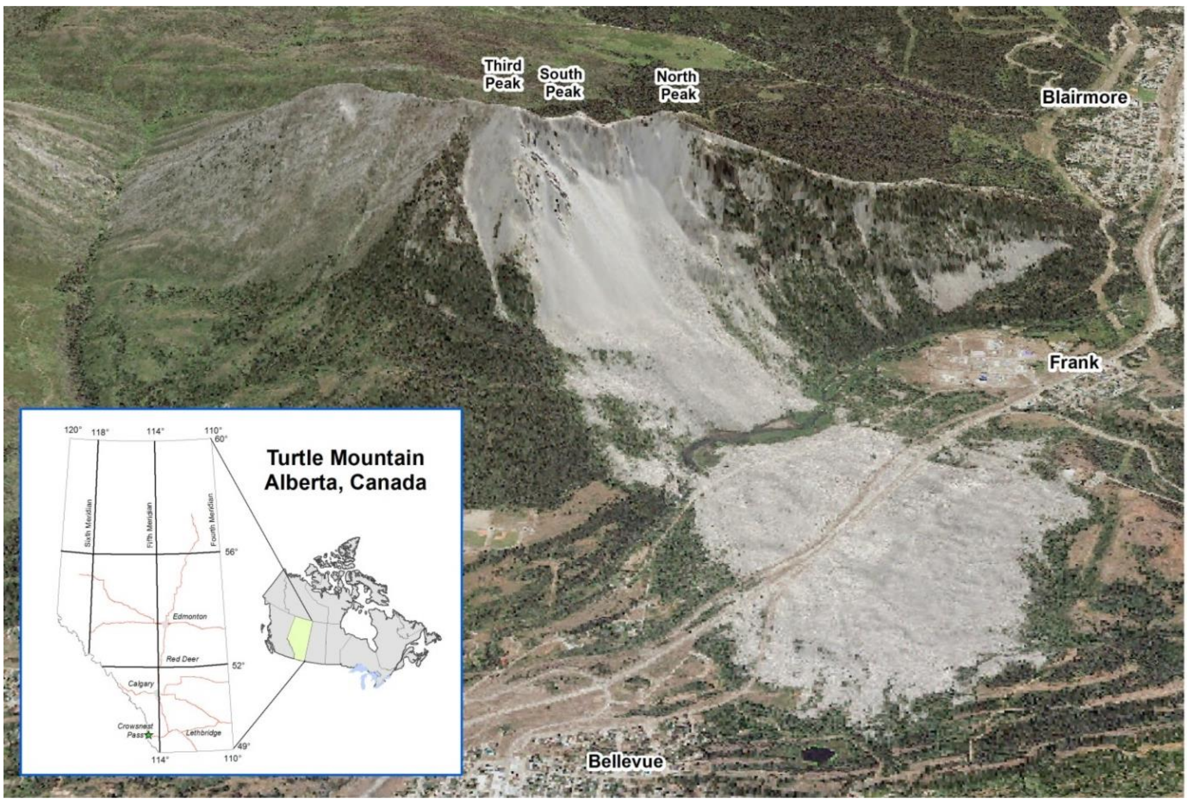

Figure 1. Location of Turtle Mountain in southwestern Alberta and full-extent aerial view of the Frank Slide.

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 2018.

The main activities undertaken concerning the sensor network during 2018 included

- replacement of a receiver for 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, 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 2018, 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 this period, LiSAmobile continued to provide high-quality data throughout 2018 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 2018, 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,
- mechanical maintenance on the radar head with lubrication of moving parts,
- internal radome cover and gasket checks,
- upgrade storage and processing to include a new CPU,
- installation of a cellular network connection for redundancies,
- 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 (housing structure) 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 precipitation events. The inspection revealed the radome had continued to withstand all the environmental factors and protected the LiSAmobile system efficiently as designed.

