UTAH FRONTIER OBSERVATORY FOR RESEARCH IN GEOTHERMAL ENERGY (FORGE) PROJECT – PHASE 3

GROUND DEFORMATION MONITORING

Technical Report 3

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December 12, 2019

Research supported by the U.S. Department of Energy (DOE), Geothermal Technologies Office under DOE award number DE-EE0007080 to the University of Utah, Energy & Geoscience Institute and the Utah Geological Survey. The views and conclusions contained in this document are those of the authors and should not be interpreted as representing the official opinions or policies of the U.S. Government. Mention of trade names or commercial products does not constitute their endorsement by the U.S. Government.

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ACCOMPANYING DIGITAL FILES

The following PDF files contain the baseline processing reports produced by Trimble Business Center software for the two initial monitoring campaigns and the two subsequent monitoring campaigns.

- Initial Monitoring Campaign A: FORGE_12-18-2018_BaselineProcessingReport.pdf
- Initial Monitoring Campaign B: FORGE_03-10-2019_OPUS_BaselineProcessingReport.pdf
- Monitoring Campaign 1: FORGE_04-30-2019_OPUS_BaselineProcessingReport.pdf
- Monitoring Campaign 2: FORGE_06-05-2019_BaselineProcessingReport.pdf
- Monitoring Campaign 3: FORGE_11-19-2019_BaselineProcessing.pdf

REPORT NOTES

The decimal degree latitude and longitude values in shown in the report and the accompanying tables are accurate only to 8 decimal places that correspond to approximately 1.1 mm. The UTM northing and easting, elevation, and adjusted elevations shown in the report and the accompanying tables are accurate only to 3 decimal places that correspond to approximately 1 mm. We have included the full numeric output from GNSS post-processing for completeness.

ABSTRACT

As part of the Utah Frontier Observatory for Research in Geothermal Energy (FORGE) Project site monitoring for potential deleterious effects resulting from the stimulation of a potential geothermal reservoir in deep granitic rocks, a ground deformation monitoring program was developed and implemented by the Utah Department of Natural Resources, Utah Geological Survey (UGS). This monitoring program included the design and installation of 20 geophysical deformation monitoring stations and one new rock-socketed base station, along with two initial and three subsequent three-dimensional position monitoring campaigns using high-accuracy and precision Global Navigation Satellite System (GNSS) equipment. The ground deformation monitoring to date generally shows a somewhat noisy site that is likely due to a combination of seasonal temperature and groundwater variation and an unknown contribution from the nearby operating Blundell geothermal power plant.

INTRODUCTION

As part of the Utah Frontier Observatory for Research in Geothermal Energy (FORGE) Project site monitoring for potential deleterious effects resulting from the stimulation of a potential geothermal reservoir in deep granitic rocks, a ground deformation monitoring program was developed and implemented by the Utah Department of Natural Resources, Utah Geological Survey (UGS). This monitoring program included the design and installation of 20 geophysical deformation monitoring stations and one new rock-socketed base station, along with two initial and three subsequent three-dimensional position monitoring campaigns using high-accuracy and precision Global Navigation Satellite System (GNSS) equipment.

Utah FORGE Project

The Utah FORGE Project is a dedicated underground field laboratory sponsored by the U.S. Department of Energy for developing, testing, and accelerating breakthroughs in enhanced geothermal system (EGS) technologies. The field laboratory that is located northwest of Milford, Utah, comprises a large volume of hot crystalline granite bedrock between two deep directionally drilled wells at around 8000 feet below the ground surface.

Investigations will commence in 2020, as the facility is being constructed and continue through 2024. Competitive funding rounds will be open for public application to attract outstanding programs of innovative research and development in geothermal engineering and science. Near term goals are aimed at perfecting drilling, stimulation, injection-production, and subsurface imaging technologies required to establish and sustain continuous fluid flow and energy transfer from an EGS reservoir.

GROUND DEFORMATION MONITORING NETWORK DESIGN

We designed the ground deformation network with consideration in reducing potential error sources to the smallest levels generally achievable. This includes locating base stations in favorable locations and the use of surface ground decoupled monuments.

Reduction of Potential Error Sources

When determining the potential errors, the type of errors need to be evaluated. There is the epistemic uncertainty, where data error or uncertainty is limited to the acquired data and how it is understood. With aleatory variability, perceived errors are due to the randomness of the process. These variables are categorized into two types, discrete and continuous. A discrete variable is a single value determined within an allotted timeframe and are parameterized by the probability of each possible value. A continuous variable is a value that does not end and is not countable and is parameterized by the probability density function. The goal of reducing epistemic uncertainty errors will be driven by our methodology refinement, including data processing and equipment maintenance. Reducing our aleatory errors will be based on measurement length and satellite network adjustment processing.

Other error sources not related to the network design and installation, such as the satellite constellation configuration, geomagnetic conditions, monument thermal changes, and atmospheric related sources, are discussed in the Ground Deformation Monitoring Methods section below.

Topographic

Topographic error results from the existing or constructed ground surface obscuring radio signals from the various GNSS satellites, resulting in signal loss from shadowing or multipath errors where radio signals reflect off various ground surfaces before reaching the GNSS receiver. As the Utah FORGE Project site generally consists of a gently sloping ground surface to the west, significant topographic error effects are not anticipated, except for some reduction in the potential to receive signals near the western and eastern horizons due to the Beaver Lake and Mineral Mountains, respectively. This error is not reducible further, as ground deformation monitoring is needed adjacent to the project site.

Vegetation

Vegetation-related error results from vegetation blocking or reducing the GNSS satellite radio signal. As the Utah FORGE Project site consists only of low grasses and shrubs less than about 1 meter in height (about half of the GNSS receiver height above the ground), vegetation-related error is not anticipated.

Object Multipath

Multipath error results from GNSS radio signals that are reflected off objects, such as buildings, metal poles, vehicles, and other objects. As the Utah FORGE Project site currently does not contain any structures, with the exception of the SunEdison-TerraForm wind farm near the northwestern area of the project and the PacifiCorp Blundell geothermal power plant near the southeastern area of the project (and within the signal shadow from the Mineral Mountains), multipath error is anticipated to be very low. In addition, Trimble R8, R10, and Alloy GNSS receivers used in this project contain multipath suppression to reduce the effects of multipath on signal quality.

Frozen Ground

To significantly reduce ground deformation monitoring error from freezing ground issues, where seasonal freeze-thaw cycles with ice growth may deform the near-ground surface, we evaluated the available frost depth data for the Utah FORGE Project site. Limited published data is available, and no direct, nearby data, such as from shallow subsurface temperature sensor profiles, are available. However, Bilotta and others (2015) estimated frost depth in the general project area as ranging from 0.9 to 1.2 meters (3.0 to 3.9 feet) below the ground surface (figure 1), based upon nationwide climate records from 1981 to 2010. Local geotechnical engineering consultants typically consider a frost depth of 30 inches (0.8 meter), based on their field observations, for foundation and other engineering design along the Wasatch Front (Chesnut, 2018, personal communication), which generally experiences colder weather in the winter months than the project site.

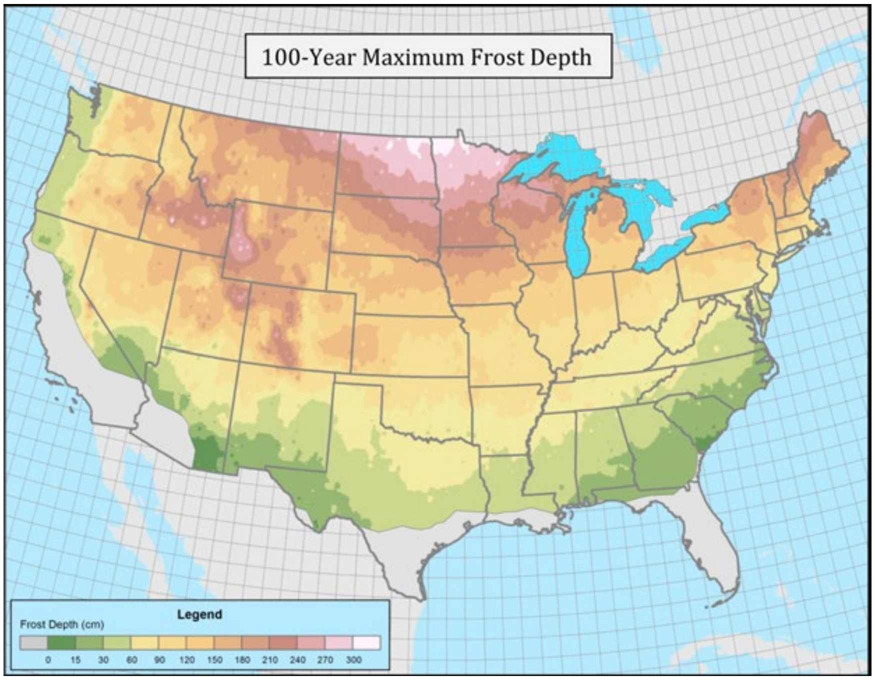


Figure 1. Maximum 100-year frost depth for the conterminous U.S. (Bilotta and others, 2015).

Based on the available frost depth estimates, we consider a potential frost depth of 1.1 meters (3.5 feet) to be a reasonable value for use in the design of ground deformation monitoring stations.

Ground Deformation Monitoring Network Design

The ground deformation monitoring network was designed so that potential ground deformation as a result of Utah FORGE Project subsurface activities could be accurately monitored. Twenty ground deformation monitoring stations were located around the project area, generally in a circular pattern, but located in existing cultural and environmental concern-cleared areas, considering the FORGE subsurface layout, and the locations of the existing PacifiCorp Blundell geothermal plant and the SunEdison-TerraForm Power Milford Flat wind farm (figures 2 and 3). Both existing facilities contain structures highly sensitive to ground deformation (power turbine-generators and wind towers, respectively). Stations GDM-01, 02, 04, 07, and 14 are located between the Milford Flat wind farm and the FORGE site. Stations GDM-13, 18, and 20 are located along an existing natural gas pipeline right-of-way between the Blundell power plant and the FORGE site.

Due to the use of static, least-squares reduction post-processing of GNSS data, a minimum of two base stations are required. One base station was identified at the existing NGS BAILEY benchmark, and a second location was identified west of the project site, north of the Badger Knolls. An alternate or third base station location was also identified at the existing The Utah Reference Network (TURN) reference station UTMI mounted at the old Milford Valley Memorial Hospital site in Milford, Utah. Figures 2 and 3 show the layout of the monitoring network.

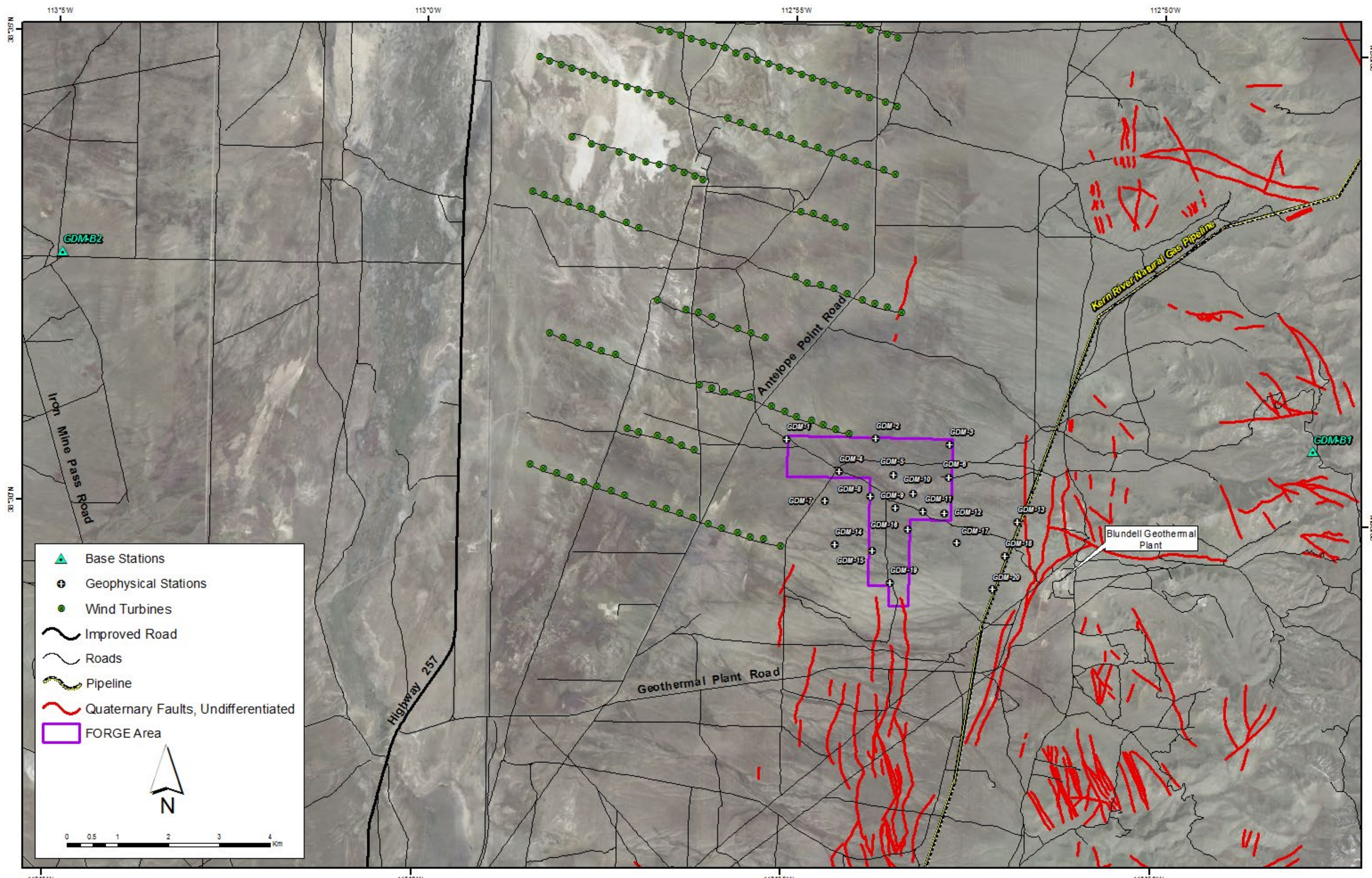


Figure 2. Map of the Utah FORGE Project ground deformation monitoring network showing the two base stations, FORGE project area, and monitoring stations.

