AER/AGS Open File Report 2017-03

Alberta Energy Regulator

# Turtle Mountain Field Laboratory, Alberta (NTS 82G): 2015 Data and Activity Summary

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D.E. Wood, D.K. Chao and T.C. Shipman

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

| | |
|---|---|
| Tel: | 780.638.4491 |
| Fax: | 780.422.1918 |
| E-mail: | AGS-Info@aer.ca |
| Website: | www.ags.aer.ca/ |

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## Abstract

Since 2005, Turtle Mountain has been the site of ongoing monitoring and research focused on understanding the structure and kinematics of movements of the unstable eastern slopes. As this site provides a rich dataset and optimal conditions for the application of new and evolving warning and characterization technologies, the site has been termed the 'Turtle Mountain Field Laboratory.' This report provides a summary of both the results and 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, 2015.

The TMMS is a near-real-time early warning monitoring system that provides data from a network of eight geotechnical sensors on South Peak of Turtle Mountain (site of the 1903 Frank Slide) in the Crowsnest Pass, 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 of the Alberta Emergency Management Agency should significant movements occur.

As part of this responsibility, the AGS performs an annual detailed review of the data stream. 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 three main sections.

The first section contains information about the major changes to the TMMS's network during the 2015 field season. This includes a review of the main repair and maintenance activities, synopsis of abandoned stations, and a summary of system performance and reliability.

The second section provides data analysis and interpretation for the primary and secondary instrumentation. These interpretations include slope conditions and displacement behaviour from instrumentation results.

The last section presents information on the open house hosted by the AER in the Crowsnest Pass and the TMMS's transition from a near-real-time early warning system to a near-real-time remote monitoring system.

# 1 Introduction

In 2005, the Alberta Geological Survey (AGS) assumed responsibility for the long-term monitoring of Turtle Mountain, the site of the 1903 Frank Slide (Figure 1 and 2). The first priority for monitoring Turtle Mountain is to provide an early warning to residents of the Crowsnest Pass in the event of a second catastrophic rock avalanche. The secondary priority is to provide an opportunity for the research community to test and develop instrumentation and monitoring technologies and to better understand the mechanics of slowly moving rock masses, hence the working name ‘Turtle Mountain Field Laboratory’ (TMFL). The AGS will make available to the research community data from the TMFL, which will enable researchers to test and develop new monitoring technologies for the mountain. This ongoing research will aid in understanding the movements of South and Third Peak, and more recently North Peak, thereby providing a better model for prediction of future movements.

This annual report provides the public and researchers with a synthesized update on data trends and research on the mountain as a stimulus for further study.

