AER/AGS Open File Report 2015-09

Alberta Energy Regulator

Turtle Mountain Field Laboratory, Alberta (NTS 82G): 2013 Data and Activity Summary

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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, 2013.

The TMMS is a near-real-time monitoring system that provides data from a network of approximately 80 geotechnical sensors on the 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, AGS performs an annual detailed review of the data stream.

This report comprises three main sections.

The first contains information about the major changes to the physical sensor network of the monitoring system during the summer of 2013. 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/year.

The third focuses on results from the most recent data, including an update on the displacement trends revealed by a series of eighteen points as part of a periodic GPS monitoring system and an update on continuing ground-based InSAR monitoring.

1 Introduction

In 2005, 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, Figure 2). The first priority for monitoring and studying Turtle Mountain is to provide an early warning to residents 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 on 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 research. This report is a brief overview and, in many cases, refers to other papers/articles that provide additional detail regarding the information discussed.

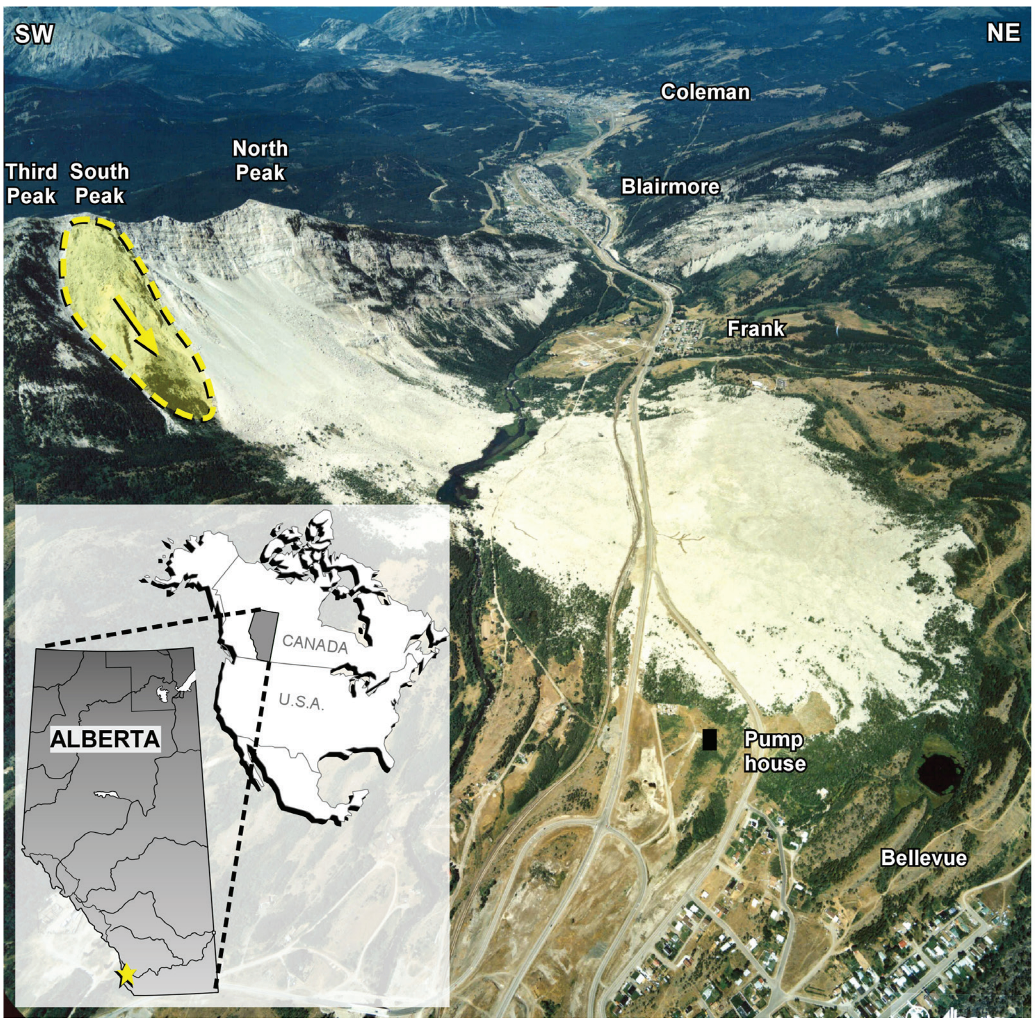


Figure 1. Location of Turtle Mountain in southwestern Alberta and full-extent aerial view of the Frank Slide. The dashed line below South Peak outlines the area identified by Allan (1931, Figure 2) as being most unstable.

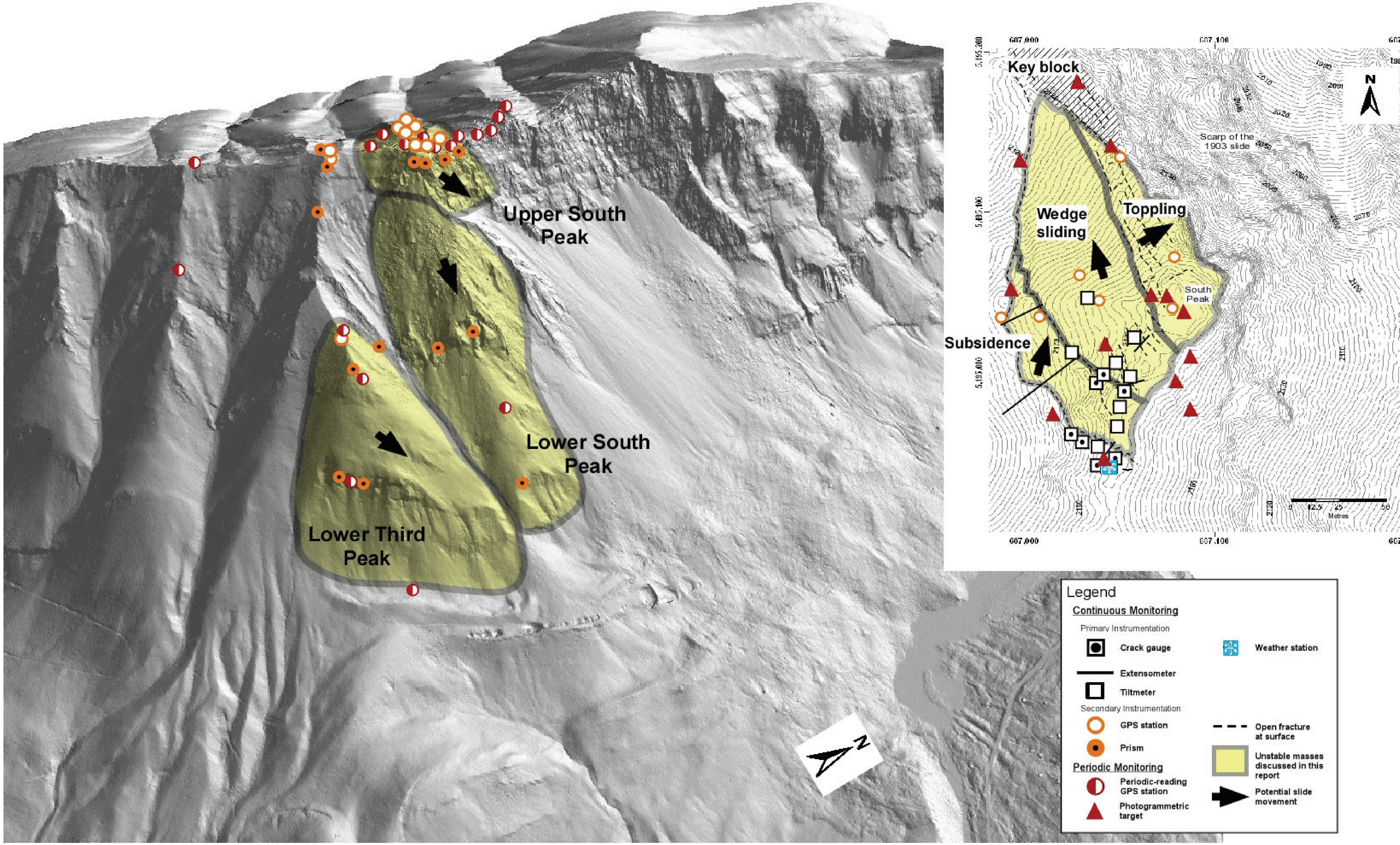


Figure 2. Overview, as of December 2013, of the monitoring network on Turtle Mountain as a whole and South Peak of Turtle Mountain in particular (inset). For readability, primary monitoring instrumentation is shown only on the inset.

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 2013. 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 2013 included

- firmware updates to several dGPS stations and
- maintenance, software updates, and recalibration to the GB-InSAR (IBIS) equipment.

2.1 Repairs and Maintenance

2.1.1 dGPS Firmware Update

Throughout the spring and summer of 2013, several dGPS sensors went offline. During a site visit in July, it became apparent that several of the stations would require a firmware update. NavStar Geomatics Ltd. (NavStar) returned later in October to complete the update, and all stations came back online. The dGPS stations continued to run throughout the remainder of 2013.

2.1.2 Ground-Based InSAR Software Update and Maintenance

In the fall of 2012, the radar head was returned to the vendor (Ingegneria Dei Systemi [IDS]) to correct a calibration issue experienced throughout the summer season. IDS restored the radar head's radio frequency from the higher frequency (AGS setting) to the lower frequency (Industry Canada standard) and returned the instrument to the AGS. The IBIS unit was reinstalled at the Bellevue pump house in May of 2013.

During installation a malfunction of the USB cable within the rail was noted. A system workaround was installed for the USB cable issue; however, the system continued to experience problems. These problems were shared with IDS and a June maintenance trip was scheduled.

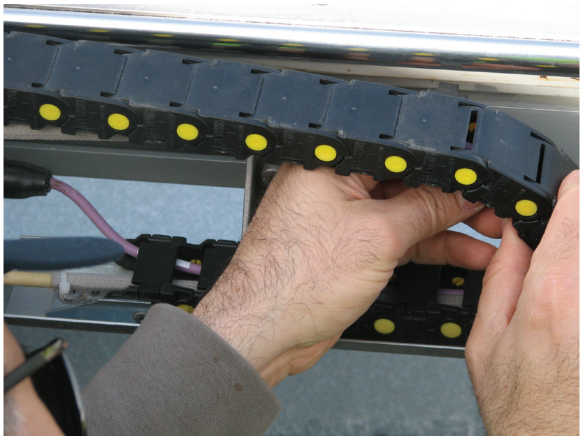
IDS and AGS staff visited the pump house site in late June. During the visit the USB cable nested within the rail was replaced (Figure 3), the software was updated, and the frequency was changed back to the original AGS setting.

The IBIS system continued to run consistently throughout the summer until it malfunctioned in early September due to a computer error. During the winter months the IBIS system will be reviewed based on overall performance and data collection.

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 2013.

The TMMS has been operational for more than nine years. 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. For the primary sensor network (crackmeters,



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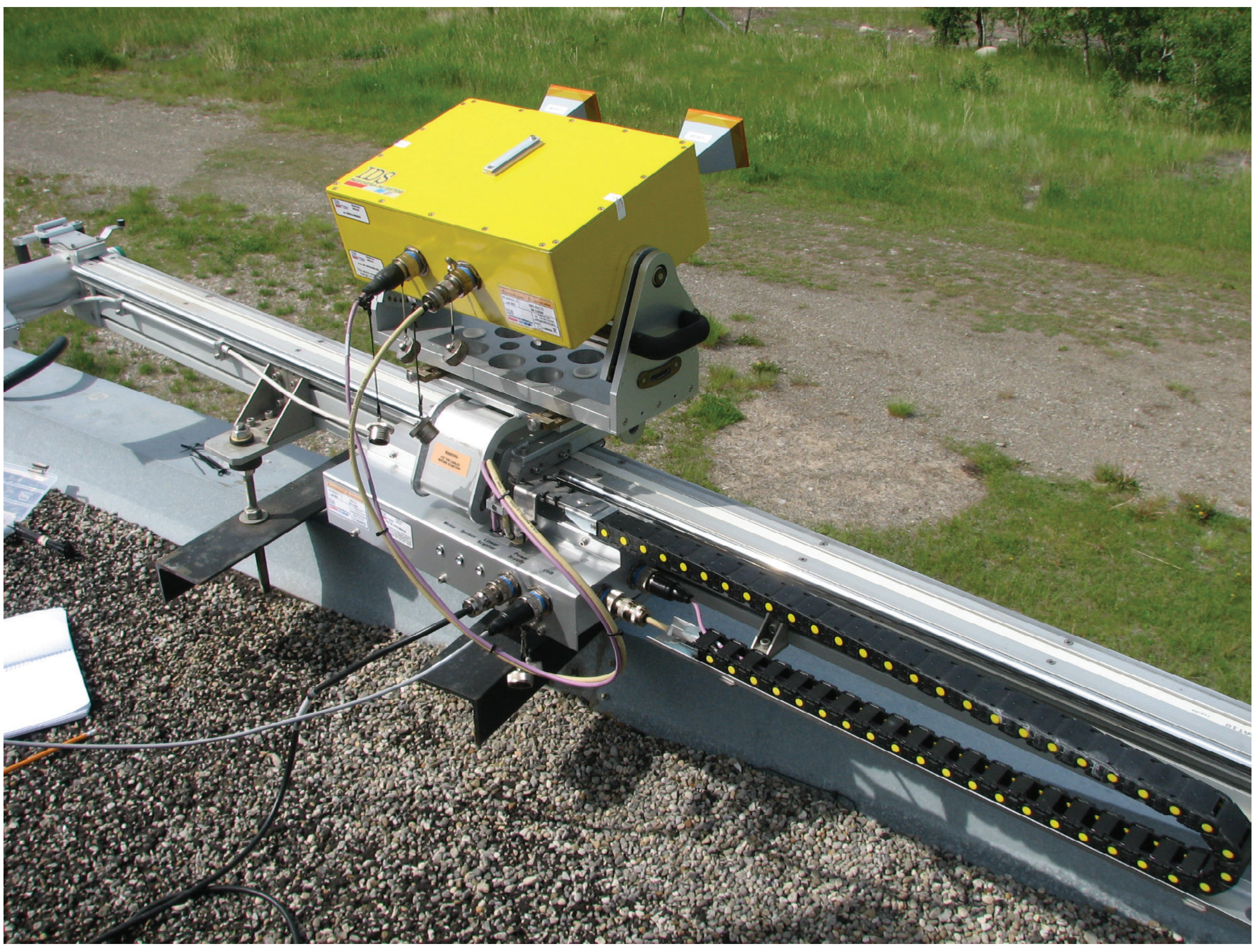

c)

Figure 3. (a) IBIS GB-InSAR equipment rail track maintenance; (b) USB cable embedded in rail track; (c) IBIS GB-InSAR equipment rail, track, and radar head.

tiltmeters, extensometers), we find that factors such as high humidity in tiltmeters, snow loading on crackmeters, and lightning strikes can severely affect the instruments' ability to operate. To mitigate the effects of these environmental factors, desiccant packs have been put inside tiltmeter enclosures, protective roofs have been installed over each crackmeter array, and lightning protection has been 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. 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 cost of repairing this equipment is high.