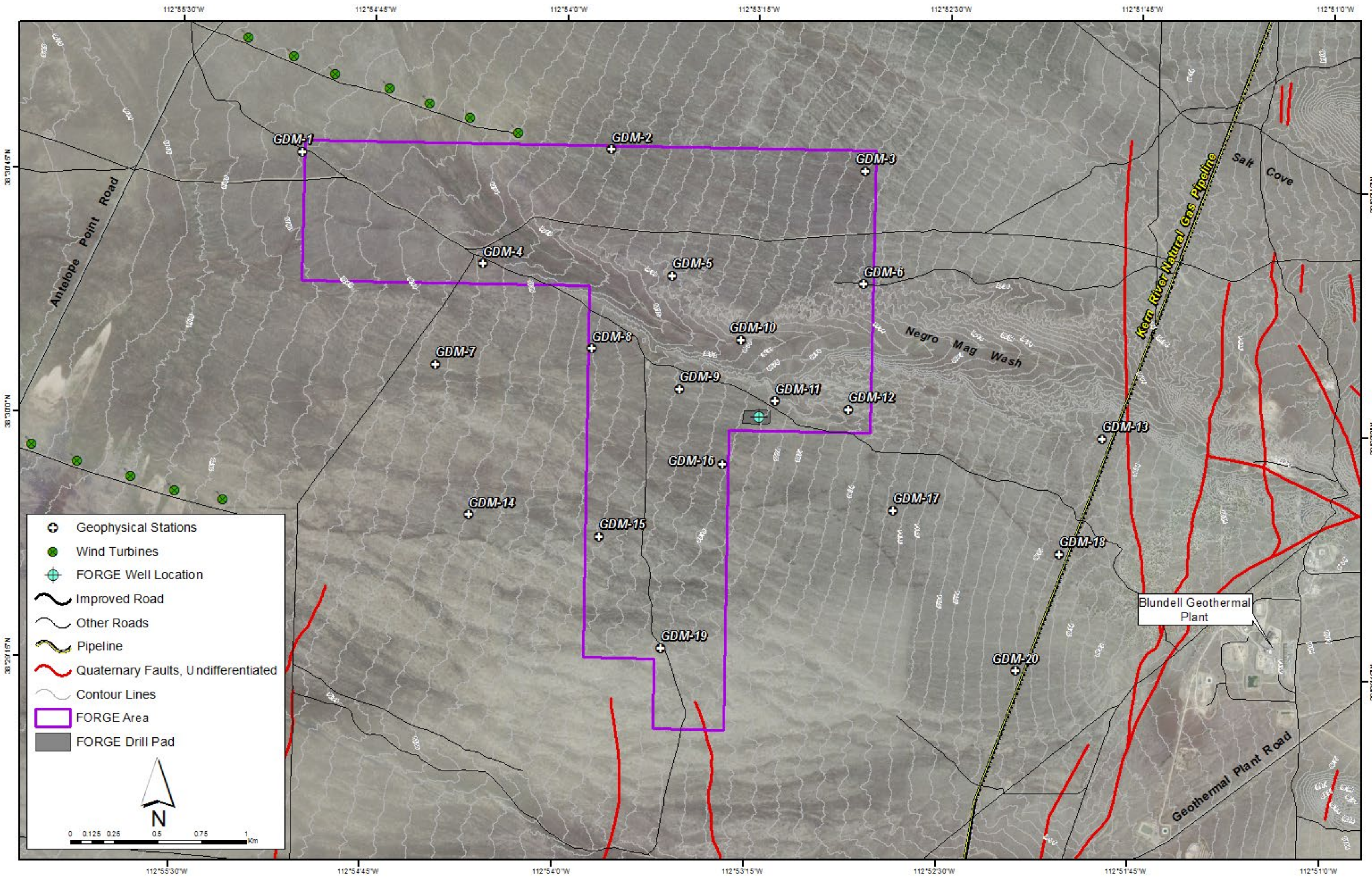


Figure 3. Detailed map of the Utah FORGE Project ground deformation monitoring network stations (GDM-1 to GDM-20). Contours developed from 2016 State of Utah 0.5-meter lidar acquisition project data (AGRC, 2017).

Ground Deformation Monitoring Station Design

Ground deformation monitoring stations and the network were designed to reduce potential error as low as reasonably possible for high accuracy and precision data.

Monitoring Stations

In order to create a highly stable point from which to measure potential horizontal and/or vertical ground deformation, geophysical deformation monitoring stations (GDM-1 to GDM-20) were designed using the National Geodetic Survey (NGS) three-dimensional rod monument specifications (Federal Geodetic Control Committee, 1988). Station monument stability is greatly improved with the use of a floating plastic sleeve around the upper three feet of the monument rod, decoupling the rod from the near-ground surface. This allows for the near-ground-surface to move from the effects of frost heave, diurnal or seasonal temperature changes, inadvertent vehicle traffic, and other factors without directly affecting the monument rod and subsequent deformation monitoring.

As detailed in figure 4, the monument consists of a 12-inch hole drilled with a wheeled power auger, a Berntsen MHDR12 aluminum spiral drive point mounted on the end of a Berntsen MHDRR3 ¾-inch by 3-foot threaded aluminum rod with a Berntsen DSLKM lock washer. Successive aluminum rods and lock washers are added to the overall rod that is driven into the ground with an electric-powered reciprocating driver (jack hammer) to effective refusal. A minimum design length of 3.7 m (12 feet) of rod was used. A Berntsen MHDRDP1 aluminum datum point is installed on the top of the driven rod approximately 3 to 4-inches below the existing ground surface within the drilled hole.

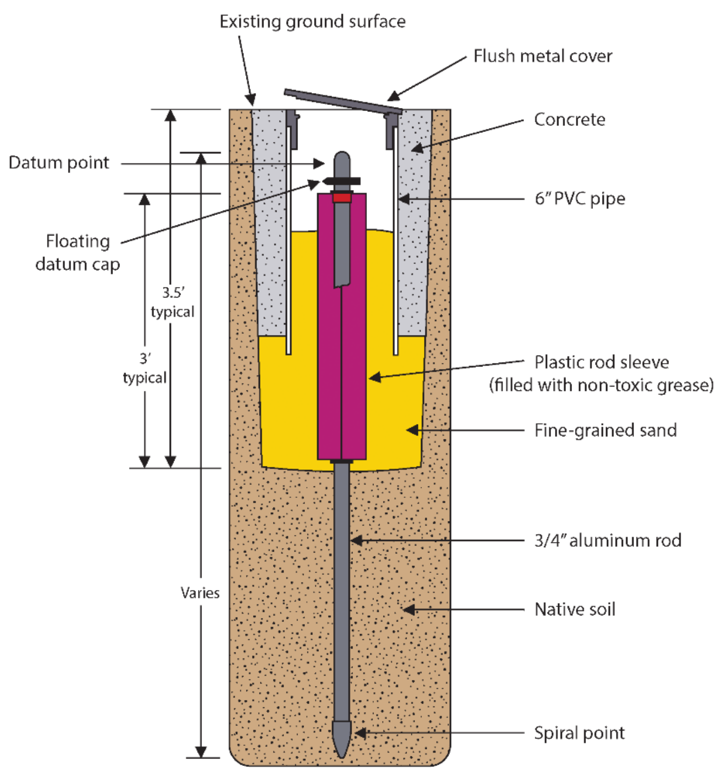


Figure 4. Typical ground deformation monitoring station design.

A 6-inch by 2-foot white schedule 40 PVC pipe is then placed over the driven rod and centered. A Berntsen TSS3-B plastic top security sleeve, partially filled with Bel Ray 301567 No-Tox Food Grade

Clear Grease 1 and capped at each end with Berntsen blue plastic bushings, is slid over the exposed aluminum rod and inside the PVC pipe, so the datum point is exposed. Fine-grained, washed sand is then packed between the PVC pipe and the rod sleeve and in the area between the native soil and the PVC pipe. A Berntsen RBD325CH aluminum, floating datum cap is then placed over the datum point, denoting the monitoring station identification. Each floating datum cap is stamped: *Utah FORGE Project – State of Utah*, *Geophysical Station GDM-x*, where x denotes the specific station number. The plastic sleeve system allows the rod to be decoupled from the near-ground surface that may experience deformation in the upper 1.1 meters (3.5 feet) as detailed previously. The datum point allows for the stable positioning of a four-leg, fixed-height tripod.

A Berntsen BMAC6 6-inch aluminum access cover is placed over the top of the 6-inch PVC pipe so that the cover top surface us flush with the existing ground surface. The cover is stamped: *Utah FORGE Project – State of Utah*, *Geophysical Station – Do Not Disturb*. A 16-inch square wood dimensional 2x4 frame is then centered horizontally with the access cover and flush with the top. Portland cement concrete (PCC) is then placed to fill the void between the wood frame, PVC pipe, and the access cover, and properly surface finished. The access cover protects the rod and datum point from inadvertent damage, such as from vehicles, livestock, etc. The PCC concrete pad provides protection to the monitoring station and a surface for future geophysical gravity measurements with a gravimeter.

Base Station

For the second base station, a Berntsen C35D 3-1/2-inch, rock-socketed aluminum marker, similar to the U.S. Army Corps of Engineers Type 1 Disc style, with a 3-5/16-inch mounting stem, was used. This marker is very similar to that used for other permanent survey benchmarks on competent bedrock. The marker is stamped: *Utah FORGE Project – State of Utah*, *Geophysical Station GDM-B2*, and allows for the stable positioning of a four-leg, fixed-height tripod.

GROUND DEFORMATION MONITORING STATION INSTALLATION

Each of the ground deformation monitoring stations were installed using the NGS style monuments described in the Ground Deformation Monitoring Station Design section. Once each specific monitoring station site was located in the field, a wheeled Ground Hog hydraulic power auger was used to drill a 12-inch hole (figure 5), which was then cleaned of loose soil and debris. A Makita reciprocating driver was used to drive the monument rod into the existing soil at the bottom of the drilled hole (figure 6) to effective refusal without damaging the rod. A plywood template was used to keep the rod aligned during the driving process.

Figure 5. Drilling the initial hole (left) and driving the monument rod (right).

The wood frame was left in place to help protect the concrete pad edges from damage. A metal T-post was then driven into the ground with a post driver (figure 5) and the upper portion painted bright orange, so that the individual station could be easily located in the future.

Figure 6. Installed monument rod, datum point, and floating datum cap (left) and a partially completed monitoring station awaiting concrete placement and finishing (right).

Before leaving each site, the soil spoils were smoothed out around the completed station, taking care to not bury vegetation, and all tools, supplies, and debris were removed. The completed station was installed so that the top surface is flush with the existing ground surface, minimizing any visual effects and disturbance to other activities in the area (figure 6).

Network Base Stations

To determine highly accurate three-dimensional locations of the ground deformation monitoring stations, highly accurate and precise locations of the two base stations are required. During the ground deformation network installation, the UGS continuously occupied the existing NGS BAILEY bench mark for over 48 hours (GDM-B1) from December 18 to 19, 2018, and the newly installed geophysical station (GDM-B2) to collect GNSS position data for subsequent processing with the NGS Online Positioning User Service (OPUS) to produce high-accuracy National Spatial Reference System (NSRS) coordinates of the stations that will be used as base stations in the network.

The OPUS system supports up to 48 hours of continually collected GPS-only position data that can only include up to one crossing of Coordinated Universal Time (UTC) midnight (NOAA, 2018). In addition, OPUS uses a 10-degree horizon cutoff mask, a 30 sec observation rate, and uses dual frequency GPS L1 and L2 signals only.

The Jet Propulsion Laboratory (JPL) Automatic Precise Positioning Service (APPS) system supports an unlimited time period of continually collected GNSS (GPS, GLONASS, Galileo, and BeiDou) position data for a ≤10 MB uploaded RINEX data file (JPL, 2018). However, we were unable to process the data station data using APPS in time for this report, due to receiver configuration file issues. In the future, we plan on resolving this issue, so APPS can be used to potentially determine more precise base station locations.

Base Station GDM-B1

Network base station GDM-B1 is located at the existing NGS BAILEY (JO0533) horizontal third order bench mark (https://www.ngs.noaa.gov/cgi-bin/ds_mark.prl?PidBox=JO0533, see appendix A) in the Mineral Mountains within Beaver County, Utah. This benchmark is a survey disk set in 1957 by the U.S. Geological Survey (USGS) in a competent granite rock outcrop, is in good condition (figure 7), and has two additional reference marks set in 1957 associated with it. Generally, full coverage of the sky is available, due to the benchmark location on an unnamed high point within the Mineral Mountains. Due to the location and founding of the benchmark in competent granite rock, this benchmark is considered stable and not moving with respect to the project site area. No evidence of nearby landsliding, creep, or other ground movement was observed on any of our visits to the benchmark site.

Figure 7. NGS BAILEY benchmark (left) and overall site (right).

The NGS reports the current survey control position for this benchmark, based on classical geodetic methods and adjustment in June 1998, as (NGS, 2018; table 1):

Table 1. *NGS BAILEY benchmark coordinates.*

Horizontal NAD83 (1994)		Vertical NAVD88 Ortho Height (Geoid12B)	
Latitude	Longitude	2414.7 meters	7922 feet
38.513184	-112.798212		

The UGS continuously reoccupied this bench mark from December 18 to 19, 2018, to collect 25 hours of GNSS position data for processing with NGS OPUS and JPL APPS to produce high-accuracy National Spatial Reference System (NSRS) coordinates of the station that will be used as base station GDM-B1 in the ground deformation network. The OPUS datasheet is contained in appendix B. The coordinates of base station GDM-B1 determined from OPUS are listed in table 2.

Table 2. *NGS BAILEY benchmark coordinates from UGS reoccupation during Monitoring Campaign Initial A and B.*

Positioning Service	Campaign	Horizontal NAD83 (2011) (Epoch: 2010.0000)		Vertical NAVD88 Height (Geoid12B)	
		Latitude	Longitude	Ellipsoid	Orthometric
NGA OPUS	Initial A	38.513184761 ± 3 mm	-112.798211311 ± 5 mm	2393.613 m ± 8 mm	2413.744 m ± 28 mm
	Initial B	38.513184631 ± 13 mm	-112.798211411 ± 7 mm	2393.687 m ± 9 mm	2413.818 m ± 28 mm

Base Station GDM-B2

A Berntsen C35D 3-1/2-inch, rock-socketed aluminum marker (U.S. Army Corps of Engineers Type 1 Disc style) was installed on December 7, 2018, west of the FORGE project area on a low granitic knoll as Base Station GDM-B2 (figure 8). The marker was installed by drilling a 7/8-inch hole in exposed bedrock, approximately 4 inches deep to accommodate the mounting stem, carefully chiseling a flat surface for the marker and using grouting concrete to set the marker as recommended by the manufacturer. Due to the location and founding of the benchmark in competent granite rock, this benchmark is considered stable and not moving with respect to the project site area. No evidence of nearby landsliding, creep, or other ground movement was observed on any of our visits to the benchmark site.

Figure 8. Base station GDM-B2 cap (left) and site (right).

The UGS continuously occupied this new station from December 17 to 18, 2018, to collect nearly 26 hours and March 10-13, 2019 to collect nearly 65 hours of GNSS position data for processing with NGS OPUS to produce high-accuracy NSRS coordinates of the station that will be used as base station GDM-B2 in the ground deformation network. The OPUS datasheet is contained in appendix B. The coordinates of base station GDM-B2 determined from OPUS are shown in table 3.