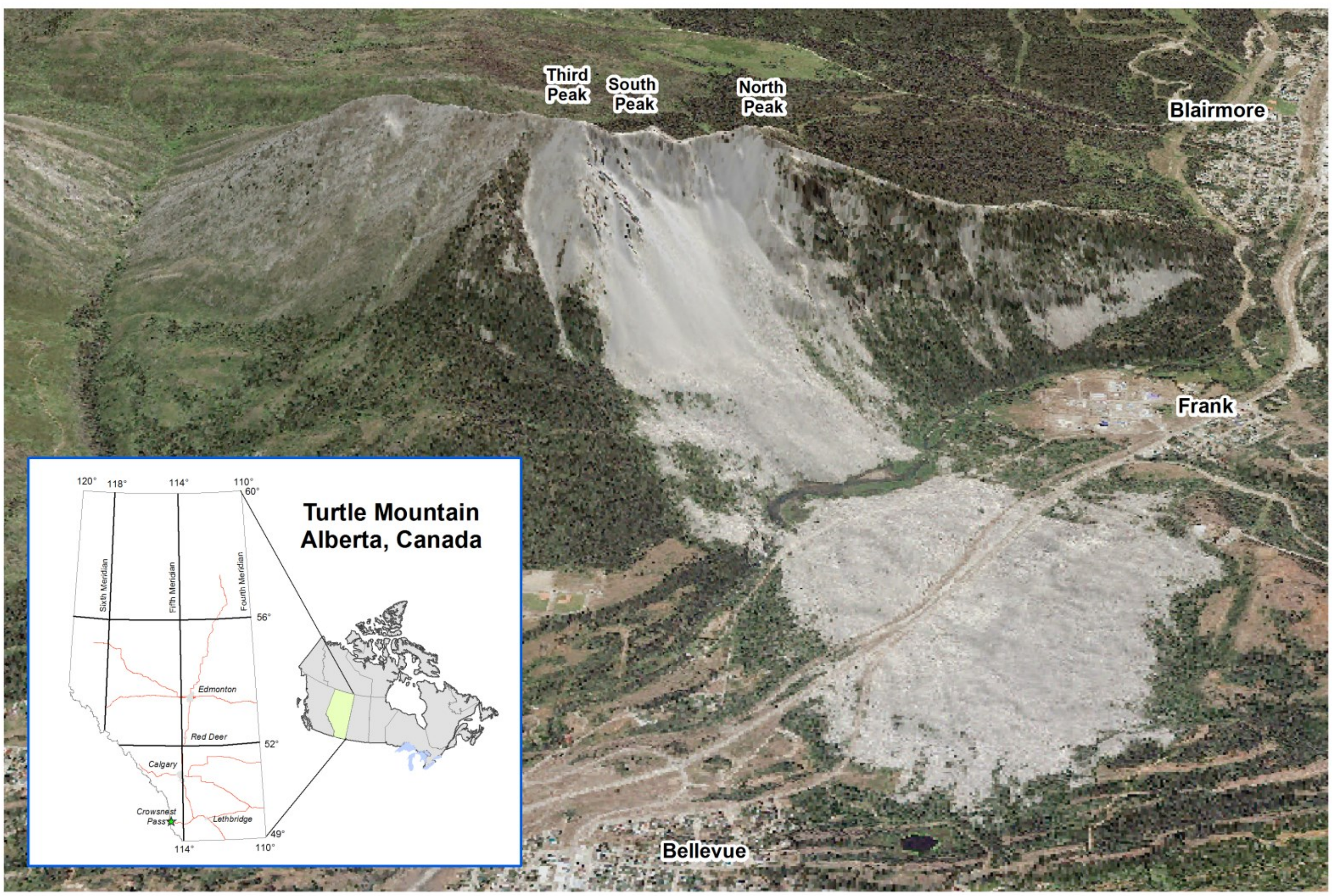


**Figure 1. Location of Turtle Mountain in southwestern Alberta and full-extent aerial view of the Frank Slide.**

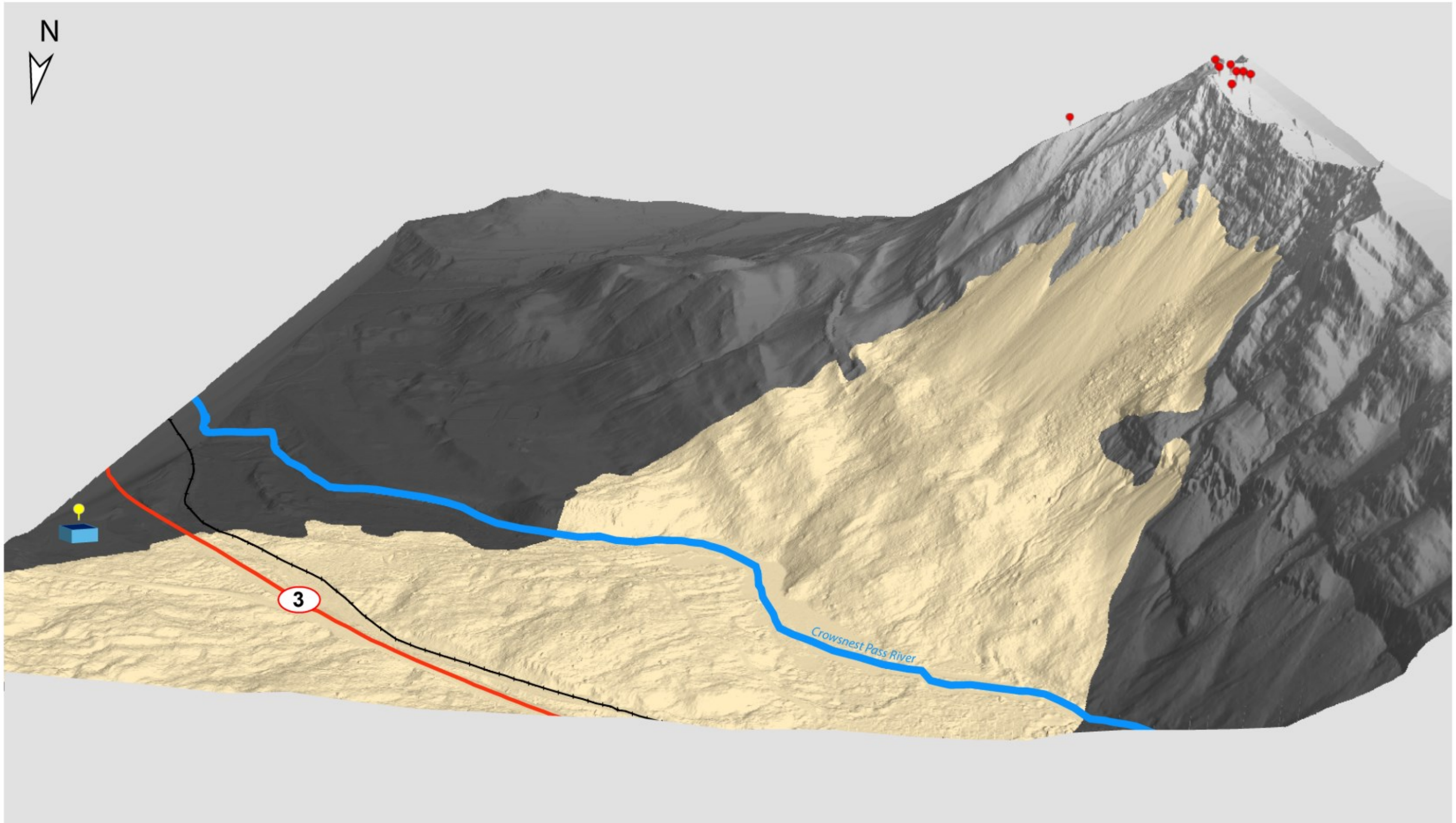


**Figure 2. Overview, as of December 2015, of the monitoring network on Turtle Mountain. The yellow pin marks the location of the LiSAmobile system and the red pins mark the locations of the dGPS rover stations. The tan area depicts the extent of the original 1903 slide.**

# 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 2015.

The main activities undertaken with respect to the sensor network during 2015 included

- firmware update for the dGPS,
- dGPS annual maintenance,
- weather station failure investigation, and
- annual LiSAmobile GB-InSAR equipment maintenance.

NavStar Geomatics Ltd. dGPS units became the primary sensors for the TMMS in 2014 and provide up-to-the-minute status reports via email and the desktop application GeoExplorer. When sensor thresholds are exceeded, the AGS reviews the data with input from NavStar to determine if the exceedance was due to sensor malfunction or actual movement. NavStar conducted minor software upgrades to GeoExplorer throughout 2015.

Ellegi leased a GB-InSAR system known as LiSAmobile to the AGS for a one-year probationary period in 2014, giving us time to review the equipment and monitoring system. Over this period, we have received monthly data updates and monitoring reports on a quarterly basis. The quarterly report is reviewed by the Turtle Mountain Monitoring Program (TMMP) team and then compared to the dGPS results provided by NavStar. The AGS's lease with Ellegi provides customer service and technical support in case of emergency or equipment changes. The one-year probationary period during 2014 allowed the AGS to verify that the services and equipment provided by Ellegi are optimal for monitoring surface displacements within the line of sight.

Due to the poor quality and reliability of data collection from the previous extensometers, crackmeters, and tiltmeters, the AGS has determined that these sensors will be decommissioned in forthcoming years. Additional documentation of the inoperable sensors are noted in Wood et al. (2016) and therefore not included in this summary.

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

## 2.1 Repairs and Maintenance

### 2.1.1 *NavStar Annual Maintenance*

In 2015, an annual maintenance campaign was planned for late June, which included a team from NavStar and the AGS. The field maintenance objectives included

- diagnosing the loss of power and communication at Lower Saddle and Third Peak B stations,
- updating dGPS and Wi-Fi radio firmware on all stations on South Peak,
- investigating clouded web camera images from suspected condensation, and
- completing routine maintenance such as replacing frayed or exposed cables, tightening guidewires, and checking each station for any maintenance issues.

On September 6, 2014, we lost contact with the Third Peak B station on South Peak. Various attempts to bring the station back online remotely were attempted by NavStar and it became apparent that an on-site trip was needed to investigate further. It was suspected that the loss of power and communication was caused by outdated firmware for both the dGPS and Wi-Fi radios.

Upon arrival to Third Peak B, it was apparent that the loss of power and communication was due to a bent station mast. Damage to the support structure caused the solar panel and enclosure to shift, causing the loss of power and communication to the entire station. In 2013, large amounts of snow were observed on the mountain top that buried the solar panels located at the Third Peak B station. Snow loading against the solar panels from both winters 2013 and 2014 are suspected to have been the cause of the bent station mast. The bent station mast eventually caused the solar panels, control box, and guidewires to relax, causing the station to go offline.