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. These instruments have been non-operational due to lightning damage and have not been replaced. Therefore, there is no displacement data to discuss for the 2013 monitoring report. The reader may refer to earlier reports (2005 to 2012) for historical information and graphs. The crackmeter network will remain non-operational until further notice.

3.1.2 Tiltmeters

The results from the tiltmeter network are relevant 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 (Figure 2, inset). Spatial coverage is therefore limited, with no sensors situated within the most active part of the rock mass at the northeastern part of South Peak. The monitoring results between 2005 and 2013 are shown in Figure 4.

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 4), with the magnitude and rate of rotation at each station remaining essentially constant for the monitoring period from 2005 through 2013. This implies that the pattern of deformation of the rock mass has been constant, which is consistent with the trends seen in past crackmeter data.

During 2013 the tiltmeters have continued to display annual fluctuations, which can be attributed to changing temperatures. TM-7 does appear to be showing a trend other than that of yearly fluctuation, but neither TM-8 nor TM-2, which are nearby, seem to be affected. Similarly TM-3 does not show any

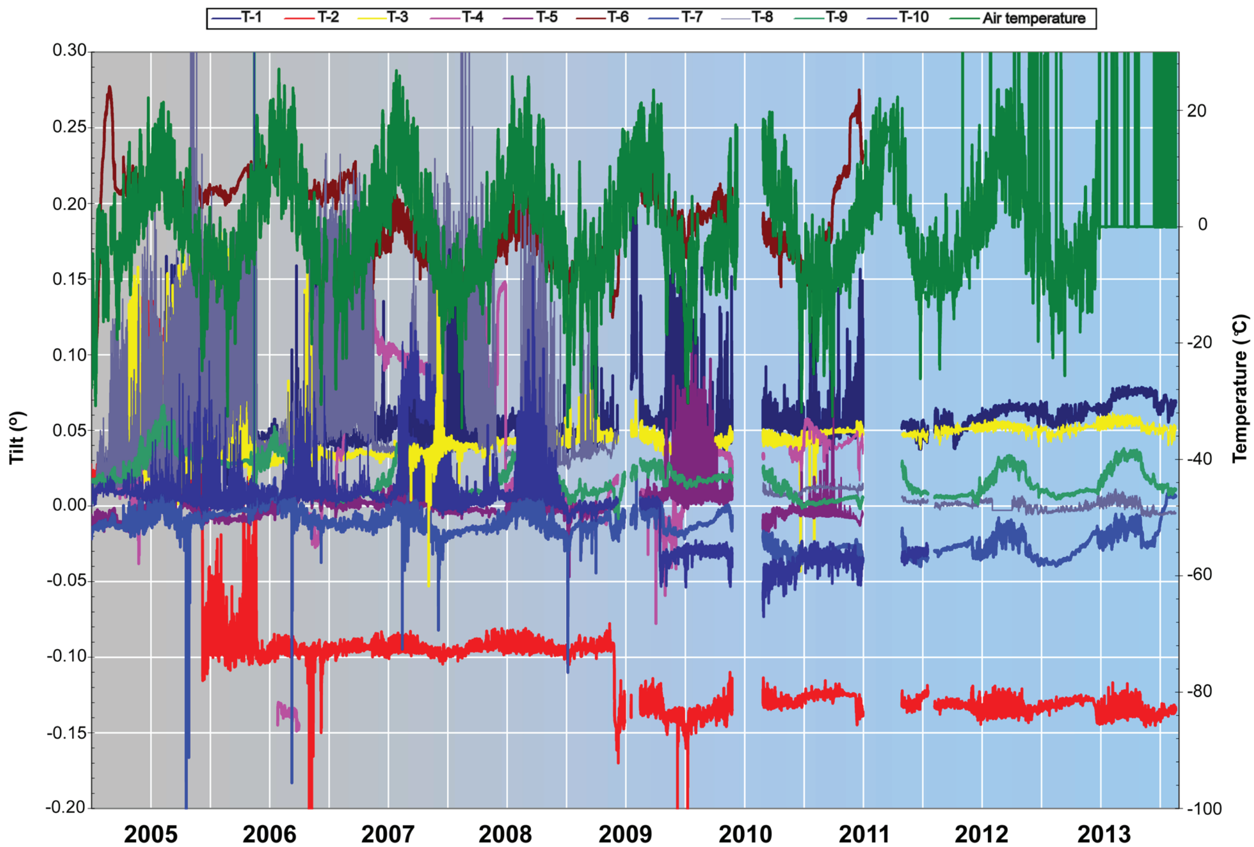

Figure 4. Plot of tilt versus time for tiltmeters, South Peak, Turtle Mountain.

movement. It is likely that TM-7 is either malfunctioning or is located on an isolated block that may be moving independently of the overall mass of South Peak.

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 5). This noticeable difference likely arises from difference in resolution between sensor types, with resolution in the extensometers being two orders of magnitude lower than that of the crackmeters. Extensometers EX-2 and EX-3 continue to read 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 5 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.

Of the three extensometers that were operational during 2013 (EX-1, EX-2 and EX-3), there have been no movements above the noise level, and no discernable trends. By the end of the year, only EX-1 and EX-2 were operational. Due to the low resolution and lack of any useful data, these instruments will be retired in the coming years.

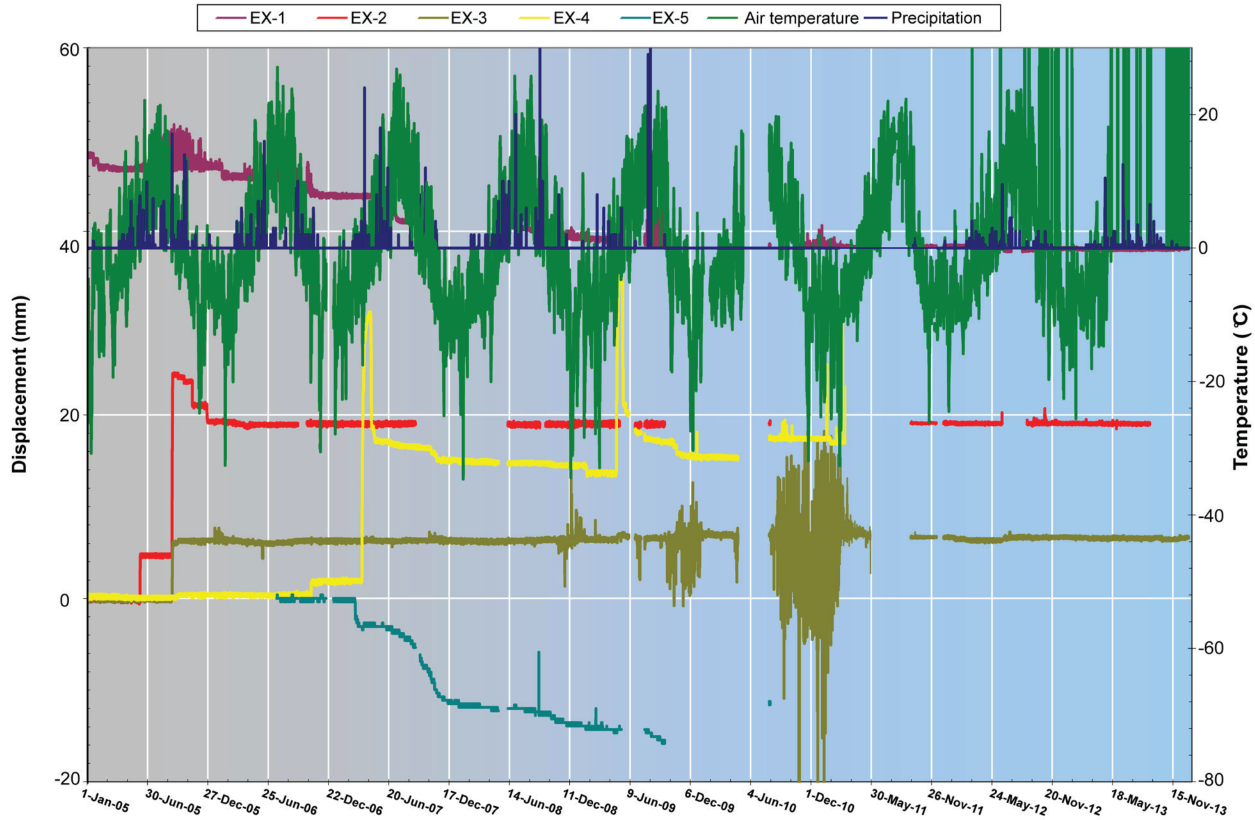

Figure 5. Plot of displacement versus time for extensometers, South Peak, Turtle Mountain.

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 in 2008 (Moreno and Froese, 2008a). These Novatel SuperStar II dGPS units have a resolution in the millimetre range in the horizontal direction and in the centimetre range in the vertical direction. Later in 2008, this network was complemented with four dGPS stations: two on South Peak (areas with the largest potential movements) and two on the middle to lower part of the eastern slope below South Peak (areas of suspected movement; Figure 2).

The trends in displacement at the dGPS stations during 2013 (Figure 6 and Figure 7) are consistent with monitoring results of past years, which show seasonal variations without significant displacements associated with movement.

3.1.5 Ground-Based InSAR

Beginning in April 2011, a ground-based radar device was installed for monitoring small displacements on the eastern face of the mountain. The IBIS GB-InSAR instrument 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-metre track approximately every 10 minutes, recording return phases of the radar signal (Figure 8).

The instrument was reinstalled in May 2013 after repairs were completed in the fall of 2012 due to calibration problems with the radar head. Shortly after installation, the AGS became aware of a change in the frequency setting for the radar head, which was reset to the Industry Canada standard. AGS holds

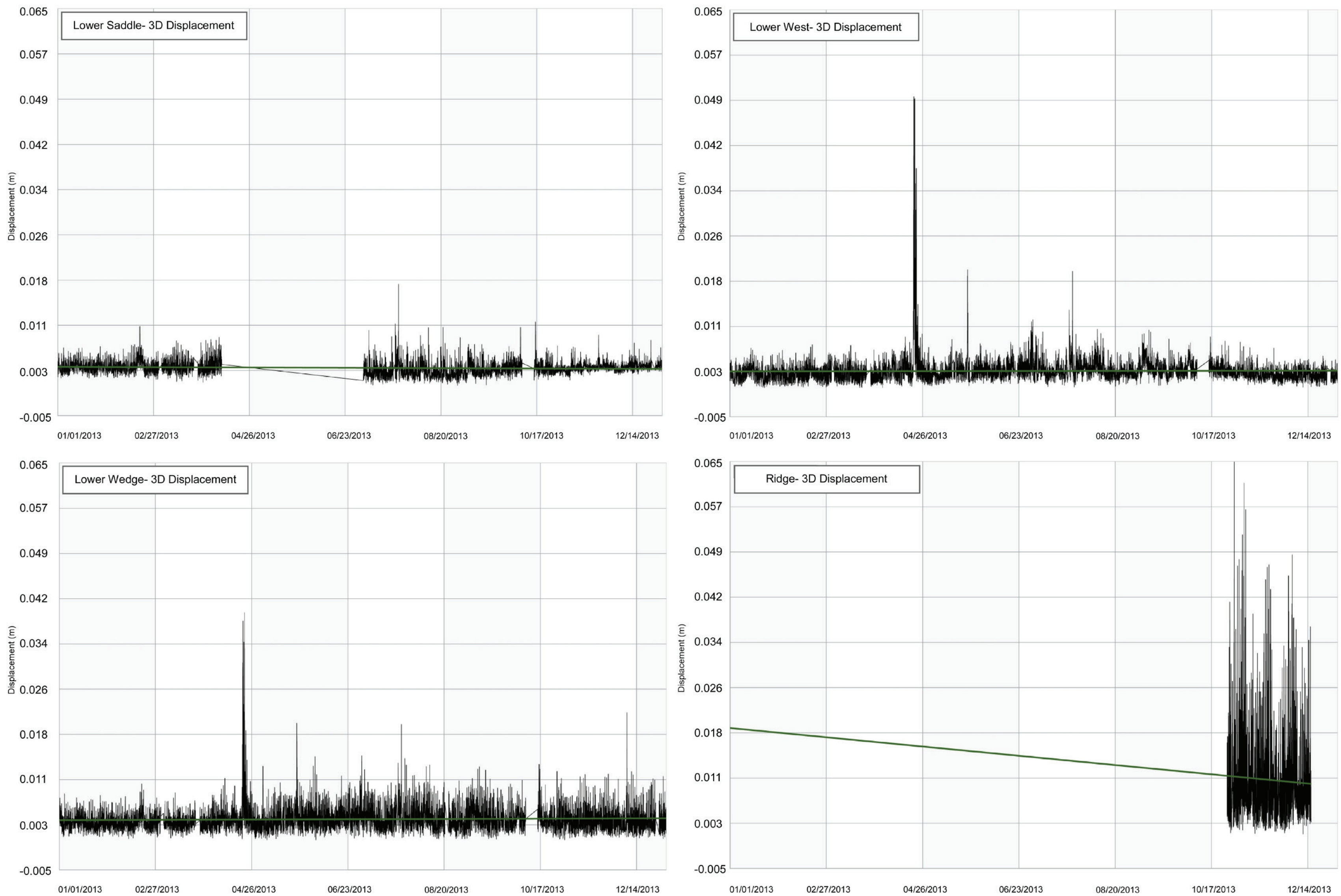

Figure 6. dGPS station results for Turtle Mountain during 2013. The 3D displacement values are depicted for each corresponding station. The green line indicates the linear trend line.