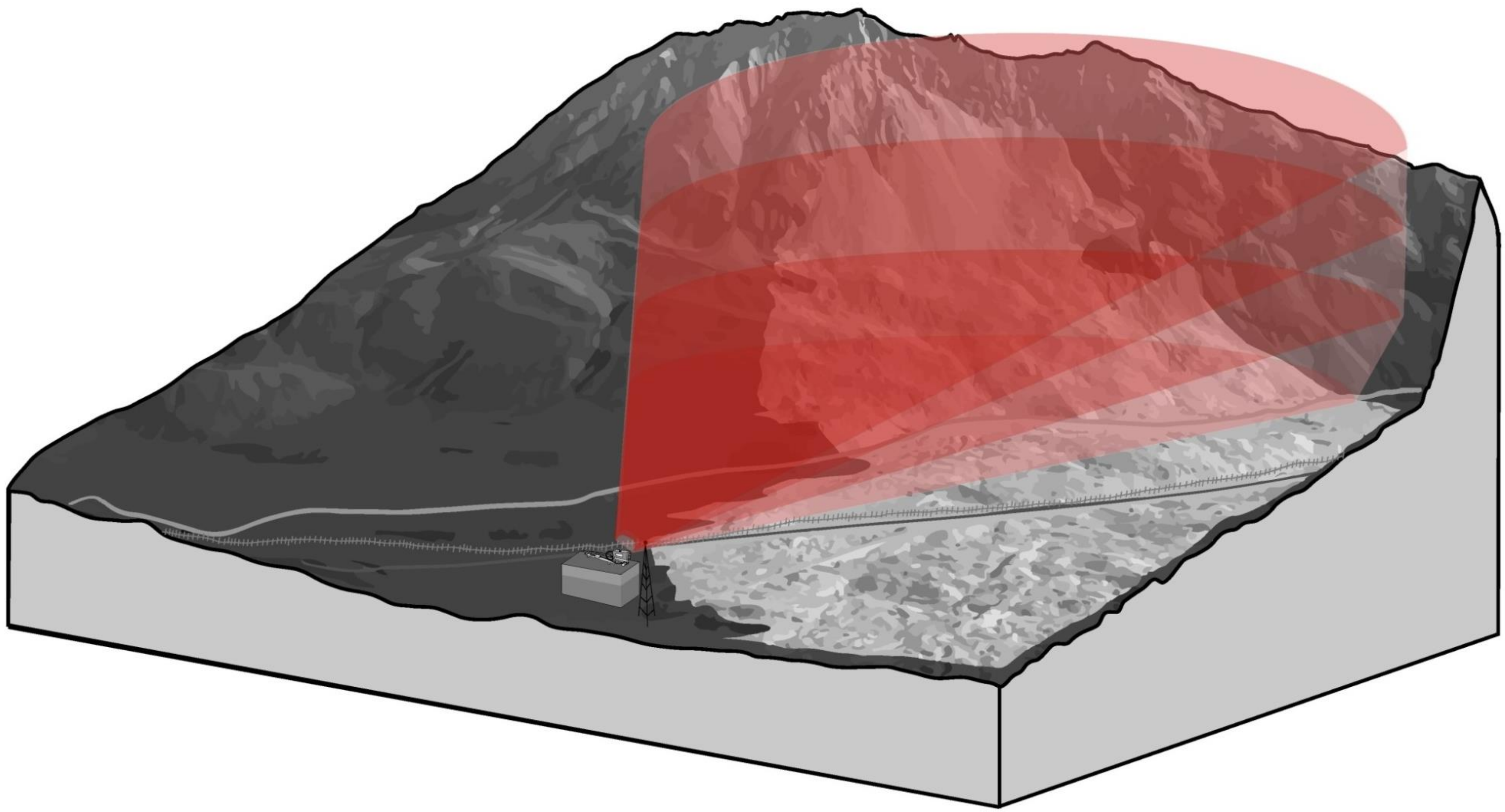

Figure 2. Overview, as of December 2018, of the primary monitoring equipment. The drawing marks the location of the LiSAmobile system, and the red beam depicts the scanning of the mountain. The light grey area represents the extent of the original 1903 slide. The image is not drawn to scale, and its purpose is to highlight the area LiSAmobile scans.

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 internal computer (Figure 3) used for on-site processing and storage was upgraded with a faster and larger central processing unit. This will allow for larger files to be uploaded from LiSAmobile to Milan, Italy. In addition, LiSAmobile was aligned with an optical image projection that enables a new feature on the near-real-time monitoring system. This included the alignment of 2D radar displacement maps overlain on a photo of Turtle Mountain to increase the readability of displacement maps.

In 2018, the AGS identified that additional redundancies should be installed at the Bellevue pump house to account for communication transmission outages. Although these outages are infrequent and no data is lost, Ellegi now has the ability to switch to the cellular network, as needed. This allows for AGS to stay within the predefined business continuity plan during alert-level green, outlined in Wood et al. (2017b).

Figure 3. Upgraded internal computer unit installed during LiSAmobile annual maintenance.