Table 3. *Coordinates for Base Station GDM-B2 from UGS occupation during Monitoring Campaign Initial A and B.*

Positioning Service	Campaign	Horizontal NAD83 (2011) (Epoch: 2010.0000)		Vertical NAVD88 Height (Geoid12B)	
		Latitude	Longitude	Ellipsoid	Orthometric
NGA OPUS	Initial A	38.54416875 ± 3 mm	-113.081878961 ± 5 mm	1572.183 m ± 1 mm	1592.906 m ± 27 mm
	Initial B	38.544168819 ± 5 mm	-113.081878969 ± 6 mm	1572.245 m ± 5 mm	1592.968 m ± 28 mm

Base Station UTMI

Network base station UTMI is located at the existing TURN Virtual Reference Network (VRS) station UTMI mounted at the old Milford Valley Memorial Hospital site in Milford, Utah. This station is part of the TURN network (http://turngps.utah.gov/) operated by the State of Utah, Utah Automated Geographic Reference Center, which provides automatic real-time kinematic (RTK) position solutions to users.

Unfortunately, this continually operating station used an older Trimble NetR3 receiver prior to April 17, 2019, with only 72 channel GPS and GLONASS capability, so is unable to provide data for Galileo, BeiDou, and QZSS position solutions. The TURN network has since replaced this older receiver with a Trimble Alloy receiver with full GNSS satellite capability. The TURN reports the current position for reference station UTMI as (TURN, 2019; table 4):

Table 4. *TURN Base Station UTMI coordinates.*

Horizontal NAD83 (2011) (Epoch: 2010.0000)		Vertical NAD83 Ellipsoidal Height
Latitude	Longitude	
38.401892	-113.010330	1506.239 meters

Figure 8. TURN UTMI Milford reference station.

Additional Base Stations

Several other continually operating base stations were identified that could be used in static post-processing of the GNSS data as alternate and/or as additional base stations as needed.

Base Station UTBR

Base station UTBR is located at the existing TURN VRS station UTBR mounted at the Utah Department of Transportation Maintenance Station in Beaver, Utah. A 440 channel Trimble NetR9 GNSS receiver is used at this base station. The TURN reports the current position for reference station UTBR as (TURN, 2019; table 5):

Table 5. *TURN Base Station UTBR coordinates.*

Horizontal NAD83 (2011) (Epoch: 2010.0000)		Vertical NAD83 Ellipsoidal Height
Latitude	**Longitude**	1795.065 meters
38.284097	-112.640031	

Base Station UTRI

Base station UTRI is located at the existing TURN VRS station UTRI mounted at a site just south of Snow College in Richfield, Utah. Unfortunately, this continually operating station uses an older Trimble NetR5 receiver with only 76 channel L1, L2, L2C, and L5 GPS and L1 and L2 GLONASS capability, so is unable to provide data for Galileo, BeiDou, and QZSS position solutions. The TURN network is in the process of replacing older receivers at stations, such as UTRI with new receivers, such as the Trimble NetR9 with full GNSS satellite capability, but the replacement has not yet taken place. The TURN reports the current position for reference station UTRI as (TURN, 2019; table 6):

Table 6. *TURN Base Station UTRI coordinates.*

Horizontal NAD83 (2011) (Epoch: 2010.0000)		Vertical NAD83 Ellipsoidal Height
Latitude	**Longitude**	1629.258 meters
38.763067	-112.101953	

Base Station UTFI

Base station UTFI is located at the existing TURN VRS station UTFI mounted on the Millard County Courthouse building in Fillmore, Utah. A 440 channel Trimble NetR9 GNSS receiver is used at this base station. The TURN reports the current position for reference station UTFI as (TURN, 2019; table 7):

Table 7. *TURN Base Station UTFI coordinates.*

Horizontal NAD83 (2011) (Epoch: 2010.0000)		Vertical NAD83 Ellipsoidal Height
Latitude	**Longitude**	1562.626 meters
38.967863	-112.324302	

Base Station UTCE

Base station UTCE is located at the existing TURN VRS station UTCE mounted on the Utah Division of Wildlife Resources building near the Cedar City Airport in Cedar City, Utah. A 440 channel Trimble NetR9 GNSS receiver is used at this base station. The TURN reports the current position for reference station UTCE as (TURN, 2019; table 8):

Table 8. *TURN Base Station UTCE coordinates.*

Horizontal NAD83 (2011) (Epoch: 2010.0000)		Vertical NAD83 Ellipsoidal Height
Latitude	**Longitude**	1705.412 meters
37.704215	-113.086806	

Base Station P080

Base Station P080 is located at the existing EarthScope Plate Boundary Observatory (PBO) station P080 (https://www.unavco.org/instrumentation/networks/status/pbo/overview/P080) mounted on a custom deep-drilled and braced monument, just north of U.S. 50/U.S. 6 in White Pine County, Nevada. A Polar X5 GNSS receiver is used at this base station. UNAVCO reports the current position for PBO station P080 as (table 9):

Table 9. *EarthScope Plate Boundary Observatory station P080 coordinates.*

Horizontal NAD83		Vertical NAD83 Ellipsoidal Height
Latitude	**Longitude**	1973 meters
39.11944	-114.27722	

Base Station P106

Base Station P106 is located at the existing PBO station P106 (https://www.unavco.org/instrumentation/networks/status/pbo/overview/P106) mounted on a custom deep-drilled and braced monument, approximately 8.6 kilometers south southeast of Leamington, Utah. Unfortunately, this continually operating station uses an older Trimble NetRS receiver with only 24 channel L1, L2, and L2C GPS capability, so is unable to provide data for GLONASS, Galileo, BeiDou, and QZSS position solutions. UNAVCO reports the current position for PBO station P106 as (table 10):

__Table 10.__ EarthScope Plate Boundary Observatory station P106 coordinates.

Horizontal NAD83		Vertical NAD83 Ellipsoidal Height
Latitude	**Longitude**	1560 meters
39.45896	-112.26235	

Base Station ECHO

Base station ECHO is located at the existing PBO station ECHO (https://www.unavco.org/instrumentation/networks/status/pbo/overview/ECHO) mounted on a custom deep-drilled and braced monument, located at Echo Canyon State Park in Lincoln County, Nevada. A 440 channel Trimble NetR9 GNSS receiver is used at this base station. UNAVCO reports the current position for PBO station ECHO as (table 11):

__Table 11.__ EarthScope Plate Boundary Observatory station ECHO coordinates.

Horizontal NAD83		Vertical NAD83 Ellipsoidal Height
Latitude	**Longitude**	1684 meters
37.91553	-114.26425	

Ground Deformation Monitoring Network Stations

Ground deformation monitoring stations GDM-1 to GDM-20 were installed between December 6-10, 2018 at the locations indicated in figures 2 and 3.

Station GDM-1

Ground deformation monitoring station GDM-1 was installed on December 6, 2018 with 3.7 m (12 feet) of rod (figure 9).

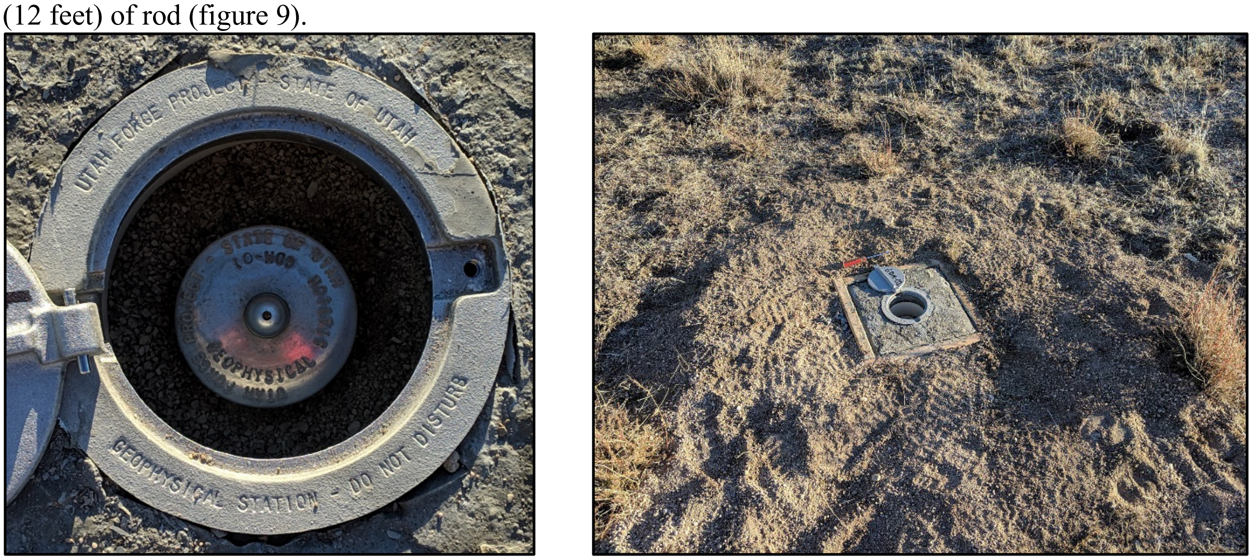


Figure 9. Ground deformation monitoring station GDM-1 cap (left) and overall view (right).

Station GDM-2

Ground deformation monitoring station GDM-2 was installed on December 6, 2018 with 3.7 m (12 feet) of rod (figure 10).

Figure 10. Ground deformation monitoring station GDM-2 cap (left) and overall view (right).

Station GDM-3

Ground deformation monitoring station GDM-3 was installed on December 7, 2018 with 3.7 m (12 feet) of rod (figure 11).

Figure 11. Ground deformation monitoring station GDM-3 cap (left) and overall view (right).

Station GDM-4

Ground deformation monitoring station GDM-4 was installed on December 6, 2018 with 3.7 m (12 feet) of rod (figure 12).

Figure 12. Ground deformation monitoring station GDM-4 cap (left) and overall view (right).

Station GDM-5

Ground deformation monitoring station GDM-5 was installed on December 7, 2018 with 3.7 m (12 feet) of rod (figure 13).

Figure 13. Ground deformation monitoring station GDM-5 cap (left) and overall view (right).

Station GDM-6

Ground deformation monitoring station GDM-6 was installed on December 6, 2018 with 3.7 m (12 feet) of rod (figure 14).

Figure 14. Ground deformation monitoring station GDM-6 cap (left) and overall view (right).

Station GDM-7

Ground deformation monitoring station GDM-7 was installed on December 9, 2018 with 2.7 m (9 feet) of rod (figure 15). Early refusal was met at 2.7 m.


Figure 15. Ground deformation monitoring station GDM-7 cap (left) and overall view (right).

Station GDM-8

Ground deformation monitoring station GDM-8 was installed on December 7, 2018 with 4.0 m (13 feet) of rod (figure 16). An extra 0.3 m (1 foot) section of rod was used.

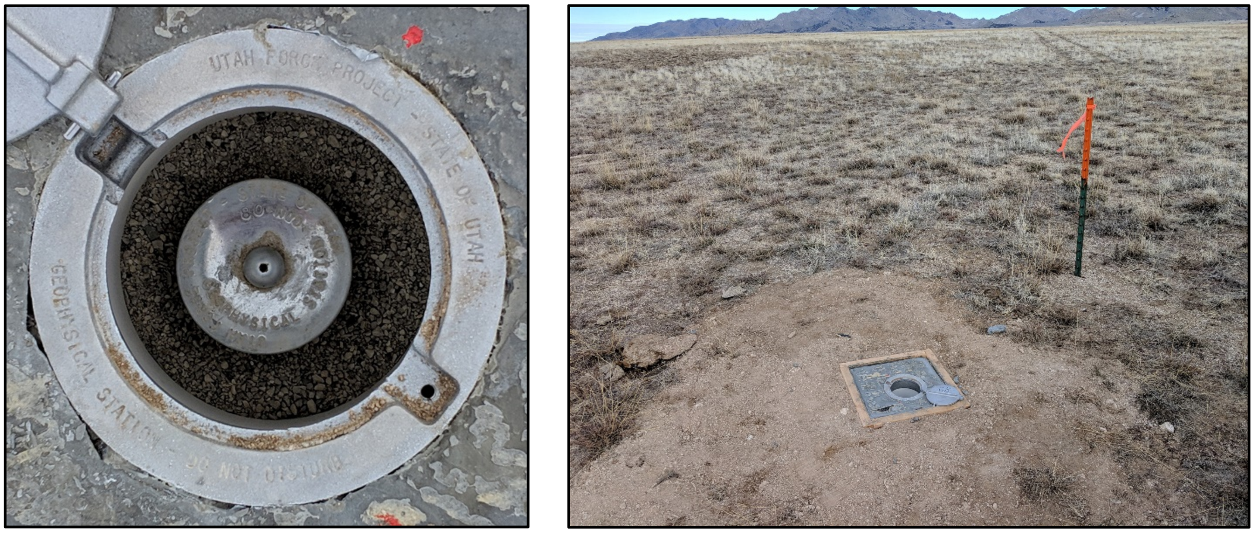


Figure 16. Ground deformation monitoring station GDM-8 cap (left) and overall view (right).

Station GDM-9

Ground deformation monitoring station GDM-9 was installed on December 8, 2018 with 3.7 m (12 feet) of rod (figure 17). Early refusal was met at an adjacent location, so rods were extracted, and a new hole augured about 30.5 m (100 feet) southeast of the original location.

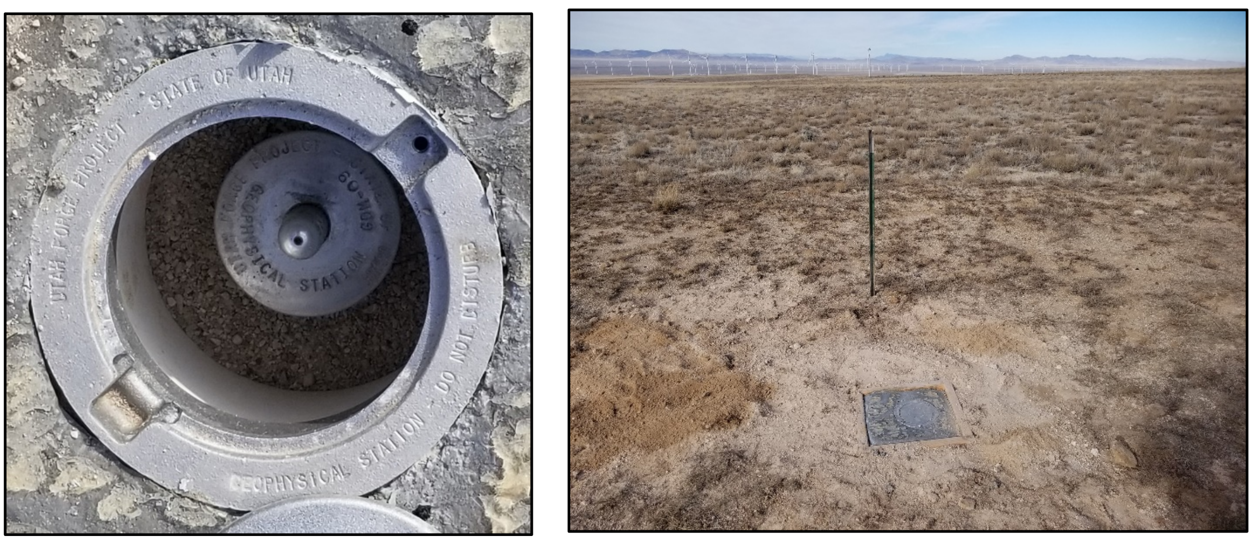


Figure 17. Ground deformation monitoring station GDM-9 cap (left) and overall view (right).