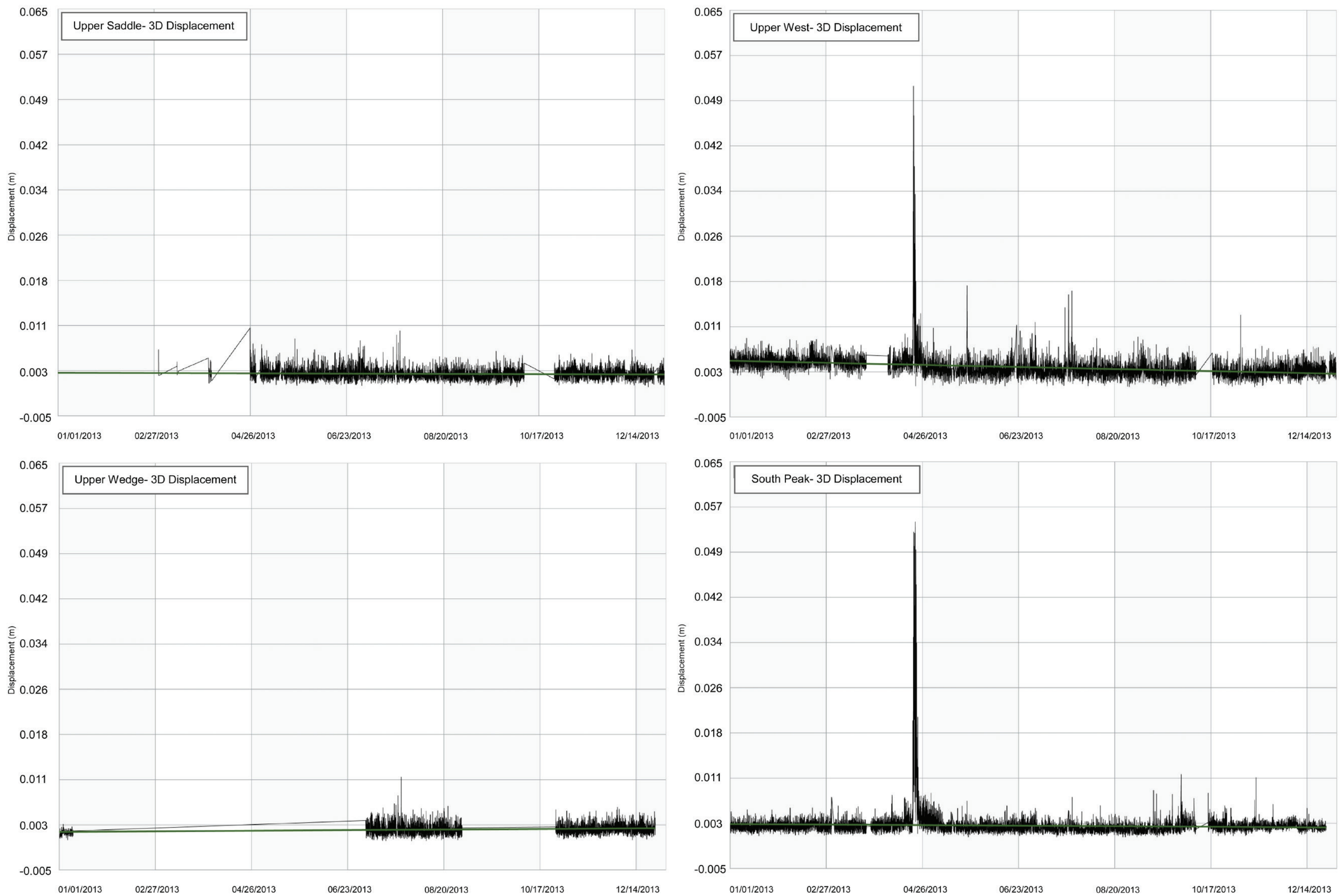

Figure 7. dGPS station results for Turtle Mountain during 2013. The 3D displacement values are depicted for each corresponding station. The green line indicates the linear trend line.

Figure 8. IBIS GB-InSAR equipment facing the eastern face of the mountain.

a licence for a frequency which provides a higher resolution. Because of this difference the manufacturer visited the site in June 2013 to change the frequency setting and to complete annual maintenance on the rail. A new USB cable was also installed within the radar head since the instrument had experienced communication problems between the instrument laptop and radar head. For the month of May and part of June, before the maintenance visit, the USB cable was bypassed. The IBIS system ran continuously after installation in May until June on the Industry Canada standard frequency and after the maintenance trip in June until early September. In September the instrument began to have communication problems again, which IDS has attributed either to USB communication problems or a glitch in the laptop programming. Newer software is available for the laptop and will need to be installed before next season.

Unfortunately, due to a change in the analysis program (Guardian), displacement results have not been calculated properly and are showing high amounts of atmospheric noise. Because of this software problem, the data from 2013 remains unusable for displacement mapping at this time.

3.2 Discussion and Interpretation of Monitoring Data

Since the installation of most of the sensors in 2005 and 2006, new studies have improved 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.

3.2.1 Crackmeters

The time-series data of crack opening and temperature for the crackmeters deployed at Turtle Mountain have been described in earlier reports from 2005 to 2012. The historical 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 non-operational, and there is no plan to repair the system.

3.2.2 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, which makes the small displacements almost impossible to detect. Because of difficulties in maintaining this monitoring system (discussed in Section 3.1.2), the tiltmeter monitoring system is largely non-operational, and there is no plan to repair the system.

3.2.3 Extensometers

The extensometer network does 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 our new 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 only very large movements. Because of difficulties in maintaining this monitoring system (discussed in Section 3.1.3), the extensometer monitoring system is largely non-operational, and there is no plan to repair the system.

3.2.4 Continuous-Reading dGPS Monitoring Network

In contrast to the previous three sensor types, many of the more recent dGPS stations have been installed based our new understanding of the deformation mechanisms on South Peak and on other portions of the eastern face of Turtle Mountain.

The Upper West station continues to have very pronounced seasonal fluctuation (Figure 7), which is likely due to the instability of the pillar. A detailed on-site inspection of the pillar in previous years has revealed evident signs of deterioration; also, the pillar is on a heavily broken rock. This material can be very susceptible to freeze and thaw events, which can result in large local displacements.

Upper Saddle and Lower Saddle stations seem to show continuous movement (Figure 6 and Figure 7). Considering these are positioned in the most unstable locations, this is not unexpected. South Peak station continues to show some seasonal fluctuations (Figure 7), but these are still within the normal ranges and within measurement error.

Throughout 2013, select dGPS stations have experienced a gap in the data collection due to firmware, Internet connectivity, or high snow cover issues. It is suspected that the high spike observed in April 2013 is due to a large snow storm. According to Environment Canada, the Crowsnest Pass region received up to 22.5 mm of total precipitation within 48 hours, resulting in 27 cm of snow on ground recorded.

The dGPS system continues to operate and is the most reliable early warning system currently on the mountain.

3.2.5 Ground-Based InSAR

As stated in Section 3.2, the AGS was unable to process the data properly due to software issues; therefore, no discussion and interpretation are available.

4 Supporting Studies and Research

4.1 Terrestrial LiDAR Scanning

In June of 2012, Humair, with the University of Lausanne, Switzerland, conducted a terrestrial light detection and ranging (LiDAR) scanning campaign of the face of Turtle Mountain (Figure 9). Scanning took place both at the base and on the peaks of the mountain (Figure 10). In July 2013 these scans were repeated at the same locations. By comparing the two datasets, deformation can be detected and measured (Figure 11). The reader may refer to Appendix 1 for a copy of the full report on this study (Humair et al., 2013).

The results of this study identified many rockfalls and large boulders which appear to be toppling. On North Peak, 57 rockfalls were found to have occurred, while South Peak showed only 3. It is not known if the smaller amount on South Peak is from a difference in geological conditions, or if it is a result of being scanned from a greater distance than North Peak. In addition to these rockfalls, two large boulders on the northern side of the saddle appear to be moving eastwards towards the valley (Figure 12). Since rockfalls are common and the saddle is one of the most unstable parts of the mountain, these results are not unexpected.

Over the 390-day interval, no large-scale movement was detected. While many rockfalls and localized movements were detected, the displacement was below the detection threshold of approximately 10 cm. It should be noted that this threshold is larger than that of other instrumentation used on Turtle Mountain; however, other sensors on Turtle Mountain have indicated that deformation is typically on the millimetre scale. It would be beneficial to compare these data to other monitoring results, such as the GB-InSAR data, since these are the only two sensors that study the entire face of the mountain. The data from this study may be used to validate other Turtle Mountain instrumentation results but should not be considered primary deformation data.

4.2 Periodic-Reading dGPS Monitoring Network

As outlined in Moreno and Froese (2008b), a series of fourteen monitoring points were installed by the University of Calgary Geomatics Engineering Department in May 2007 (Teskey and Ebeling, 2011). This network was later augmented with the addition of four target points in 2008. These monitoring points are located in potentially unstable zones highlighted by LiDAR studies (Moreno and Froese, 2008b), including portions of the eastern face, below South and Third peaks, and the unstable saddle area between North and South peaks (Figure 2). The researchers expected that this layout would provide the coverage required to obtain a more complete picture of the movement patterns in these potentially unstable areas.

During 2013, data was obtained and analyzed by the AGS. Original data showed some spikes believed to be due to instrument error. To smooth the time-series curve, the automatic gain control (AGC) of 1000 recorded periods was applied. Each recorded period has an original length of approximately one hour. The AGS also tried iterative linear regression to summarize the movement trends of dGPS data. Linear regression results show that the uncertainties are bigger than the measurements, which indicates that no useful information can be extracted from this dGPS. This is further supported by the fact that the curve after AGC processing shows no obvious linear trends.

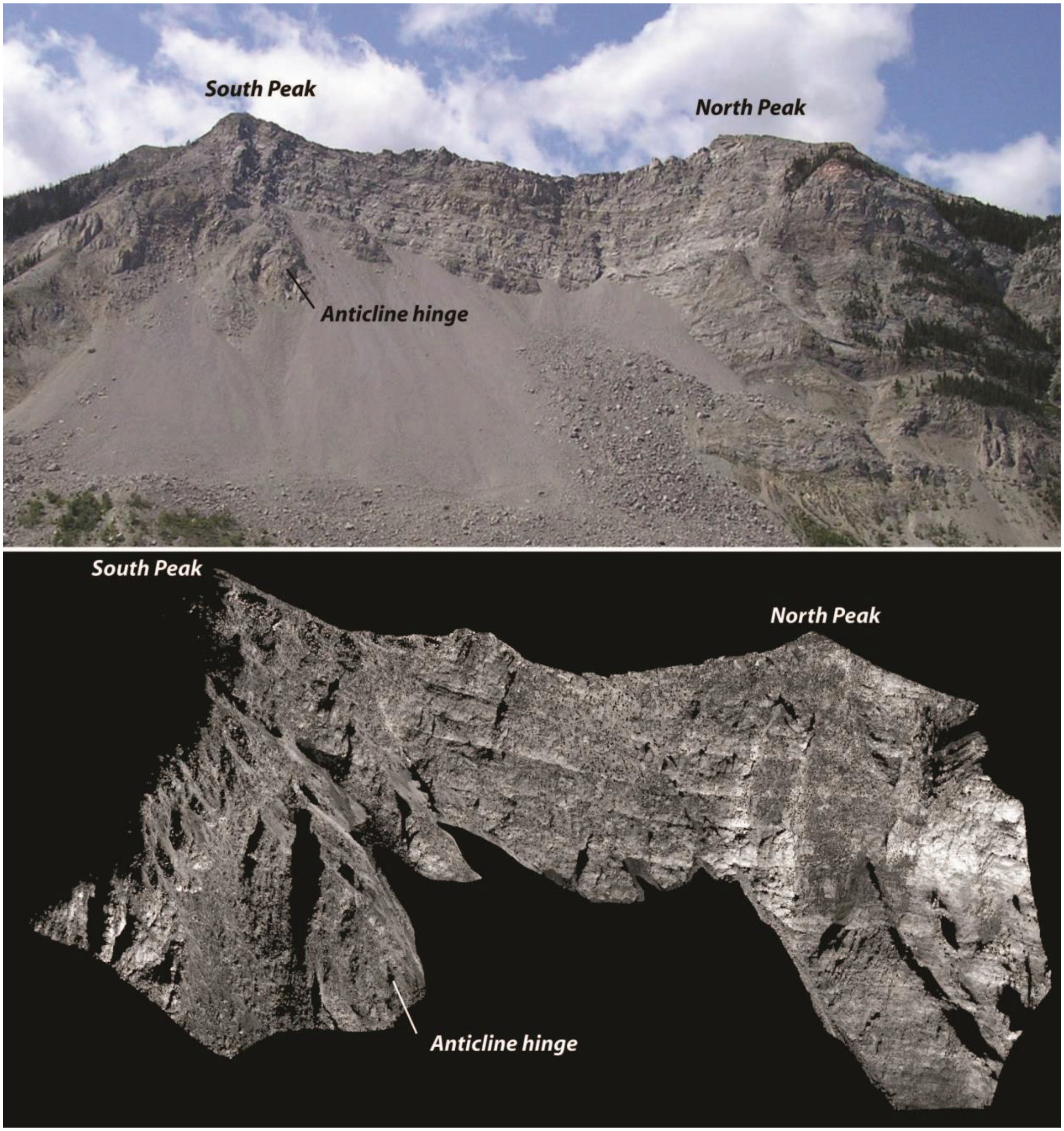

Figure 9. Photo of Turtle Mountain showing the eastern face (top) and corresponding terrestrial LiDAR image (bottom). From Humair et al. (2013, Figure 4).