2.1.2 TMMS Radio Network Repair

In June 2018, the TMMS went offline suddenly due to a power outage across the Crowsnest Pass. While the monitoring system still had the ability to obtain and store information internally, the communication link was lost between the Crowsnest Pass, Calgary, Edmonton, and Milan. Upon further investigation, after the power was restored in the area, it was evident that the TMMS was impacted by the power outage at both the Bellevue pump house and Frank Slide Interpretive Centre (FSIC). Data collected during this disruption was temporarily stored on local disks and was transmitted once the network connection was re-established; therefore, no data was lost.

First, we found the uninterruptable power source (UPS) had failed prior to the power outage, and the back-up power had been drained during the course of the outage. Once the power returned, LiSAmobile was pulling AC power from the Bellevue pump house, and the backup batteries were no longer available in the event of another outage. The UPS batteries and fuses were replaced, and the UPS alarm was reset, which allowed us to power cycle the equipment located at the pump house. The UPS regained functionality and began to store power in the new batteries. In 2019, the UPS will be replaced with a newer model that has remote alarm capabilities which will allow us to monitor for power cycling, outages, and storage remotely.

Second, we tested the radio communication connection between the Bellevue pump house transmitter (PUMP) and the PUMP-FSIC receiver and were unable to communicate point-to-point successfully. The received signal strength indication (RSSI) value was inspected from the top of the pump house antennae towards the FSIC (Figure 4). We determined the radio transmitter located at the pump house was able to send a good signal (mid-high RSSI value, mid-strong transmission) to the FSIC; however, it could not be received. We found the radio receiver located at the FSIC had failed and could not complete the radio transmission to the Crowsnest Pass Provincial Building, located in Blairmore, Alberta. NavStar Geomatics Ltd. was contracted to replace and configure the PUMP-FSIC radio receiver with a new Tranzeo TR500 (5 GHz). The new radio was installed successfully and has had an average statistic transmission of 97-100% packet completeness, and 0% failed packet per sample period.

Over the last decade of monitoring the trees between the pump house and FSIC have grown and could potentially impact future communication transmissions between these two points (lower RSSI values). In the upcoming years, it would be beneficial to trim the tops of these trees to maintain a strong transmission between these points.

Figure 4. Testing the RSSI value from the top of the pump house antennae towards the 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 5) 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. (2018).

Figure 5. LiSAmobile system without radome.

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. 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 6). Positive values (blue colours) indicate displacement away from the sensor, while 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 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 2018 and are provided by Ellegi to the AGS in quarterly reports (Q15 to Q18 for 2018). 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 Q15 to Q18 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., Q15, Q16, Q17, Q18) is shown in Tables 1, 2, 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). AGS monitors all displacement movements (blue, red, and green) reported by Ellegi.

