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Alberta Energy Regulator

Turtle Mountain Field Laboratory, Alberta (NTS 82G): 2012 Data and Activity Summary

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Turtle Mountain Field Laboratory, Alberta (NTS 82G): 2012 Data and Activity Summary

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- G. Bjorgan (NavStar Geomatics Ltd., Kelowna, BC)

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, 2012.

The TMMS is a near-real-time monitoring system that provides data from a network of approximately 80 geotechnical sensors on South Peak of Turtle Mountain (site of the 1903 Frank Slide) in the Crowsnest Pass. 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 Peak and Third Peak areas.

This report comprises three main sections.

The first contains information about the major changes to the TMMS's physical sensor network during the summer of 2012. This includes a review of the main repair and maintenance activities, a summary of new installations, and a summary of system performance and reliability.

The second provides interpretations of slope conditions and displacement behaviour from instrumentation results. Since climatic factors have affected some of the sensors, this discussion focuses only on the sensors that have provided reliable annual data. Meteorological data receive special attention because they have been essential in explaining general displacement trends observed in the surface instrumentation. In general, near-real-time data continue to show trends related both to seasonal thermal cycles and to slow, long-term creep of the South Peak mass. The observed trends highlight very slow movement along the deep fractures on the west side of South Peak, approximately less than a millimetre per year.

The third focuses on results from the most recent data collected by the ground-based InSAR monitoring.

1 Introduction

In 2005, the Alberta Geological Survey (AGS) assumed responsibility for the long-term monitoring and studying of a large, slowly moving rock slide at Turtle Mountain, the site of the 1903 Frank Slide (Figure 1). The first priority for monitoring and studying Turtle Mountain is to provide an early warning to residents of the Crowsnest Pass in the event of a second catastrophic rock avalanche originating from South Peak. 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 all 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 the entire South Peak mass, including the lower slope 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. This report is a brief overview and refers to other papers and articles that provide additional detail regarding the information discussed.

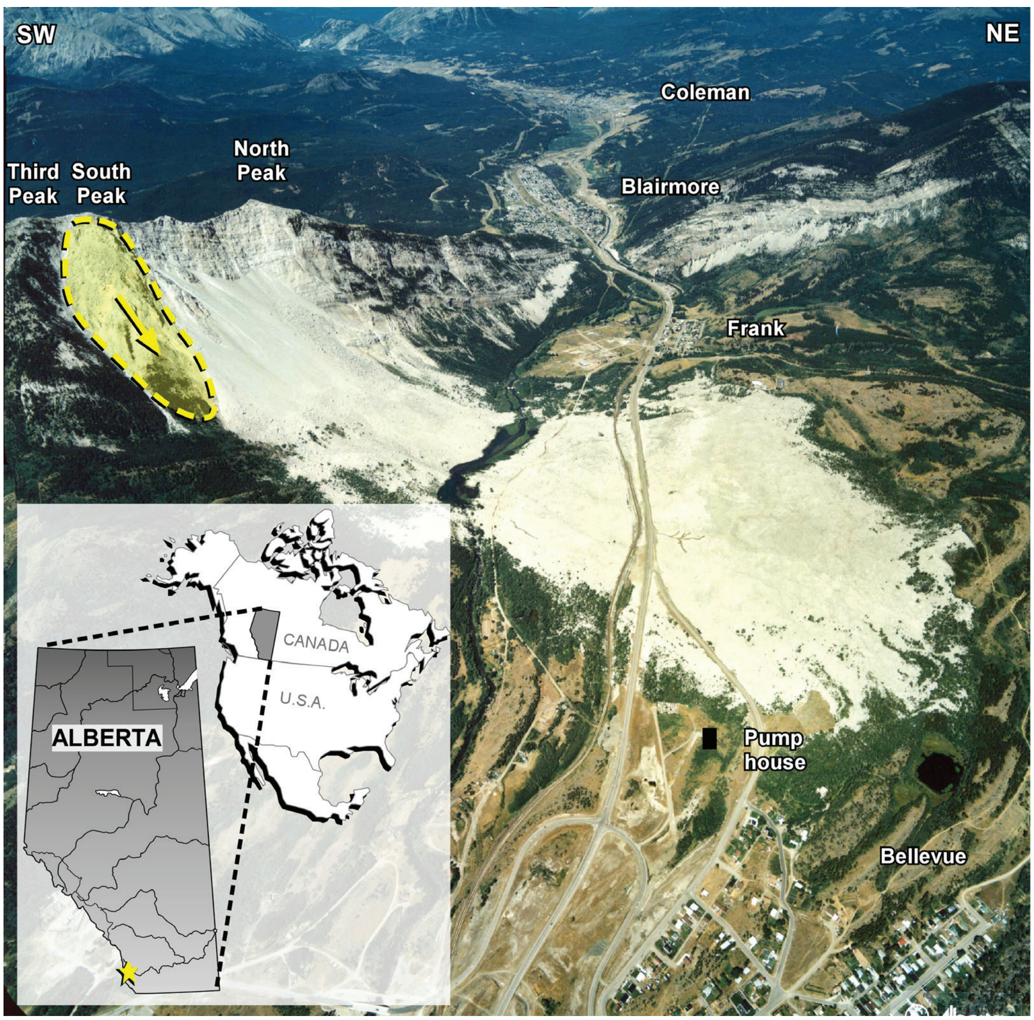

Figure 1. Location of Turtle Mountain in southwestern Alberta and full-extent aerial view of the Frank Slide. The dashed line below South Peak outlines the area identified by Allan (1931, Figure 2) as being most unstable.

2 Sensor Network Activity

This section provides an overview of the major upgrades, repair and maintenance activities, and performance of the sensor network of the monitoring system during 2012. Documentation of the hardware that makes up the various components of the communication stations was provided in Moreno and Froese (2006, 2008a) and is therefore not included in this summary.

The main activities undertaken with respect to the sensor network during 2012 included

- repair of damaged differential Global Positioning System (dGPS) radio station mast,
- extensometer and tiltmeter repairs,
- replacement of solar panel for the AGS weather station,
- improvement to security of WiFi access points for the dGPS,
- upgrades to new NavStar GMS 301 dGPS units, and
- updating firmware of WMA100B power managers of the dGPS.

The following sections provide a brief overview and photographs of these activities. Figure 3 provides an overview of the sensor-network layout as of December 2012.

2.1 New Installations/Repair

2.1.1 Turtle Mountain Signage

New signs were added to each sensor on Turtle Mountain this year. The signs describe the project and give the contact information for the AGS, including our website address (Figure 2).