Station GDM-10

Ground deformation monitoring station GDM-10 was installed on December 8, 2018 with 5.5 m (18 feet) of rod (figure 18). Generally, easy rod driving at this location.

Figure 18. Ground deformation monitoring station GDM-10 cap (left) and overall view (right).

Station GDM-11

Ground deformation monitoring station GDM-11 was installed on December 6, 2018 with 3.7 m (12 feet) of rod (figure 19).

Figure 19. Ground deformation monitoring station GDM-11 cap (left) and overall view (right).

Station GDM-12

Ground deformation monitoring station GDM-12 was installed on December 7, 2018 with 3.7 m (12 feet) of rod (figure 20).

Figure 20. Ground deformation monitoring station GDM-12 cap (left) and overall view (right).

Station GDM-13

Ground deformation monitoring station GDM-13 was installed on December 10, 2018 with 3.7 m (12 feet) of rod (figure 21). The original hole could only be augured to 1.0 m (3 feet), so a new hole was augured 1.8 m (6 feet) north.

Figure 21. Ground deformation monitoring station GDM-13 cap (left) and overall view (right).

Station GDM-14

Ground deformation monitoring station GDM-14 was installed on December 9, 2018 with 1.5 m (5 feet) of rod (figure 22). Early refusal was met at 1.5 m.

Figure 22. Ground deformation monitoring station GDM-14 cap (left) and overall view (right).

Station GDM-15

Ground deformation monitoring station GDM-15 was installed on December 9, 2018 with 3.7 m (12 feet) of rod (figure 23). An alternative hole 3.2 m (10.5 feet) north was unsuccessful. A reciprocating driver and fluted bit were used to break through a hard caliche layer during the auger drilling phase of the station installation.

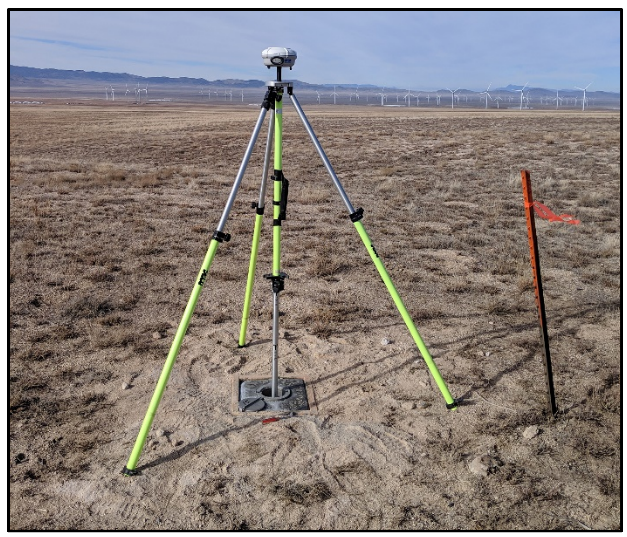


Figure 23. Ground deformation monitoring station GDM-15 cap (left) and overall view (right).

Station GDM-16

Ground deformation monitoring station GDM-16 was installed on December 8, 2018 with 3.7 m (12 feet) of rod (figure 24).

Figure 24. Ground deformation monitoring station GDM-16 cap (left) and overall view (right).

Station GDM-17

Ground deformation monitoring station GDM-17 was installed on December 10, 2018 with 3.7 m (12 feet) of rod (figure 25).

Figure 25. Ground deformation monitoring station GDM-17 cap (left) and overall view (right).

Station GDM-18

Ground deformation monitoring station GDM-18 was installed on December 10, 2018 with 1.5 m (5 feet) of rod (figure 26). Early refusal was met at 1.5 m.

Figure 26. Ground deformation monitoring station GDM-18 cap (left) and overall view (right).

Station GDM-19

Ground deformation monitoring station GDM-19 was installed on December 9, 2018 with 3.7 m (12 feet) of rod (figure 27).

Figure 27. Ground deformation monitoring station GDM-19 cap (left) and overall view (right).

Station GDM-20

Ground deformation monitoring station GDM-20 was installed on December 10, 2018 with 3.7 m (12 feet) of rod (figure 28).

Figure 28. Ground deformation monitoring station GDM-20 cap (left) and overall view (right).

GROUND DEFORMATION MONITORING NETWORK METHODS

We designed the ground deformation network with consideration in reducing potential error sources to the smallest levels generally achievable. In addition to those errors, additional error sources during monitoring, include satellite constellation configuration, geomagnetic conditions, tripod calibration, monument thermal changes as a result of ground surface temperature changes, and atmospheric-related sources. These errors were also reduced to the lowest levels reasonably achievable.

The overall monitoring approach is the use of GNSS to produce highly accurate and precise locations for the fixed, non-moving base stations and the possibly moving ground deformation monitoring stations using static and/or fast static methods with least-squares reduction. The use of least-squares reduction requires at least two fixed base stations. The use of precision GNSS methods, along with highly stable ground monumentation and by reducing other potential error sources to the lowest levels reasonably achievable, ensures that small ground deformation values will be detectable above error values.

Reduction of Potential Monitoring Error Sources

Additional error sources are also present during GNSS monitoring in the field, and primarily consist of errors resulting from satellite constellation configuration, geomagnetic conditions, tripod calibration, and atmospheric conditions. To reduce these errors to low levels, monitoring was not performed during time periods of less than optimal satellite constellation configuration, geomagnetic conditions, and atmospheric conditions. In addition, each tripod was calibrated before each monitoring campaign.

Satellite Constellation Configuration

Positional Dilution of Precision (PDOP) is a measure of error resulting from the satellite constellation geometry above the site to be measured with GNSS. Low PDOP values indicate a well distributed satellite geometry, with high values indicating a poorly distributed or clustered geometry. The Horizontal Dilution of Precision (HDOP) and the Vertical Dilution of Precision (VDOP) represent the geometry in the horizontal and vertical dimensions, respectively, with similar low and high value definitions. A P-, H-, and VDOP value of 0 is the highest value and represents the lowest level of error.

Prior to each monitoring campaign, we determined the PDOP, HDOP, and VDOP values using Trimble GNSS Planning Online (https://www.gnssplanning.com) website for the time period of the campaign (included with the data for each campaign) and did not perform GNSS monitoring during periods of:

- PDOP > 1.4 [1.5 for the Initial A campaign]
- HDOP > 0.9
- VDOP > 1.2 [1.3 for the Initial A campaign]

Geomagnetic Conditions

The planetary K-index or Kp is a measure of disturbances in Earth's magnetic field from geomagnetic storms resulting from the Sun's activity. These geomagnetic storms can cause errors and/or disruption of the GNSS radio signals. Kp ranges from 0 to 9, with 1 indicating calm conditions and ≥5 indicating a geomagnetic storm.

In the U.S., the National Oceanic and Atmospheric Administration (NOAA), Space Weather Prediction Center provides estimated 3-hour Kp values (https://www.swpc.noaa.gov/products/planetary-k-index). NOAA issues space weather notifications as needed. Watches are issued when the highest predicted NOAA estimated Kp-indices for a day are K = 5, 6, 7, or >= 8 and is reported in terms of the NOAA G scale. K-index Warnings are issued when NOAA estimated Kp-indices of 4, 5, 6, and 7 or greater are expected. K-index Alerts are issued when the NOAA estimated Kp-indices reach 4, 5, 6, 7, 8, or 9 (NOAA, 2018).

Prior to each monitoring campaign, we determined the NOAA estimated Kp values for the time period of the campaign (included with the data for each campaign) and did not perform GNSS monitoring during periods of Kp ≥4.

Tripod Calibration

Due to physical use, tripods may become out-of-plumb between their vertical measurement point and the GNSS instrument with respect to a level bubble used to properly setup the tripod at each monitoring station. Prior to each monitoring campaign, we calibrated each tripod using a ChrisNik TruePlumb calibration device, ensuring the TruePlumb device was also calibrated using a plumb bob between the tripod mount locations. During each tripod check, the calibration of the level bubble was verified, and if necessary, adjusted to be plumb with the center tripod rod (figure 29).

Figure 29. Typical calibration of a four-leg, fixed height tripod.

Ground Temperatures

Changes in ground temperatures between ground deformation monitoring campaigns can introduce small changes in the length of the aluminum rods driven into the ground as part of each monitoring station, due to linear thermal expansion or contraction.

To quantify this error, the temperature of the top of each monitoring station 6061-T6 aluminum alloy rod was measured with a Yokogawa TX10-02 digital thermometer instrument with a model #90020 probe (figure 30). The instrument has a resolution of 0.1°C with an accuracy of ±(0.1% of reading + 0.7°C) between -100.0°C and 199.9°C (Yokogawa, 2000). For example, at a temperature of 0°C, the accuracy is ±0.70°C and at a temperature of 25°C, the accuracy is ±0.73°C. Since the instrument has a resolution of 0.1°C or one decimal place, the accuracy over the anticipated temperature range is ±0.7°C.

Figure 30. Typical measurement of monument rod temperature.

The change in rod length, based on the change in rod temperature between the initial monitoring campaign and each monitoring campaign was calculated from:

$$\Delta = L_0 * \alpha (t_1 - t_0)$$

where, L_0 is the initial length of the aluminum rod, α is the linear expansion coefficient (0.0000236 m/m°C) for 6061-T6 aluminum alloy (Amesweb, 2018), t_0 is the initial rod temperature in Celsius, and t_1 is the final rod temperature in Celsius. The temperature-induced change in rod length was accounted for in the GNSS data processing, in that report section (included with the data for each campaign).

Atmospheric Conditions

Ultraviolet and x-ray emissions from the Sun may cause ionization with the ionosphere in the upper part of Earth's atmosphere. This ionization may cause refraction of radio waves passing through the ionosphere, causing signal delay and subsequent positional error. Ionospheric delay is frequency dependent under normal conditions and dual-frequency (L1 and L2) code and carrier observations are normally used to essentially remove ionospheric signal delay errors (Trimble, undated). All our GNSS receivers are dual-frequency capable and in data post-processing, ionospheric signal delay errors are reduced as possible.

A second ionospheric error source results from the ionization causing scintillation or fluctuations in the phase and amplitude of GNSS signals. Scintillation can cause loss of signal tracking or cycle slips, and the effects of scintillation are not removed by dual-frequency (L1 and L2) observations (Trimble, undated).

Ionospheric conditions can be determined by measuring the total electron content (TEC) and scintillation in the ionosphere to calculate an ionospheric index (*ionoindex*):

$$ionoindex = max\left(\frac{TEC}{12}, \frac{index_{scintillation}}{10}\right)$$

where *ionoindex* ranges from 0 to 10 (minimum to maximum; Trimble, undated). Generally, *ionoindex* values <2.5 are considered minimal, 2.5 to 7.5 are considered medium, and >7.5 are considered strong. Prior to each monitoring campaign, we determined the *ionoindex* values for the time period of the campaign (included with the data for each campaign) and did not perform GNSS monitoring during periods ≥2.5.

Groundwater Conditions

Seasonal groundwater level changes can and do affect the ground surface elevations above. Unfortunately, since no local groundwater monitoring wells or networks currently exist at the FORGE site, we are unable to determine the magnitude of seasonally fluctuating groundwater level and flow on the monitoring measurements. The error introduced by the seasonally fluctuating groundwater level and flow is currently unknown.

Global Navigation Satellite System (GNSS)

The GNSS consists of multiple, global satellite navigation systems and currently consists of the United States Global Positioning System (GPS), the Russian Federation Global'naya Navigatsionnaya Sputnikovaya Sistema (GLONASS), the European [Union] Global Navigation Satellite System (EGNSS) or Galileo, and China's BeiDou systems. Currently, the GPS system consists of 31, GLONASS consists of 24, Galileo consists of 22, and BeiDou consists of 33 operational satellites for a total of 111 operational GNSS satellites. In addition, Japan's Quasi-Zenith Satellite System (QZSS) consists of four operational satellites with signals that may be sporadically received over the FORGE monitoring area. India's Indian Regional Navigation Satellite System (IRNSS), operationally known as the Navigation with Indian Constellation (NAVIC), consists of seven operational satellites; however, no signals may be received over the FORGE monitoring area.

All our GNSS receivers can receive non-encrypted signals from the GPS, GLONASS, and Galileo systems (a maximum of 78 satellites and 235 individual signals). Which specific satellites and signals are received depends on the satellite constellation during the time period of each station observation and continually changes as all the satellites are in motion around the Earth in varying planes. The sections below describing the various GNSS systems only list the publically available signals for GNSS positioning, and not those encrypted, for military use, or test signals.

GPS System

The United States GPS system consists of 31 operational satellites from three designs, including Blocks IIA, IIR, IIRM, and IIF, and differ in their capabilities as shown below:

- Block IIA satellites (1 operational) transmit a L1C/A signal.
- Block IIR satellites (11 operational) transmit L1C/A and L2 signals.
- Block IIRM satellites (7 operational) transmit L1C/A, L2, and L2C signals.
- Block IIF satellites (12 operational) transmit L1C/A, L2, L2C, and L5 signals.

Future Block IIIA satellites will add L1C signals in addition to those transmitted by the older, Block IIF satellites. The first and second Block IIIA satellites were launched on December 23, 2018 and August 22, 2019, respectively, and are currently in the testing and validation phase.

GLONASS System

The Russian Federation GLONASS system consists of 24 operational satellites from two designs, including Uragan-M and Uragan-K1.

- Utagan-M satellites (23 operational) transmit L1 and L2 signals, with five satellites also transmitting the L5 signal.
- Uraga-K1 satellites (1 operational) transmit L1, L2, L3, and L5 signals.

Galileo System

The European Union Galileo system consists of 23 operational satellites from two designs, including In-Orbit Validation (IOV, 3 satellites) and Full Operational Capability (FOC, 20 satellites). Both designs transmit E1, E5a, E5b, and E6 signals.

BeiDou System

The Chinese BeiDou system consists of 33 operational satellites from two designs, including BeiDou-2 and BeiDou-3.

