AER/AGS Open File Report 2022-01

Turtle Mountain Field Laboratory, Alberta (NTS 82G): 2020 Data and Activity Summary

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Alberta Energy Regulator
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Abstract

This report provides a summary of both the lessons learned from the Turtle Mountain monitoring system (TMMS), and from studies undertaken by the Alberta Geological Survey (AGS) and collaborators between January 1 and December 31, 2020. The TMMS is a near–real-time remote monitoring system that provides data from a network of sensors and monitoring systems on Turtle Mountain, located in the Crowsnest Pass of 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 2020. This includes a summary of system performance and reliability, review of the system outage and repair activities, and alternative monitoring efforts.
- The second section discusses the safety update at the pump house near Bellevue.
- The third section provides data analysis and interpretation from the primary monitoring equipment, known as LiSAmobile.
- The fourth section discusses supporting studies and research.
- The last section features information on two videos produced by the Alberta Energy Regulator to highlight the changes on Turtle Mountain in 2020.

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, refer to Wood et al. (2017a, b, 2018a, b).

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

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

2 Sensor Network Activity

This section provides an overview of the major upgrades, repair, maintenance activities, and performance of the sensor network of the monitoring system during 2020.

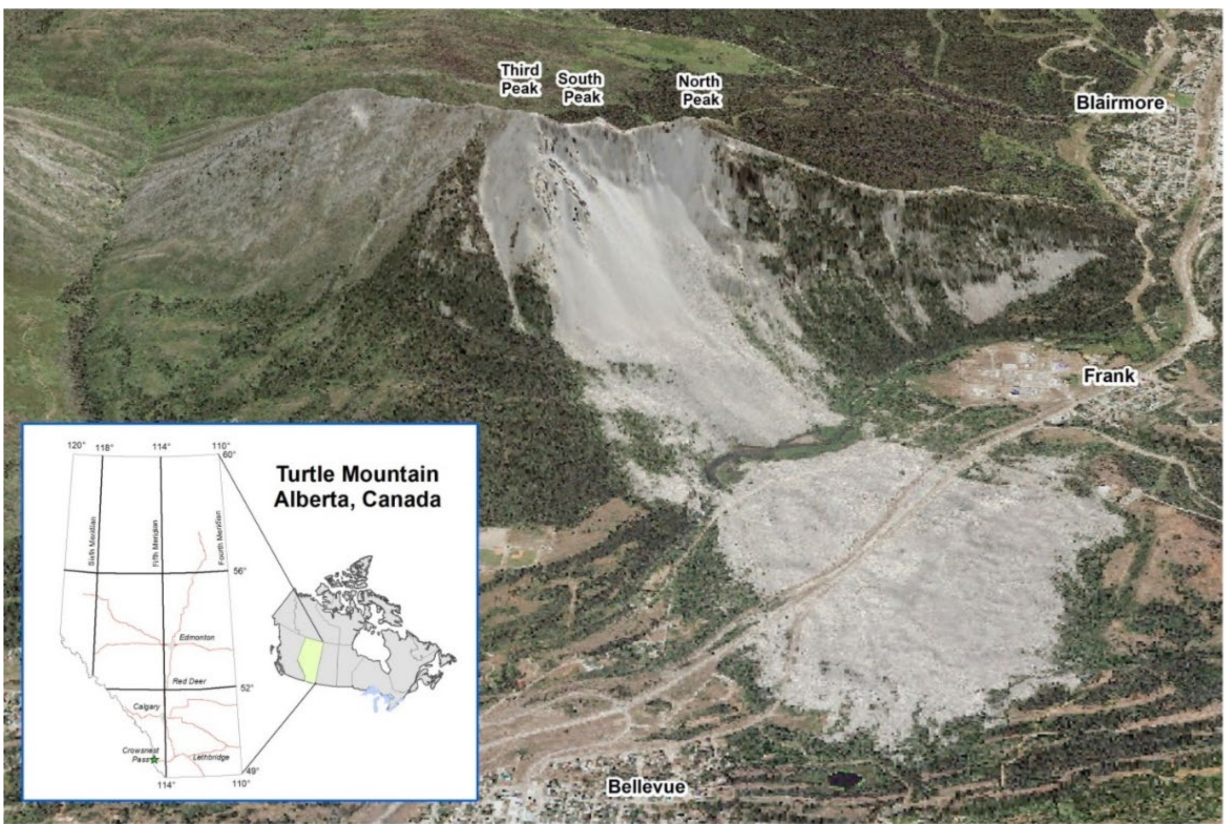

Figure 1. Location of Turtle Mountain in southwestern Alberta and full-extent aerial view of the Frank Slide.

The main activities undertaken concerning the sensor network during 2020 included

- an emergency repair of LiSAmobile ground-based interferometric synthetic aperture radar (GB-InSAR) system after an equipment outage,
- implementation of the AGS Internal Emergency Response Plan for the TMMP, and
- alternative monitoring efforts during the outage.

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, except for repair, maintenance, and a short outage in 2020. The AGS's lease with Ellegi provides customer service and technical support in case of an emergency or equipment changes.

In 2016, LiSAmobile was transitioned from being the secondary monitoring system to the primary monitoring system (Figure 2). In addition, the AGS also supports secondary monitoring campaigns periodically. 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 2020, no secondary monitoring campaigns were selected for supporting studies and research (Section 5).