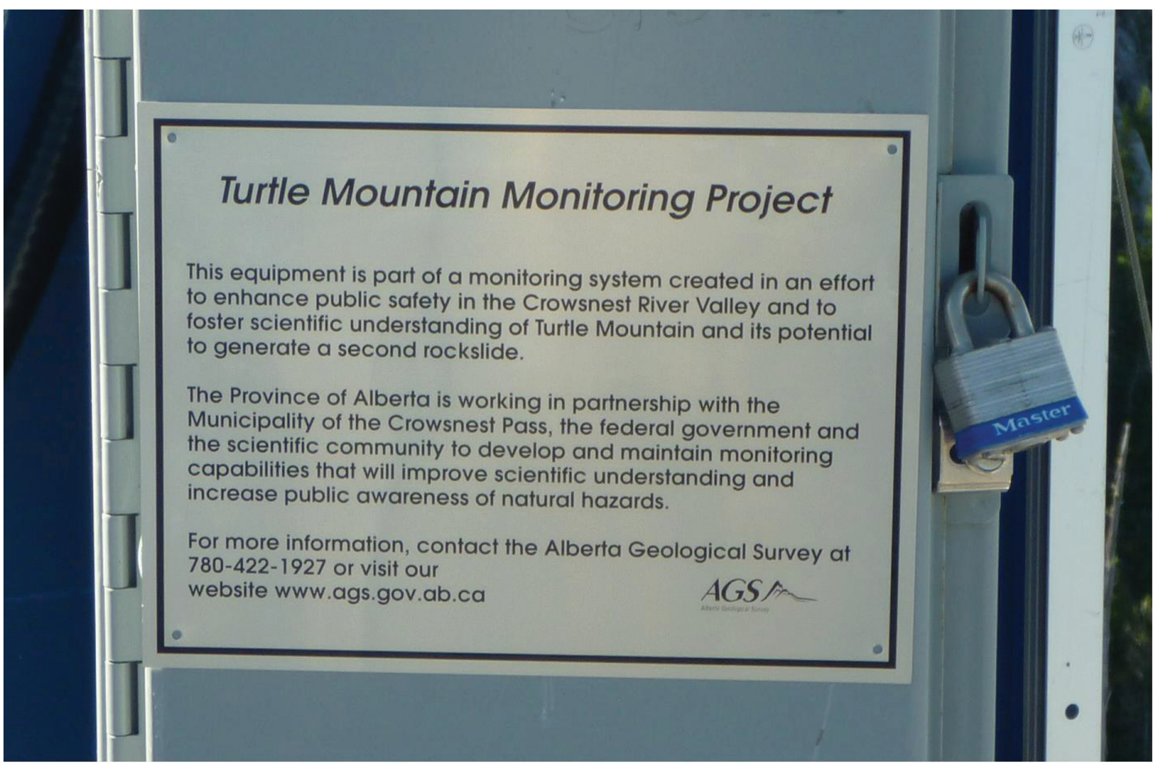

Figure 2. New Turtle Mountain Monitoring Project signage placed on the mountaintop equipment and on the IBIS station located at the pump house in Bellevue, Alberta.

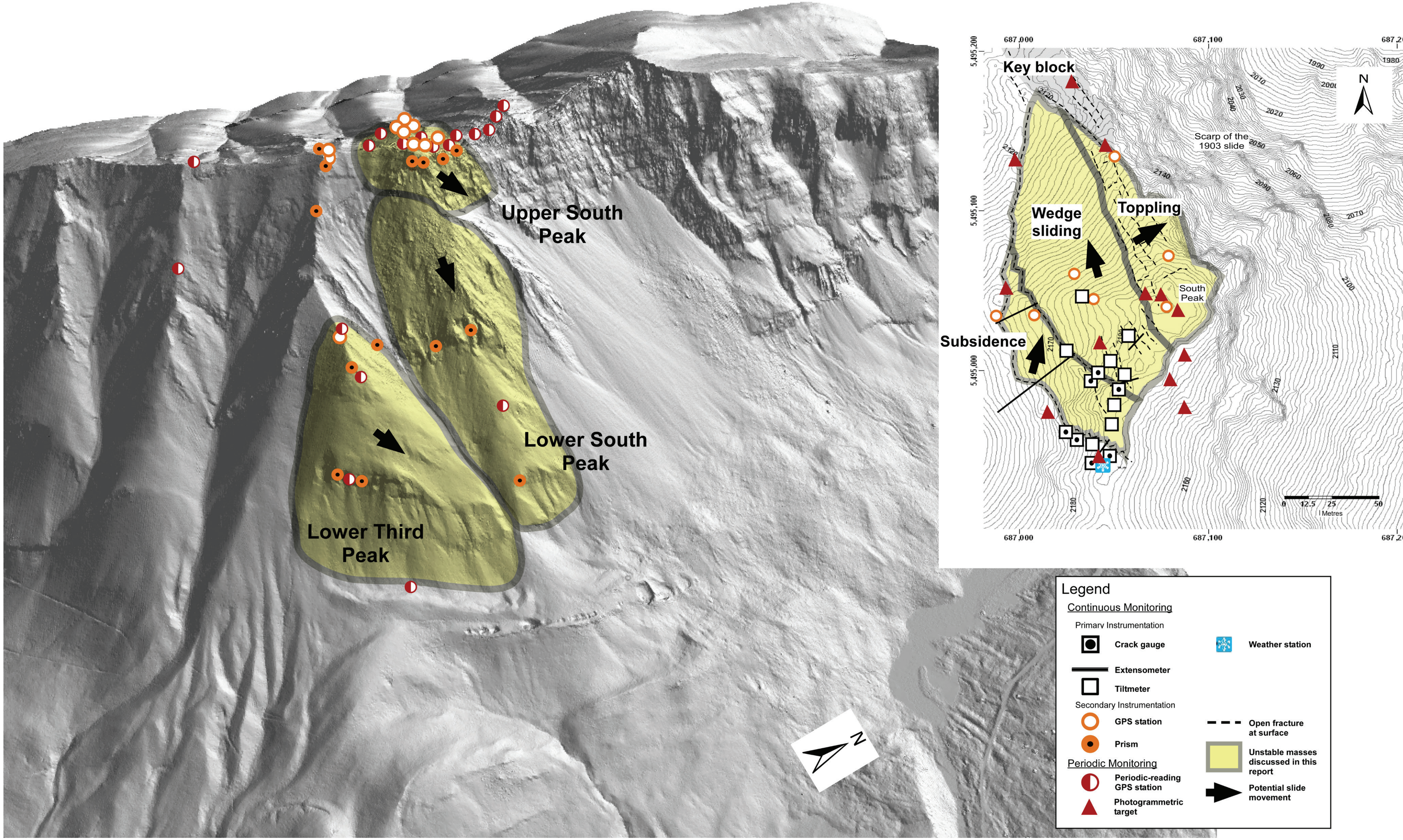

Figure 3. Overview, as of December 2012, of the monitoring network on Turtle Mountain as a whole and South Peak of Turtle Mountain in particular (inset), southwestern Alberta. For readability, primary monitoring instrumentation is shown only on the inset.