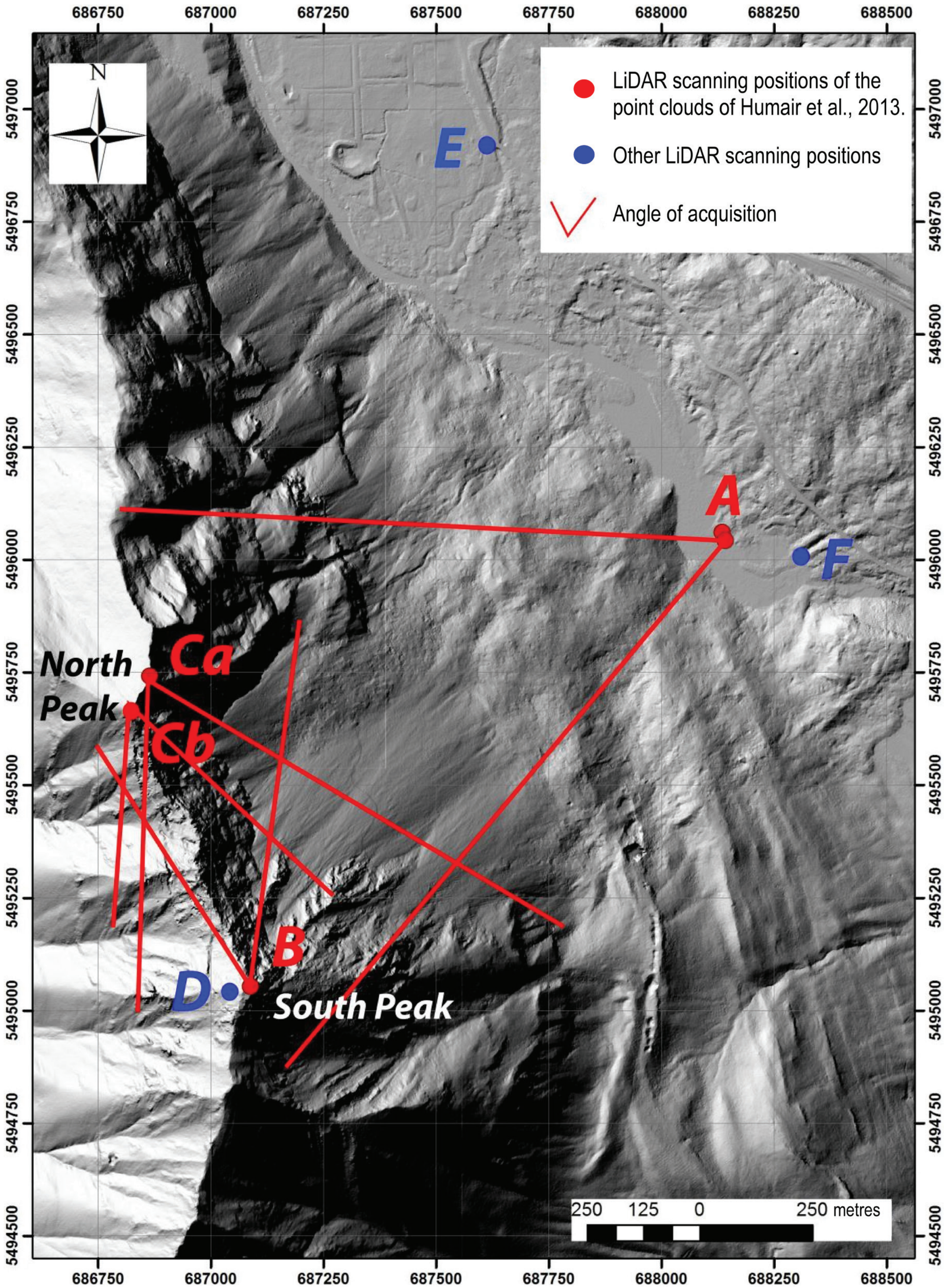

Figure 10. LiDAR map of Turtle Mountain showing locations and acquisition angles of terrestrial LiDAR scanning campaign positions. Modified from Humair et al. (2013, Figure 5).

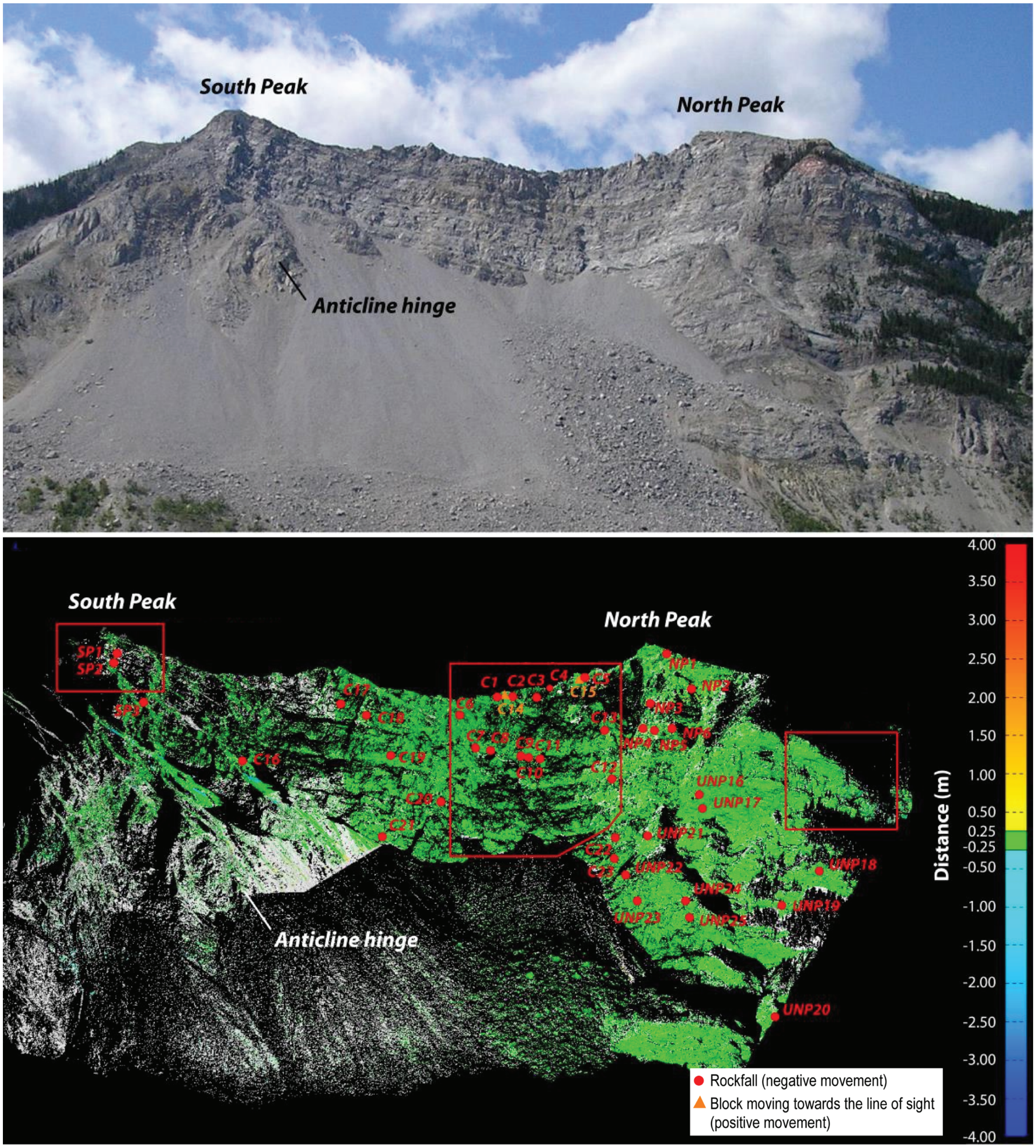

Figure 11. Points, identified as rockfall or block movement, detected during terrestrial LiDAR scanning of the eastern face of Turtle Mountain. The red outlines depict areas of interest further discussed in Appendix 1. Modified from Humair et al. (2013, Figure 9).

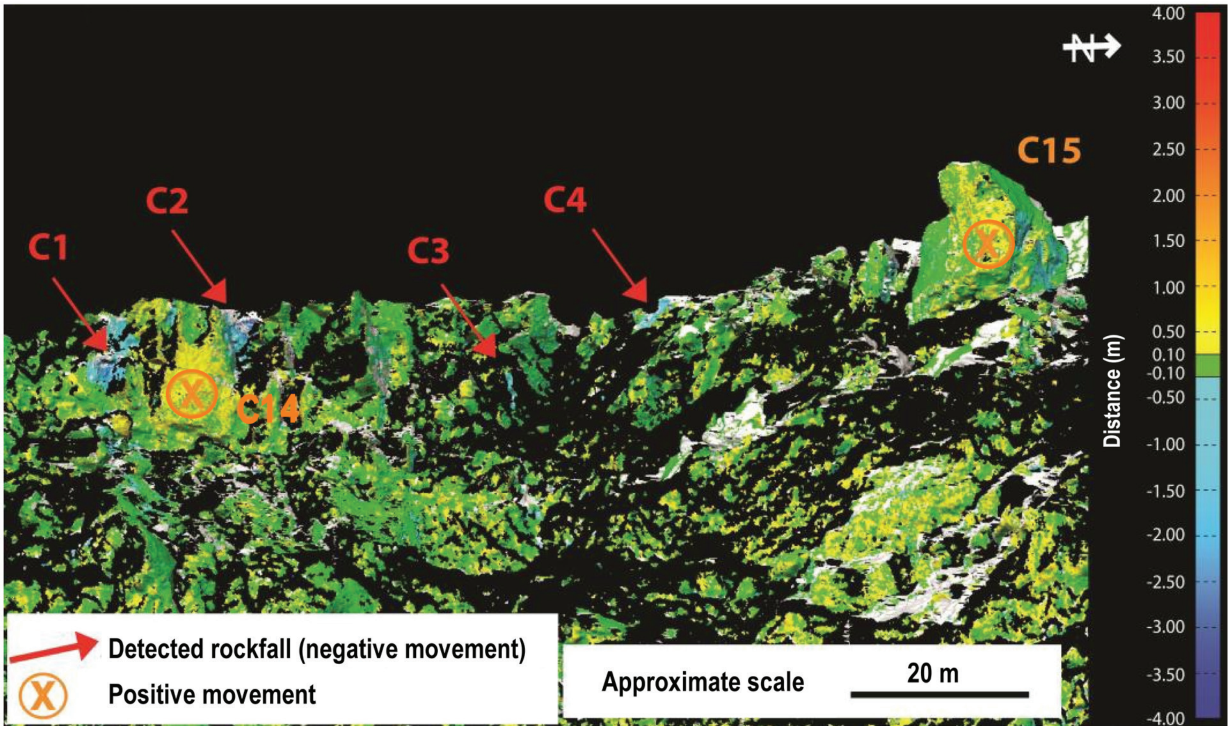

Figure 12. Close-up view of the area of interest of detected rockfalls and positive movements observed on North Peak on Turtle Mountain. Modified from Humair et al.(2013 , Figure 13).

4.3 RadarSat-2 Analysis

Space-borne radar imagery was acquired for analyzing surface movement changes of the Turtle Mountain from 2008 to 2012.

Two tracks (U4 and U20) of RadarSAT-2 data used for InSAR were available from the Canada Space Agency. U20 imaged the back of Turtle Mountain and therefore provides only limited information for the surface motion vectors. U4 images the front of the landslide site, with an incident angle of 45 degrees. The area of positive motion towards the satellite can be observed in the highlighted zone (Figure 13), with a ground motion at 1.8 cm/year. The smearing effect in the back of the mountain is due to the look angle of the satellite. The red colour indicates that the ground is moving towards the satellite (max ~1.9 cm/year) and blue colour (min ~−1.3 cm/year) suggests the opposite direction of movement. InSAR is unable to detect any rock falls due to its lower resolution (~10–20 m) in comparison to LiDAR.

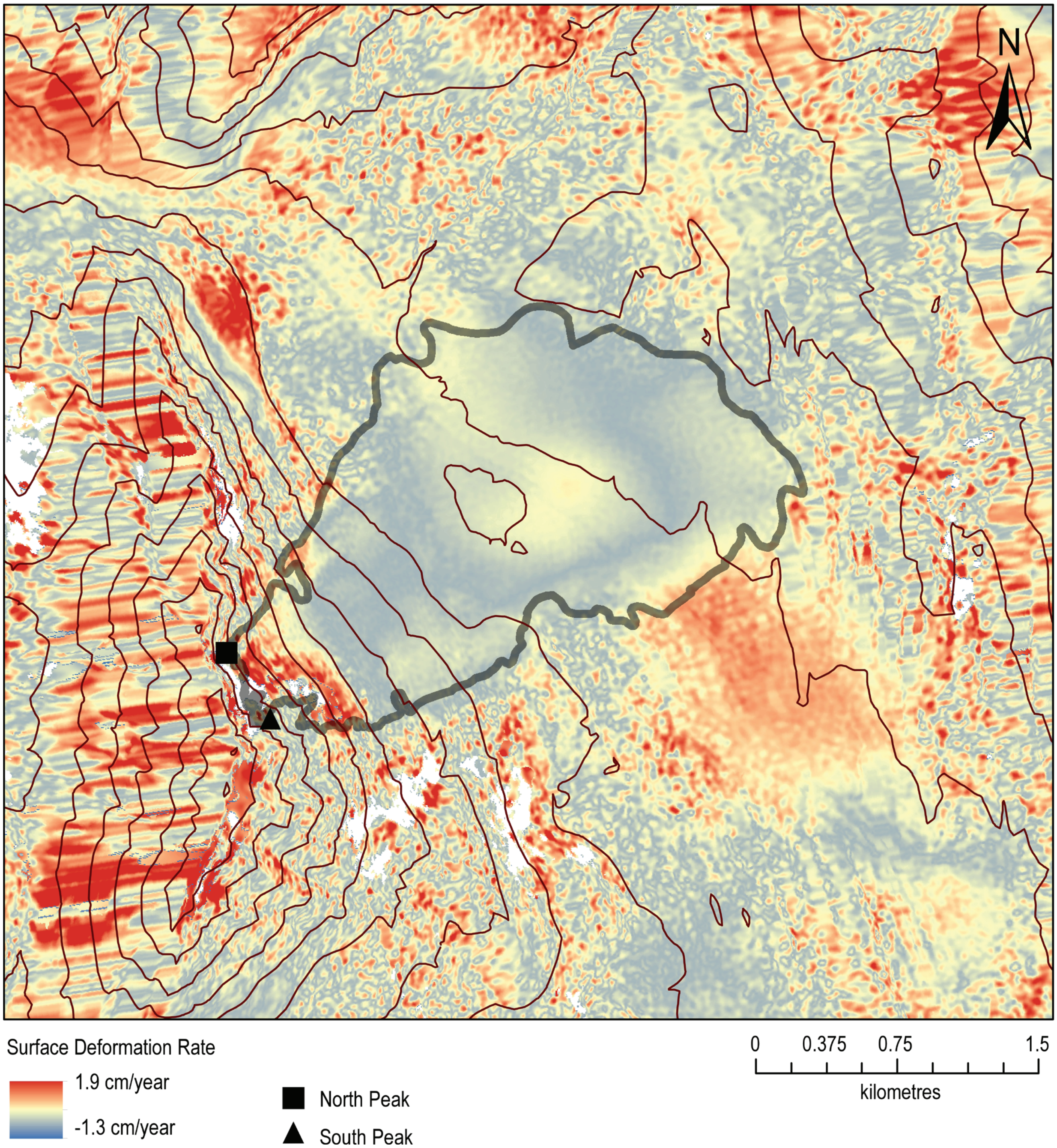

Figure 13. Surface deformation observed using InSAR from RadarSAT-2, track U4. Red colour indicates the ground surface is moving towards the satellite and blue colour suggests the opposite direction of movement. Thick, grey line delineates the original slide boundaries of the 1903 Frank Slide. Dark red lines are elevation contours (50 metre contour interval).