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 2020, LiSAmobile continued to provide high-quality data for most of the year, except for a 37-day mechanical outage in April and May. Despite this interruption, Ellegi continues to provide a premium level of technical support, innovative shelter technology, and timely detailed reporting. The AGS will continue to use LiSAmobile as the primary monitoring sensor.

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

2.1 Repairs and Maintenance

Ellegi and the AGS were unable to conduct regular annual maintenance in June due to international border closures and travel restrictions during the COVID-19 outbreak. However, the mechanical components of LiSAmobile were examined and fully tested in Italy by Ellegi following the repair of the equipment in April.

2.1.1 LiSAmobile Outage

Ellegi notified the AGS on April 1, 2020, that they lost data transmission from LiSAmobile to Italy. An inspection by a local contractor ruled out electrical and communication failures. The AGS staff were dispatched shortly after to the Crowsnest Pass to conduct a detailed diagnostic of LiSAmobile. With guidance from Ellegi, it was determined that the linear positioner (drive belt) connected to the radar unit was misaligned and damaged, preventing the radar unit from moving (Figure 3). Fortunately, this mechanical failure did not affect the radar unit and its signal transmission/receiving functions.

Components from LiSAmobile, including the linear positioner, motor, and track, were shipped back to Ellegi in Milan, Italy, for repair, service, and testing. The radar unit was placed in local storage during the repair. On May 7, the AGS staff arrived on site to reinstall LiSAmobile and began testing with Ellegi. After testing the alignment and movement of the radar unit along the track, and several hours collecting and sending measurement data to Ellegi for analysis, LiSAmobile was officially returned to fully operational status on May 8.

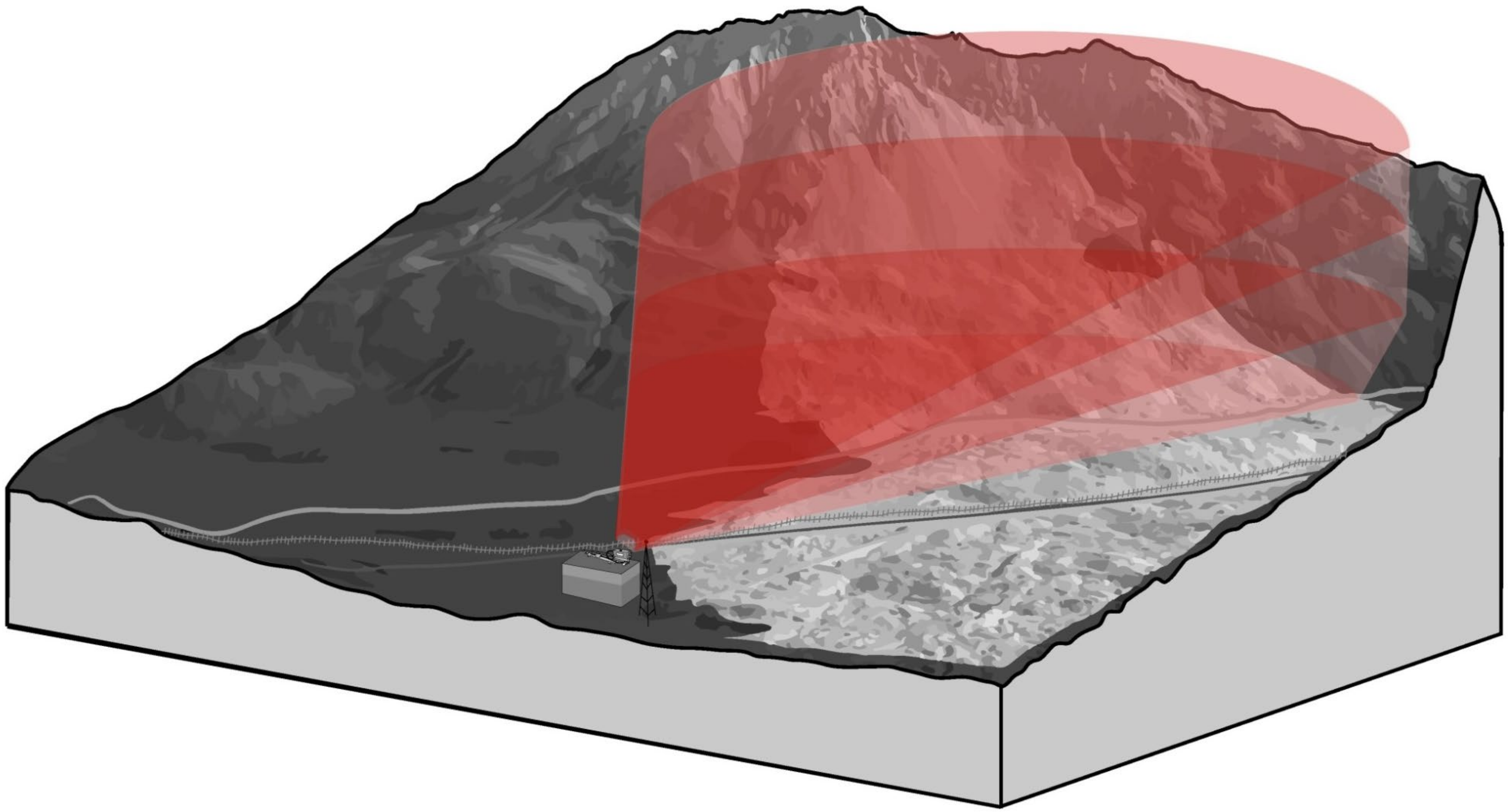

Figure 2. Overview, as of December 2020, of the primary monitoring equipment at Turtle Mountain, Alberta. The drawing marks the location of the LiSAmobile system, and the red beam depicts the scanning of the mountain. The light grey area represents the extent of the original 1903 slide. The image is not drawn to scale, and its purpose is to highlight the area LiSAmobile scans.