2.1.2 dGPS Upgrades

During 2012, all dGPS units were upgraded from GMS200 units to GMS301 units for several reasons. The new units are more resistant to lightning, have improved accuracy, and use approximately 35% of the power consumption of the previous units.

The WMA100 power managers were in need of firmware updates in order to improve the reliability and performance of the system. This summer the updated firmware was loaded onto all the WMA100 systems, which provides the ability to remotely shut down certain elements of the system to save power in times of limited sunlight.

The Upper Wedge solar controller was damaged in 2011 due to a power surge. The damage to the controller allowed power through to the battery uncontrolled, which reduced the storage capacity of the system. The solar controller and batteries were replaced and full functionality was restored

During the June reconnaissance trip, the Upper West dGPS station was found to have fallen due to the turnbuckles having been removed (Figure 4), likely because of vandalism or wind vibration. To reduce the chances of this happening again, all dGPS stations were equipped with safety cables.

In September, a heavy wind event caused a guy wire of the dGPS radio station to fail, causing the mast to fall. There was damage to the solar panels, weather station mounting bracket, and WiFi access point antenna, and they needed to be replaced. Solar panels were taken from the pit station, since a replacement panel was not in stock.

2.1.3 Weather Station Solar Panel Upgrade

Despite replacing the original weather station batteries in 2011, there were still power issues. After the reconnaissance trip in June it was thought that the addition of a new, larger solar panel may improve charging capabilities. A new 85W panel and a 10A solar controller were installed during the August annual repair trip to supply adequate charge for the station (Figure 5).

2.1.4 Primary System Repairs

Extensometers (EX), EX-1, EX-2, and EX-3 were damaged by a lightning event on June 23.

During the June reconnaissance trip to Turtle Mountain, EX-1 and EX-3 were repaired by replacing the surge arrestors at both stations. During the same trip, EX-2 was deemed irreparable because the signal cable was inoperable and materials were not available for replacement. EX-1 was damaged again in July, presumably by lighting, and was later repaired during the August field trip along with EX-2.

Two tiltmeters (T), T-4 and T-8 were damaged by lightning and were replaced in August.

At the end of the field season, T-1, T-2, T-3, T-7, and T-9 were operational, as well as EX-1, EX-2, and EX-3.

2.2 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 2012.

a)

b)

Figure 4. a) Fallen Upper West station b) fallen radio station.

Figure 5. New weather station solar panel.

2.2.1 Primary Sensors

The Turtle Mountain monitoring system (TMMS) has been operating for more than eight years. This has enabled us to understand not only the challenges of maintaining a reliable and essentially continuously running system but also to identify the factors that affect the normal operation of the monitoring network. For the primary sensor network (crackmeters, tiltmeters, extensometers), we find that factors such as high humidity in tiltmeters, snow loading on crackmeters, and lightning strikes can severely affect instruments. To mitigate these effects, desiccant packs have been put inside tiltmeter enclosures, protective roofs have been installed over each crackmeter array, and lightning protection added to all sensors. These measures have yielded mixed results. While desiccant packs have helped improve tiltmeter reliability considerably, the protective roof has been able to protect the crackmeters against snow loading only in a few cases. None of the different measures taken to protect the primary sensor network against electrical surges has worked well, thus making lightning strikes the main cause of sensor damage.

2.2.2 Secondary Sensors

The secondary sensor network consists of the electronic distance measurement (EDM) system and the continuous-reading dGPS system. Operation of these two systems has yielded mixed results. Although the dGPS system performed relatively well during the reporting period, the EDM system has been affected by environmental factors such as rain and snow. These factors have introduced large errors into the data or have made prism reading impossible. Given the nature of the site, prisms for the EDM system are also susceptible to damage from falling rocks, which has happened in the past to some stations.

Over the past couple of years, several modifications have been introduced to all continuous-reading dGPS stations to increase their reliability. This includes changes to improve

- power supply (new glass-mat batteries) and consumption (lower-consumption dGPS units),
- communication (new radios),
- data quality (lower-noise dGPS units), and
- resistance against environmental factors (new metal enclosures and dGPS units with a greater resistance to lightning strikes).

3 Data Analysis

This section provides interpretations of slope conditions and displacement behaviour based on instrument results with a focus on only those sensors that operated normally during the reporting period.

3.1 Deformation Monitoring Data

3.1.1 Crackmeters

The continuously recording crackmeters serve to determine whether the surface fractures open at constant rates or if fracture opening occurs rapidly in one event. However, as already stated in Section 2.2, these sensors are sensitive to snow and ice loading, which introduces large errors in the readings. These instruments have been nonfunctional due to lightening damage and have not been replaced. Therefore, there is no current displacement data to discuss. The reader may refer to earlier reports (listed in the references) for historical information.

3.1.2 Tiltmeters

The results from the tiltmeter network are important because they allow an understanding of the rotating component of the displacements. This system, consisting of ten sensors, was installed in 2005 by AMEC Earth and Environmental (2005). The sensors are located in two clusters: one at the sliding wedge and the other at the subsiding zone behind the sliding wedge. Spatial coverage is therefore limited, and no sensors are located within the most active part of the rock mass at the northeastern part of South Peak. The tiltmeter monitoring results between 2005 and 2012 are shown in Figure 6.

About half of the sensors show the effects of high humidity inside the instrument enclosure, making the interpretation of small rotations very difficult. In spite of this, some trends can be identified. In general, all sensors show annual fluctuations (but with no long-term cumulative rotations) and diurnal fluctuations associated with daily air temperature cycles.

Small rotations are observed by tiltmeters T-1 and T-3 (Figure 6), with the magnitude and rate of rotation at each station remaining essentially constant for the monitoring period from 2005 through 2012. This implies that the pattern of deformation of the rock mass has been constant, which is consistent with the trends seen in the crackmeter data.