After examination of the physical damage to the support structure, it was uncertain if the station power and communication would recover. The Third Peak B station was dismantled and the bent mast was replaced with a spare. The station was reconstructed and both the dGPS and Wi-Fi radio firmware were updated. Fortunately, the station was able to reconnect to the TMMS network. Additional guidewires and structural support were added to the station to help with future snow loading. The structural support of Third Peak B will be reviewed after the winter, and additional reinforcement may be required and added to the station during the next field season. The remaining stations were checked for maintenance concerns such as slack guidewires and frayed cords due to rodent mastication.

Lower Saddle station experienced voltage problems in April 2015. Remote investigation showed that the loss of voltage at the station was most likely due to a broken solar controller or solar panel. The solar controller displayed low voltage output that is associated with batteries unable to maintain a full charge. This malfunction was diagnosed on site and the solar controller was replaced. Within the hour the station batteries started recharging and the system returned online.

It was believed that the malfunction was fixed at the Lower Saddle site as the station was charging and communicating accurately before leaving site. Within 24 hours it became evident that the Lower Saddle station was no longer maintaining a charge properly. It is presumed that the batteries were damaged before the solar controller malfunction. The solar controller monitors and maintains the voltage input and output at the station. This prohibits the batteries from overcharging or completely draining the power supply. The batteries at the Lower Saddle station will need to be replaced and the station reviewed before the 2016 field season. At that time it will be determined if all the batteries will be replaced at the other eight stations or alternate monitoring methods will be used.

The latest firmware was updated successfully for both the dGPS stations and Wi-Fi radio communication links. The firmware for the NavStar GMS 301 dGPS units was updated to version 3.0 and the Wi-Fi radio to version 4.41 for each of the stations. The Ridge station was the only site where the Wi-Fi radio firmware was not updated due to loss in connection; however, this is not expected to be an issue as the Ridge station has been performing consistently. The Wi-Fi radios' received signal strength indication will be reviewed at the end of 2015, and new Wi-Fi antennas may be purchased to increase transmission distance.

The images taken by web cameras located on South Peak and at the Bellevue pump house became progressively distorted during the spring. It was presumed that the seal on the camera lens had become brittle over the years and had failed. Upon examination of the camera lens it was determined that condensation build-up was the cause of the poor-quality images (Figure 3a). Lenses were replaced on the Bellevue (Figure 3b) and South Peak web cameras.

(a)

(b)

**Figure 3. (a) Bellevue web camera image before lens change showing distorted image from condensation; (b) Bellevue web camera image after the lens was replaced.**

## 2.1.2 *LiSAmobile Annual Maintenance*

In 2015, an annual maintenance campaign was planned for late June which included a team from Ellegi and AGS. The field maintenance objectives included

- external and internal radome cover and gasket checks,
- power box inspection,
- dusting and lubrication of instrument components,
- radio frequency evaluation, and
- mechanical shutdown and restart testing.

During the site maintenance the LiSAmobile radome was inspected for damage and water leak exposure.

The radome was tested throughout 2014 for its ability to withstand environmental factors such as large temperature fluctuations during the spring and fall, high and low temperatures during the summer and winter, respectively, extreme winds, and severe amounts of precipitation. It withstood environmental factors in 2014 and 2015 very well. The radome showed no visible damage and was able to protect the system continuously. The radome will continue to be evaluated throughout 2016.

## 2.2 Non-Operational Instruments

Due to the poor quality and reliability of data collection from the previous primary sensors, AGS terminated the use of the extensometers, crackmeters, and tiltmeters. Increased weather complications throughout the previous years have caused the previous primary sensors to fail regularly. The replacement and upgrading of the previous primary sensors had become costly and difficult to manage due to the environmental conditions on the mountain. Data from these instruments are no longer collected and are currently classified as non-operational.

After review of the instrument data in 2013 and 2014, we decided that the use of certain instruments would be discontinued in the 2015 field season. This was based on different underlying issues with each instrument (the reader may refer to previous reports). The term 'non-operational instrument' means an instrument that has been abandoned due to poor-quality and inadequate data. At the end of 2015, the non-operational instruments will be reassessed. We will then determine if they can be repaired or otherwise made fully operational or if the equipment will be decommissioned and removed from South Peak.

### 2.2.1 *Weather Station*

The weather station became inoperable during a snow storm in March 2014. Various attempts to bring the station back online were made remotely from Edmonton. The weather station began recording and sending data sporadically (about once a week), but these data appear to be corrupt and incomplete. A snow storm in early October 2014 caused the remaining instruments to fail, causing the weather station to be classified as a non-operational instrument.

In June 2015, we visited the weather station to troubleshoot the condition of the electronic components and instrumentation. It was decided not to repair the station during the 2015 field season due to extensive damage to electronic components and missing instruments. The missing instruments are assumed to have been lost during extensive wind or snow storms or due to vandalism.

The weather station's status will be reviewed at the end of 2015. This review will decide if the station will be repaired during the 2016 field season or if the equipment will remain non-operational and be decommissioned.

## 2.3 Performance

Continuous slope monitoring is very difficult 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 with a series of preventive measures, including frequent inspections, replacement of aging equipment, and system modifications and upgrades. This section provides detailed information on sensor performance in 2015.

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. Throughout 2015, the primary system remained the dGPS, and the LiSAmobile system was the secondary monitoring system. Both systems will continue to be tested and evaluated to provide optimal monitoring of Turtle Mountain.

### 2.3.1 Continuous-Reading dGPS Monitoring Network

Throughout 2015, the continuous-reading dGPS system supported by NavStar performed relatively well. The dGPS system is vulnerable to precipitation and extreme weather on Turtle Mountain, with potential to produce inaccurate results. After the 2015 field season maintenance trip, most dGPS stations were operational. However, by late fall it was determined that aging batteries at these stations would need to be replaced in 2016. The dGPS monitoring stations will be reviewed in 2016 by the AGS and we will decide whether to make the dGPS stations fully operational or to decommission the equipment.

### 2.3.2 LiSAmobile GB-InSAR

The newly installed LiSAmobile system (Figure 4a) was leased to the AGS and installed in June 2014. 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).

Ellegi's LiSAmobile performance in 2015 showed continuous high-quality data with little to no interruptions since installation in June 2014. Internet connection was lost briefly in December 2015 due to communication disruption across the entire Crowsnest Pass. LiSAmobile has the ability to continue to collect and store data until the Internet connection is re-established; therefore, no displacement data was lost. Ellegi's LiSAmobile probationary period and one-year pilot ended in June 2015. After the one-year pilot, the AGS determined that Ellegi and LiSAmobile can provide high-quality customer service, state-of-the-art ground-based InSAR equipment, innovative shelter technology providing all-season monitoring, and timely detailed reporting. The AGS extended the lease to continue to evaluate the performance of the system (Figure 4b) throughout 2016.