Figure 3. Linear positioner (drive belt) connected to the radar unit was misaligned and damaged, preventing the radar unit from moving along the track of the LiSAmobile unit at Turtle Mountain, Alberta.

During reinstallation of LiSAmobile, the radome (housing structure) 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. These exposures include high and low temperatures during summer and winter, high wind gusts, and heavy precipitation events. Inspection confirmed the radome continues to withstand all the environmental conditions and protects the LiSAmobile system efficiently as designed.

2.1.2 Alert Level and Incident Command System

During the LiSAmobile outage, the TMMP team recommended that the AGS raise the Turtle Mountain monitoring alert level from green to yellow (Wood et al., 2017b), as reliable and consistent data could not be obtained in a timely fashion, and activate the Incident Command System (ICS) protocol. The ICS is a control system for managing emergency incidents from finding a missing person to fighting a forest fire. The AGS implemented the ICS protocol from April 7 to May 11, 2020. The TMMP team, AGS management, and AER staff were assigned with different responsibilities according to the ICS organizational and reporting structure. All internal and external communications, decisions made, and monitoring details were recorded daily and signed off by the Incident Commander. These daily activity logs were reviewed at the debriefing with the AER's Incident Management Team (IMT) to identify response improvements for future outages.

At alert level yellow, the TMMP team met daily with AGS management, AER's Emergency Management Agency (Field Incident Response Support Team), and the IMT to discuss deployment to site, COVID-19 safety precautions, implementation of ICS management, and alternative monitoring efforts. These daily meetings were replaced with weekly updates after LiSAmobile was sent back to Italy for servicing. During the outage period, the TMMP team developed procedures to continue daily monitoring for any visible rock movements with webcams installed at the pump house in Bellevue and on the South Peak. The alert level was changed back to green on May 11, 2020, four days after LiSAmobile was functional and had began collecting data.

2.1.3 Alternative Monitoring Efforts

During the outage of LiSAmobile as the primary monitoring system, the AGS elected to use two alternative monitoring efforts: InSAR analysis of satellite images and monitoring of feed from live webcams.

2.1.3.1 RADARSAT

The AGS requested assistance from the Canada Centre for Mapping and Earth Observation (CCMEO) in Ottawa to provide emergency monitoring of Turtle Mountain under the Natural Resources Canada's (NRCan) Emergency Geomatics Service (EGS). Their focus was on the subsidence, wedge, and toppling zones at the upper South Peak (Figure 4) with the following objectives:

1) planning for aerial coverage and ordering of RADARSAT-2 (RS2) and RADARSAT Constellation Mission (RCM) data that would be suitable for InSAR monitoring
2) performing historical InSAR analysis on RS2 archive data that could be connected to newly acquired data
3) performing InSAR analysis on RS2 and RCM data as soon as new data was collected with sufficient coherence
4) alerting the AGS immediately if any significant movement was observed

The CCMEO acquired 203 RS2 and 31 RCM images between 2014 and June 2020 for this monitoring and analysis. These images included a total of eight ascending and descending beam modes (look directions) with spatial resolutions between 3 and 11 m at various incident angles and line of sight (LOS). Two time-series image stacks were generated using image-to-image displacement maps. Analysis of the RCM time-series image stack did not reveal any significant rock displacement between April and June 2020. The RS2 time-series analysis identified a deformation rate of up to 5 mm/year on the east-facing upper and lower slopes between 2014 and 2020. Most of the deformation appeared during winter and spring in the lower eastern slope at the debris zone. Refer to Lehrbass et al. (2021) for the complete report.