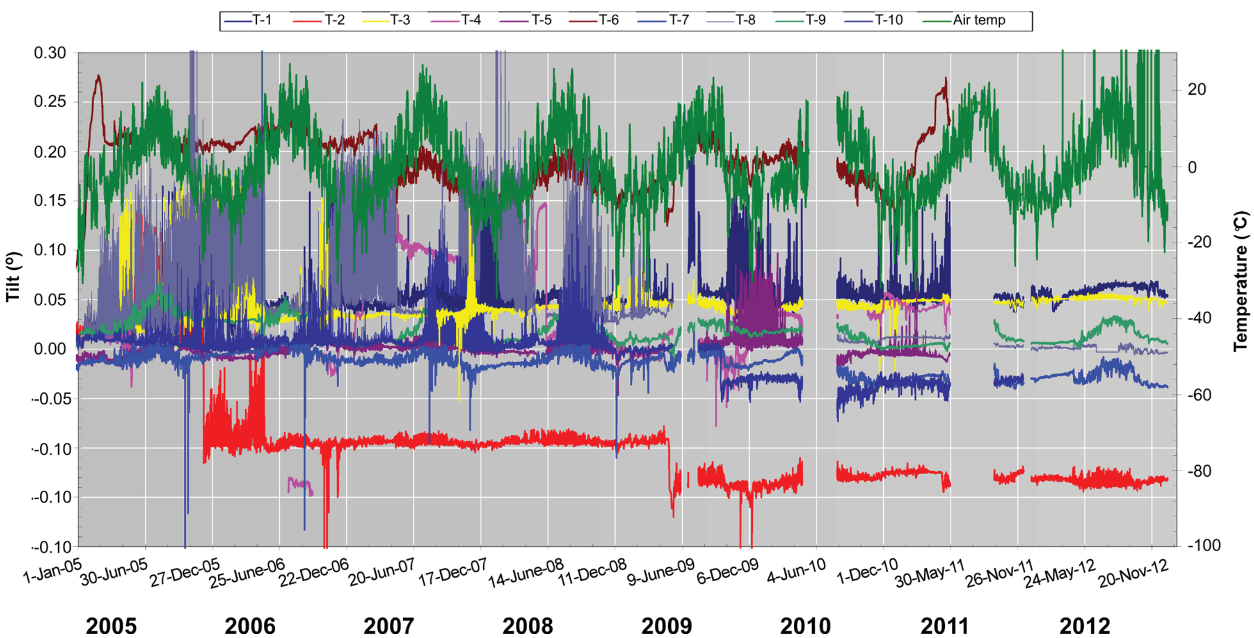

Figure 6. Plot of tilt versus time for tiltmeters, South Peak, Turtle Mountain.

3.1.3 Extensometers

Displacement versus time plots for the extensometers do not show the cyclical daily and annual fluctuations observed in crackmeter and tiltmeter data (Figure 7). This noticeable difference likely arises from a difference in resolution between sensor types, with resolution in the extensometers two orders of magnitude lower than that of the crackmeters. Extensometers EX-2 and EX-3 continue to be extended at 19 and 6.17 mm of extension, respectively. These displacements were recorded during two periods of heavy precipitation in early June and early September of 2005; Moreno and Froese (2006) discussed the specifics of these events. In addition, the displacement versus time plot in Figure 7 shows a number of transient jumps or steps recorded by sensors EX-4 and EX-5; however, these events are believed to be associated with sensor drift rather than rock displacement. The exact cause of these steps has yet to be determined, but we believe that it will not affect the sensors' ability to measure real deformations.

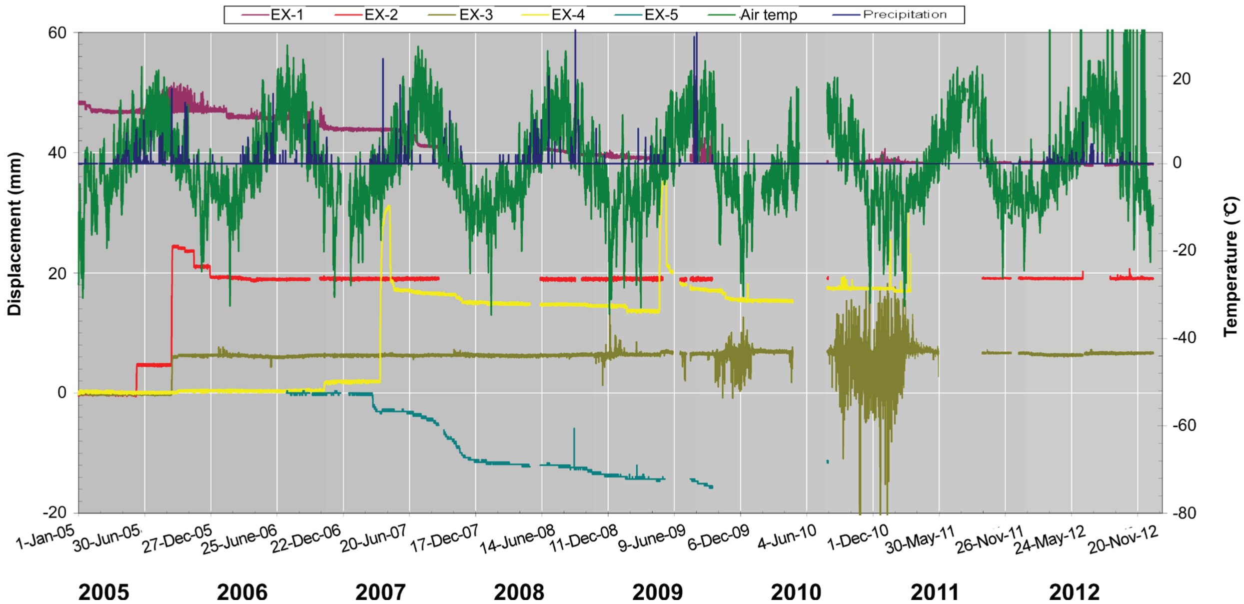

Figure 7. Plot of displacement versus time for extensometers, South Peak, Turtle Mountain.

3.1.4 Continuous-Reading dGPS Monitoring Network

To determine the detailed history of displacements on active fractures, six single-frequency dGPS stations were installed near prominent fractures (Moreno and Froese, 2008a). These Novatel SuperStar II dGPS units have millimetre resolution in the horizontal direction and centimetre resolution in the vertical direction. Later in 2008, this network was complemented with four dGPS stations: two on South Peak (areas with the largest movements) and two on the middle to lower part of the eastern slope below South Peak (areas of suspected movement; Figure 3).

The monitoring results from the dGPS stations are shown in Figure 8. Measurable displacement rates can be seen at the Lower and Upper Saddle and Upper West stations. Annual displacement rates at the Lower and Upper Saddle stations range mainly between 0.5 and 2 mm/year, which is consistent with previous photogrammetric monitoring (Moreno and Froese, 2006). In contrast to these measurements, the Upper West station indicates a displacement of more than 6 mm. This is almost certainly incorrect and likely related to a poorly constructed concrete pillar. A detailed on-site inspection of the pillar revealed evident signs of deterioration; also, the pillar is on a heavily broken rock, which can be very susceptible to freeze-thaw events and result in large local displacements.

3.1.5 EDM System

As discussed in Moreno and Froese (2008b), twenty prisms were installed during the summer of 2007. In general, all records show evidence of the annual displacement fluctuation seen most clearly with the crackmeters. However, with the exception of prism PR-15, it is not possible to give a definite magnitude and direction of displacement at this time due to the small scale of the displacements measured. As mentioned in Section 2, this system has historically been affected by several environmental factors that introduce large errors into the data.