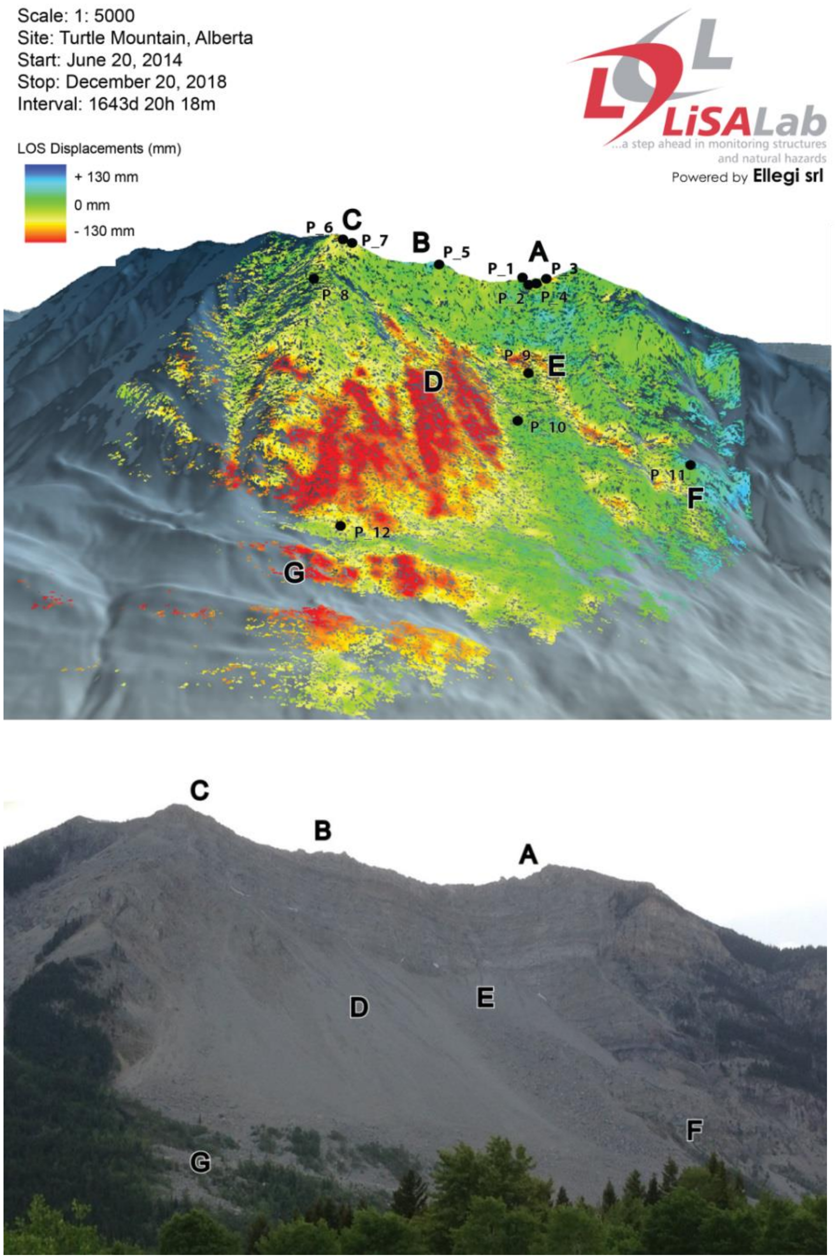

Figure 6. 3D displacement map (top) measured from June 20, 2014, to December 20, 2018, and view of the eastern face of Turtle Mountain (bottom). Letters A to G denotes the location of regions described in Tables 1 to 8.

Table 1. LiSAmobile generalized displacement in regions of interest for the period from June 20, 2014, to March 20, 2018 (1368 days).

Region	Location Description	Displacement (mm)	Approximate Region Area (m^2)
A	Close to North Peak	23.3 to 169.4	4600
B	Between North and South Peak	≤14.0	600
C	Close to South Peak	≤46.7	1200
D	Debris area toe of South Peak rock wall	-	-
E	Debris area toe of North Peak rock wall	≤51.0	-
F	Mid to lower vegetative rock wall	-	-
G	Debris zone run out area	≤64.0	-

Table 2. LiSAmobile measured displacement at points of interest (POI) for the period from June 20, 2014, to March 20, 2018 (1368 days) with observations specific to Q15.

Region	Point of Interest (POI)	Displacement (mm)	Displacement Descriptions Specific to Q15
A	P_1	23.0 to 169.0	Positive trend observed in Q15, subject to errors due to snow cover.
	P_2		
	P_3		
	P_4		
B	P_5	≤14.0	Acceleration of movement in January followed by fluctuations into February, subject to errors due to snow cover.
C	P_6	-	Fluctuations in Q15, subject to errors due to snow cover.
	P_7		
D	P_8	≤39.5	Rate of displacement maintained prior to Q15, followed by an accelerated rate of displacement in Q15.
E	P_9	≤51.0	Small fluctuations throughout Q15, 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	≤64.0	Acceleration of movement is reported at the beginning of January until the end of Q15.

Generalized displacement in Q15 for all seven regions was relatively unchanged compared to Q14. A positive cumulative displacement is observed for all POI (except P_12) at the end of Q15, most likely due to persistent snow cover in the region. Ellegi reported that snow cover trends are apparent in the data for all seven regions in Q15. The Crowsnest Pass area is subject to errors due to large amounts of snow accumulation during winter months.

The Q15 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, 2018 (1460 days).

Region	Location Description	Displacement (mm)	Approximate Region Area (m^2)
A	Close to North Peak	30.8 to 175.6	4600
B	Between North and South Peak	≤15.2	600
C	Close to South Peak	≤70.6	1200
D	Debris area toe of South Peak rock wall	-	-
E	Debris area toe of North Peak rock wall	≤59.0	-
F	Mid to lower vegetative rock wall	-	-
G	Debris zone run out area	≤65.0	-

Table 4. LiSAmobile measured displacement at points of interest (POI) for the period from June 20, 2014, to June 20, 2018 (1460 days) with observations specific to Q16.