# 3 Data Analysis

## 3.1 Deformation Monitoring Data

### 3.1.1 *Continuous-Reading dGPS Monitoring Network*

To detail the history of displacements on active fractures, six single-frequency dGPS stations were installed near prominent fractures (Moreno and Froese, 2008a). These dGPS units have millimetre resolution in the horizontal direction and centimetre resolution in the vertical direction. The reader may refer to previous reports for additional information. The trends in displacement at the dGPS stations during 2015 (Figure 6 and 7) are consistent with monitoring results of past years, which show seasonal variation without significant displacements associated with large movements.

### 3.1.2 *LiSAmobile Ground-Based InSAR*

In June 2014, a ground-based radar device was installed at the Bellevue pump house (Figure 5) for monitoring small displacement on the east face of Turtle Mountain. The LiSAmobile GB-InSAR uses the interferometric synthetic aperture radar technique to measure small displacements at each point on the surface of the mountain.

(a)

(b)


**Figure 4. (a) LiSAmobile system without radome and temperature regulation unit; (b) LiSAmobile system completely assembled (Photos courtesy of Ellegi).**

**Figure 5. LiSAmobile system at the Bellevue pump house station.**

LiSAmobile consists of two main parts: the radar head and mechanical components. The radar head is an active radar sensor that transmits microwave pulses towards an object and receives in return a backscattered signal. The radar head, which consists of two antennas (transmit and receive), is attached to a linear positioner (cradle) mounted on a horizontal track. The travel distance of the radar head along the track can be adjusted to allow for optimal scanning coverage of the mountain face. The radar head travels back and forth along the 2.5 metre track once every ~8.5 minutes.

The LiSAmobile system is connected via the Internet through a Wi-Fi connection that allows VPN access. The data are processed onsite and the results are transferred to Ellegi via VPN to be assessed.

The LiSAmobile system obtains raw data from measurements from the radar head. This data is processed by the LiSAmobile system and then 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.

The LiSAmobile system has been operational without interruption since its installation in June 2014.

## 3.2 Discussion and Interpretation of Monitoring Data

### 3.2.1 *Continuous-Reading dGPS Monitoring Network*

During 2015, the entire dGPS monitoring network experienced various interruptions throughout the year due to varying weather conditions, aging station batteries, and outdated firmware. Large storms that produce excessive rain and snow have the ability to disable the system temporarily throughout the year.

Four dGPS stations experienced data transmission problems in 2015 (Figure 6 and 7): Lower Saddle station data became sporadic in late April, Ridge station went offline in early December, Upper Saddle station stopped transmitting data in late June, and South Peak station started sending sporadic data in mid-October.

The remaining four dGPS stations (Lower and Upper West, and Lower and Upper Wedge) transmitted data with only minor interruptions.

AGS decided not to interpret the 2015 dGPS data because of the questionable data quality. We expect that deformations will continue to be in the millimetre range, as Turtle Mountain's rock masses are moving very slowly. At the end of 2015, the AGS will complete an internal review of the dGPS network data. These internal reviews help the AGS continue to test and develop new monitoring technologies and equipment for the mountain.