5 Waterton Workshop

April 1, 2013, marked 10 years since the province announced funding to monitor Turtle Mountain. The AGS marked this 10-year anniversary by holding a workshop to review the monitoring strategies and results with an expert panel. Invited to participate were several landslide experts, Turtle Mountain team staff, ERCB managers,[1] representatives from the Municipality of Crowsnest Pass, the Alberta Emergency Management Agency (AEMA), and the Frank Slide Interpretive Centre staff.

Members of Expert Panel:

- Lars Harald Blikra, Chief Geologist, Åknes/Tafjord Early Warning Centre, Norway
- Giovanni Crosta, Professor, University of Milano Bicocca, Italy
- Jacques Locat, Professor, University of Laval, Quebec, Canada

Presenters:

- Corey Froese, Geotechnical Engineer, ERCB/AGS
- Jill Pearse, Remote Sensing Specialist, ERCB/AGS
- Jamie Warren, Geological Technologist, ERCB/AGS
- Monica Field, Manager, Frank Slide Interpretative Centre, Alberta Culture and Tourism
- Michel Jaboyedoff, Professor, University of Lausanne, Switzerland
- Florian Humair, PhD Student, University of Lausanne, Switzerland
- Glen Bjorgan, Manager, NavStar Geomatics Ltd.

Other Attendees:

- Todd Shipman, Geologist, ERCB/AGS
- Kevin Parks, Vice President, Reserves & Resources Branch, ERCB
- Shane Schreiber, Acting Managing Director, Alberta Emergency Management Agency
- Jon Wright, GIS and Public Alerting Technologist, Alberta Emergency Management Agency
- Frank Besinger, Director of Planning, Engineering and Operations, Municipality of Crowsnest Pass

The AGS asked the expert panel to consider three specific directions for the future of the Turtle Mountain Monitoring Program. These options are to

- maintain the early warning system and near-real-time monitoring system,
- update the near-real-time monitoring system using ground-based InSAR technology and decommission the early warning system, or
- discontinue monitoring altogether.

The workshop was held in Waterton, Alberta, and included one day of presentations and discussion, followed by a field trip to Turtle Mountain the next day. The AGS expects to receive a report with recommendations from the three panel experts sometime in 2014. Once the recommendations are received, the program will undergo internal review to plan for the future.

1 The Energy Resources Conservation Board (ERCB) was the main predecessor of the Alberta Energy Regulator (AER). The ERCB ceased to exist with the proclamation of the *Responsible Energy Development Act* on June 17, 2013, which established and transferred staff and responsibilities to the AER.

6 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 are 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 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. An average of two lightning events capable of causing sensor damage are recorded each year. Each event can disable up to 50% of the primary system, with the associated cost of repairing this equipment being 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 has effectively replaced the primary system as the main early warning monitoring system. The GB-InSAR system has the potential to supplement the existing dGPS monitoring system on the mountain. However, more testing is needed before it can be used as a reliable monitoring alternative rather than just a tool for characterization.

Communication of the risk associated with these hazards to the affected population is also ongoing. We publish the most recent results annually (Moreno and Froese, 2008b, 2009a, 2011, 2012; Froese et al., 2009; Moreno et al., 2013; and Warren et al., 2014) 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 AGS 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 AEMA's emergency response protocol for Turtle Mountain. This protocol establishes that the AER (formerly the ERCB), through the AGS, is responsible for determining the appropriate alert level for a potential emergency at Turtle Mountain. Thus, to ensure this role is fulfilled, the AER maintains its own internal emergency response protocol (based on Moreno and Froese, 2009b). The emergency response protocol is revised as often as required to ensure it is current, reflects best practice, and is fit for its purpose. As a minimum, one review per year is done. The most recent review was completed in November 2012 (no changes were made to protocol).

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Appendix 1 – Rock slope deformations monitoring using LiDAR between June 2012 and July 2013, Turtle Mountain (Alberta, Canada)

UNIL | Université de Lausanne
Faculté des géosciences
et de l'environnement

Rock slope deformations monitoring using LiDAR between June 2012 and July 2013. Turtle Mountain (Alberta, Canada).

Acquisition campaigns: 10-12 June 2012
07-09 July 2013

Faculty of Geosciences and Environment - University of Lausanne
Centre of Research on Terrestrial Environment [CRET]
Institute of Earth Sciences [ISTE]

Humair Florian, PHD student - [redacted]
Michoud Clement, PhD student
Carrea Dario, PhD student
Michel Jaboyedoff, Professor

2013, December 20th

Table of contents

1. Introduction

Turtle Mountain area (Alberta, Canada) became well known in 1903 when one of the most damaging rock avalanches of the Rockies occurred. Over the past years, this area has become an important field laboratory where characterization and monitoring of rock mass movements' techniques are tested as the stability of large portions of the mountain's eastern face is still questionable (Froese et al. 2009; Froese et al., 2012). In order to complete the existing monitoring data, the University of Lausanne performed two Terrestrial LiDAR acquisitions covering most of the mountain's eastern face as well as the western face's uppermost part (Figures 4 and 6). The two acquisitions were performed in 2012 (June 10^{th} and 12^{th}) and 2013 (July 7^{th} and 9^{th}).

The detection and quantification of slope movements is enabled by comparing sequential (multi-temporal) Terrestrial Laser Scanning (TLS) point clouds. Several (two in this case) TLS datasets of the same area acquired at different time, exposed to a shortest distance comparison, allow revealing the change in the topography and therefore detecting 3D slope movements (Oppikofer, 2009).

The present report provides the results of the application of Terrestrial LiDAR technique to the displacements analysis during the 13 months period separating the two acquisitions. The comparison between the reference point cloud (2012) and the control point cloud (2013) aims at two objectives:

- The detection of large movements, i.e. of large portions of the rock mass at the scale of the entire study area.
- The detection of blocks activity, i.e. of small scale movements as rockfall activity or block toppling (forward movements with respect to the line of sight (LOS))

This report is divided into four sections: LiDAR principles and methods related to data processing are described in section 2. Section 3 presents the data and discusses the potential margin of errors. The detected movements are presented in section 4 and section 5 concludes the present report together with section 6 which includes the complement and caution advice.

2. LiDAR:principles and data processing procedure

2.1 LiDAR principles

Merging both Aerial Laser Scanning (ALS) and Terrestrial Laser Scanning (TLS) techniques, LiDAR (Light Detection and Ranging) is an active remote sensing technique based on the principle of Time of Flight (TOF). A laser pulse is sent out by an instrument (here ground-based scanner), back-scattered by an object (here the rock face or vegetation) and then recorded by the instrument (Lichti, 2002; Oppikofer, 2009). The output is a three-dimensional point cloud of the topography consisting of points characterized by the coordinates x, y, z as well as signal strength. The measurement of the distance (ρ) that separates the LiDAR instrument from the object to be scanned is obtained by the following equation (Baltsavias, 1999), including the TOF and the speed of light (c):

$$\rho = c \cdot \frac{TOF}{2}$$

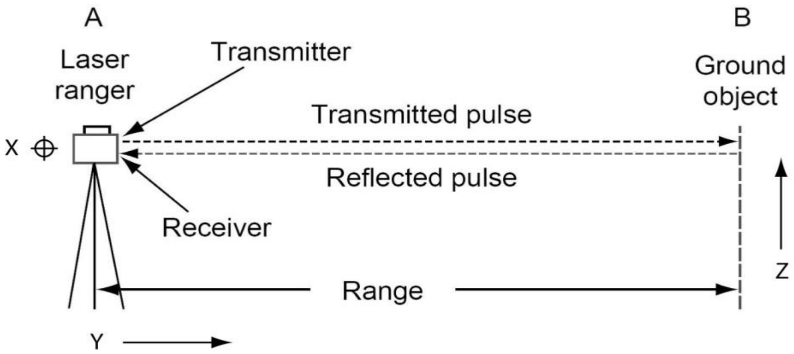

Figure 1 : Sketch of LiDAR principle, here TLS (Modified after Petrie & Toth, 2008).

Figure 2: TLS data acquisition during 2012 campaign from point of acquisition A (Figure 4 and Table 1).

2.2 Data processing

Once the data acquired, the different scans go through a succession of processing stages that include:

- The compilation of raw scans using Optech's Parser to transform the point clouds in Cartesian coordinates data x, y, z and signal strength.
- A manual cleaning of the data using PIF-Edit software (Innovmetric) to remove parasitic signal, vegetation or/and unwanted objects.
- The alignment (co-registration) which consists in merging together the individual scans acquired from different positions into a single point cloud containing all data. This step is performed using PolyWorks software ® (Innovmetric) by manual alignment first (identification on common points in the different scans) and then by iterative procedure (point-to-surface Iterative Closest Point algorithm) (Besl and McKay, 1992; Teza, 2007; Oppikofer, 2009).
- The Georeferencing of the aligned point cloud from the scanner reference system to real world coordinates (here NAD1983 UTM11N) by aligning it on ALS - High Resolution Digital Elevation Model (HRDEM) (cell size 1m in this case) using PolyWorks ® (Innovmetric).
- The detection of movement between the acquisitions which consists in, first, a co-registration of the 2013's acquistion on the 2012's one and, in a second stage, in a shortest distance comparison between the two point clouds..

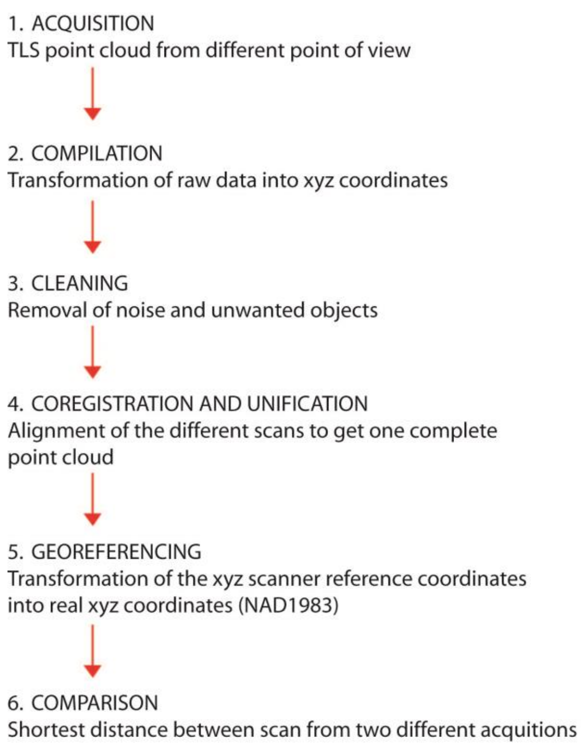

Figure 3: Flowchart of the TLS acquisition and processing methods. Modified after Oppikofer, 2009.

3. Data

The two TLS data acquisitions have been performed with a 390 days interval:

- The first acquisition (**June, 10th and 12th, 2012)** consisting in six different scans (Table 2) constitutes the **reference point cloud**.
- The second acquisition (**July, 7th and 9th, 2013)** consisting in nine different scans (Table 3) constitutes the **control point cloud**.

XYZ point cloud data are acquired for both campaigns with the same instrument, i.e. *Optech ILRIS Long Range* laser scanner. Choice was made to perform scans from different point of view (Figure 5) in order to get information from the largest outcropping surface possible and to avoid as more as possible shadowing effects. Consequently, most of the eastern face (from North Peak to South Peak) is covered. In addition, the uppermost part of the western side of the mountain has also been scanned (Figure 6).

Table 1 summarizes the GPS positions of the acquisitions position and tables 2 and 3 contain the properties of each scan.