- BeiDou-2 satellites (15 operational) transmit E1, E2, E5B, and E6 signals.
- BeiDou-3 satellites (18 operational) transmit B1C, B2a, B2b, and B3l signals.

QZSS System

The Japanese QZSS system consists of four operational satellites of a similar design transmitting L1C/A, L1C, L1S, L2C, and L5 signals (National Space Policy Secretariat, 2018). Only signals from one satellite for a few hours daily are receivable at the FORGE monitoring area and it is typically outside the normal GNSS signal acquisition time during the daylight hours.

IRNSS System

The Indian IRNSS system consists of seven operational satellites of a similar design transmitting an L5 signal. Currently, none of the IRNSS signals are receivable over the FORGE monitoring area.

GNSS Equipment

GNSS equipment used for the Utah FORGE Project includes a suite of four Trimble R8 Model 3 and one R10 GNSS receivers, two Trimble TSC2 controllers, a Samsung tablet and Trimble DL software controller, Trimble Business Center processing software, five Seco fixed-height tripods, and a ChrisNik tripod calibration device as detailed in table 12, along with various supporting equipment.

Table 12. *Listing of UGS GNSS and related equipment used for the Utah FORGE Project.*

<table>
<tr><th>Type</th><th>Model</th><th>UGS Code</th><th>Model Code</th><th>Serial Number</th><th>Current Firmware or Software Version</th></tr>
<tr><td rowspan="5">Receiver</td><td rowspan="4">Trimble R8</td><td>R8-1</td><td>67250-66</td><td>4944405157</td><td>5.42</td></tr>
<tr><td>R8-2</td><td>67250-66</td><td>5032443762</td><td>5.42</td></tr>
<tr><td>R8-3</td><td>67250-66</td><td>4945405478</td><td>5.42</td></tr>
<tr><td>R8-4</td><td>67250-66</td><td>5032443751</td><td>5.42</td></tr>
<tr><td>Trimble R10</td><td>R10-2</td><td>R10-2</td><td>5829F00577</td><td>5.41</td></tr>
<tr><td rowspan="3">Controller</td><td rowspan="2">Trimble TSC2</td><td>TSC2-1</td><td>TA-TSC2-1</td><td>SSB1C57159</td><td>Access 2016.12 (12488)</td></tr>
<tr><td>TSC2-2</td><td>TA-TSC2-1</td><td>SS97C40861</td><td>Access 2016.12 (12488)</td></tr>
<tr><td>Samsung Tablet</td><td>--[1]</td><td>SM-P605V.02</td><td>IMEI: 990004460757168</td><td>Trimble DL 1.0.209</td></tr>
<tr><td>Software</td><td>Trimble Business Center (TBC)</td><td>--[1]</td><td>--[1]</td><td>--[1]</td><td>5.20</td></tr>
<tr><td rowspan="5">Tripod</td><td rowspan="5">Seco 5119-11</td><td>1</td><td>5119-11</td><td>None</td><td>--[1]</td></tr>
<tr><td>2</td><td>5119-11</td><td>None</td><td>--[1]</td></tr>
<tr><td>3</td><td>5119-11</td><td>None</td><td>--[1]</td></tr>
<tr><td>4</td><td>5119-11</td><td>None</td><td>--[1]</td></tr>
<tr><td>5</td><td>5119-11</td><td>None</td><td>--[1]</td></tr>
<tr><td>Calibration</td><td>ChrisNik TruePlumb</td><td>--[1]</td><td>16TPL2000</td><td>None</td><td>--[1]</td></tr>
<tr><td rowspan="2">Temperature</td><td rowspan="2">Yokogawa TX10</td><td>1</td><td>TX10-02</td><td>2403323</td><td>--[1]</td></tr>
<tr><td>2</td><td>TX10-02</td><td>2403296</td><td>--[1]</td></tr>
</table>

[1] – Not applicable.

The internal firmware of the Trimble receivers and controllers and the Trimble Access controller and Trimble Business Center processing software is currently at the latest release at the time of the last monitoring campaign.

GNSS Receivers

The Trimble R8 GNSS 220-channel receiver (figure 31) can receive GPS, GLONASS, Galileo, and Satellite-Based Augmentation System (SBAS) Wide Area Augmentation System (WAAS, North America) satellite signals consisting of:

- GPS (L1C/A, L2C, L2E, and L5)
- GLONASS (L1C/A, L1P, L2C/A, and L2P)
- Galileo (E1, E5A, and E5B)
- SBAS (L1C/A and L5; not recorded during static methods)

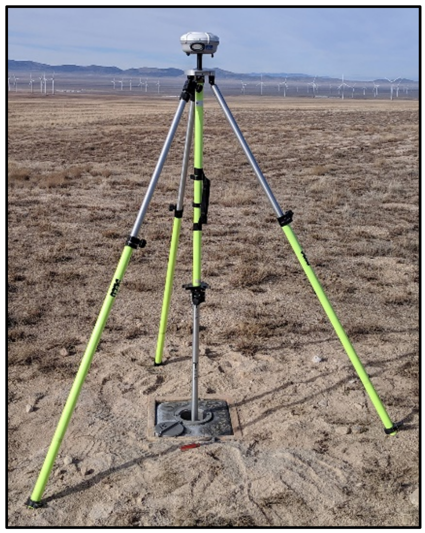


Figure 31. Trimble R8 GNSS receiver on a fixed-height tripod.

The Trimble R10 GNSS 672-channel receiver (figure 32) can receive GPS, GLONASS, Galileo, BeiDou, IRNSS, and SBAS WAAS, EGNOS, and QZSS satellite signals consisting of (Trimble, 2018):

- GPS (L1C/A, L2C, L2E, and L5)
- GLONASS (L1C/A, L1P, L2C/A, L2P, and L3)
- Galileo (E1, E5A, E5B, E5 AltBOC, E6)
- BeiDou (B1, B2, and B3)
- IRNSS (L5) – *no signals receivable over the FORGE project area.*
- SBAS (L1C/A and L5; not recorded during static methods)
- QZSS (L1C/A, L1-SAIF, L1C, L2C, and L5)

Figure 32. Trimble R10 GNSS receiver.

The Trimble Alloy GNSS 672-channel receiver used at the Milford TURN UTMI station can receive GPS, GLONASS, Galileo, BeiDou, IRNSS, and SBAS WAAS, EGNOS, and QZSS satellite signals consisting of (Trimble, 2018):

- GPS (L1C/A, L2C, L2E, and L5)
- GLONASS (L1C/A, L1P, L2C/A, L2P, and L3)
- Galileo (L1 CBOC, E5A, E5B, E5 AltBOC, E6)
- BeiDou (B1, B2, and B3)
- IRNSS (L5 and S-band) – *no signals receivable over the FORGE project area.*
- SBAS (L1C/A and L5; not recorded during static methods)
- QZSS (L1C/A, L1-SAIF, L1C, L2C, L5, and LEX/L6)

Four-Leg, Fixed Height Tripods

Seco 5119-11-FLY fixed height tripods with a 2-meter center staff were used for GNSS monitoring at the base and ground deformation monitoring stations (figure 33). These tripods allow for high accuracy and precision GNSS monitoring and relatively quick setup at each monitoring station.

Figure 33. Typical four-leg, fixed height tripod with a Trimble R8 GNSS receiver at the GDM-B1 base station, photo date December 10, 2018.

GNSS Analysis Methods

GNSS satellite data can be processed in several ways, depending upon the end use. For the high accuracy and precision required by the Utah FORGE Project ground deformation monitoring, the static and fast static methods are appropriate. The static method, where occupation times are typically over one hour, will be employed for locating the base stations. The fast-static method, where occupation times are typically less than one hour, will be employed for locating the individual ground deformation monitoring stations. Both methods are functionally similar, except for the occupation time, the time spent recording GNSS satellite data at a specific site.

Baselines to Network Base Stations

Baselines are a direct line between monitoring stations and each base station and are used to determine the monitoring occupation time or the estimated amount of time needed of GNSS data collection by a receiver. As described in the Network Base Stations section above, three base stations (two existing and one newly installed) are used in the monitoring network (table 13). Table 14 includes baseline distances for other base stations that may be used as a backup in the case of interrupted GNSS satellite signals. The minimum static/fast static survey data collection or occupation time (t_{min}) in minutes at each monitoring station was estimated from:

$$t_{min} = 20 + L_{max} * 1\,km$$

where, L_{max} is the maximum baseline distance in kilometers. The t_{min} values were rounded up to the nearest integer and the static survey adjusted occupation time was calculated by adding three minutes to the minimum occupation time as a safety factor. Given the high accuracy desired in monitoring ground deformation, we extended the occupation time to ≥90 min after the initial monitoring campaign A. Baselines up to 70 km in length are can be used with a ~90 min occupation time.

Network Adjustment for Least Squares Reduction

Network adjustment is the means to adjust the monument position vectors with a least squares error adjustment, specifically, the combined adjustment. There are five benefits to perform this type of adjustment. These benefits are to estimate and remove random errors; provide a single solution when there is redundant data; minimize corrections made to the observations; detect blunders and large errors; and generate information for analysis, including estimates of precision. In addition, network adjustments help to prevent systematic errors in control points and that any remaining errors are properly distributed, as random and small. Least squares adjustment to the network provides good positional closures and overall estimate repeatability, for current and future measurements. To ensure a successful adjustment, two criteria are needed: (1) the network needs to close mathematically and geometrically, and (2) the overall sum of the weighted square of the residuals must be minimized. Once the criteria are achieved, the measurements of the overall network are adjusted to more accurate positioning allowing for comparable future measurements.

Table 13. *Monitoring station baseline distances and static survey occupation times based on local network base stations.*

Monitoring Station	Baseline Distances (km)				Occupation Time (min)		
	Base Station			Maximum			
	GDB-B1	GDB-B2	TURN UTMI		Minimum	Adjusted	Final
GDM-1	10.37	14.72	14.83	14.72	35	38	60
GDM-2	8.62	16.42	15.90	16.42	37	40	60
GDM-3	7.17	17.86	16.77	17.86	38	41	60
GDM-4	9.35	15.88	14.94	15.88	36	39	60
GDM-5	8.28	16.93	15.59	16.93	37	40	60
GDM-6	7.20	18.00	16.30	18.00	38	41	60
GDM-7	9.66	15.79	14.32	15.79	36	39	60
GDM-8	8.77	16.61	14.97	16.61	37	40	60
GDM-9	8.30	17.15	15.14	17.15	38	41	60
GDM-10	7.92	17.41	15.59	17.41	38	41	60
GDM-11	7.77	17.69	15.48	17.69	38	41	60
GDM-12	7.37	18.10	15.75	18.10	39	42	60
GDM-13	5.98	19.54	16.72	19.54	40	43	60
GDM-14	9.60	16.25	13.80	16.25	37	40	60
GDM-15	8.89	16.99	14.23	16.99	37	40	60
GDM-16	8.13	17.51	15.01	17.51	38	41	60
GDM-17	7.24	18.52	15.55	18.52	39	42	60
GDM-18	6.40	19.49	16.12	19.49	40	43	60
GDM-19	8.72	17.54	14.04	17.54	38	41	60
GDM-20	6.87	19.47	15.52	19.47	40	43	60

Table 14. *Monitoring station baseline distances based on other, distant base stations.*

Monitoring Station	Baseline Distances (km)							
	Base Station							Maximum
	UNAVCO			TURN				
	P080	P106	ECHO	UTFI	UTCE	UTRI	UTBR	
GDM-B1	121.89	114.78	144.56	65.14	134.55	66.65	28.94	144.56
GDM-B2	121.89	123.89	124.89	80.92	128.79	88.68	48.19	124.89
GDM-1	135.97	119.27	135.43	72.08	132.99	76.16	35.13	135.97
GDM-2	137.98	118.42	136.98	70.82	133.14	74.52	33.99	137.98
GDM-3	138.79	117.83	138.23	69.86	133.43	73.19	32.95	138.79
GDM-4	137.16	119.32	136.04	71.78	133.71	75.43	33.98	137.16
GDM-5	138.24	118.81	137.08	70.98	133.90	74.33	33.13	138.24
GDM-6	139.08	118.41	137.91	70.34	134.05	73.46	32.48	139.08
GDM-7	137.24	119.95	135.54	72.37	134.25	75.88	33.74	137.24
GDM-8	137.98	119.46	136.39	71.68	134.27	75.01	33.18	137.98
GDM-9	138.47	119.40	136.71	71.48	134.50	74.65	32.73	138.47

Monitoring Station	Baseline Distances (km)							
	Base Station							Maximum
	UNAVCO			TURN				
	P080	P106	ECHO	UTFI	UTCE	UTRI	UTBR	
GDM-10	138.63	119.04	137.11	71.08	134.30	74.25	32.69	138.63
GDM-11	138.97	119.26	137.12	71.21	134.67	74.22	32.31	138.97
GDM-12	139.45	119.19	137.45	71.00	134.88	73.85	31.89	138.45
GDM-13	140.73	118.55	138.76	70.02	135.09	72.51	30.92	140.73
GDM-14	137.85	120.63	135.31	72.86	135.13	76.04	32.98	137.85
GDM-15	138.53	120.40	135.90	72.44	135.33	75.41	32.39	138.53
GDM-16	138.91	119.68	136.73	71.63	134.97	74.59	32.23	138.91
GDM-17	139.88	119.48	137.46	71.17	135.36	73.81	31.39	139.88
GDM-18	140.86	119.27	138.23	70.68	135.73	73.01	30.56	140.86
GDM-19	139.17	120.79	135.94	72.64	135.99	73.33	31.68	139.17
GDM-20	140.98	119.95	137.73	71.32	136.34	73.49	30.22	140.98

Static and Fast-Static Methods

Static and fast-static GNSS position methods rely on processing the recorded GNSS satellite data, along with the use of one or more fixed position, base stations. The fast-static method generally is used for occupation times less than one hour and the static method is generally used for occupation times greater than one hour.

GNSS Data Processing

GNSS satellite data collected and recorded by four Trimble R8 and one R10 GNSS receivers were saved in Trimble's proprietary data format and in RINEX format and processed with Trimble Business Center (TBC) software using the fast-static or static method with least-squares reduction methods. GNSS satellite data from the TURN UTMI station was downloaded from the TURN website (http://turngps.utah.gov/).

GROUND DEFORMATION NETWORK MONITORING CAMPAIGNS

A total of four monitoring campaigns have been completed at the Utah FORGE Project site (table 15), with the initial monitoring campaign A that occurred on December 18, 2018 and initial monitoring campaign B from March 10 to 12, 2019, and three additional monitoring campaigns.

Table 15. *Ground deformation monitoring campaign summary.*

Monitoring Campaign	Dates	Notes
Initial A	12/18/2018	R8 firmware v5.37 used, R8s not recording Galileo signals.
Initial B	3/10-12/2019	R8 firmware v5.40 used.
1	4/30/2019	R8 firmware v5.40 used.
2	6/4-6/2019	R8 firmware v5.40 used.
3	11/18-19/2019	R8 firmware v5.42 used.