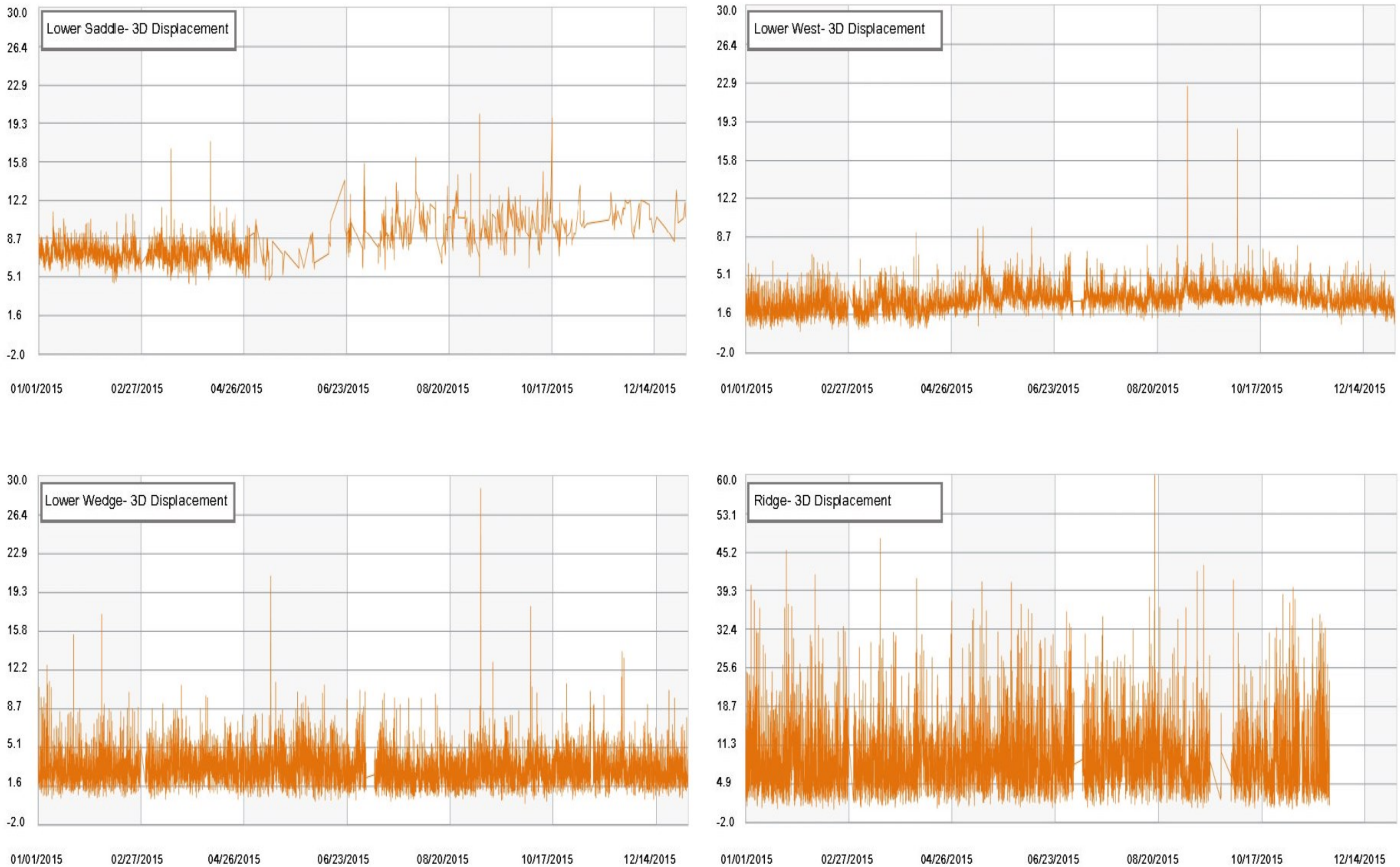


**Figure 6. Surface displacements derived from dGPS stations during 2015.**

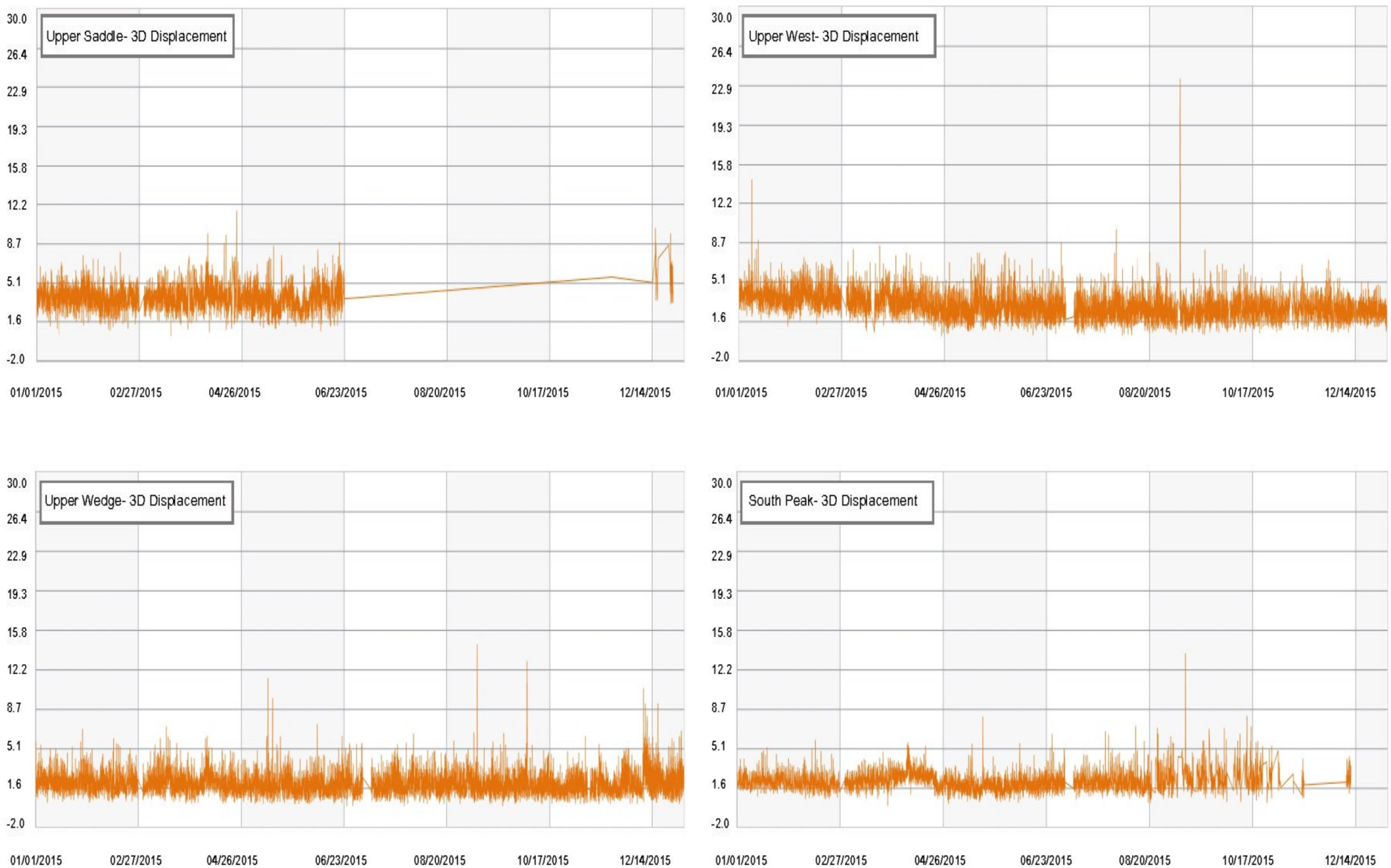


**Figure 7. Surface displacements derived from dGPS stations during 2015.**

### 3.2.2 *LiSAmobile Ground-Based InSAR*

The displacement maps displayed in Figure 8 and 10 depict 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 2015 and provided by Ellegi to the AGS in quarterly reports (Q3 to Q6). 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), which are further subdivided into twelve points of interest (POIs, labeled P_1 through P_12). 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) are considered to be due to measurement errors introduced by atmospheric moisture within the line of sight. Testing will continue in region F to attempt to improve the image and understand the region's behaviour better in 2016.