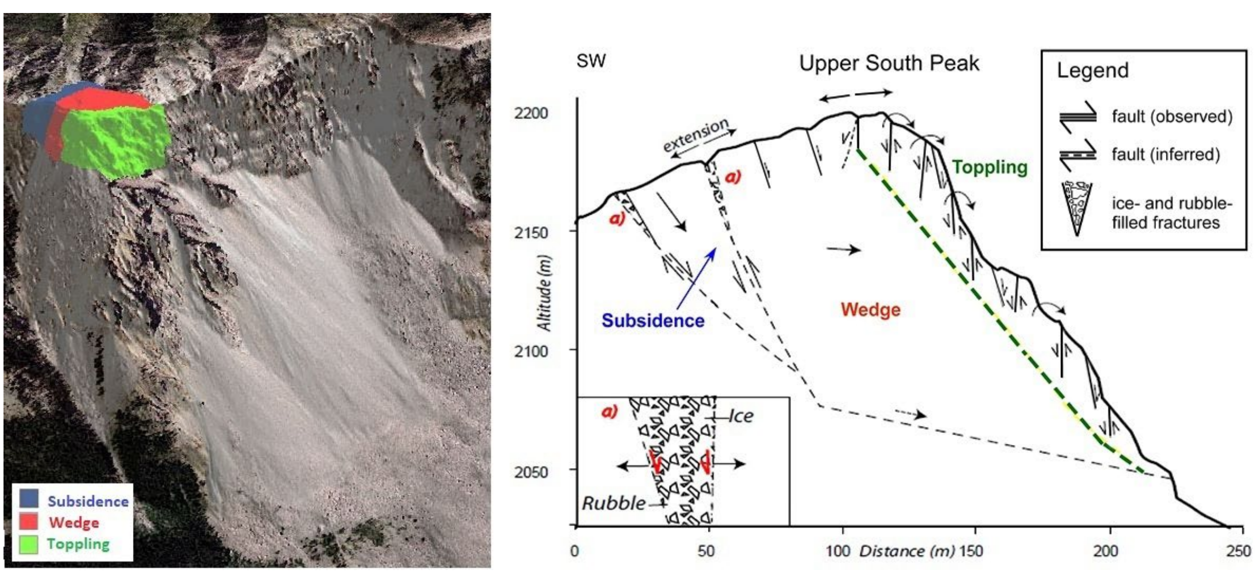

Figure 4. Subsidence, wedge, and toppling zones at the upper South Peak, Turtle Mountain, Alberta, monitored by Canada Centre for Mapping and Earth Observation (CCMEO) in the spring of 2020 (modified from Lehrbass et al., 2021).

2.1.3.2 Sentinel-1

The AGS also used freely available Sentinel-1A and B satellite imagery from the European Space Agency (ESA) to monitor rock displacements from April 3 to 27, 2020. The satellites have a revisit rate of every 12 days and their Interferometric Wide swath with VV (vertical transmit and vertical receive) polarization images have a spatial resolution of 5 by 20 m. An image stack from August 5, 2017, to April 3, 2020, was produced for LOS planning and measurement calibrations. The image stack was created using single look complex (SLC) descending mode. Five additional image stacks were created using SLC's ascending and descending modes for March 30 to April 27, 2020. The parallel small baseline subset (P-SBAS) processing chain was used to generate the Earth deformation time series and mean velocity maps. Analysis of these image stacks revealed no significant rock displacements from March 30 to April 27.

2.1.3.3 Webcams

Monitoring the live feed from webcams at Bellevue and on the South Peak began on April 2, one day after the outage. Members of the TMMP team took photos with both webcams seven times a day at two-hour intervals from 8:00 am to 8:00 pm, and reviewed their daily recordings at the end of each day for visible rock movements. This effort continued until the alert level was changed back to green. The webcam monitoring did not detect any visible movements.

3 Hand Railing Installation at Bellevue Pump House

In March 2020, the AGS had metal hand railings installed around the roof of the pump house to ensure the safety of its staff and other workers. The railings on both sides and the back of the building are fixed in place, with an opening designed for access to the roof. The railing at the front can be folded down against the front wall while LiSAmobile is in operation to avoid interfering with its radar signals (Figure 5). The railing is folded up and locked to the side railings during the repairs and maintenance of LiSAmobile.

Figure 5. Front hand railing in the open position at the Bellevue pump house (Turtle Mountain, Alberta) so the railing does not interfere with LiSAmobile readings.

4 Data Collection and Analysis

4.1 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 6) uses the InSAR technique to measure small displacements at each point on the surface of the mountain. For additional information, refer to Wood et al. (2016).

The LiSAmobile system is connected via the Internet through a Wi-Fi connection that allows virtual private network (VPN) access. The LiSAmobile system obtains raw data from measurements from the radar head. These data are processed onsite by LiSAmobile, the results are transferred, and the data quality is evaluated by Ellegi and used to create displacement maps showing a pixelated image of ground displacements that range from positive to negative values (Figure 7). Positive values (blue colours) indicate displacement away from the sensor, whereas negative values (red colours) indicate displacement towards the sensor.

4.2 Discussion and Interpretation of Monitoring Data from LiSAmobile

The displacement map displayed in Figure 7 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 2020 and are provided by Ellegi to the AGS in quarterly reports (quarterly reporting period [Q] 23 to Q26 for 2020). Each report contains the cumulative data starting from June 20, 2014, to the end of the respective quarterly reporting period.

The data are divided into nine regions (A–I; Figure 7), which are further subdivided into 14 points of interest (POIs, labelled P_1 through P_12, P_18, and P_20 in Figure 7). Regions H and I, and P_18 and P_20 belong to the morphologically connected channels extending to the valley bottom below region C (South Peak). They were added to the data collection in February 2020 after displacements were observed in December 2019. Additional documentation of the LiSAmobile parameters can be found in Wood et al. (2016).

The high displacement rates detected in the vegetation zone (region F, Figure 7) are considered to be measurement errors introduced by atmospheric moisture within the line of sight.

Figure 6. LiSAmobile system without radome (housing structure), Turtle Mountain, Alberta.