GNSS Receiver Configuration

The Trimble R8 and R10 GNSS receivers were identically configured in fast-static mode for the Initial A campaign and subsequently changed to static for the Initial B and later campaigns, a 5° satellite elevation cutoff (does not record satellite signals below 5° above the horizon), a PDOP warning of 1.5, and a receiver height of 1.930 m above the monitoring station cap.

Initial Monitoring Campaign A

Monitoring parameters for the initial monitoring campaign A on December 18, 2018, are summarized in table 16 with details in figures 34 to 43. During the entire campaign, PDOP, HDOP, VDOP, and Kp values were below threshold values. Unfortunately, the Trimble R8 GNSS receivers did not record Galileo signals, due to a manufacturer firmware issue. As a result, an additional campaign (Initial B) will be performed and used as the start of ground deformation for the FORGE project.

Table 16. *Initial monitoring campaign A GNSS parameters.*

Dilution of Precision			Kp	Tripod Calibration
Precision (PDOP)	**Horizontal (HDOP)**	**Vertical (VDOP)**		
1.27 – 2.06	–	–	1 – 3	Yes

```
Product: Daily Geomagnetic Data          DGD.txt
Issued: 1230 UT 31 Dec 2018
#
#  Prepared by the U.S. Dept. of Commerce, NOAA, Space Weather Prediction Center
#  Please send comment and suggestions to SWPC.Webmaster@noaa.gov
#
#               Last 30 Days Daily Geomagnetic Data
#
#                Middle Latitude        High Latitude           Estimated
#              - Fredericksburg -     ---- College ----      --- Planetary ---
#  Date          A     K-indices        A     K-indices        A     K-indices
2018 12 17      5  1 1 2 1 1 2 2 2     2  0 0 0 0 2 0 1 1     6  1 1 2 1 1 2 2 2
2018 12 18      5  2 1 1 1 2 2 2 1     9  2 1 0 3 4 3 2 0     7  3 1 1 1 2 2 3 1
2018 12 19      4  0 1 1 2 1 2 1 2     5  0 0 2 3 2 1 1 1     6  1 1 1 2 1 2 1 2
```

Figure 34. 3-hour Kp values during Initial Monitoring Campaign A for December 18, 2018 (bold text) and the day before and the day after (NOAA, 2018b).

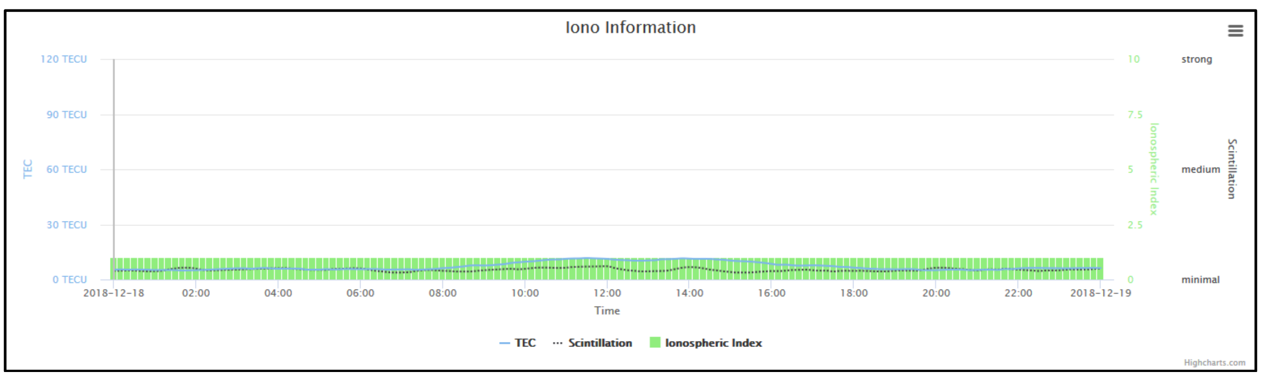


Figure 35. Ionospheric index values during Initial Monitoring Campaign A for December 18, 2018 (Trimble, 2018).

R8 Receivers

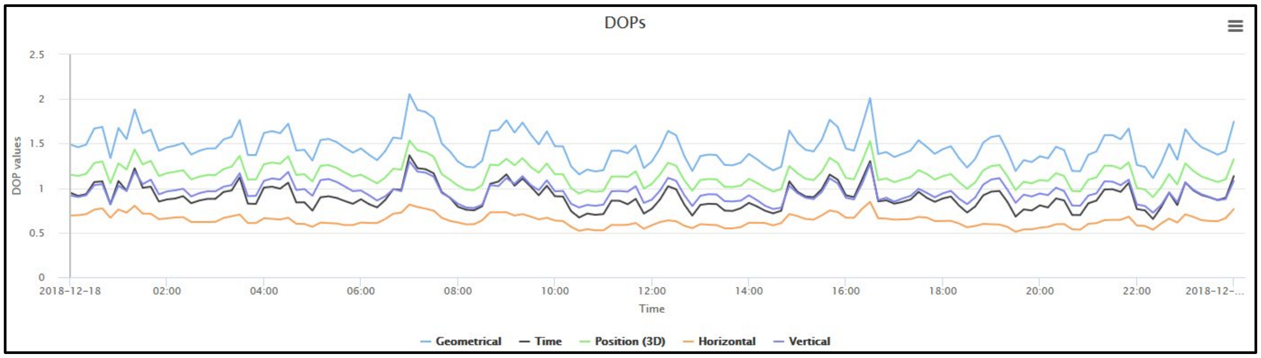


Figure 36. PDOP (green), HDOP (orange), and VDOP (dark blue) values during Initial Monitoring Campaign A for December 18, 2018, from 0000 to 2400 hours using GPS and GLONASS satellites (Trimble, 2018).

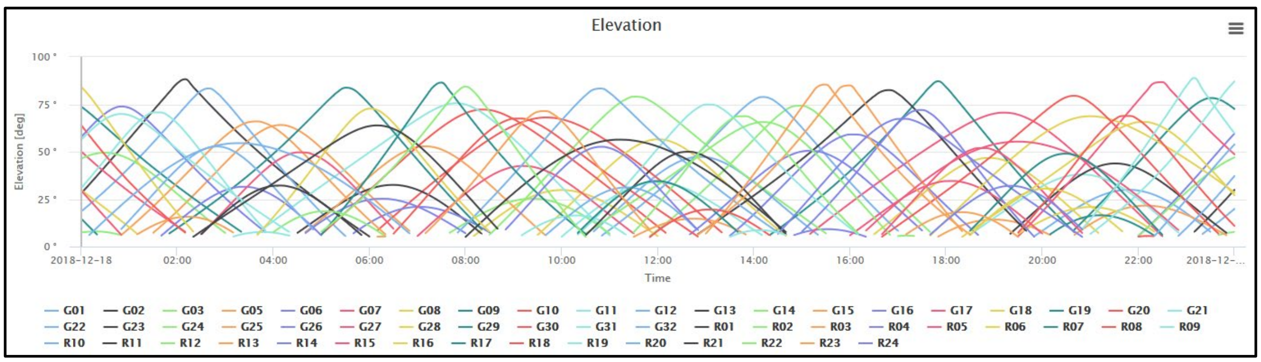


Figure 37. Monitoring line-of-sight satellite tracks and horizon elevations with a 5° satellite elevation cutoff and a 2 m antenna height during Initial Monitoring Campaign A for December 18, 2018, from 0000 to 2400 hours using GPS (Gxx) and GLONASS (Rxx) satellites (Trimble, 2018).

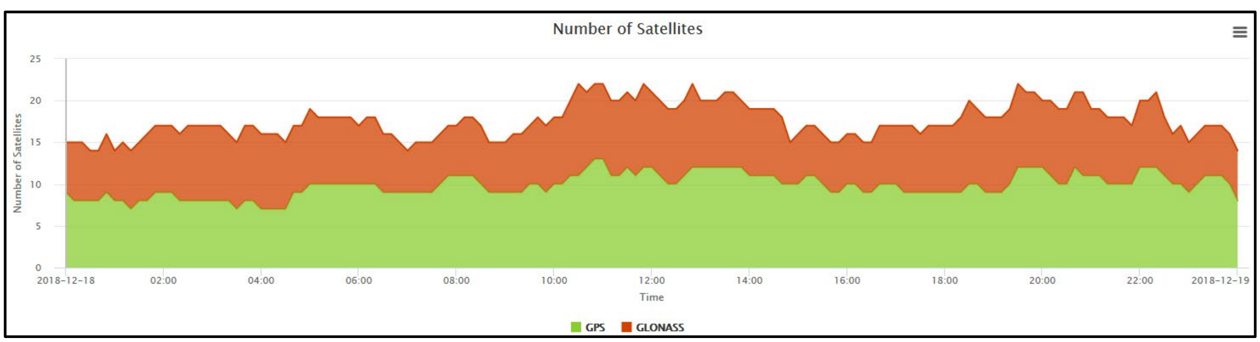


Figure 38. Number of satellites visible with a 5° satellite elevation cutoff and a 2 m antenna height during Initial Monitoring Campaign A for December 18, 2018, from 0000 to 2400 hours using GPS and GLONASS satellites (Trimble, 2018).

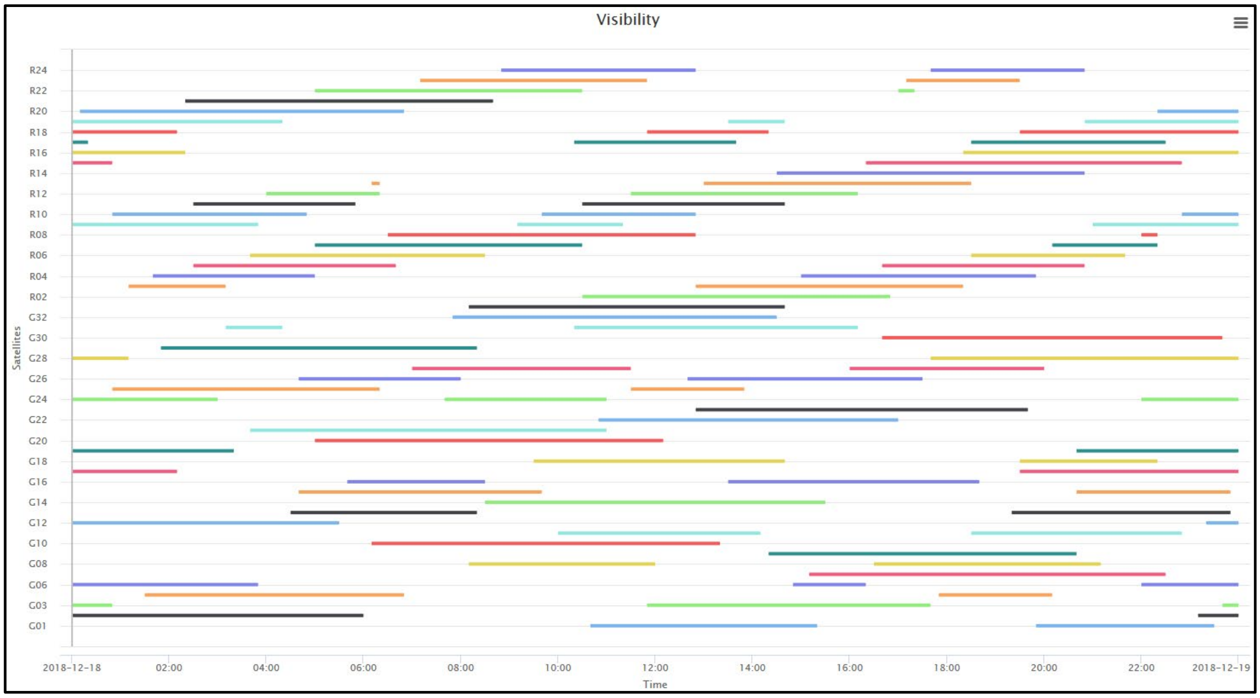


Figure 39. Individual satellite visibility with a 5° satellite elevation cutoff and a 2 m antenna height during Initial Monitoring Campaign A for December 18, 2018, from 0000 to 2400 hours using GPS (Gxx) and GLONASS (Rxx) satellites (Trimble, 2018).

R10 and Alloy Receivers

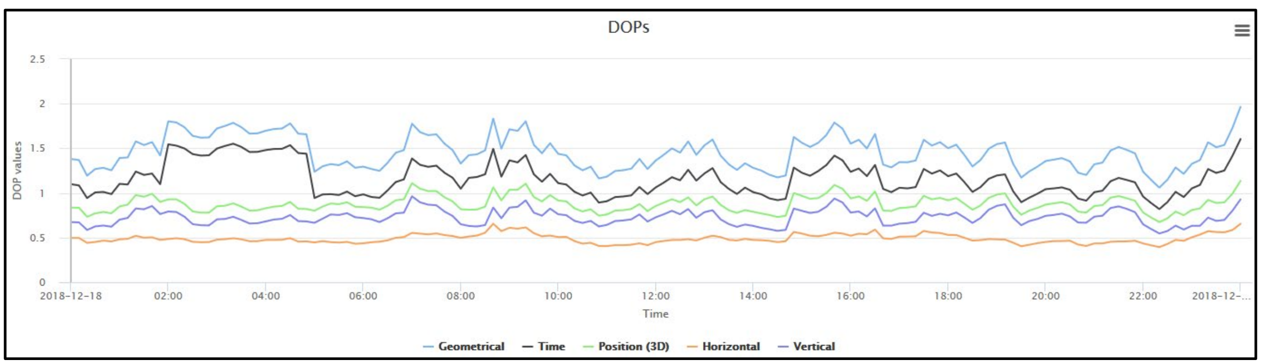


Figure 40. PDOP (green), HDOP (orange), and VDOP (dark blue) values during Initial Monitoring Campaign A for December 18, 2018, from 0000 to 2400 hours using GPS, GLONASS, Galileo, BeiDou, and QZSS satellites (Trimble, 2018).