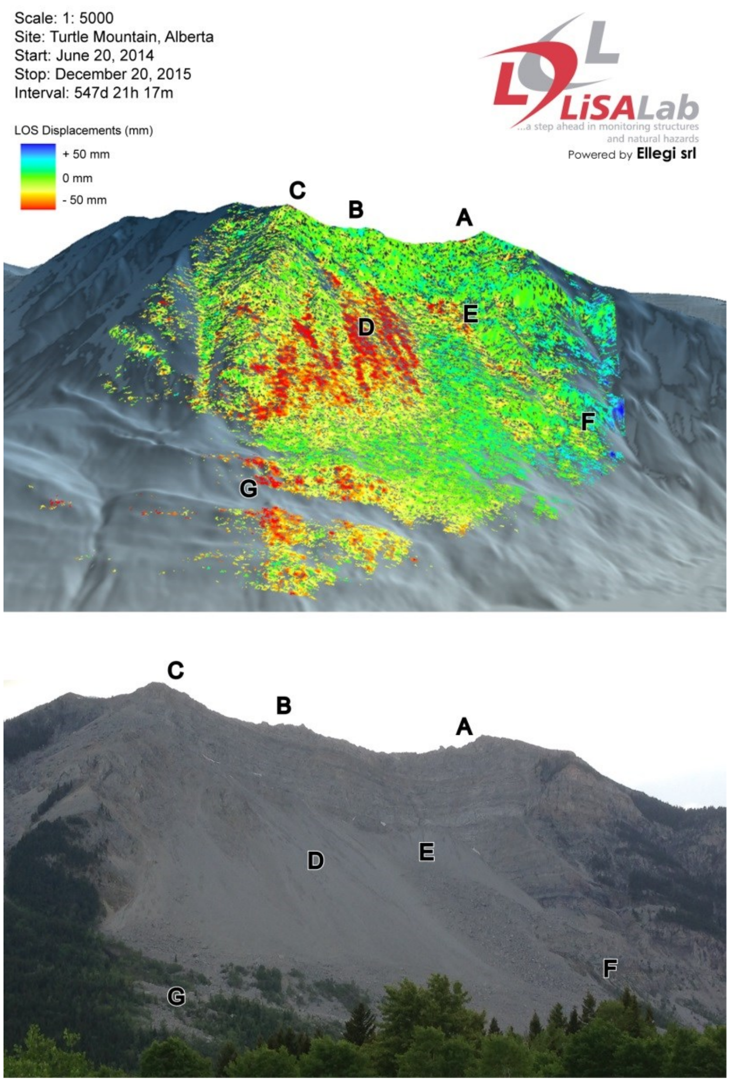


**Figure 8. Line of sight (LOS) 3D displacement map (top) measured from June 20, 2014 to December 20, 2015 (548 days), and view of the eastern face of Turtle Mountain (bottom). Blue colours indicate displacement away from sensor, red colours indicate displacement towards sensor. Letters A to G denote location of regions described in Tables 1–8.**

The results from report Q3 to Q6 provided to the AGS by Ellegi are shown in Table 1 through 8.

LiSAmobile data shows no large displacements of larger coherent blocks of material (generalized movement) have been identified near North and South peaks throughout 2015. 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., Q3, Q4, Q5, Q6) is shown in Table 1, 3, 5, and 7, respectively. Measured displacement at points of interest (POI) for the same time periods are presented in Table 2, 4, 6, and 8.

On the displacement maps (Figure 8 and 10) 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 (Table 1 to 8) and is reporting the cumulative movements towards the sensor.

**Table 1. LiSAmobile generalized displacement in regions of interest for the period from June 20, 2014, to March 20, 2015 (273 days).**

| Region | Location Description | Displacement (mm) | Approximate Region Area ($m^2$) |
|---|---|---|---|
| A | Close to North Peak | 8.0 to 38.0 | 4600 |
| B | Between North and South Peak | ≤14.0 | 600 |
| C | Close to South Peak | 9.0 | 1200 |
| D | Debris area toe of South Peak rock wall | ≥15.0 | - |
| E | Debris area toe of North Peak rock wall | ≥15.0 | - |
| F | Mid to lower vegetative rock wall | - | - |
| G | Debris zone run out area | ≤15.0 | - |

**Table 2. LiSAmobile measured displacement at points of interest (POI) for the period from June 20, 2014, to March 20, 2015 (273 days) with observations specific to quarter Q3.**

| Region | Point of Interest (POI) | Displacement (mm) | Displacement Descriptions Specific to Q3 |
|---|---|---|---|
| A | P_1 | 8.0 | Continuous movement. |
| | P_2 | | |
| | P_3 | | |
| | P_4 | ≤38.0 | Continued decelerated movement. |
| B | P_5 | 13.0 | Continuous movement subject to errors due to snow cover. |
| C | P_6 | ≤9.0 | Continuous movement subject to errors due to snow cover. |
| | P_7 | | |
| D | P_8 | - | Data is omitted due to errors introduced by snow cover. |
| E | P_9 | - | Debris zone POI data is omitted due to errors introduced by snow cover. |
| | P_10 | | |
| F | P_11 | - | Data is omitted due to error introduced by snow cover. |
| G | P_12 | ≤4.2 | Rate of displacement is unchanged. |

Generalized displacement in Q3 for all seven regions was calculated to be smaller than that in Q2. Measured displacements at some POIs were subject to errors due to snow cover and atmospheric moisture (e.g., fog, snowfall, rain).

The Q3 summary report from Ellegi noted that the system was operational from the installation date in June 2014, with minimal interruptions. In January 2015, maintenance was performed on the equipment to replace a transmission cable, and an Internet outage was reported throughout the Crowsnest Pass. During these disruptions in service, no data was lost due to on-site memory logging.

**Table 3. LiSAmobile generalized displacement in regions of interest for the period from June 20, 2014, to June 20, 2015 (365 days).**

| Region | Location Description | Displacement (mm) | Approximate Region Area ($m^2$) |
|---|---|---|---|
| A | Close to North Peak | 8.0 to 54.0 | 4600 |
| B | Between North and South Peak | ≤ 12.0 | 600 |
| C | Close to South Peak | 22.0 | 1200 |
| D | Debris area toe of South Peak rock wall | ≥ 15.0 | - |
| E | Debris area toe of North Peak rock wall | ≥ 15.0 | - |
| F | Mid to lower vegetative rock wall | - | - |
| G | Debris zone run out area | > 15.0 | - |

**Table 4. LiSAmobile measured displacement at points of interest (POI) for the period from June 20, 2014, to June 20, 2015 (365 days) with observations specific to Q4.**

| Region | Point of Interest (POI) | Displacement (mm) | Displacement Descriptions Specific to Q4 |
|---|---|---|---|
| A | P_1 | 4.5 | Continuous movement, rate of displacement unchanged. |
| | P_2 | | |
| | P_3 | | |
| | P_4 | 54.2 | Continued decelerated rate of displacement until May 2015, then acceleration until the end of Q4. |
| B | P_5 | ≤23.0 | Accelerated movement until the end of May 2015, followed by deceleration until the end of Q4. Measurements in area are subject to errors due to snow cover. |
| C | P_6 | ≤22.5 | Continuous movement from early March 2015 until the end of Q4. Measurements in area are subject to errors due to snow cover. |
| | P_7 | | |
| D | P_8 | 10.0 | Debris zone exhibited a stabilized trend from early April to end of Q4. |
| E | P_9 | - | Data is omitted due to errors introduced by snow cover. |
| | P_10 | | |
| F | P_11 | - | Data is omitted due to errors introduced by snow cover. |
| G | P_12 | ≤4.2 | Rate of displacement is unchanged. |

Generalized displacement in Q4 for all seven regions was slightly larger than that measured in Q3, which is expected during the spring. Measured displacements at some POIs were subject to errors due to snow cover and atmospheric moisture, such as heavy rainfall or fog. The Q4 report marks the end of the one-year probationary period of LiSAmobile.

The Q4 summary report from Ellegi noted that the system was operational from the installation date in June 2014, with minimal interruptions. On June 3, 2015, a rockfall near region C was observed by the LiSAmobile system. Ellegi was able to provide the AGS detailed information regarding the rockfall area, displacement measurements, and debris scatter. The data collected from rockfalls are used to validate LiSAmobile's efficiency and capacity to collect data for larger-scale movements.