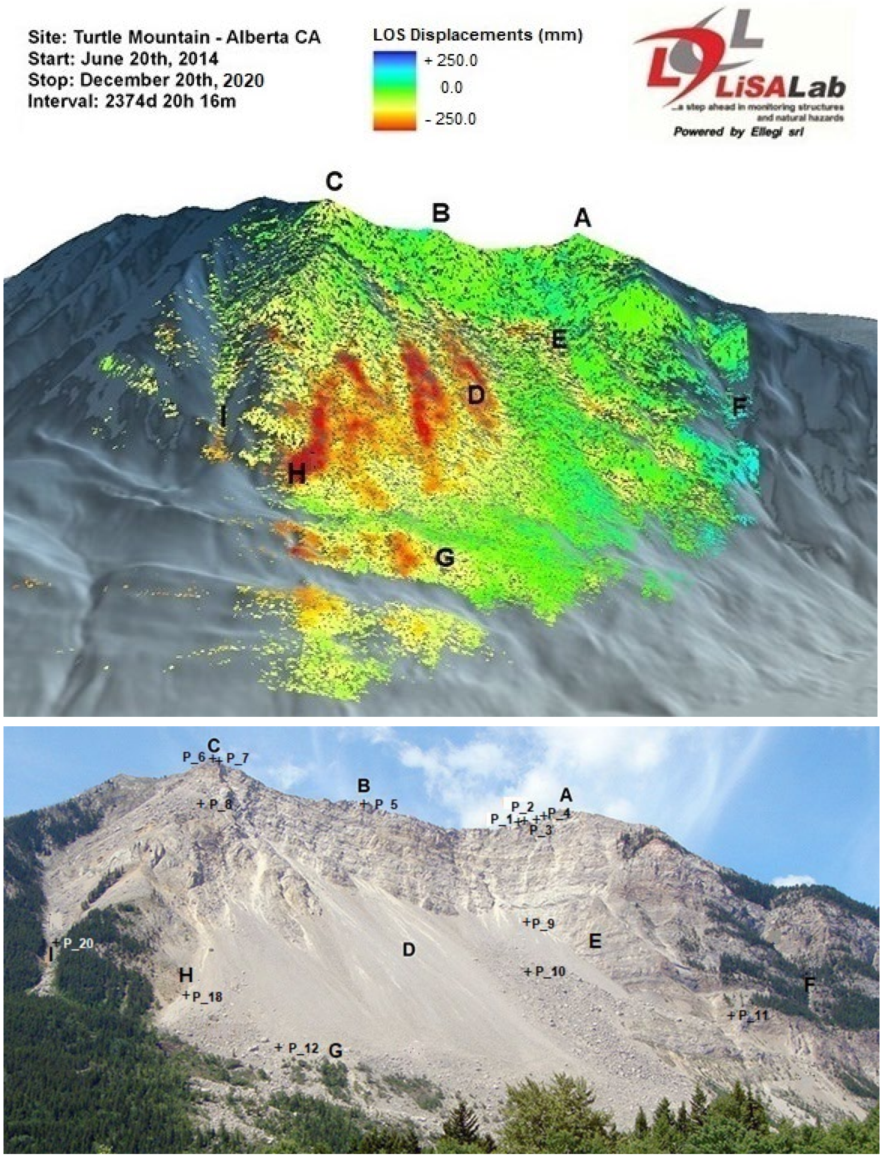

Figure 7. Three-dimensional (3D) displacement map (top) measured from June 20, 2014, to December 20, 2020, and view of the eastern face of Turtle Mountain, Alberta (bottom). Letters A to I denote the locations of regions described in Tables 1 to 8. Letters P_1 to P_20 denote points of interest. Abbreviations: d, day; h, hour; LOS, line of sight; m, minute.

The results from reports Q23 to Q26 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., Q23, Q24, Q25, Q26) 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 7, 8) both positive and negative displacement values are depicted using colours. Blue colours indicate displacement away from a sensor (positive value), for example, rocks calving off and exposing new rock surfaces from behind. Red colours indicate displacement towards the sensor (negative value), such as rocks falling and accumulating in the debris zones (regions D, E, and G). Green colours depict a neutral range of displacement with minimal movements towards or away from the sensor.

For simplicity, the AGS has removed the negative sign from the reported displacement tables (Tables 1–8) 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.

Table 1. LiSAmobile generalized displacement in regions of interest for the period from June 20, 2014, to March 20, 2020 (2099 days).

Region	Location Description	Displacement (mm)	Approximate Region Area (m^2)
A	Close to North Peak	14.0 to 189.0	4600
B	Between North and South peaks	≤7.0	600
C	Close to South Peak	≤84.0	1200
D	Debris area toe of South Peak rock wall	-	-
E	Debris area toe of North Peak rock wall	≤84.0	-
F	Mid to lower vegetative rock wall	-	-
G	Debris zone runout area	≤75.0	-
H	Elongated channel (right) to the valley	-	-
I	Elongated channel (left) to the valley	-	-

Table 2. LiSAmobile measured displacement at points of interest (POI) for the period from June 20, 2014, to March 20, 2020 (2099 days), with observations specific to quarterly reporting period (Q) 23.

Region	Point of Interest (POI)	Displacement (mm)	Displacement Descriptions Specific to Q23
A	P_1	21.0 to 183.0	Positive trend observed in Q23, subject to errors due to snow cover.
	P_2		
	P_3		
	P_4		
B	P_5	≤8.0	Fluctuations in Q23, subject to errors due to snow cover.
C	P_6	≤84.0	Fluctuations in Q23, subject to errors due to snow cover.
	P_7		
D	P_8	≤61.7	Minor fluctuations and an acceleration in Q23, subject to errors due to snow cover.
E	P_9	≤75.0	An acceleration followed by a positive displacement in Q23, subject to errors due to snow cover.
	P_10	-	Little to no movement in Q23, subject to errors due to snow cover.
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	≤89.0	A small acceleration in Q23, subject to errors due to snow cover.
H	P_18	-	An acceleration in February caused by snowfall or temperature fluctuation.
I	P_20	-	An acceleration in February caused by snowfall or temperature fluctuation.