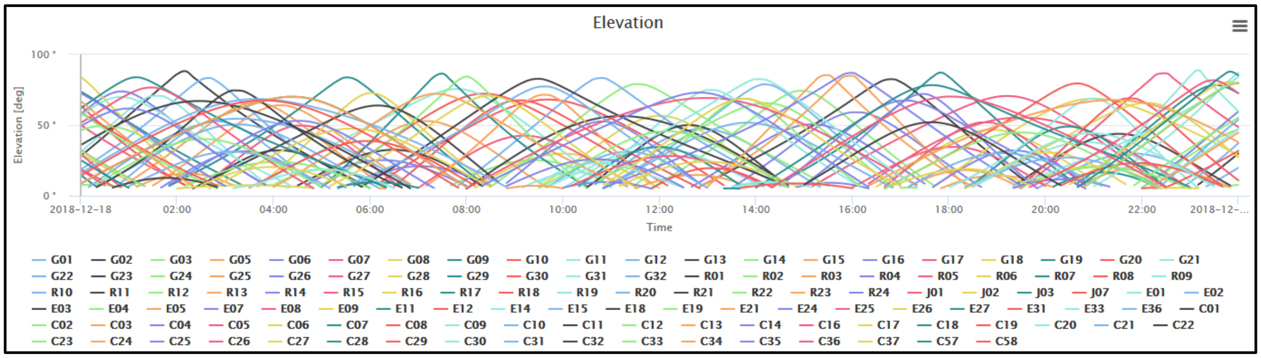


Figure 41. Monitoring line-of-sight satellite tracks and horizon elevations with a 5° satellite elevation cutoff and a 2 m antenna height during Initial Monitoring Campaign A for December 18, 2018, from 0000 to 2400 hours using GPS (Gxx), GLONASS (Rxx), Galileo (Exx), BeiDou (Cxx), and QZSS (Jxx) satellites (Trimble, 2018).

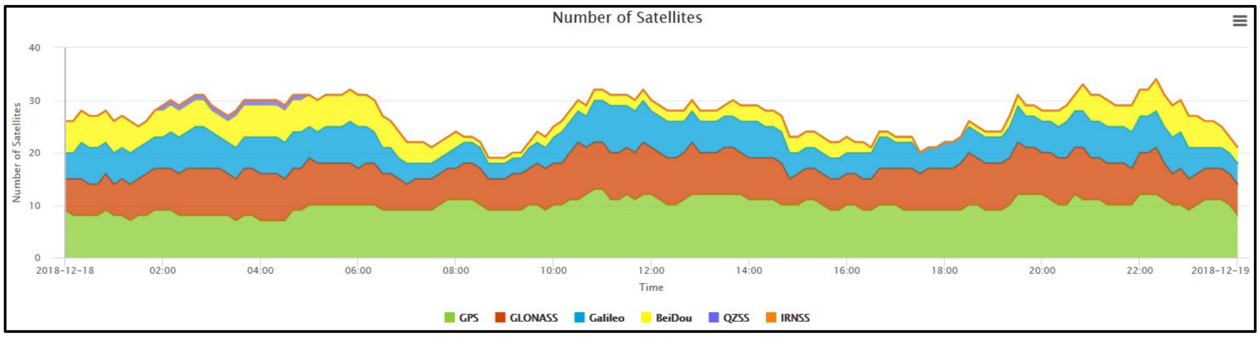


Figure 42. Number of satellites visible with a 5° satellite elevation cutoff and a 2 m antenna height during Initial Monitoring Campaign A for December 18, 2018 from 0000 to 2400 hours using GPS, GLONASS, Galileo, BeiDou, and QZSS satellites (Trimble, 2018).

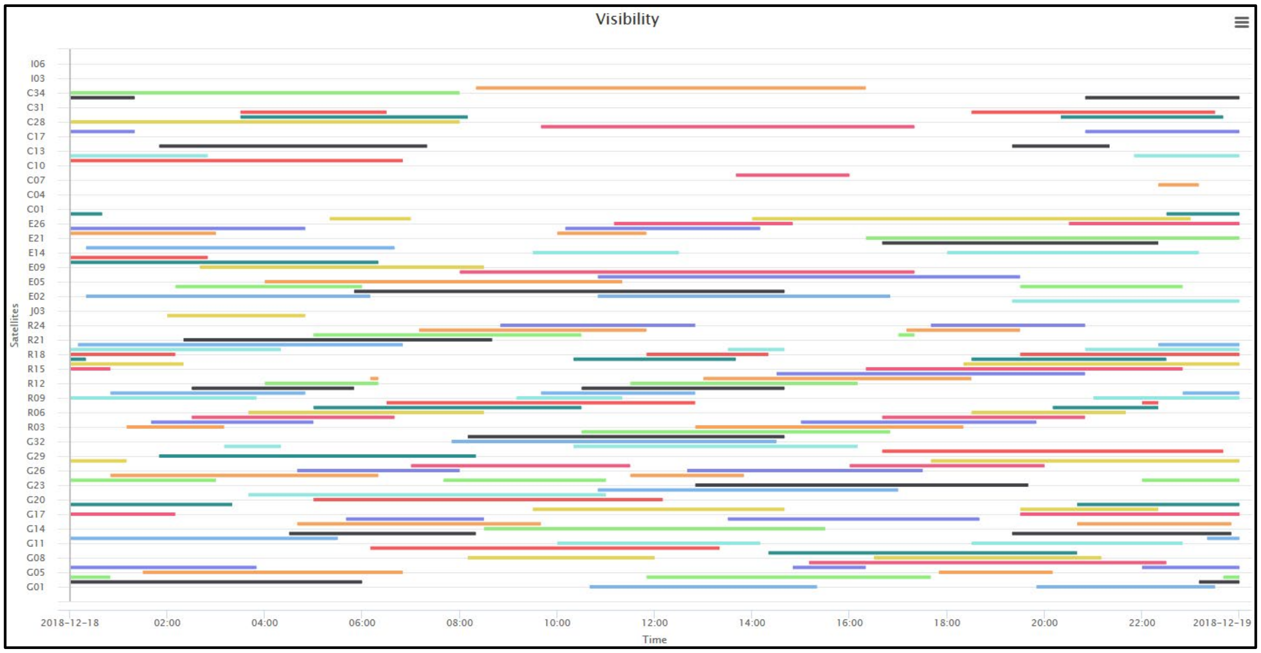


Figure 43. Individual satellite visibility with a 5° satellite elevation cutoff and a 2 m antenna height during Initial Monitoring Campaign A for December 18, 2018 from 0000 to 2400 hours using GPS (Gxx), GLONASS (Rxx), Galileo (Exx), BeiDou (Cxx), and QZSS (Jxx) satellites (Trimble, 2018).

Initial Monitoring Campaign B

Monitoring parameters for the initial monitoring campaign B on March 10 to 12, 2019, are summarized in table 17 with details in figures 44 to 53. During the entire campaign, PDOP, HDOP, VDOP, and Kp values were below threshold values. The Trimble R8 GNSS receivers correctly recorded Galileo signals during this campaign.

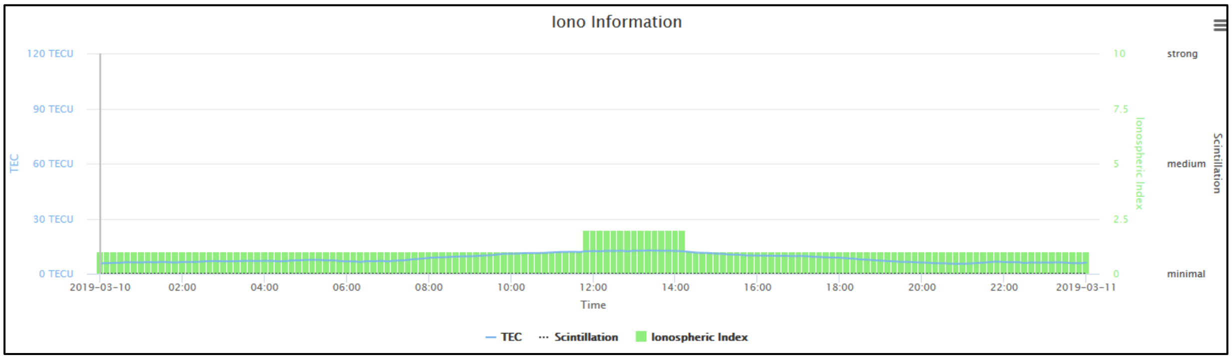
Table 17. *Initial monitoring campaign B GNSS parameters.*

Dilution of Precision			Kp	Tripod Calibration
Precision (PDOP)	Horizontal (HDOP)	Vertical (VDOP)		
1.43 – 1.80	–	–	0 to 3	Yes

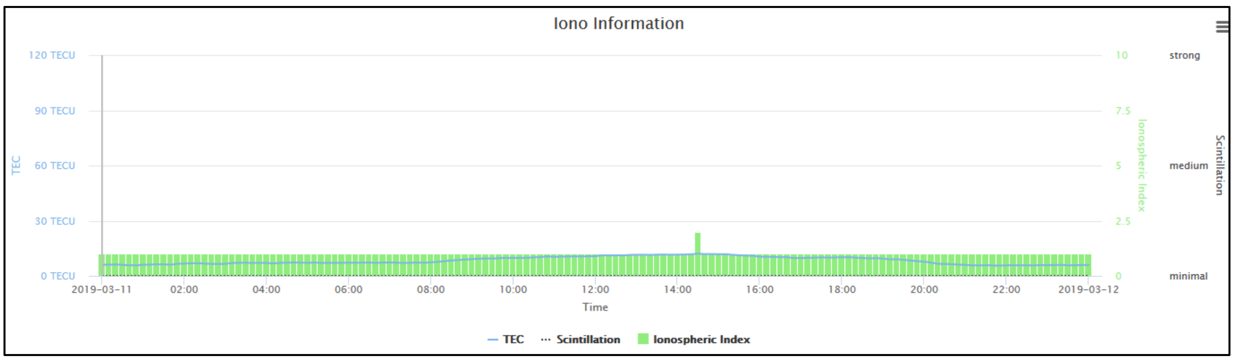
```
Product: Daily Geomagnetic Data          DGD.txt
Issued: 1830 UT 03 Apr 2019

# Prepared by the U.S. Dept. of Commerce, NOAA, Space Weather Prediction Center
# Please send comment and suggestions to SWPC.Webmaster@noaa.gov
#
#                Last 30 Days Daily Geomagnetic Data
#
#                Middle Latitude        High Latitude            Estimated
#              - Fredericksburg -     ---- College ----        --- Planetary ---
#  Date        A     K-indices        A     K-indices          A     K-indices
2019 03 09     4   1 0 1 1 2 2 1 2    7   0 0 1 3 4 2 1 1      5   1 0 1 2 2 1 1 2
2019 03 10     3   2 2 1 0 1 1 1 0    2   0 2 1 1 0 0 0 0      4   2 2 1 0 1 0 1 0
2019 03 11     3   0 0 1 1 2 1 1 1    4   0 0 0 4 2 0 0 0      3   0 0 1 2 1 0 1 0
2019 03 12     5   1 1 3 2 2 1 0 1    9   1 0 4 4 3 1 0 0      7   2 1 3 2 2 1 1 1
2019 03 13     4   1 2 1 0 1 2 2 0    3   1 1 2 2 0 0 1 0      4   1 2 2 1 0 0 2 1
```

Figure 44. Initial monitoring campaign A 3-hour Kp values for March 10 to 12, 2019 (bold text), and the day before and the day after (NOAA, 2019).

A



B



C

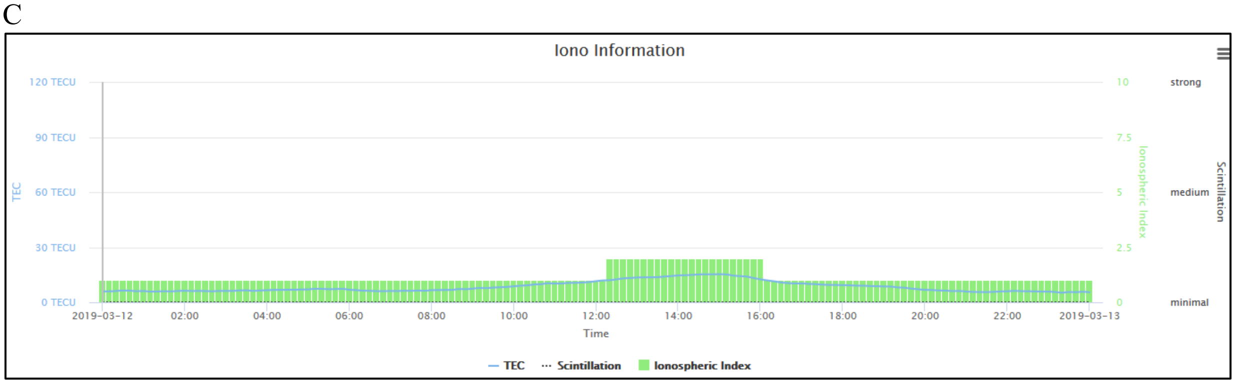
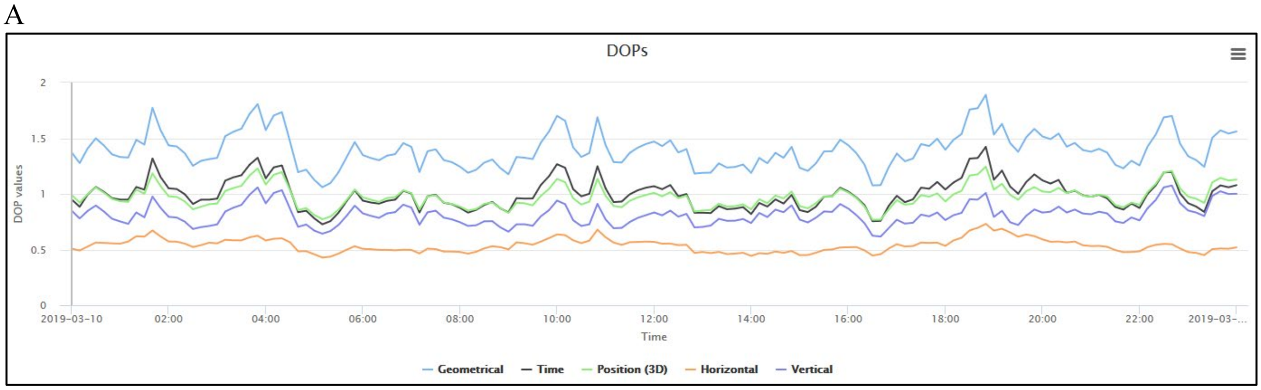


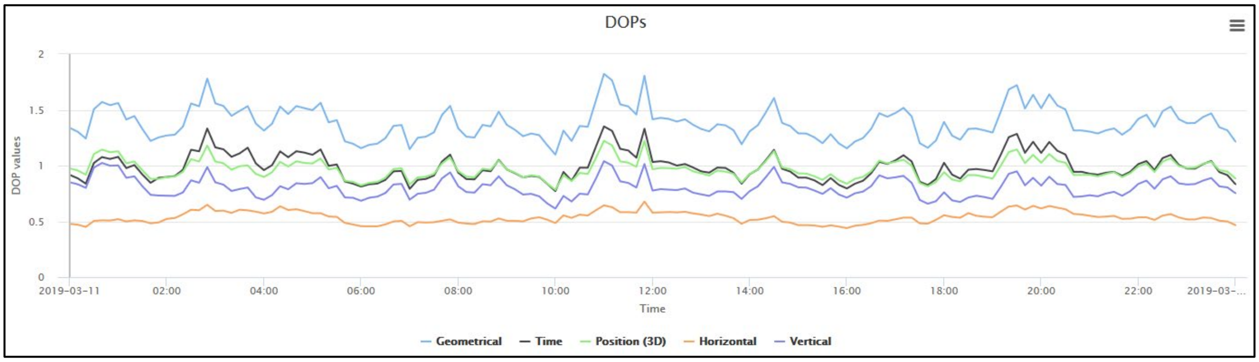
Figure 45. Ionospheric index values during Initial Monitoring Campaign B for March 10 to 12, 2019, panels A to C, respectively (Trimble, 2019).