**Table 5. LiSAmobile generalized displacement in regions of interest for the period from June 20, 2014, to September 20, 2015 (457 days).**

| Region | Location Description | Displacement (mm) | Approximate Region Area ($m^2$) |
|---|---|---|---|
| A | Close to North Peak | 5.5 to 66.0 | 4600 |
| B | Between North and South Peak | ≤ 20.0 | 600 |
| C | Close to South Peak | 23.0 | 1200 |
| D | Debris area toe of South Peak rock wall | ≥ 40.0 | - |
| E | Debris area toe of North Peak rock wall | ≥ 22.0 | - |
| F | Mid to lower vegetative rock wall | - | - |
| G | Debris zone run out area | ≤5.0 | - |

**Table 6. LiSAmobile measured displacement at points of interest (POI) for the period from June 20, 2014, to September 20, 2015 (457 days) with observations specific to Q5.**

| Region | Point of Interest (POI) | Displacement (mm) | Displacement Descriptions Specific to Q5 |
|---|---|---|---|
| A | P_1 | 5.4 | Continuous movement, rate of displacement unchanged. |
| | P_2 | | |
| | P_3 | | |
| | P_4 | 66.0 | Continued deceleration of displacement until the end of June, followed by a constant rate of displacement until mid-August; lastly an accelerated rate of displacement until the end of Q5. |
| B | P_5 | 20.0 | No significant movement until the end of Q5. Measurements in area are subject to errors due to accumulated moisture. |
| C | P_6 | ≤22.0 | Continuous movement from June until the end of Q5. Measurements in area are subject to errors due to accumulated moisture. |
| | P_7 | | |
| D | P_8 | - | No significant movement in Q5. |
| E | P_9 | 22.5 | No significant movement throughout Q5; however measurements in area are subject to errors due to accumulated moisture in late September. |
| | P_10 | | |
| F | P_11 | - | Data is omitted due to errors introduced by vegetation in the LOS. |
| G | P_12 | ≤4.2 | Rate of displacement is unchanged. |

Generalized displacement in Q5 for all seven regions accelerated minimally compared to Q4 and otherwise generally showed stable (unchanged) rates of displacement during summer 2015. The Q5 summary report from Ellegi noted that the system was operational from the installation date in June 2014, with minimal interruptions.

Analyses from Q1 to Q5 identify an area with a very slow rate of displacement near region C, between South and Third Peak. In-depth analyses over 457 days allow Ellegi to evaluate the displacement rates within the region, identifying small-scale movements over a larger area. Ellegi identified this area to have a surface area of 45 000 $m^2$ and measured a displacement value of −2.4 mm over 457 days. 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 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.

**Table 7. LiSAmobile generalized displacement in regions of interest for the period from June 20, 2014, to December 20, 2015 (548 days).**

| Region | Location Description | Displacement (mm) | Approximate Region Area ($m^2$) |
|---|---|---|---|
| A | Close to North Peak | 6.8 to 80.0 | 4600 |
| B | Between North and South Peak | ≤27.0 | 600 |
| C | Close to South Peak | ≤ 25.0 | 1200 |
| D | Debris area toe of South Peak rock wall | ≥ 40.0 | - |
| E | Debris area toe of North Peak rock wall | >25.0 | - |
| F | Mid to lower vegetative rock wall | - | - |
| G | Debris zone run out area | -5.0 | - |

**Table 8. LiSAmobile measured displacement for the period from June 20, 2014, to December 20, 2015 (548 days) with observations specific to Q6.**

| Region | Point of Interest (POI) | Displacement (mm) | Displacement Descriptions Specific to Q6 |
|---|---|---|---|
| A | P_1 | 6.8 | Continuous movement, rate of displacement unchanged. Persistent snow cover is observed in December 2015. |
| | P_2 | | |
| | P_3 | | |
| | P_4 | 80.0 | Continued acceleration until the end of October, then deceleration until the end of Q6. |
| B | P_5 | ≤27.0 | Acceleration until the end of October, then deceleration. Persistent snow cover is observed in December 2015. |
| C | P_6 | ≤ 25.0 | Rate of displacement unchanged displaying stable behaviour observed until the end of Q6. Persistent snow cover is observed in December 2015. |
| | P_7 | | |
| D | P_8 | N/A | Displaced rate of movement is maintained in Q6, similar to Q4 and Q5 data. Specific displacement value was not reported. Persistent snow cover is observed in December 2015. |
| E | P_9 | ≤ 22.5 | Rate of displacement unchanged displaying stable behaviour until the end of Q6. Persistent snow cover is observed in December 2015. |
| | P_10 | | |
| F | P_11 | - | POI data is omitted due to errors introduced by snowfall. |
| G | P_12 | ≤4.2 | Rate of displacement is unchanged, similar to Q5. A fast acceleration in movement is reported during the end of December 2015; likely due to an error introduced by snow cover. |

Generalized displacement in Q6 for all seven regions accelerated minimally from Q5, with the overall rate of movement unchanged. Measured displacements at some POIs were subject to errors due to atmospheric moisture, such as heavy rainfall, fog, and accumulating snow cover. The Q6 summary report from Ellegi noted that the system was operational from the installation date in June 2014, with minimal interruptions.

On November 18, 2015, between regions C and B, another small rockfall was observed by the LiSAmobile system. Ellegi was able to provide the AGS detailed information regarding the rockfall area, displacement measurements, and debris scatter. Through rockfall analysis, the AGS is able to better understand the value and capacity of data collected from the monitoring equipment. It is normal for large blocks to fall off the cliff face because of chemical weathering, rock thermal expansion and contraction, frost wedging (freeze-thaw cycles), and the existence of a near-vertical cliff face.