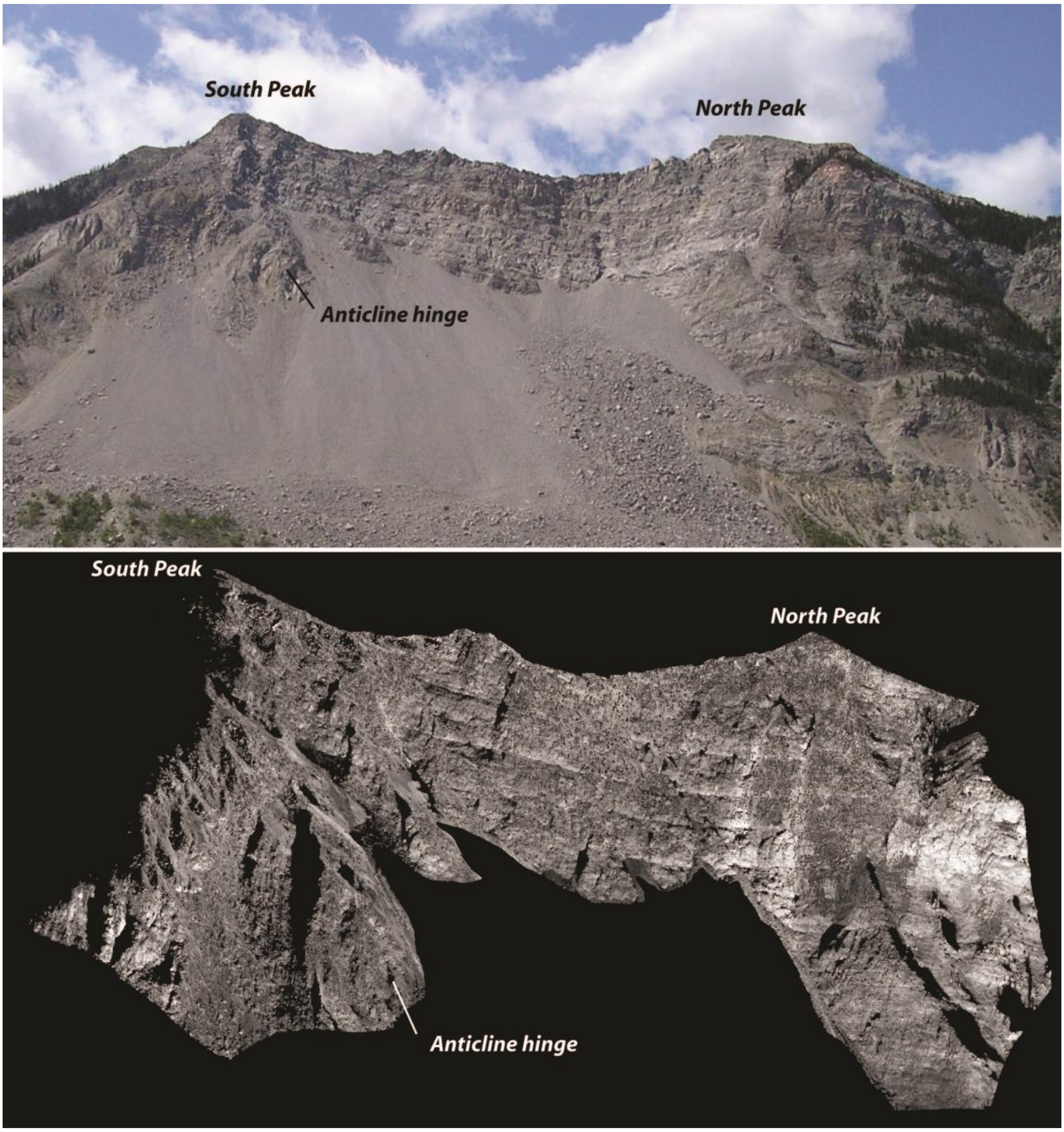

Figure 4: (Above) Picture of the Frank Slide scar, on the eastern face of Turtle Mountain. (Below) Corresponding 2012 point cloud (PolyWorks software).

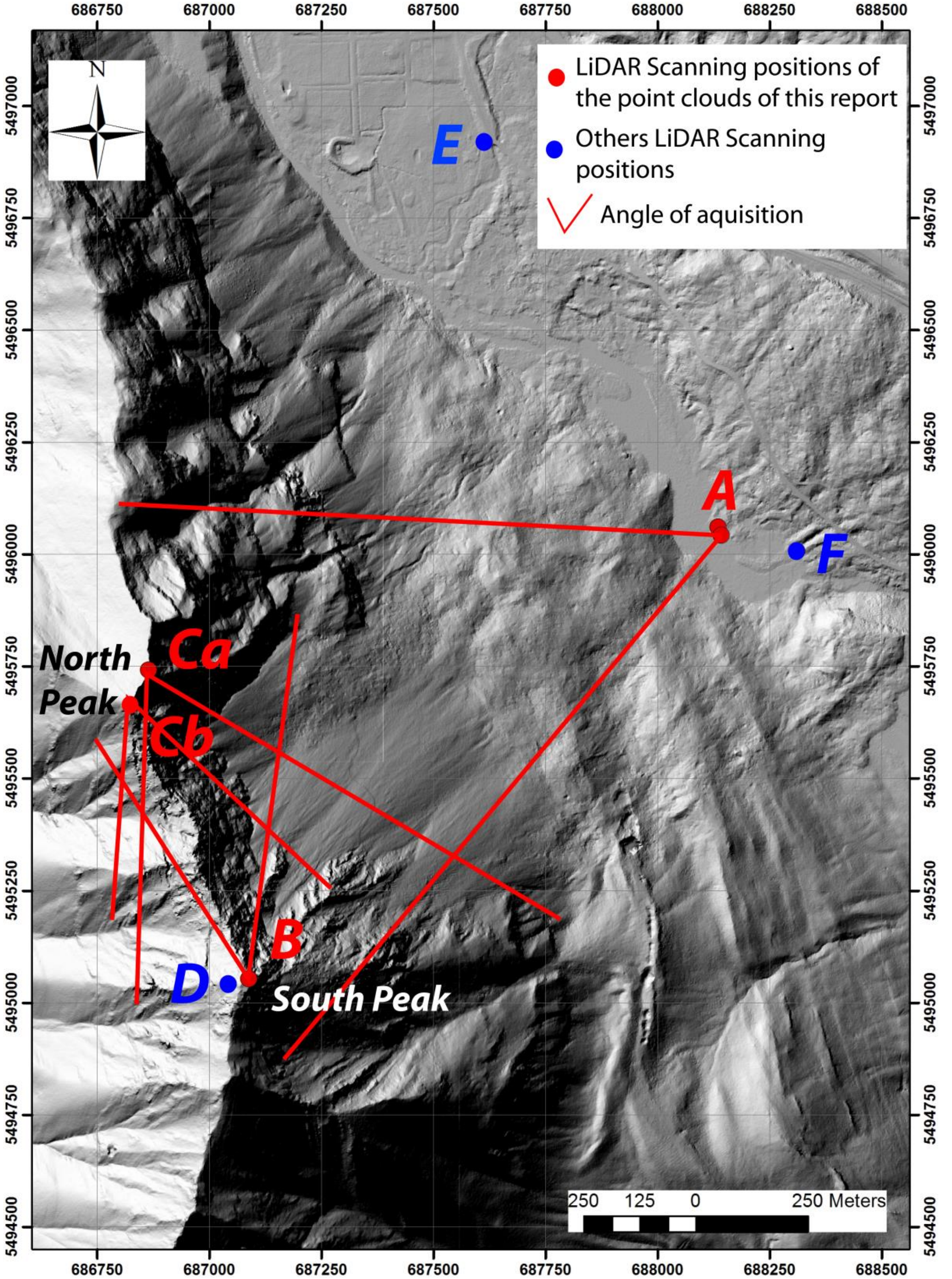

Figure 5: Hillshade map of Turtle Mountain area showing the different GPS position of the LiDAR during acquisitions and indicative acquired area.

Table 1 Coordinates of the three acquisition positions.

Acquisition position	Coordinates
A	0688137/5496040
B	0687077/5495058
Ca	0686864/5495731
Cb	0686827/5495661

Table 2: Information on the 2012 acquisition's scans. Note that the mean point spacing is given for the mean distance between points and device. This value is thus higher for longer acquisition range and smaller for shorter ranges.

Scan No	Scan name	date	Shot position	Number of point after cleaning	Mean point spacing at the mean distance (mm)	Mean Distance (m)
14	Frank_062012_04bis	10.06.12	A	14208055	118.7	1187.41
15	Frank_062012_05bis2	10.06.12	A	16001004	114.0	1139.68
16-17	Frank_062012_north01	12.06.12	B	20910663	63.7	398.19
18	Frank_062012_north02	12.06.12	B	7848515	65.0	406.41
19	Frank_062012_south01	12.06.12	Ca	7681803	65.3	407.91
20	Frank_062012_south02	12.06.12	Ca	7774495	69.7	387.31

Table 3: Information on the 2013 acquisition scans.

Scan No	Scan name	date	Shot position	Number of point after cleaning	Mean point spacing at the mean distance (mm)	Mean Distance (m)
33-34-35	070713_Frank_bas_Nord	07.07.13	A	12289864	90.6	1132.29
31-32	070713_Frank_bas_Sud	07.07.13	A	9136824	83.9	1048.66
36-37	090713_Frank_bas_to_NPeak	09.07.13	A	8771618	107.9	1349.36
38	090713_Frank_bas_to_SPeak	09.07.13	A	3469626	114.5	1431.53
22-23	090713_Frank_top_to_NPeak1	09.07.13	B	4518706	50.8	423.38
21	090713_Frank_top_to_NPeak2	09.07.13	B	1268483	32.6	233.21
24-25-28-29	090713_Frank_top_to_SPeak1	09.07.13	Ca	6857194	66.7	476.16
26	090713_Frank_top_to_SPeak2	09.07.13	Ca	4814169	48.0	300.06
27	090713_Frank_top_to_SPeak3	09.07.13	Cb	8280435	68.6	244.95

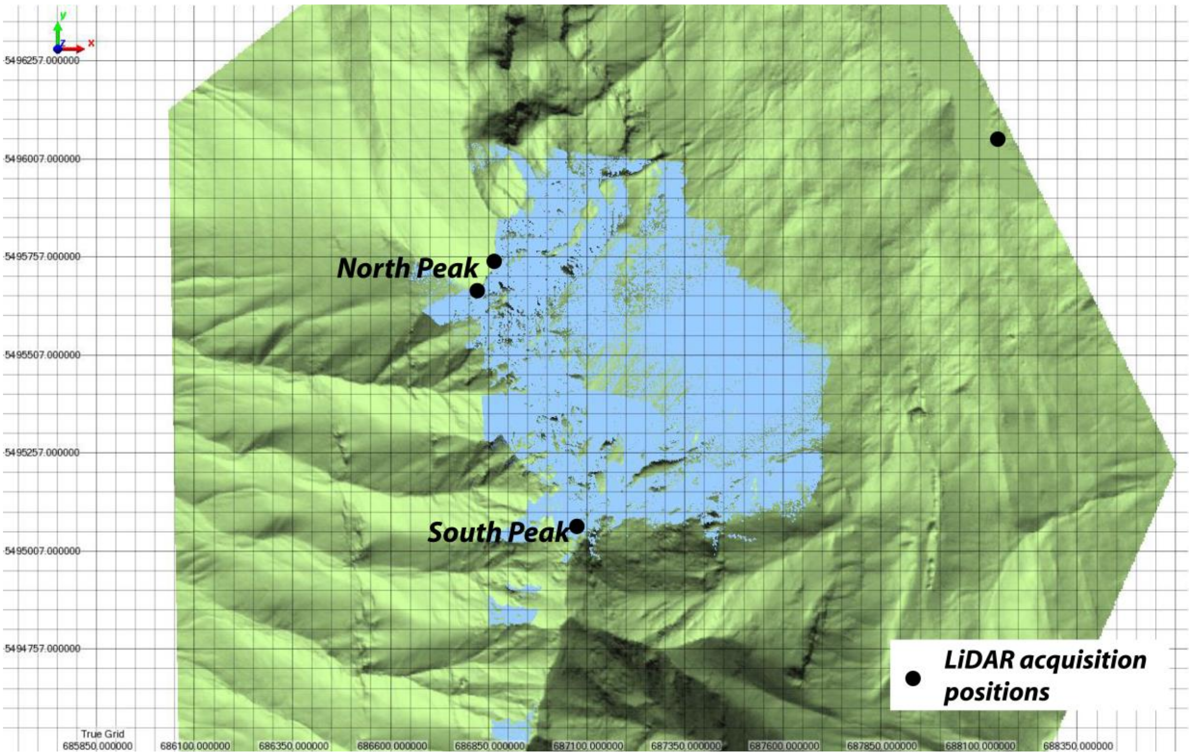

Figure 6: Drapping of the TLS point cloud on the HRDEM showing the area that is covered by the TLS data.

3.1 Margin or error and co-registration

Assessing the errors related to instrumentation and the data treatment is crucial in the field of rock slope displacement monitoring as it conditions the minimum displacements that are detectable (Oppikofer, 2009).

Main source of error is the co-registration step (section 2.2). The potential errors on movements' detection are of two types:

- In relation to the spacing (distance) between the points of the scans. Each scan has different point spacing due to the variations of aquistion parameters, e.g. distance between device and area of interest, time on field and desired precision. It can result in inadequacies in position of the same points of the two point could inducing a discrepancy. This is especially valid for furthest points with respect to the device since the spacing between those is much higher than for points closer to the scanner.

- In relation to the accuracy of co-registrations. The alignment of the reference scans (2012) shows normal distributions of its errors with a standard deviation ranging from 2.8 to 4.7 cm (APPENDIX 1). Similarly, the alignment of the control scans (2013) on the reference point cloud (2012) shows normal distributions with a standard deviation ranging from 2.3 to 5.0 cm (APPENDIX 2). This means that for 70 % of the area of the scans, the difference between the reference measurement (2012 acquisition) and the control (2013 acquisition) is considered to be smaller than 9.7cm. Therefore, only the recognition of movements higher than this specific standard deviation is possible

In order to minimize as much as possible these errors, the controlling scans (2013) were aligned to the reference point cloud (2012) using the piece-wise alignment technique (Teza et al., 2007). It consists in using subdivided TLS scans in several parts, which are afterwards aligned on the reference (Oppikofer, 2009) rather than co registering them as one image. Consequently, instead of a two steps co registration (first co-register the 2013 scans together to get one point cloud and then co-register the latter on 2012 reference point cloud), only one is performed (directly co register the different 2013 scans individually on the 2012 reference point cloud). As illustrated in figure 7, this method allowed a better matching of the controlling scans with respect to the reference scan reducing potential misinterpretation of movements. Then the artifacts (movements in the order of magnitude of 0.5m) that are present at North Peak area when 2013 point cloud is co registered as one image with 2012 point cloud (Figure 7 above) disappear when 2013 scans are individually co registered on 2012 point cloud (Figure 7 below).