Region	Point of Interest (POI)	Displacement (mm)	Displacement Descriptions Specific to Q16
A	P_1	31.0 to 176.0	Small acceleration from May onwards with continuous movement and a fluctuating trend throughout Q16.
	P_2		
	P_3		
	P_4		
B	P_5	≤15.2	Fluctuations throughout Q16.
C	P_6	≤70.6	Minimal accelerations observed throughout Q16.
	P_7		
D	P_8	≤43.7	Debris zone exhibited a stabilized trend with small acceleration at the beginning of Q16.
E	P_9	≤59.0	Exhibited continuous movement with small fluctuations until the end of Q16.
	P_10	-	Rate of displacement unchanged, displaying stable behaviour until the end of Q16.
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	Acceleration from April until June, followed by fluctuations for the remaining Q16.

Generalized displacement in Q16 for all seven regions was slightly larger than that measured in Q15, which is expected during the spring. In particular, P_12 showed an increased rate of displacement from April to June, in the debris zone. Measured displacements at some POIs were subject to errors due to snow cover and atmospheric moisture, such as heavy rainfall or fog. The Q16 report marks the end of four years since installation of the LiSAmobile system in 2014.

The Q16 summary report from Ellegi noted that the system was operational from the installation date in June 2014, with the exception of transmission issues from a broken radio detailed in Section 2.1.2. 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, 2018 (1552 days).

Region	Location Description	Displacement (mm)	Approximate Region Area (m^2)
A	Close to North Peak	34.0 to 181.3	4600
B	Between North and South Peak	≤15.1	600
C	Close to South Peak	≤69.2	1200
D	Debris area toe of South Peak rock wall	-	-
E	Debris area toe of North Peak rock wall	≤61.9	-
F	Mid to lower vegetative rock wall	-	-
G	Debris zone run out area	≤64.0	-

Table 6. LiSAmobile measured displacement at points of interest (POI) for the period from June 20, 2014, to September 20, 2018 (1552 days) with observations specific to Q17.

Region	Point of Interest (POI)	Displacement (mm)	Displacement Descriptions Specific to Q17
A	P_1	34.0 to 181.0	Slightly increased rate of displacement observed in Q17.
	P_2		
	P_3		
	P_4		
B	P_5	≤15.1	No significant displacement observed with minor fluctuations in Q17.
C	P_6	≤69.2	Continuous movement with fluctuations until the end of Q17.
	P_7		
D	P_8	≤41.1	Debris zone exhibited a constant trend with small fluctuations throughout Q17.
E	P_9	≤61.9	Small fluctuations throughout Q17.
	P_10		Rate of displacement unchanged displaying stable behaviour until the end of Q17.
F	P_11	-	Data is omitted due to errors introduced by vegetation in the instrument's line of sight.
G	P_12	≤69.0	No significant movement observed with minor fluctuations in Q17.

Generalized displacement in Q17 for all seven regions accelerated minimally, similar to Q16 and otherwise generally showed stable (unchanged) rates of displacement during summer 2018. The Q17 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 have 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 (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 vs. small) and whether pixel values are precisely measured or averaged; and therefore are subjective.

In 2017, Ellegi determined two areas of approximately 10 600 m^2 and 12 000 m^2 displayed movements of about 3.5 mm on average in both blocks, with some peaks displaying a maximum displacement of 8.0 mm (Wood et al., 2018b). In comparison with the analysis in 2017, it appears the two blocks previously identified in 2016 and 2017 continue to move with similar behaviour in 2018.

In 2018, the same study was completed between September 15, 2017, to September 15, 2018. This analysis determined the two blocks displayed movements of about 1.9–2.0 mm on average in both blocks (Figure 7), 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 6000 m^2 displayed movements of about 3.2 mm on average in the larger block, with some peaks displaying maximum displacement of more than 8.0 mm (Figure 7).

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.