From May to October 2008 and from May to November 2009 (system nonoperational in winter due to snow), the system underwent major software upgrades. During this period, data were used only for testing and therefore not written to the main database. After reviewing the measured data, and considering the negative effects environmental factors had on results, it was decided that the EDM system could not provide the required standard of measurement without significant and costly upgrades, and the system was decommissioned.

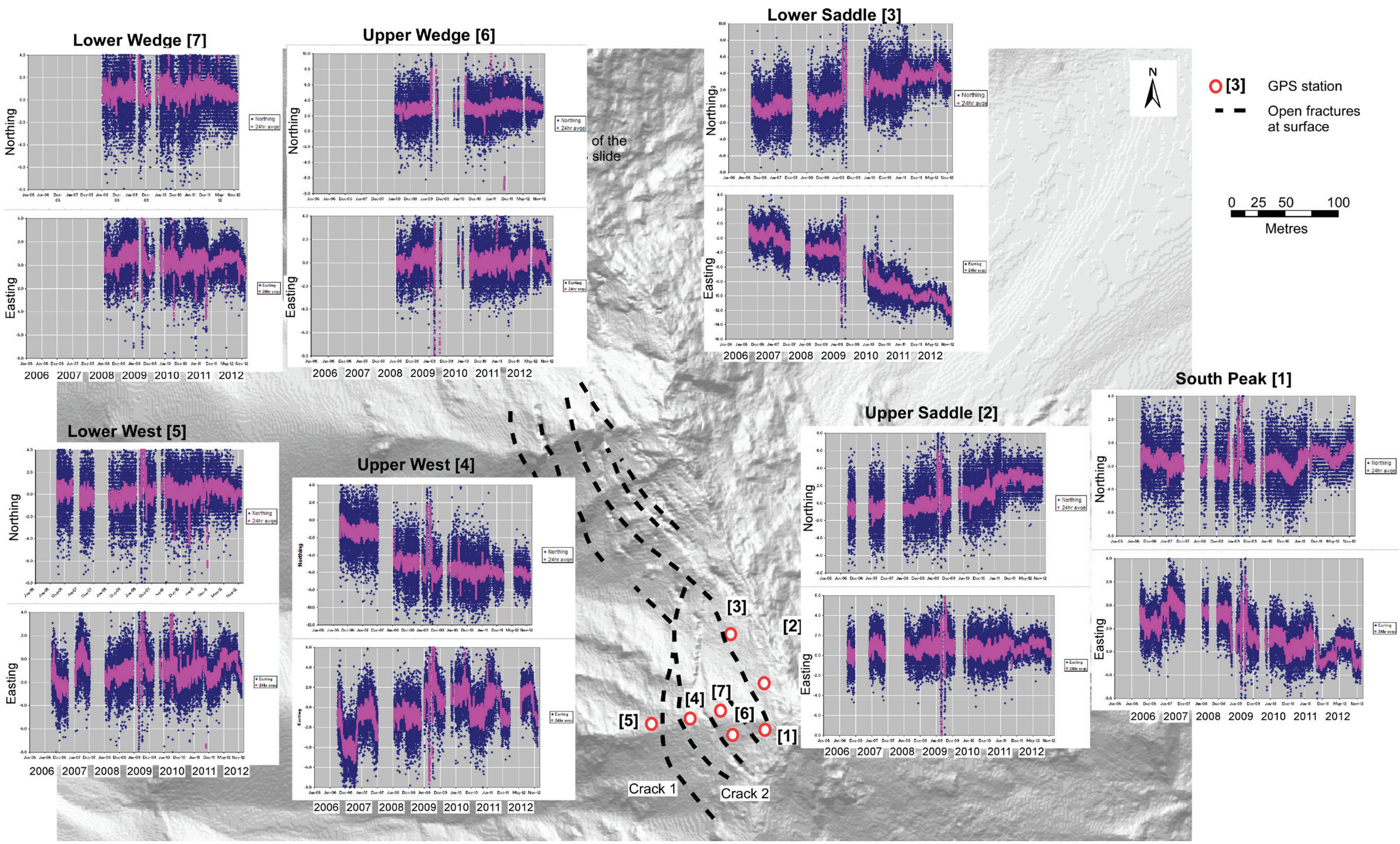

Figure 8. Surface displacements derived from dGPS stations during the period 2006–2012.

3.2 Other Monitoring Data

3.2.1 Climatic and Thermistor Data

A malfunction of the thermistor at South Peak caused several anomalous high readings in 2012, and a maximum temperature could not be conclusively determined. Environment Canada reported a maximum temperature of 31.1°C on July 12, 2012. However, the malfunction did not appear to affect minimum temperatures, and a value of −24.5°C was recorded at the top of the South Peak of Turtle Mountain (Figure 9). Significant daily temperature variations were also common. Rock temperature showed the same general trend as air temperature but was more subdued (lower maximum and higher minimum readings), with a time lag of about 12 hours relative to significant changes in air temperature. Seasonal temperature fluctuations penetrate only about 15 m into the slope (Th-2) and are negligible below that depth, with significant temperature variations measured down to a depth of 8.2 m (Th-4). On the other hand, daily temperature variations are measurable only about 4 m into the slope (Figure 9).