Therefore, we consider 10 cm as the detection threshold. This means that detection of movements with a smaller magnitude is not possible at this stage of the processing.

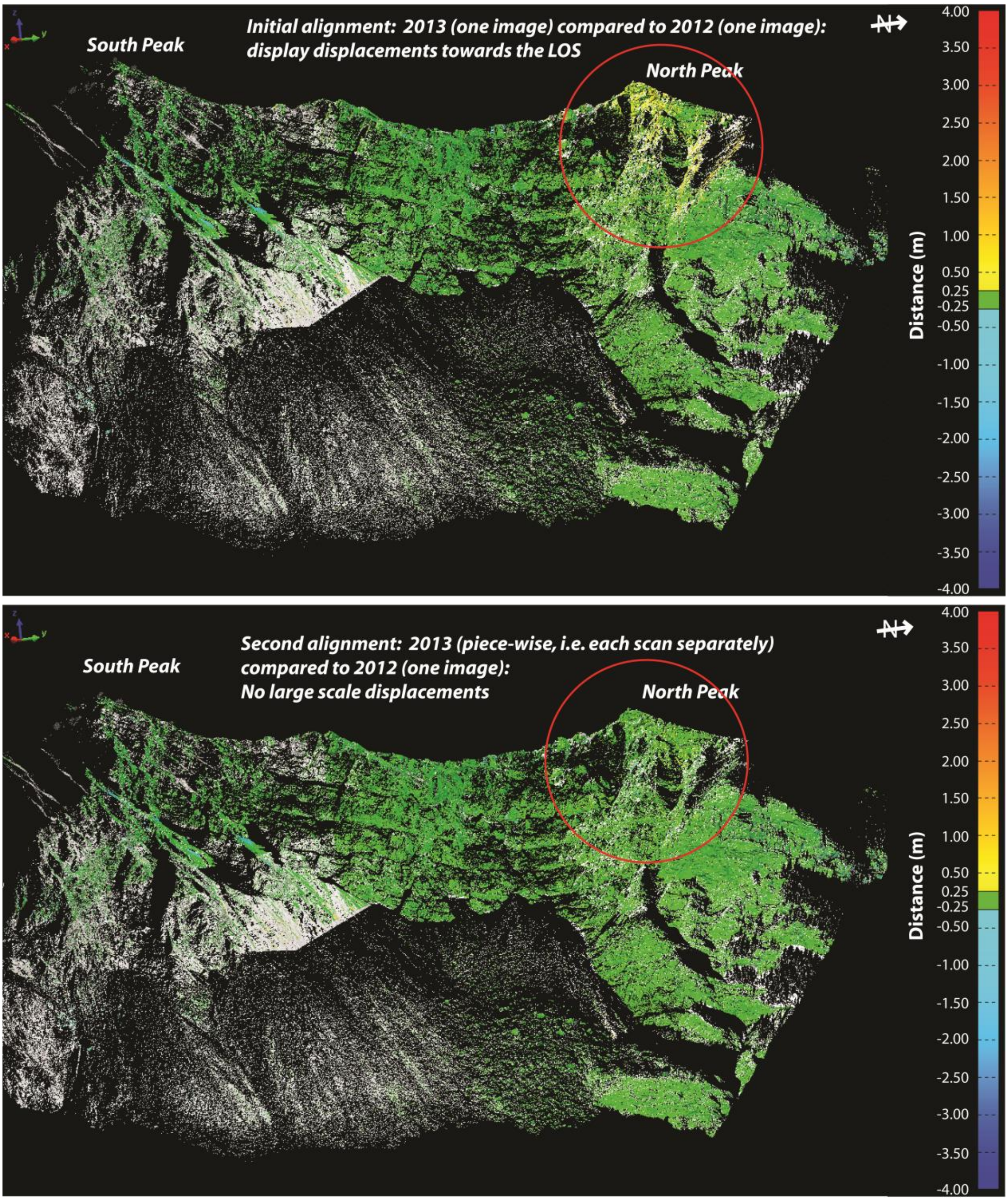

Figure 7: Complete view of eastern face comparison of the TLS scans between 2013 (09th of July) and 2012 (12 of June) showing the initial alignment between point clouds (above) and second alignment using piece-wise technique. The piece-wise alignment reduces potenital misinterpretations of movements

4. Results

As previously mentioned the detection threshold of movement is of 10 cm. (section 3.1) and was used to perform the analysis. Nonetheless, an artificial threshold of 25cm (green color) has been applied to enhance the visualization of the results. Note that this selected value does not represent the detection threshold in any case. If a lower value was chosen (as for example the detection threshold, see section 3.1), the visualization of the comparison would be much noisier, resulting in a difficult highlighting of the differences of movements. Moreover, the presence of snow coverage during 2012 acquisition at different zones is a notable potential source of misinterpretation (Figure 8). Indeed these zones display negative movements after the comparison which cannot be taken for rock displacement and were hence filter out from the analysis.

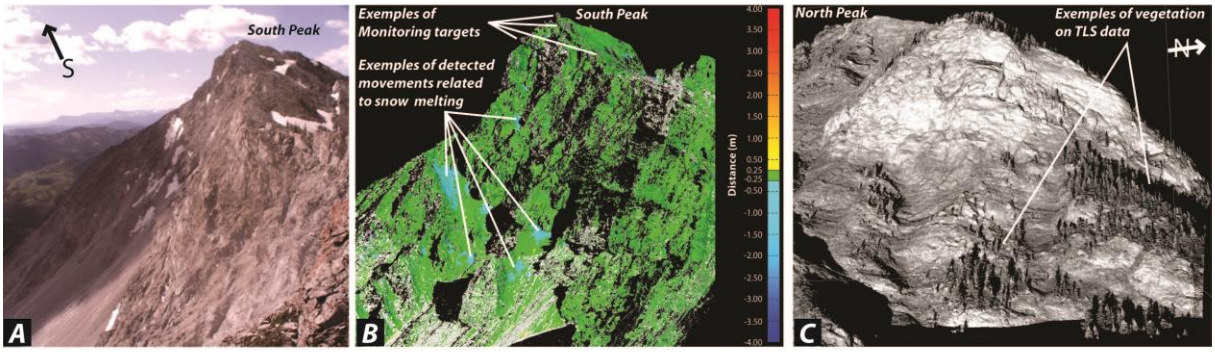

Figure 8: A) and B) Negative movements artefacts due to snow melting between 2012 and 2013 acquisitions. C) Exemple of vegetation (trees) on TLS scan.

Figures 9 and 10 show the comparison results at the scale of the mountain. It appears that there is **no displacement greater than 10cm affecting large rock compartments during the 13 months between both acquisitions.** This observation is also confirmed at the crest of the mountain in the uppermost part of the western mountain side (Figure 10).

The analysis of movements involving smaller volumes highlighted the occurrence of 57 rockfalls (negative movements) greater than 1 cubic meter (C13 on figures 9 and 12) **and 2 blocks with positive movements (toppling) during this same period.**

The spatial repartition of detected rockfalls shows their concentration in three areas:

- North Peak
- Under North Peak
- In the northern part of the Frank Slide scar.

On the contrary, the South Peak and the southern portion of the scar are less affected by rockfalls with respectively three (SPn) and one (C16) events However, there is no proof that this is due to geological processes or to the fact that these areas were scanned with a lower point density caused by longer distances of acquisition. The different close up views in figures 11 to 14 show examples of the above mentioned rockfall and positive movements. Despite the presence of noise in the image created with the analysis threshold (10 cm), 2 clear positive movements can be detected by the presence of homogeneous movement surfaces surrounded by clearly detected rockfalls (Figure 13).

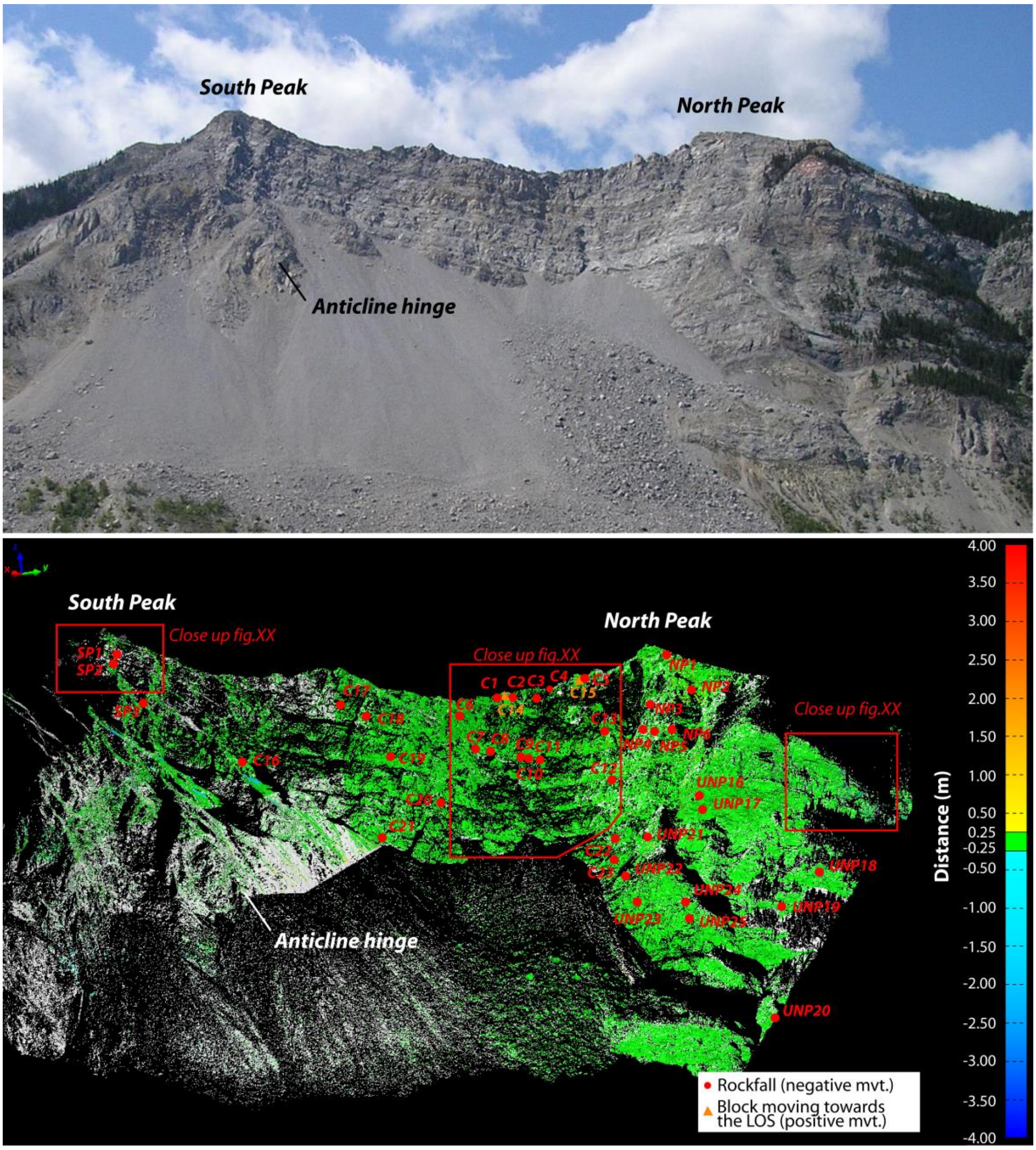

Figure 9: Picture (above) and complete view of eastern face comparison of the TLS scans between 2013 (09th of July) and 2012 (12 of June). The points of the scan control (2013) are colored according to the distance from the nearest point of the reference scan (2012). Positive movements (forward the line of sight) are represented in colors from yellow to red, while negative movements (rockfalls) are represented in colours from light blue to dark blue. The red dots correspond to the rockfall detected during the 390 days sparating both acquisitions (57 rockfalls). The orange triangles correspond to the blocks with detected positive movement (2 blocks). Three close up are shown in figures 10, 11 and 12 respectively. Rockfalls in close up corresponding to figure 12 are not shown in this map.

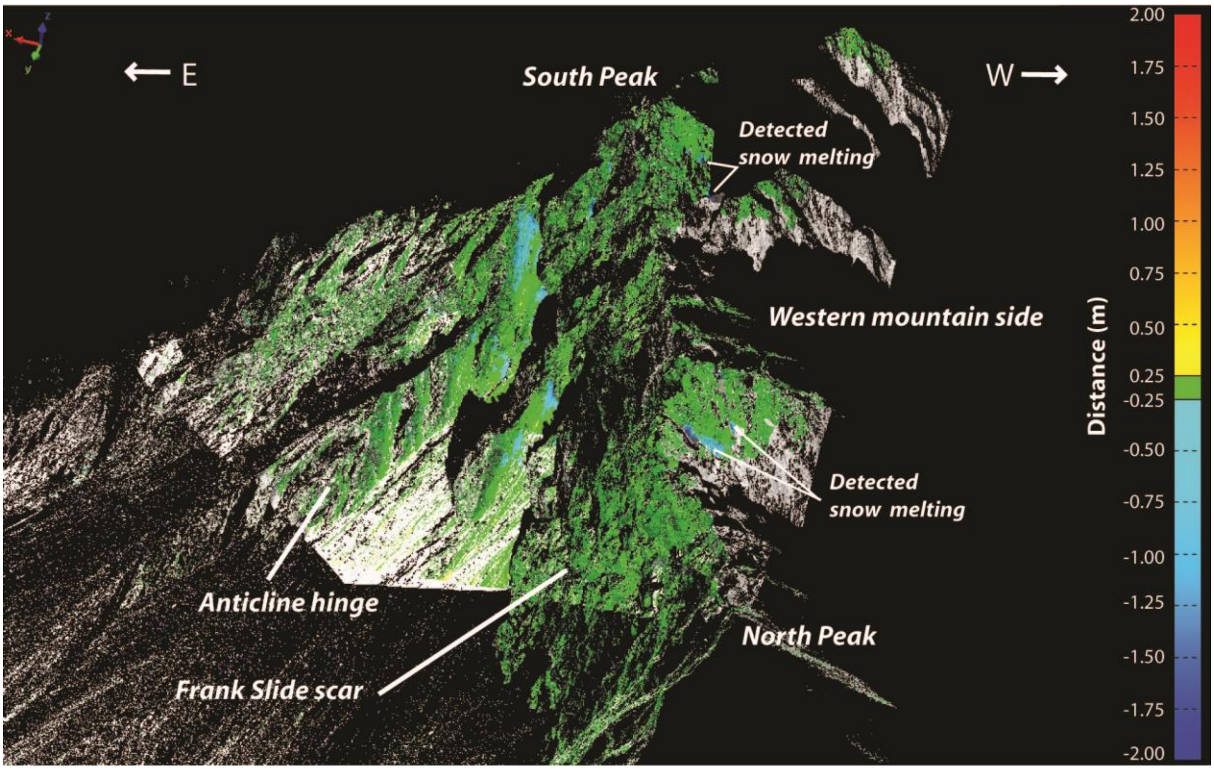

Figure 10: Comparison of the TLS scans focused on the western side of the mountain.