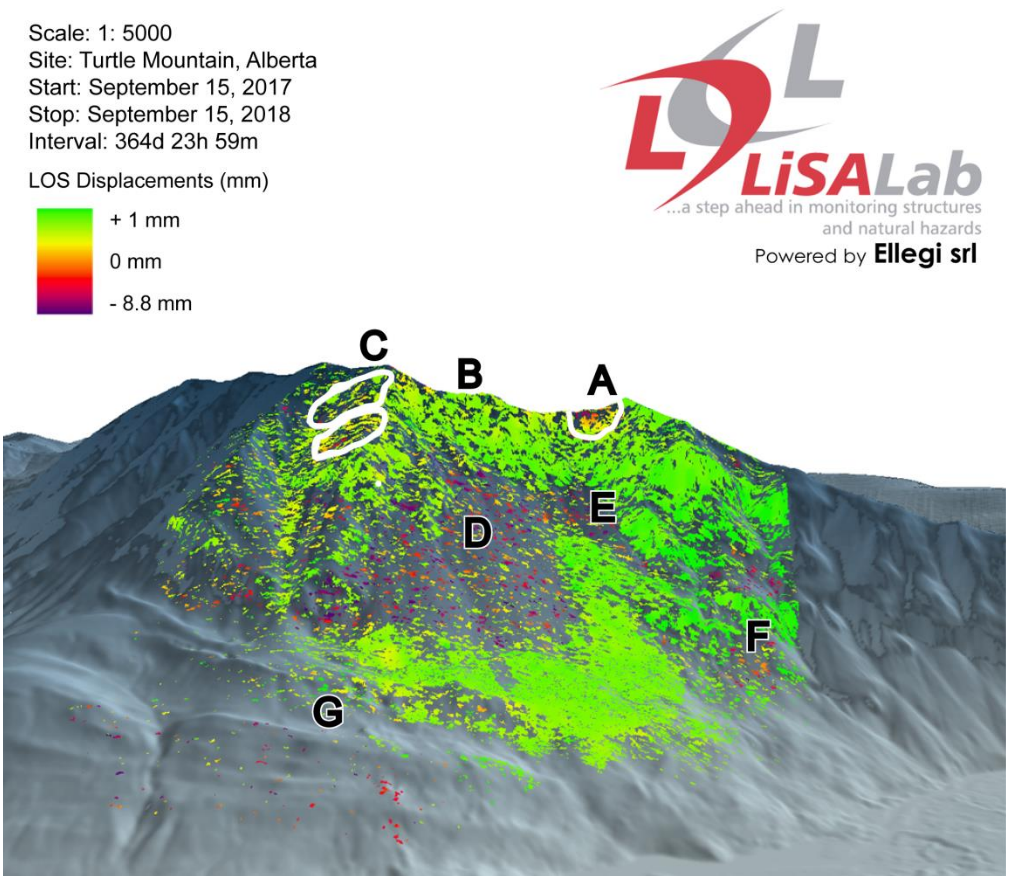

Figure 7. Annual analysis of large block movements near region A and C, from September 15, 2017, to September 15, 2018 (364d 23h 59m).

Table 7. LiSAmobile generalized displacement in regions of interest for the period from June 20, 2014, to December 20, 2018 (1643 days).

Region	Location Description	Displacement (mm)	Approximate Region Area (m^2)
A	Close to North Peak	31.4 to 180.6	4600
B	Between North and South Peak	≤11.4	600
C	Close to South Peak	≤67.8	1200
D	Debris area toe of South Peak rock wall	-	-
E	Debris area toe of North Peak rock wall	≤57.0	-
F	Mid to lower vegetative rock wall	-	-
G	Debris zone run out area	≤66.9	-

Table 8. LiSAmobile measured displacement for the period from June 20, 2014, to December 20, 2018 (1643 days) with observations specific to Q18.

Region	Point of Interest (POI)	Displacement (mm)	Displacement Descriptions Specific to Q18
A	P_1	31.4 to 180.6	Continuous movement with a slightly increased rate of displacement observed in Q18.
	P_2		
	P_3		
	P_4		
B	P_5	≤11.4	Small fluctuations throughout Q18, subject to errors due to snow cover.
C	P_6	≤67.8	Continuous movement with fluctuations until the end of Q18, subject to errors due to snow cover.
	P_7		
D	P_8	≤43.5	Small fluctuations throughout Q18, subject to errors due to snow cover.
E	P_9	≤57.0	Positive trend observed in Q18, subject to errors due to snow cover.
	P_10		
F	P_11	-	Data is omitted due to errors introduced by snow cover.
G	P_12	≤69.0	Small fluctuations throughout Q18, subject to errors due to snow cover.

Generalized displacements in Q18 for all seven regions accelerated minimally from Q17, but otherwise generally showed stable (unchanged) rates of displacement during Q18. A positive cumulative displacement is observed for all POI throughout Q18, 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 Crowsnest Pass area is known for large amounts of snow accumulation during the winter months.

The Q18 summary report from Ellegi noted that the system was operational from the installation date in June 2014, with minimal interruptions.