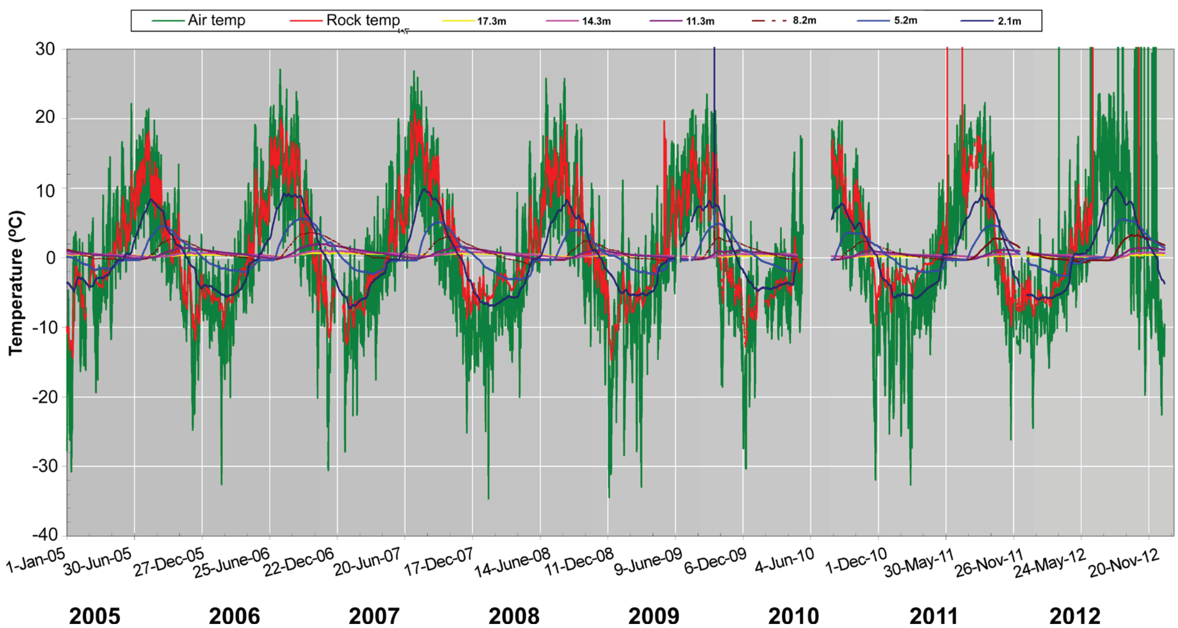

Figure 9. Air temperature and variation of rock temperature with depth in the borehole at the top of South Peak, Turtle Mountain, 2005–2012.

Below-normal precipitation during the reporting period was recorded on the South Peak of Turtle Mountain. Total precipitation in 2012 was 178.5 mm, 55% less than the average annual precipitation of 397 mm, which is based on data measured between 1971 and 2000 at the nearby Coleman weather station by Environment Canada. April and July are the only months with near-normal amounts of cumulative rainfall; all others fall well below, as shown in Figure 10.

3.3 Discussion and Interpretation of Monitoring Data

Since the installation of most of the sensors in 2005 and 2006, new studies have updated our understanding of the complex slope deformations on South Peak. The model proposed by Froese et al. (2009) indicates that South Peak is moving as three different masses: a toppling zone, with blocks moving to the east; a wedge zone that is sliding to the northeast; and a subsidence zone that is moving predominantly downward and to the west. The subsidence zone comprises the heavily fractured area on the west side of South Peak, where the majority of the sensors are located. The new understanding of the kinematics of these three separate masses has enabled a more critical evaluation of the movement trends measured by the sensors. This section is a discussion of the specific sensor trends in relation to the expected deformations.

3.3.1 Crackmeters

The time-series data of crack opening and temperature for the crackmeters deployed at Turtle Mountain have been described in Section 3.1.1. The historic displacement measurements exhibited diurnal and annual cycles, which correlate with temperature cycles and are probably of thermoelastic origin. Because of the difficulties in maintaining this monitoring system (discussed in Section 3.1.1), the crackmeter monitoring system is largely nonfunctional and there is no plan to repair the system.

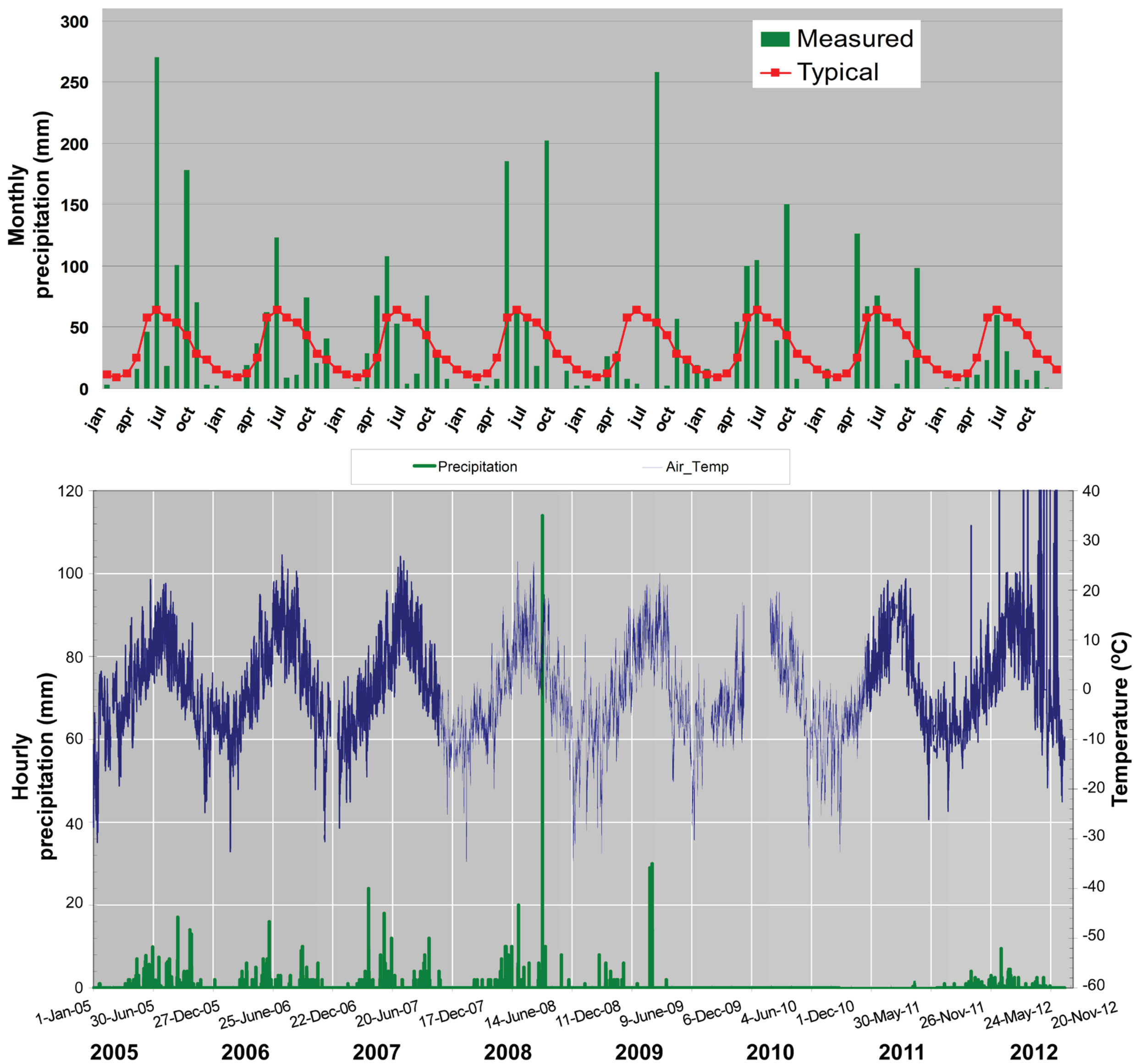

Figure 10. Measured and average monthly precipitation (top) and temperature and hourly precipitation (bottom) near Turtle Mountain, 2005–2012.

3.3.2 Tiltmeters

Most of the tiltmeters are in the subsidence zone. Therefore, we expect these sensors to register small displacements over time. Unfortunately, most of the tiltmeters display different degrees of noise in their readings (Figure 6), which makes the small displacements almost impossible to detect.