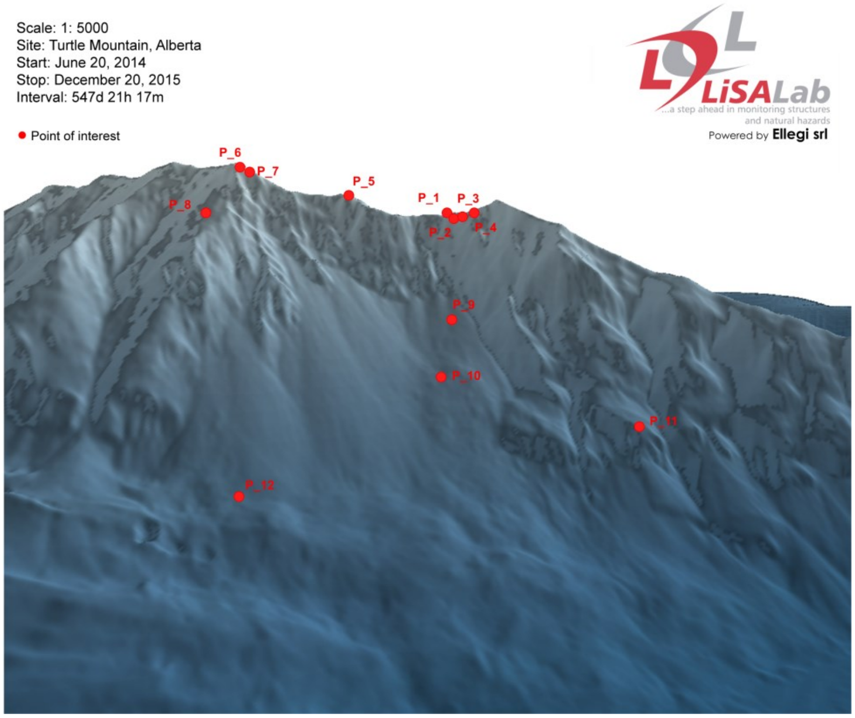


**Figure 9. Turtle Mountain points of interest (see Figure 8).**

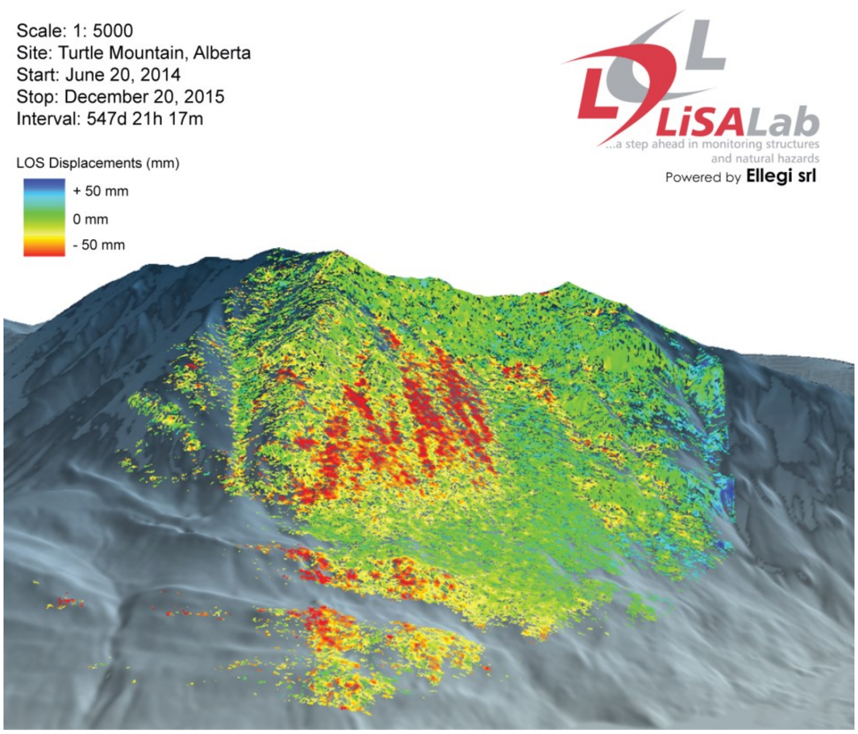


**Figure 10. Line of sight (LOS) 3D displacement map of Turtle Mountain measured from June 20, 2014, through December 20, 2015 (548 days).**

# 4 Supporting Studies and Research

In 2015, the AGS submitted an acquisition plan requesting seven spot-light SAR images from April to October 2015 using RadarSat-2 to the Canadian Space Agency (CSA). The SAR images collected from RadarSat-2 are processed using interferometric techniques to estimate relative surface displacement between each acquisition time point. The satellite-based InSAR aims to be an auxiliary observation tool and provides comparison against the ground based observation results. Due to conflicts with satellite operating times, only five images were acquired from late May to August 2015. The short time span between acquisitions and the reduced number of images limited our ability to obtain statistically reliable InSAR results. Nonetheless, the satellite-based InSAR results confirm that the deformation rate of the South Peak area of Turtle Mountain appears to be higher than that of the North Peak area which is simultaneously observed by the ground-based InSAR.

AGS will continue to collect RadarSat-2 SAR images for Turtle Mountain in the upcoming years and updates will be provided in the future reports.

# 5 Turtle Mountain Open House

On April 21, 2015, the AER hosted an open house in Crowsnest Pass to educate local residents and officials on the TMMP. AGS explained the transition from a near-real-time early warning system to a near-real-time remote monitoring system, as recommended in the 2014 expert panel report (see Wood et al., 2016, for more details on the expert panel review). This transition will include

- 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 evaluated non-operational equipment that is not considered vital to the long-term monitoring.

Attendance at the open house included 29 individuals from the public, media, Municipality of Crowsnest Pass (MCNP) council members, and other stakeholders. The AGS tracked attendance at the open house with a comment card form that also asked for a postal code. After the open house, the AGS had several meetings with the MCNP council members to discuss the transition. The AGS asked the MCNP council members to formally support the transition from a near-real-time early warning system to a near-real-time remote monitoring system. A letter of support was obtained and signed in July 2015. Next the AGS will approach the Alberta Emergency Management Agency for its support.

# 6 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 well below any level of concern and has remained essentially constant over the last decade of monitoring.

The AGS will continue to work with NavStar to maintain and upgrade the dGPS system. The Ellegi contract will be reviewed for the 2015 contract year and reassessed in the upcoming 2016 season. The AGS will complete an internal review of the monitoring equipment at the end of 2015 and will assess the limitations of the primary and secondary monitoring equipment. This assessment will help the AGS plan for the 2016 field season. The AGS will continue to investigate different forms of monitoring systems for the TMFL.

Communication of the risks associated with these hazards to the affected population is also ongoing. We publish the most recent results annually (Moreno and Froese, 2006, 2008a, 2008b, 2009a, 2011, 2012; Moreno et al., 2013; Warren et al., 2014, 2016; Wood et al., 2016) 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/activities/turtle-mountain-monitoring-program).

Based on a review of the sensor thresholds, a system of four alert levels (green, yellow, orange, and red) was developed by AMEC Earth and Environmental (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. Thus, to ensure that this role is fulfilled, the AER developed its own internal emergency response protocol (Moreno and Froese, 2009b). The emergency response protocol is revised as often as is required to ensure that its current version reflects best practice and is fit for purpose. At a minimum, one review is done every year. The AGS is currently reviewing this document based on the AGS's evaluation and recommendations from the expert panel report. An updated plan will be published that reflects transition changes to a near-real-time remote monitoring system once the transition has been finalized.

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