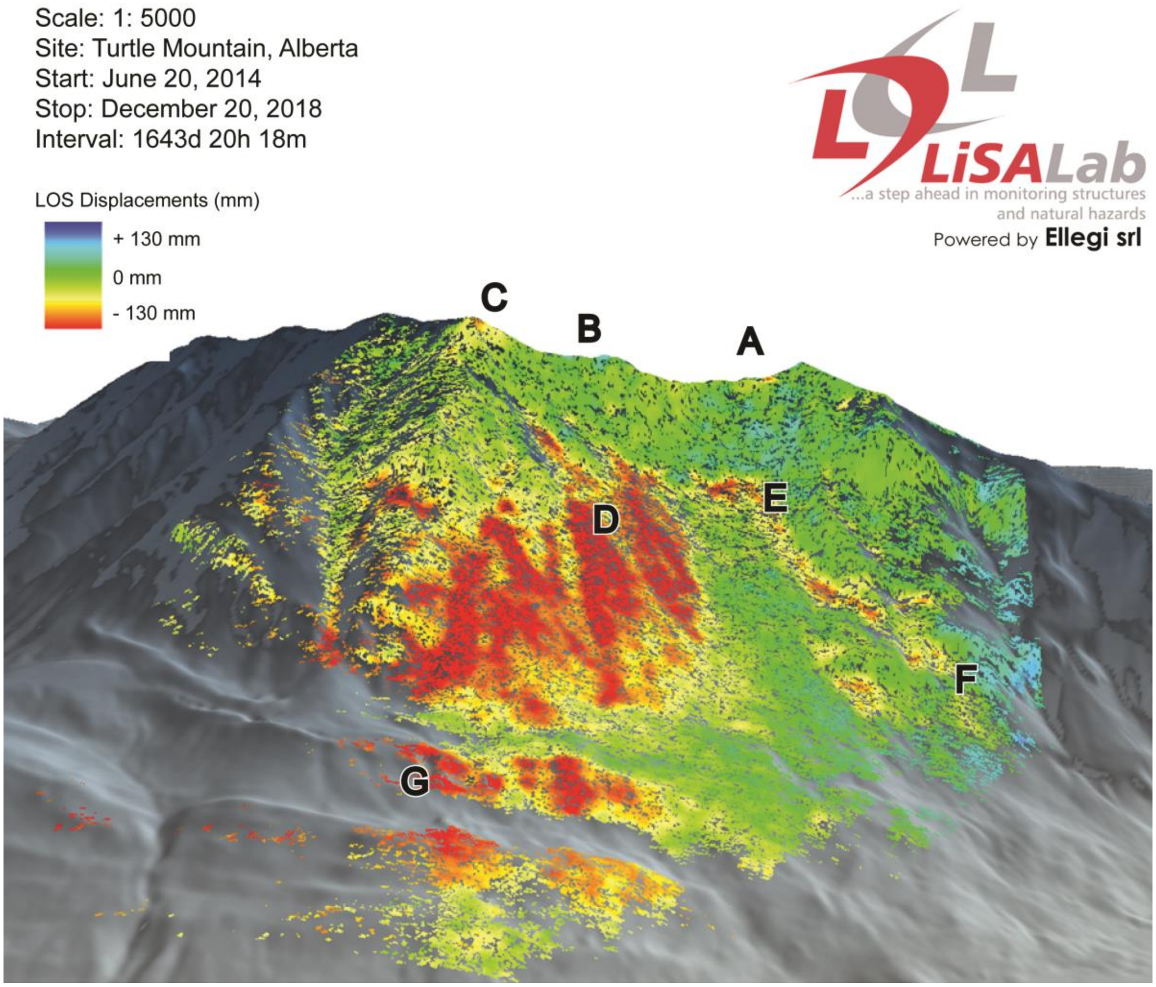

Figure 8. The line of sight 3D displacement map of Turtle Mountain measured from June 20, 2014, through December 20, 2018 (1643 days).

4 Supporting Studies and Research

During 2018, no secondary monitoring campaign was selected for supporting studies and research, based on multiple secondary campaigns ran in 2016 and 2017. 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).

5 TMMP Emergency Preparedness

In 2017, the AGS' *Roles and Responsibilities Manual for the Turtle Mountain Monitoring Program* (Wood et al., 2017b) 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 (2005) and subsequently incorporated into the Alberta Emergency Management Agency'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. Further information on these documents is available in Wood et al. (2017b) and Alberta Emergcy Management Agency (2017).