Generalized displacement in Q23 for regions A to G was relatively unchanged compared to Q22. Positive cumulative displacements were observed throughout Q23 for most of the POIs, most likely due to persistent snow cover in the region. Ellegi reported that snow cover trends are apparent in the data for Q23. The Crowsnest Pass area is subject to large amounts of snow accumulation during winter months that can affect the data.

The Q23 summary report from Ellegi noted that the system was operational from the installation date in June 2014, with minimal interruptions.

Points of interest 18 and 20 were added in Q23 after accelerated movement of debris was noted starting in December 2019, likely caused by debris creep or snow drifting.

Table 3. LiSAmobile generalized displacement in regions of interest for the period from June 20, 2014, to June 20, 2020 (2191 days).

Region	Location Description	Displacement (mm)	Approximate Region Area (m^2)
A	Close to North Peak	15.0 to 195.0	4600
B	Between North and South peaks	≤8.0	600
C	Close to South Peak	≤94.0	1200
D	Debris area toe of South Peak rock wall	-	-
E	Debris area toe of North Peak rock wall	≤86.0	-
F	Mid to lower vegetative rock wall	-	-
G	Debris zone runout area	-	-
H	Elongated channel (right) to the valley	-	-
I	Elongated channel (left) to the valley	-	-

Table 4. LiSAmobile measured displacement at points of interest (POI) for the period from June 20, 2014, to June 20, 2020 (2191 days), with observations specific to quarterly reporting period (Q) 24.

Region	Point of Interest (POI)	Displacement (mm)	Displacement Descriptions Specific to Q24
A	P_1	21.0 to 183.0	Some positive displacements throughout Q24.
	P_2		
	P_3		
	P_4		
B	P_5	≤8.0	Fluctuations throughout Q24 caused by snow-cover effects.
C	P_6	≤65.0	Some positive displacements throughout Q24 caused by atmospheric effects and snowfalls.
	P_7		
D	P_8	-	Small positive displacement caused by snow-cover effects.
E	P_9	-	No significant displacements throughout Q24.
	P_10	-	Rate of displacement unchanged, displaying semi-stable behaviour until the end of Q24.
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	≤92.0	Accelerations from Q23 were stablized in Q24.
H	P_18	-	Acceleration slowed down in Q24.
I	P_20	-	Acceleration slowed down in Q24.

Generalized displacement in Q24 for all nine regions was relatively the same as Q23. Measured displacements at some POIs were subject to errors due to snow cover and atmospheric moisture, such as heavy rainfall or fog. Points of interest 18 and 20 had slowed down in Q24 possibly due to the disappearance of snow. The Q24 report marks the end of six years since installation of the LiSAmobile system in 2014.

The Q24 summary report from Ellegi noted that the system was operational from the installation date in June 2014, except for April 2 to May 7, 2020, because of a hardware issue (see Section 2.1.1). Data collection resumed on May 8, 2020.

Table 5. LiSAmobile generalized displacement in regions of interest for the period from June 20, 2014, to September 20, 2020 (2283 days).

Region	Location Description	Displacement (mm)	Approximate Region Area (m^2)
A	Close to North Peak	16.0 to 195.0	4600
B	Between North and South peaks	≤9.5	600
C	Close to South Peak	≤107.0	1200
D	Debris area toe of South Peak rock wall	-	-
E	Debris area toe of North Peak rock wall	≤86.0	-
F	Mid to lower vegetative rock wall	-	-
G	Debris zone runout area	≤72.0	-
H	Elongated channel (right) to the valley	-	-
I	Elongated channel (left) to the valley	-	-

Table 6. LiSAmobile measured displacement at points of interest (POI) for the period from June 20, 2014, to September 20, 2020 (2283 days), with observations specific to quarterly reporting period (Q) 25.

Region	Point of Interest (POI)	Displacement (mm)	Displacement Descriptions Specific to Q25
A	P_1	15.0 to 195.0	Small positive displacements throughout Q25.
	P_2		
	P_3		
	P_4		
B	P_5	≤9.5	Fluctuations throughout Q25.
C	P_6	≤107	Continuous movement with fluctuations until the end of Q25.
	P_7		
D	P_8	-	No remarkable movement throughout Q25.
E	P_9	≤89.0	Very small displacements in Q25.
	P_10		Rate of displacement unchanged, displaying stable behaviour until the end of Q25.
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	≤92.0	Fluctuation stabilized in Q25.
H	P_18	-	Acceleration continued to slow down throughout Q25.
I	P_20	-	Acceleration continued to slow down throughout Q25.

Generalized displacement in Q25 for all nine regions accelerated minimally, similar to Q24 and otherwise generally showed stable (unchanged) rates of displacement during summer 2020. The Q25 summary report from Ellegi noted that the system was operational from the installation date in June 2014, with minimal interruptions and an outage between April 1 and May 7 due to mechanical failure and repair. The system has since been collecting data without interruption.