3.3.3 Extensometers

The five extensometers do not have the same fine level of resolution as do the crackmeters and tiltmeters, so they are sensitive only to large movements (many millimetres to centimetres). In addition, the installation of these sensors in the summer of 2004 preceded the updated understanding of deformation kinematics on South Peak. These sensors measure only the component of displacement in the line of the sensor, but the movement in some cases is expected to be at oblique angles to the orientation of the extensometer. Therefore, we expect these sensors to identify movements only during very large movements.

Of the five extensometers, EX-1 likely provides the most promise for mapping deformations across the various zones identified on South Peak by Froese et al. (2009) as it is anchored on the 'stable' portion of the mountain, with the head assembly on the large wedge. Although the sensor is oriented at an oblique angle to the expected direction of movement, it should provide an indication of deformations of the wedge.

3.3.4 Continuous-Reading dGPS Monitoring Network

In contrast to the previous three sensor types, many of the more recent dGPS stations have been installed based on the updated understanding of the deformation mechanisms on South Peak and on other portions of the eastern face of Turtle Mountain. In most reported applications of dGPS monitoring of landslides, the relative displacements accrued were in the centimetre range. At South Peak, however, the annual displacements across fractures are only a couple of millimetres, so most of the measurements observed on the dGPS stations are within measurement error. We expect that deformations will continue to be sufficiently small that additional years of data will be required to identify clear trends.

3.3.5 EDM System

As discussed in Section 3.1.5, we do not expect to be able to detect any trends due to many factors that affect the data quality of the EDM system. As a result, the system has been removed and there are no plans to resume monitoring.

3.4 Ground-Based InSAR

Beginning in April 2011, a ground-based radar device was installed for monitoring small displacements on the east face of the mountain. The IBIS ground-based InSAR instrument (GB-InSAR) uses the interferometric synthetic aperture radar technique to measure small displacements at each point on the surface of the mountain. The radar head moves back and forth along a 2 m track approximately every 10 minutes (Figure 11).

Subtraction of two successive phase maps gives an interferogram, which is used to calculate the total displacement that occurs between the two acquisitions, for each point on the mountain face. The instrument was re-installed on May 9, 2012, to acquire data for summer 2012. However, the system failed after one day, was restarted on May 30, and failed again on June 17. The vendor (Ingegneria Dei Systemi [IDS]) determined that the problem was with the calibration of the radar head, which was shipped to Italy

Figure 11. The IBIS system installed in front of Turtle Mountain. The instrument is located approximately 3 km from the mountain face.

for repair. The instrument was returned late in the fall and too late for more data gathering, resulting in limited data acquisition for the 2012 season.

The small dataset acquired between May 30 and June 17 (the one day of data acquired between May 9 and May 10 were excluded) was processed. However, it should be noted that results are not expected to be as reliable as the 2011 dataset because the signal-to-noise ratio is higher for a short time span and there is no way to determine whether the results were affected by the suspect calibration of the radar head. Note that the instrument worked continually for a few months in 2011 and there was no evidence of calibration problems at that time, so we have no reason to reject the 2011 data on that basis.

Figure 12 shows total displacement from May 30 to June 17, 2012. The data is noisy in the vegetated areas on the flanks and in the areas of debris flow. The unstable region on the North Peak observed in 2011 is not apparent in the 2012 data; however, some motion towards the instrument appears to be occurring on South Peak, which is consistent with earlier observations (Humair et al., 2011).

Total displacement towards the instrument during the same time period with satellite-based InSAR in 2011 (May 30–June 17, 2011) is shown in Figure 13. Note that during those few weeks in 2012, most of the toward-satellite motion appears to be occurring on North Peak rather than on South Peak. Since we only have a few weeks of data for 2012, further comparisons would be difficult to make. Although the radar head calibration problems in 2012 and the limited size of the dataset make it difficult to draw reliable conclusions, these results are consistent (both in location and deformation rate) with the South Peak instability that has been observed previously (Humair et al., 2011; Moreno and Froese, 2012). GB-InSAR measurements will be repeated in 2013 with the recalibrated radar head to obtain a full summer of observations; we will then see if those results are consistent with what was observed in 2011.

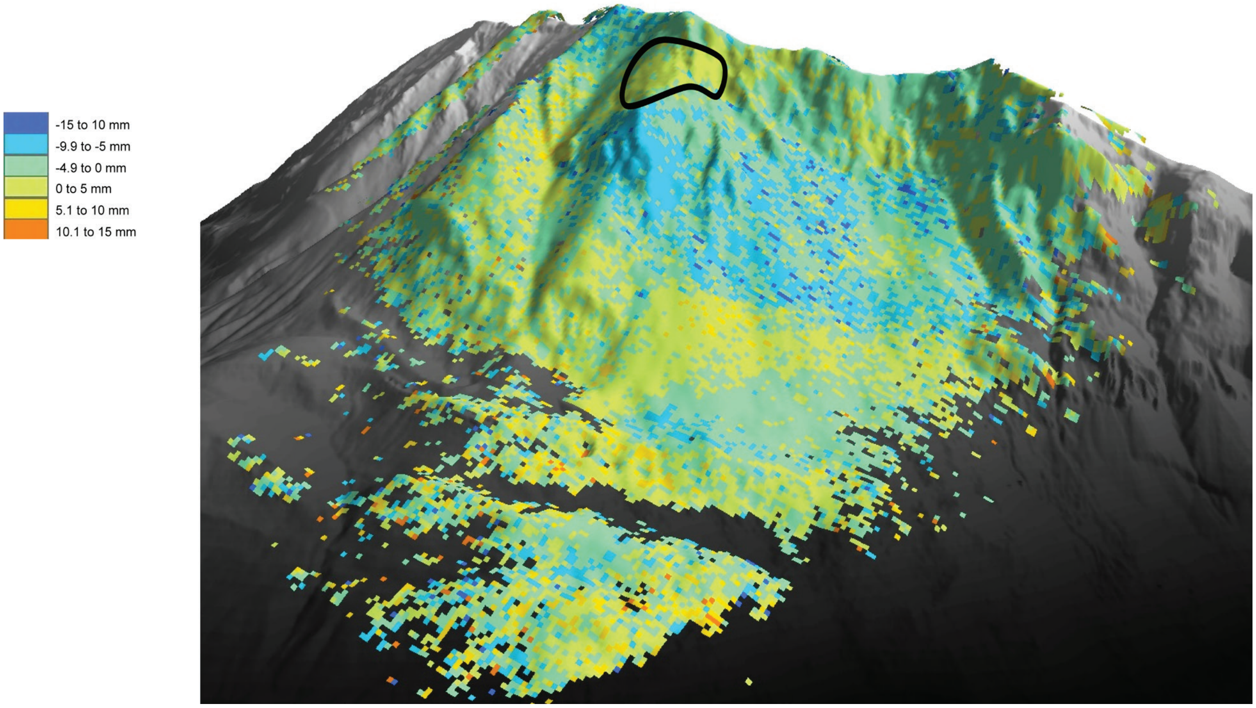

Figure 12. DEM of Turtle Mountain, viewed from the IBIS instrument location. Colours represent total displacement along the instrument line-of-sight between May 30 and June 17, 2012. Red and yellow indicates motion towards the instrument, blue indicates motion away, and green areas are zero displacement. Some motion towards the instrument appears to be occurring on South Peak (circled); however, the IBIS instrument is still undergoing testing due to a calibration issue with the radar head.