The AGS continues to work with the AER's Emergency Management Team to develop and host an internal workshop with exercise based on the internal roles and responsibilities outlined in Wood et al. (2017b). The goal of this internal training is to familiarize AGS/AER staff with the communication structure during each stage of the alert system. The internal workshop and training exercise are scheduled for Fall 2019.

Further, the AGS's internal emergency response protocol (ERP) was reviewed and updated in 2018. 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.

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 2018 annual videos are available for download on the AGS website (https://ags.aer.ca/turtle-mountain-monitoring-program). In addition, both videos are available for streaming on YouTube for Bellevue (https://youtu.be/L3-ySocp3IU) and South Peak (https://youtu.be/cXC44NkQjvE).

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 2018 and assess the program's monitoring needs for 2019. This assessment will help us plan for the 2019 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 (Warren et al., 2014 and 2016; Wood et al., 2016, 2017a, 2017b, 2018a, and 2018b; and Yusifbayov et al., 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).

8 References

Alberta Emergency Management Agency (2017): Emergency Response Protocol for Turtle Mountain; Government of Alberta, Alberta Emergency Management Agency, GoA/AEMA Report 2017-02, 12p., URL<http://www.aema.alberta.ca/documents/Emergency-Response-Protocol-for-Turtle-Mountain.pdf> [November 2018].

AMEC Earth and Environmental (2005): Turtle Mountain monitoring project, summary report—WP11.03 and 12.03, subsurface geotechnical and microseismic monitoring system; unpublished report prepared by AMEC Earth and Environmental for Alberta Municipal Affairs, 17 p.

Warren, J.E., Morgan, A.J., Chao, D.K., Froese, C.R. and Wood, D.E. (2014): Turtle Mountain Field Laboratory, Alberta (NTS 82G): 2012 data and activity summary; Alberta Energy Regulator, AER/AGS Open File Report 2014-09, 16 p., URL <http://ags.aer.ca/publications/OFR_2014_09.html> [March 2019].

Warren, J.E., Wood, D.E., Chao, D.K. and Shipman, T.C. (2016): Turtle Mountain Field Laboratory, Alberta (NTS 82G): 2013 data and activity summary; Alberta Energy Regulator, AER/AGS Open File Report 2015-09, 43 p. URL, <http://ags.aer.ca/publications/OFR_2015_09.htm> [March 2019].

Wood, D.E., Chao, D.K. and Shipman, T.C. (2016): Turtle Mountain Field Laboratory, Alberta (NTS 82G): 2014 data and activity summary; Alberta Energy Regulator, AER/AGS Open File Report 2015-10, 91 p., URL <http://ags.aer.ca/publications/OFR_2015_10.htm> [March 2019].

Wood, D.E., Chao, D.K. and Shipman, T.C. (2017a): Turtle Mountain Field Laboratory, Alberta (NTS 82G): 2015 data and activity summary; Alberta Energy Regulator, AER/AGS Open File Report 2017-03, 28 p., URL <http://ags.aer.ca/publications/OFR_2017_03.html> [March 2019].

Wood, D.E., Chao, D.K., Guo, J.F. and Shipman, T.C. (2017b): AER/AGS roles and responsibilities manual for the Turtle Mountain Monitoring Program, Alberta; Open File Report 2017-04, 28 p., URL <http://ags.aer.ca/publications/OFR_2017_04.html> [March 2019].

Wood, D.E., Yusifbayov, J.A., Chao, D.K., and Shipman, T.C. (2018a): Turtle Mountain Field Laboratory, Alberta (NTS 82G): 2016 data and activity summary; Alberta Energy Regulator / Alberta Geological Survey, AER/AGS Open File Report 2018-07, 24 p. URL <http://ags.aer.ca/publications/OFR_2018_07.html> [March 2019].

Wood, D.E., Chao, D.K., Yusifbayov, J.A., and Shipman, T.C. (2018b): Turtle Mountain Field Laboratory, Alberta (NTS 82G): 2017 data and activity summary; Alberta Energy Regulator / Alberta Geological Survey, AER/AGS Open File Report 2018-12, 25 p. URL <http://ags.aer.ca/publications/OFR_2018_12.html> [March 2019].

Yusifbayov, J.A., Wood, D.E., Chao, D.K. and Warren, J.E. (2018): Turtle Mountain Decommission Project, Alberta (NTS 82G): summary report and historical signs; Alberta Energy Regulator / Alberta Geological Survey, AER/AGS Open File Report 2018-02, 13 p., URL <http://ags.aer.ca/publications/OFR_2018_02.html> [March 2019].