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 this block was in fact two different blocks (Figure 8) 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 (Figure 8). Ellegi was able to evaluate the displacement rates within this region, identifying small-scale movements over a larger area (large block movements). In 2019, both upper and lower blocks near region C continued to exhibit a slow rate of displacement, while the third area near region A was moving slower than in 2017–2018. These analyses have a one-year time frame and were compared to the results from the prior year. 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 2020, an analysis of the same areas was completed for September 15, 2019, to September 19, 2020. The lower block below region C had peaked at around –1.5 mm in 2019–2020 (Figure 8) and displayed a very similar displacement pattern as 2018–2019. The upper block in region C and smaller block near region A exhibited an annual average displacement of –3.0 mm with peaks around –5 mm in 2019–2020.

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

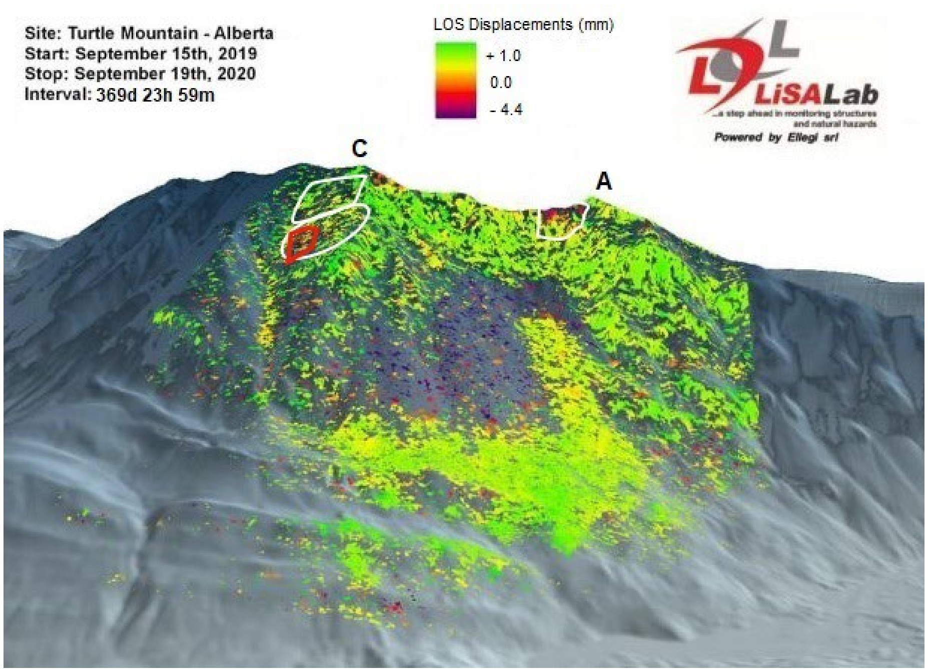

Figure 8. Annual analysis of block movements near regions A (right) and C (left; Turtle Mountain, Alberta), from September 15, 2019, to September 19, 2020 (369 days, 23 hours, 59 minutes). Areas of displacements observed starting in 2016 and 2018 are outlined in white. An area of displacements observed in quarterly reporting period 25 is outlined in red. Abbreviation: LOS, line of sight.

Table 7. LiSAmobile generalized displacement in regions of interest for the period from June 20, 2014, to December 20, 2020 (2374 days).

Region	Location Description	Displacement (mm)	Approximate Region Area (m^2)
A	Close to North Peak	22.0 to 201.0	4600
B	Between North and South peaks	≤7.0	600
C	Close to South Peak	-	1200
D	Debris area toe of South Peak rock wall	-	-
E	Debris area toe of North Peak rock wall	≤92.0	-
F	Mid to lower vegetative rock wall	-	-
G	Debris zone runout area	≤98.0	-
H	Elongated channel (right) to the valley	-	-
I	Elongated channel (left) to the valley	-	-

Table 8. LiSAmobile measured displacement at points of interest (POI) for the period from June 20, 2014, to December 20, 2020 (2374 days), with observations specific to quarterly reporting period (Q) 26.

Region	Point of Interest (POI)	Displacement (mm)	Displacement Descriptions Specific to Q26
A	P_1	22.0 to 201.0	Negative displacements in Q26 from snow cover.
	P_2		
	P_3		
	P_4		
B	P_5	≤6.93	Small fluctuations throughout Q26.
C	P_6	≤105.0	No significant displacements throughout Q26.
	P_7		
D	P_8	-	No significant displacements throughout Q26.
E	P_9	≤91.0	Stable movements in Q26.
	P_10		
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	≤98.0	Small fluctuations throughout Q26.
H	P_18	-	Small movements since November caused by possible snowpack.
I	P_20	-	Small movements since November caused by possible snowpack.

Generalized displacements in Q26 for all nine regions accelerated minimally from Q25, but otherwise generally showed stable (unchanged) rates of displacement during Q26. Ellegi observed some small displacements in the debris area at the foot of the mountain starting December 7. 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.

The Q26 summary report from Ellegi noted that the system was operational from the installation date in June 2014, except for the period between April 2 and May 7, 2020. The system has been collecting data continuously since May 8. Figure 9 shows displacements on Turtle Mountain measured from June 20, 2014, through December 20, 2020.

5 Supporting Studies and Research

During 2020, no secondary monitoring campaign was selected for supporting studies and research because 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.