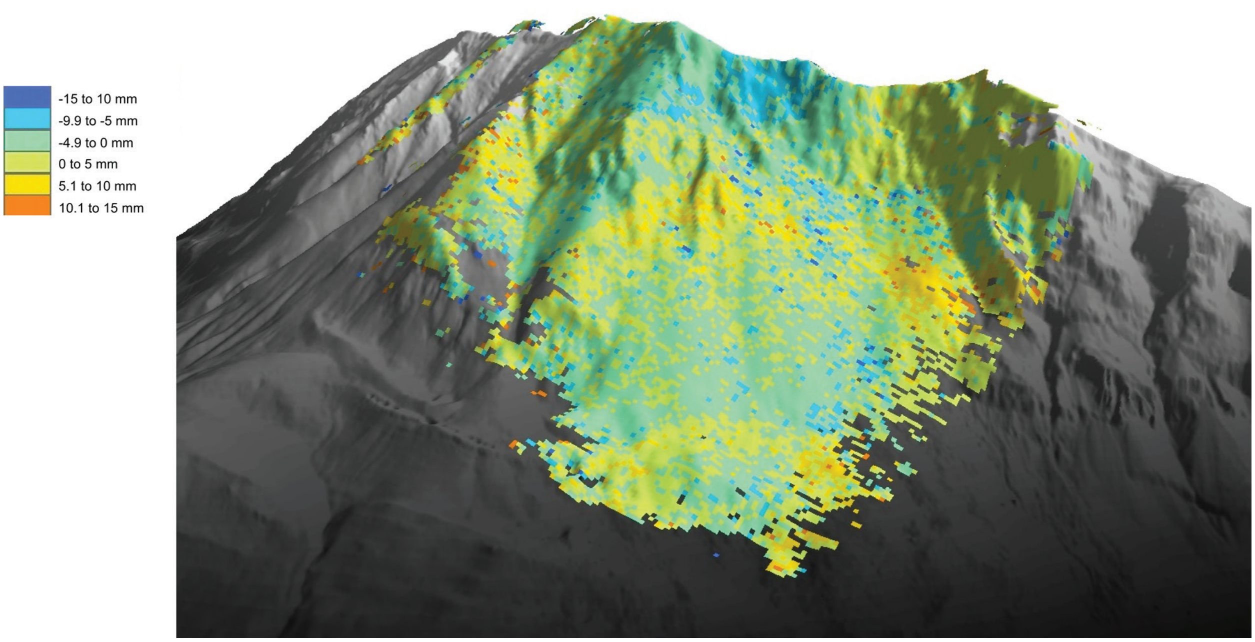

Figure 13. Displacement between May 30 and June 17, 2011 measured using satellite-based InSAR data. Note that no obvious displacement is occurring on the South Peak, whereas a displacement towards the instrument of a few millimetres has occurred on North Peak.

4 Conclusions

Recent application of modern characterization, monitoring, and modelling technologies has greatly increased our understanding of the 1903 Frank Slide and of the existing rock-slope hazard at Turtle Mountain. Based on these findings, monitoring focus was shifted to a wider area on the eastern face of Turtle Mountain below Third Peak and South Peak. Analysis of the data, from the near-real time monitoring system in these areas does not indicate any type of significant movement. This shows that any movements, if occurring, are below the detection limit of the sensors (less than a few millimetres per year). However, more data over a longer period is required to confirm this. Data analysis from the monitoring network on the upper part of South Peak is also ongoing. Displacement trends in this area have been already identified. It consists of diurnal and annual cycles that correlate with air temperature cycles. The annual cycles exhibit an active phase (with displacements in the order of millimetres per year occurring in early autumn to late winter) and a relatively inactive phase (with limited to no displacement in spring to late summer). The rate of displacement is well below any level of concern and has remained essentially constant for the eight years of monitoring.

Keeping the primary sensor network continuously running has proven to be very difficult and expensive. As discussed in Section 2, several factors affect the normal operation of the primary network, particularly lightning. On average, two lightning events that are capable of causing sensor damage are recorded each year. Each event can leave up to 50% of the primary system disabled, and the associated cost of repairing this equipment is quite high. In addition, it is recognized that the primary monitoring network is not well suited to the range of deformation expected on the mountain. Thus, the information provided by the system will become less useful as deformation continues. Therefore, we continue to investigate new monitoring techniques that are more robust and will provide measurements over the entire range of expected deformations. Typical techniques include dGPS stations (continuous-reading monitoring network) and GB-InSAR. Over the past couple of years, the dGPS monitoring system has proven to be reliable, and it is expected to slowly replace the primary system as the main early warning monitoring system. The GB-InSAR system has the potential to supplement existing dGPS monitoring system. However, more testing is needed before it can be used as a reliable monitoring alternative.

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, 2009a, 2011, 2012) and present them in public meetings with the municipal officials and residents in the affected zones. Updates are also available on the 'Turtle Mountain Monitoring Project & Field Laboratory' page of the Alberta Geological Survey website (http://www.ags.gov.ab.ca/geohazards/turtle_mountain/turtle_mountain.html).

Based on a review of the sensor thresholds, a system of four alert levels (green, yellow, orange, and red) was developed by AMEC (2005) and subsequently incorporated into the Alberta Emergency Management Agency's (AEMA) emergency response protocol for Turtle Mountain. This protocol establishes that the AER, through the AGS, is responsible for determining the appropriate alert level for a potential emergency at Turtle Mountain. Thus, to ensure that this role is fulfilled, the AER developed its own internal emergency response protocol (Moreno and Froese, 2009b). This document is revised as often as is required to ensure that it is current, reflects best practice, and is fit for its purpose. As a minimum, one review is done every year. The most recent review was completed in November 2012 with no changes made to protocol.

The AGS will continue to work with NavStar Geomatics Ltd. for maintenance of and upgrades to the dGPS system. The various meters will continue to be maintained and repaired throughout the 2013 field season. Finally, the IDS IBIS-system contract will be reviewed for the 2013 contract year.

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