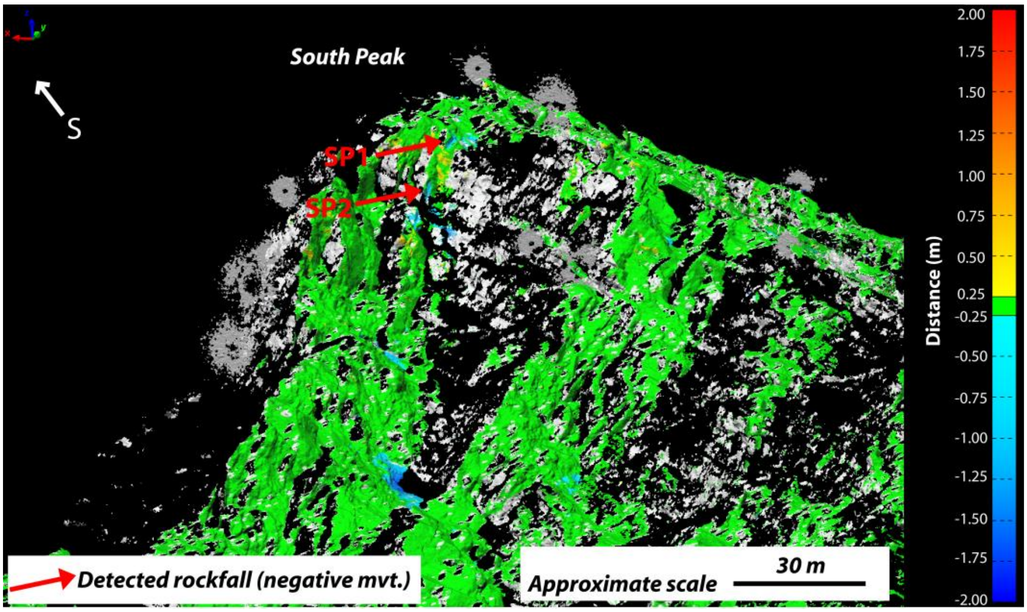

Figure 11: Comparison of the TLS scans focused on South Peak (Figure 9 for location). The red arrows correspond to the rockfall detected during the 390 days sparating both acquisitions (2 rockfalls in this area).

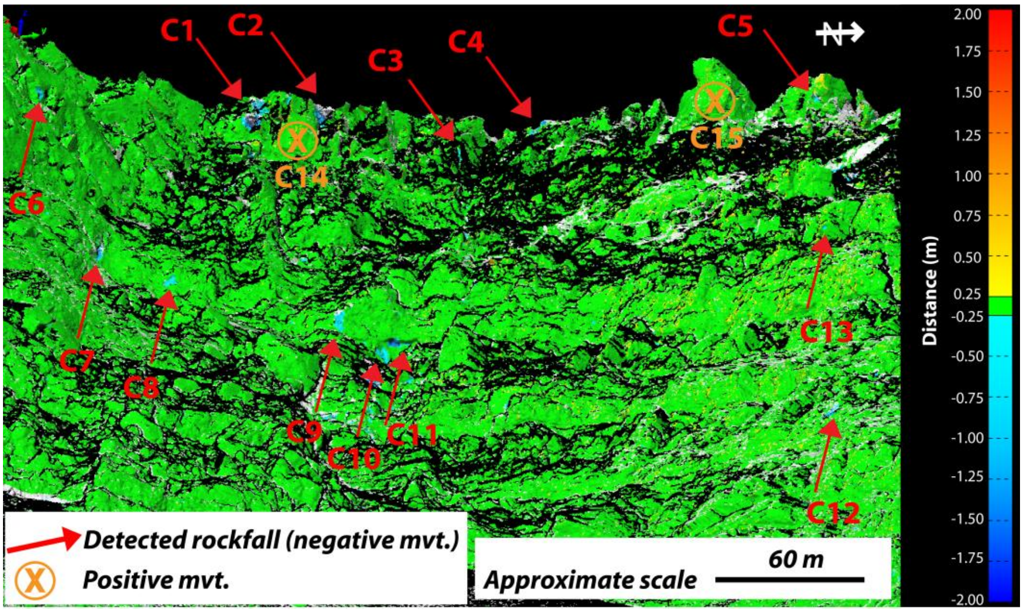

Figure 12: Comparison of the TLS scans focused on the central zone of the Frank Slide scar (Figure 9 for location). The red arrows correspond to the rockfall detected during the 390 days sparating both acquisitions (13 rockfalls in this area). The orange crosses correspond to positve movements (block moving forward) detected during the same period (2 blocks in this area).

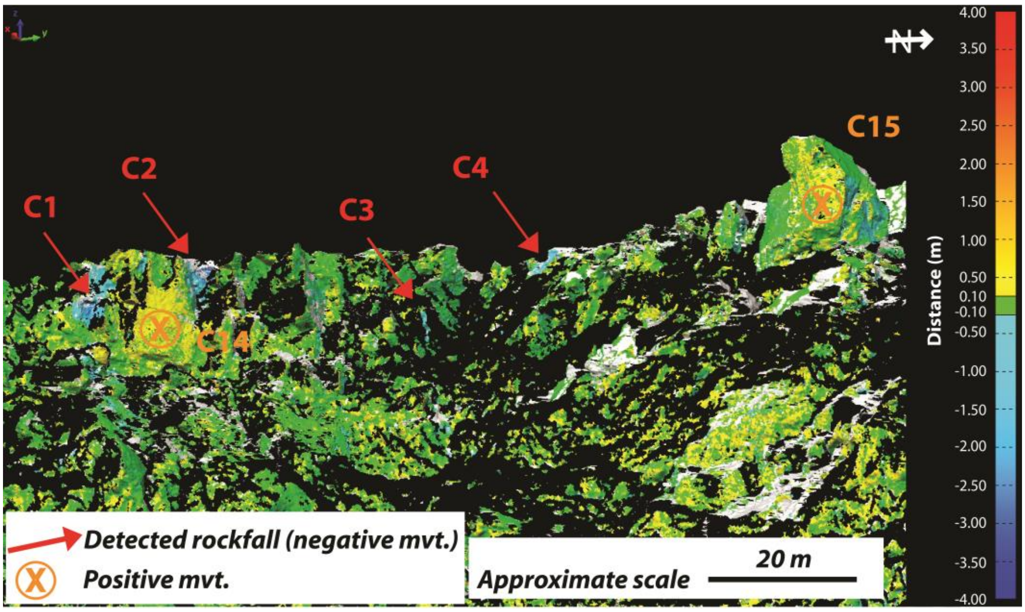

Figure 13: Comparison of the TLS scans focused on the top area of figure 11. The red arrows correspond to the rockfall detected during the 390 days sparating both acquisitions (4 rockfalls in this area). The orange crosses correspond to positve movements (block moving forward) detected during the same period (2 blocks in this area).

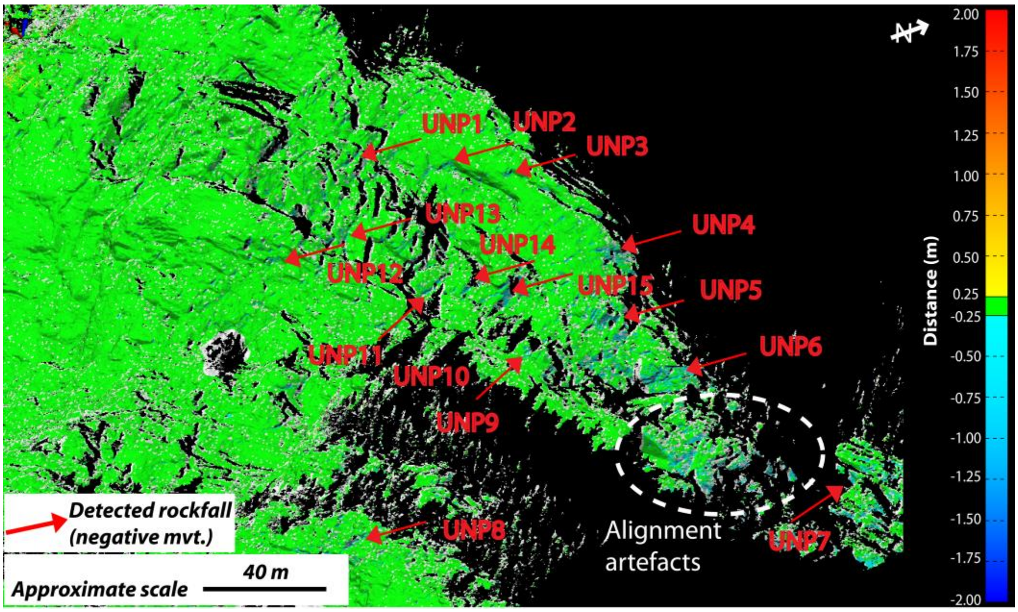

Figure 14: Comparison of the TLS scans focused on the area below North Peak (Figure 9 for location). The red arrows correspond to the rockfall detected during the 390 days sparating both acquisitions (15 rockfalls in this area).

5. Conclusions

This report provides the preliminary results of a 13 month period monitoring (between 12 June 2012 and 09 July 2013) of rock slope deformations using Terrestrial Laser Scanning technique in the surrounding of the Frank Slide scar rock avalanche at Turtle Mountain.

Based on the detection threshold that has been reached up to now (10 cm), it can be assessed that there is no movements greater than 10 cm affecting large rock compartments.

57 rockfalls and 2 blocks toppling are detected, most of them located between the middle of the Frank Slide scar to the North Peak area.

Since the range of magnitude of movements observed in Turtle Mountain using other monitoring techniques is significantly smaller than the present detection threshold (Froese et al., 2009, a reprocessing of the TLS data is required in order to lower the detection threshold. Even if such a lowering will not significantly improve the detection of rockfall, it would allow detecting potential large scale instabilities i.e. with movement smaller than 10 cm between acquisition campaigns.

6. Complement and Caution

This report is a first analysis. Additional processing will be performed in a second stage to verify if it is possible to provide a comprehensive detection of instabilities with lower magnitude of movements. **This complementary study will be the object of a complement to the present report that will be handed back at the beginning of the year 2014.**

Therefore, the results of the present report must be taken with precaution and must be considered as preliminary. The results acquired with the reached threshold cannot be currently taken for granted as the proof of absence of total movements.

7. Deliverables

1) 2012 acquisitions TLS point cloud (xyz.txt format)
2) 2013 acquisitions TLS point cloud (xyz.txt format)
3) 2012 – 2013 differences (txt format)

Acknowledgments

Marie Charrière (TU Delft) is warmly acknowledged for the proofreading of the report.

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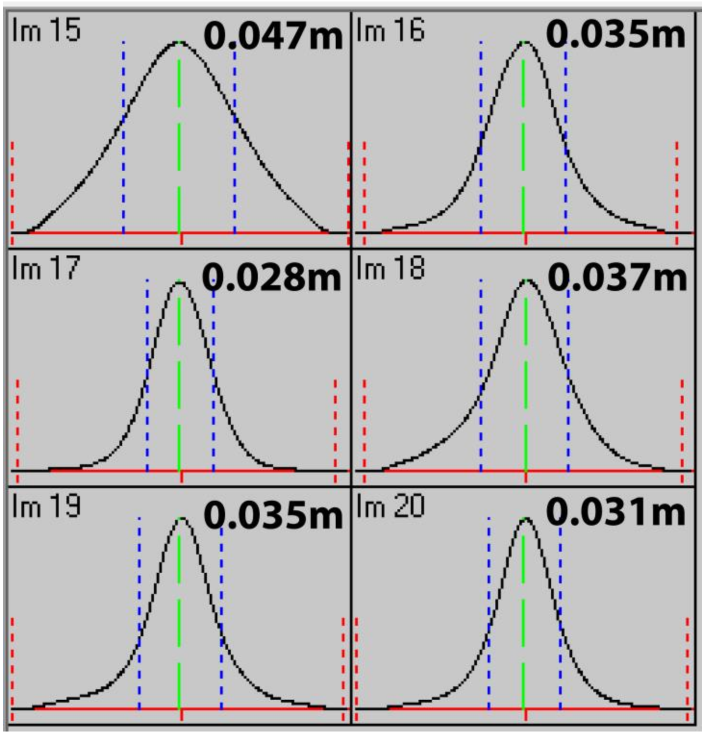
9. APPENDIXES

2012 – reference scans alignment: histograms and standard deviation.

Histograms of alignment (co registration) of the different 2012 scans together on scan frank_062012_04bis. The number of the different scans are reported in table 2 and the standard deviation of each alignment in shown.



2013 – control scans piece-wise alignment on 2012 – reference point cloud: histograms and standard deviation.

Histograms of alignment (co-registration) of the different 2013 scans on 2012 – reference point cloud. The number of the different scans are reported in table 3 and the standard deviation of each alignment in shown.