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 system (web cameras), and to illustrate the daily changes on Turtle Mountain throughout the year. Links to the 2020 annual videos are available for download on the AGS website (https://ags.aer.ca/research-initiatives/turtle-mountain-webcams). In addition, both videos are available for streaming on YouTube: Bellevue at https://www.youtube.com/watch?v=Ikx7VwNX_bk and South Peak at https://www.youtube.com/watch?v=BDPTkFAMciA.

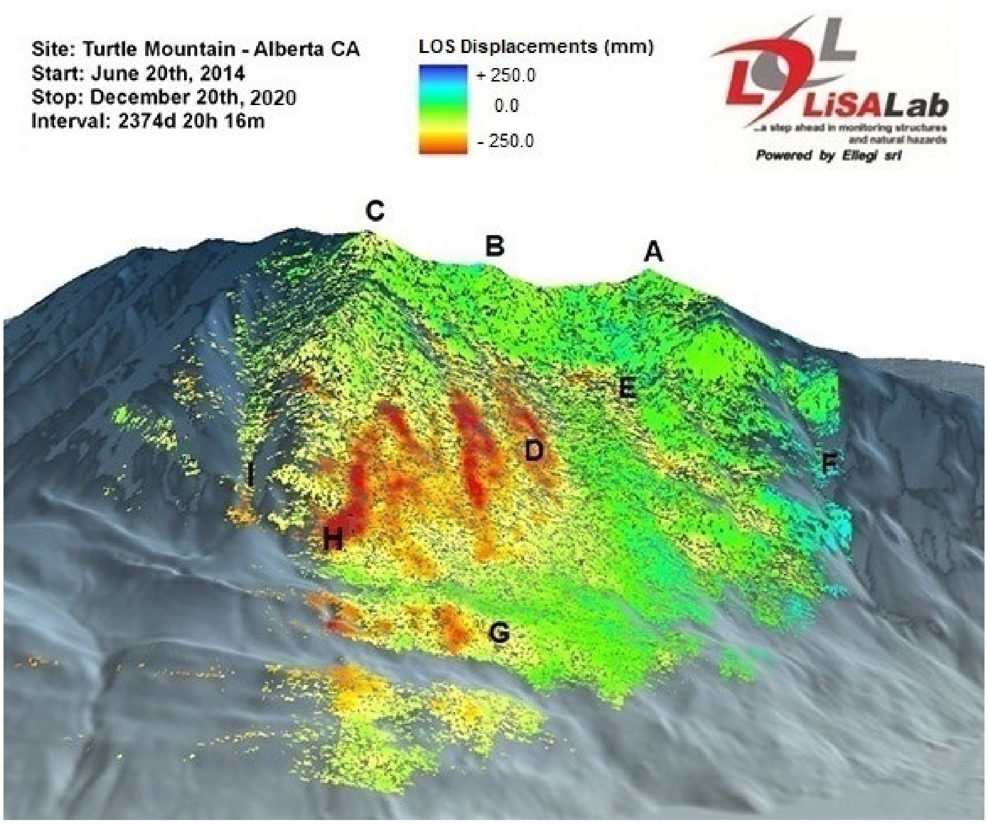

Figure 9. The line-of-sight (LOS) three-dimensional (3D) displacement map of Turtle Mountain, Alberta, measured from June 20, 2014, through December 20, 2020 (2374 days, 20 days, 16 minutes). Letters indicate regions of interest.

7 Conclusions

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

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

Communication of the risks associated with these hazards to the affected population is also ongoing. The most recent results are published annually (Warren et al., 2014, 2016; Wood et al., 2016, 2017a, b, 2018a, b; Yusifbayov et al., 2018; Wood and Chao, 2019, 2020) and presented in public meetings. The Alberta Geological Survey continues to collaborate with the Municipality of Crowsnest Pass council members and staff to provide information on the Turtle Mountain Monitoring Program. Updates are also available on the 'Turtle Mountain Monitoring Program' page of the Alberta Geological Survey website (https://ags.aer.ca/research-initiatives/turtle-mountain).

8 References

Lehrbass, B., Samsonov, S., Dudley, J., Svacina, N., Drouin, H., Decker, V. and Tolszczuk-Leclerc, S. (2021): Emergency Geomatics Service activation for Turtle Mountain, Alberta InSAR monitoring; Geomatics Canada, Open File 64, 19 p., doi:10.4095/328268.

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 <https://ags.aer.ca/publication/ofr-2014-09> [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 <https://ags.aer.ca/publication/ofr-2015-09> [March 2019].

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., URL <https://ags.aer.ca/publication/ofr-2019-07> [March 2020].

Wood, D.E. and Chao, D.K. (2020): Turtle Mountain Field Laboratory, Alberta (NTS 82G): 2019 data and activity summary; Alberta Energy Regulator / Alberta Geological Survey, AER/AGS Open File Report 2020-07, 15 p., URL <https://ags.aer.ca/publication/ofr-2020-07> [December 2020].

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 <https://ags.aer.ca/publication/ofr-2015-10> [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 <https://ags.aer.ca/publication/ofr-2017-03> [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; Alberta Energy Regulator, AER/AGS Open File Report 2017-04, 28 p., URL <https://ags.aer.ca/publication/ofr-2017-04> [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 <https://ags.aer.ca/publication/ofr-2018-07> [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 <https://ags.aer.ca/publication/ofr-2018-12> [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 <https://ags.aer.ca/publication/ofr-2018-02> [March 2019].