R8 Receivers

A



B



C

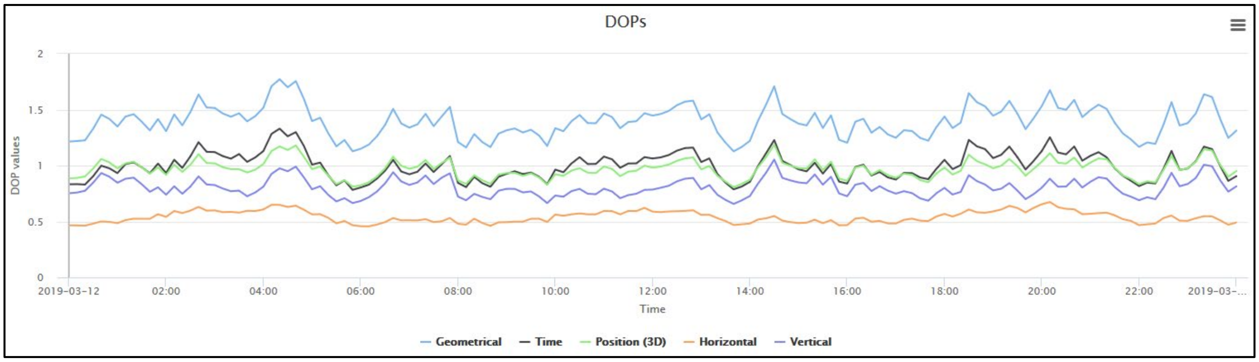
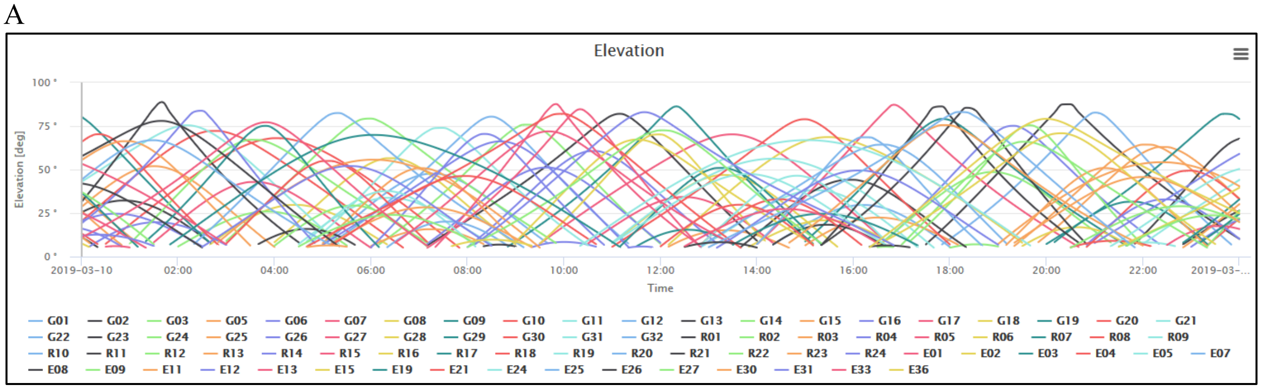
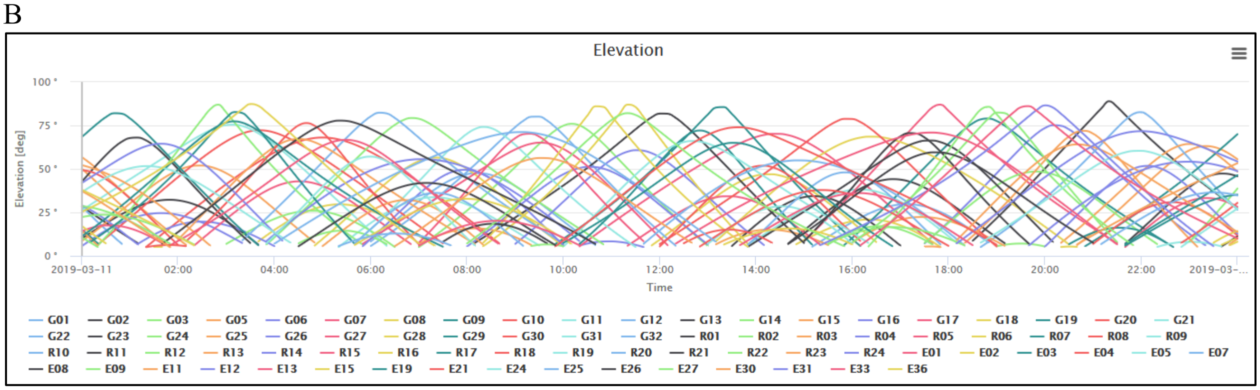


Figure 46. PDOP (green), HDOP (orange), and VDOP (dark blue) values during Initial Monitoring Campaign B for March 10 to 12, 2019, panels A to C, respectively, from 0000 to 2400 hours using GPS, GLONASS, and Galileo satellites (Trimble, 2019).

A



B



C

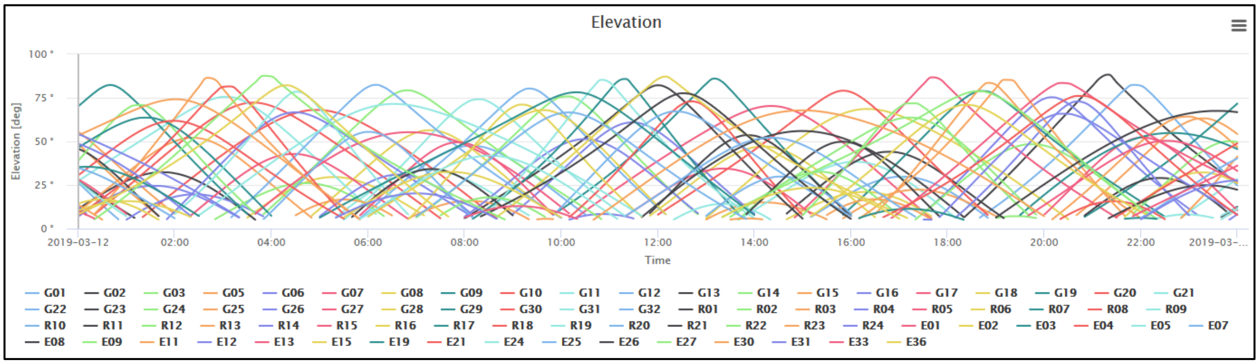
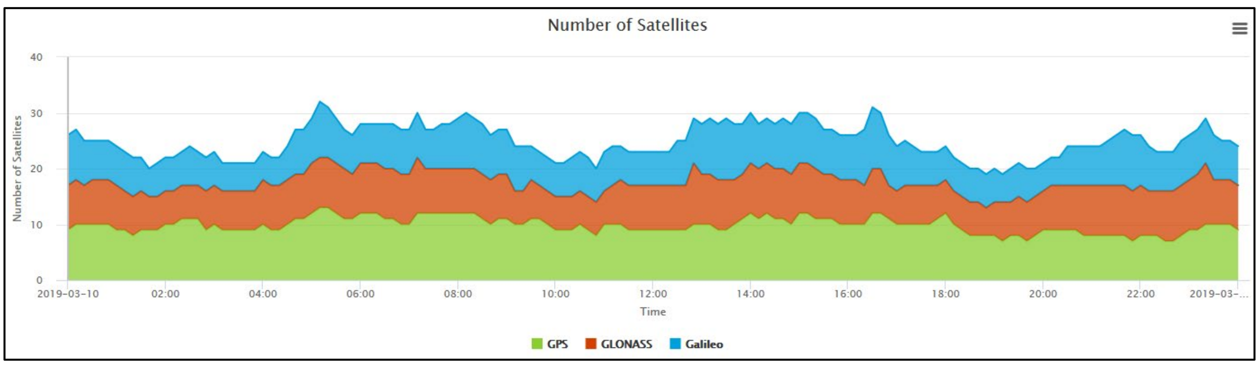
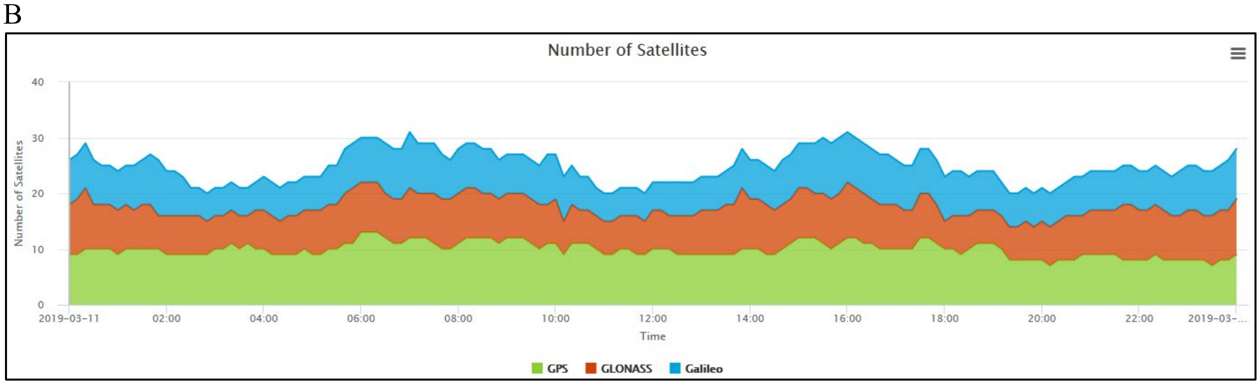


Figure 47. Monitoring line-of-sight satellite tracks and horizon elevations with a 5° satellite elevation cutoff and a 2 m antenna height during Initial Monitoring Campaign B for March 10 to 12, 2019, panels A to C, respectively, from 0000 to 2400 hours using GPS (Gxx), GLONASS (Rxx), and Galileo (Exx) satellites (Trimble, 2019).

A



B



C

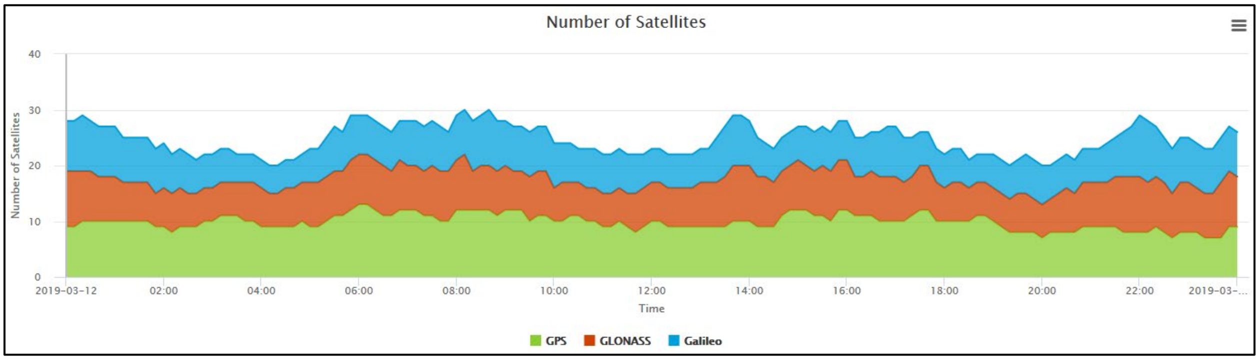
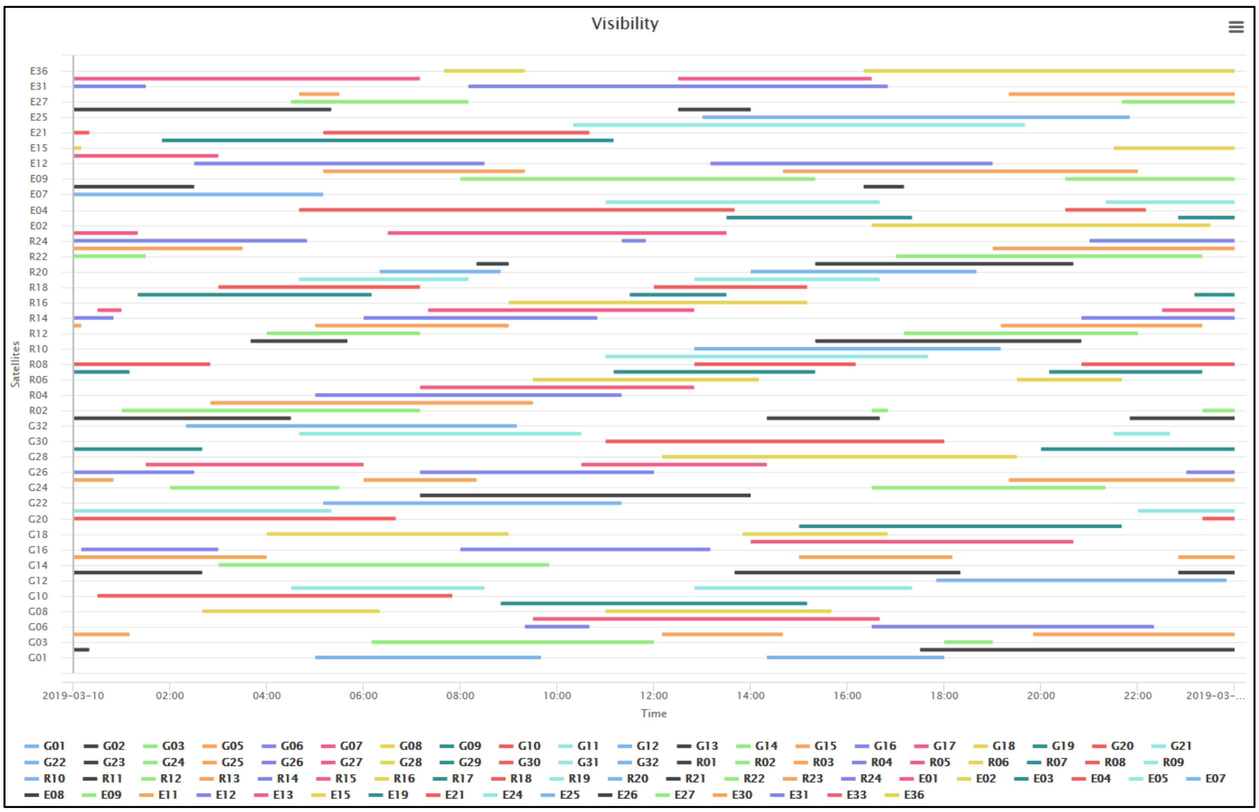
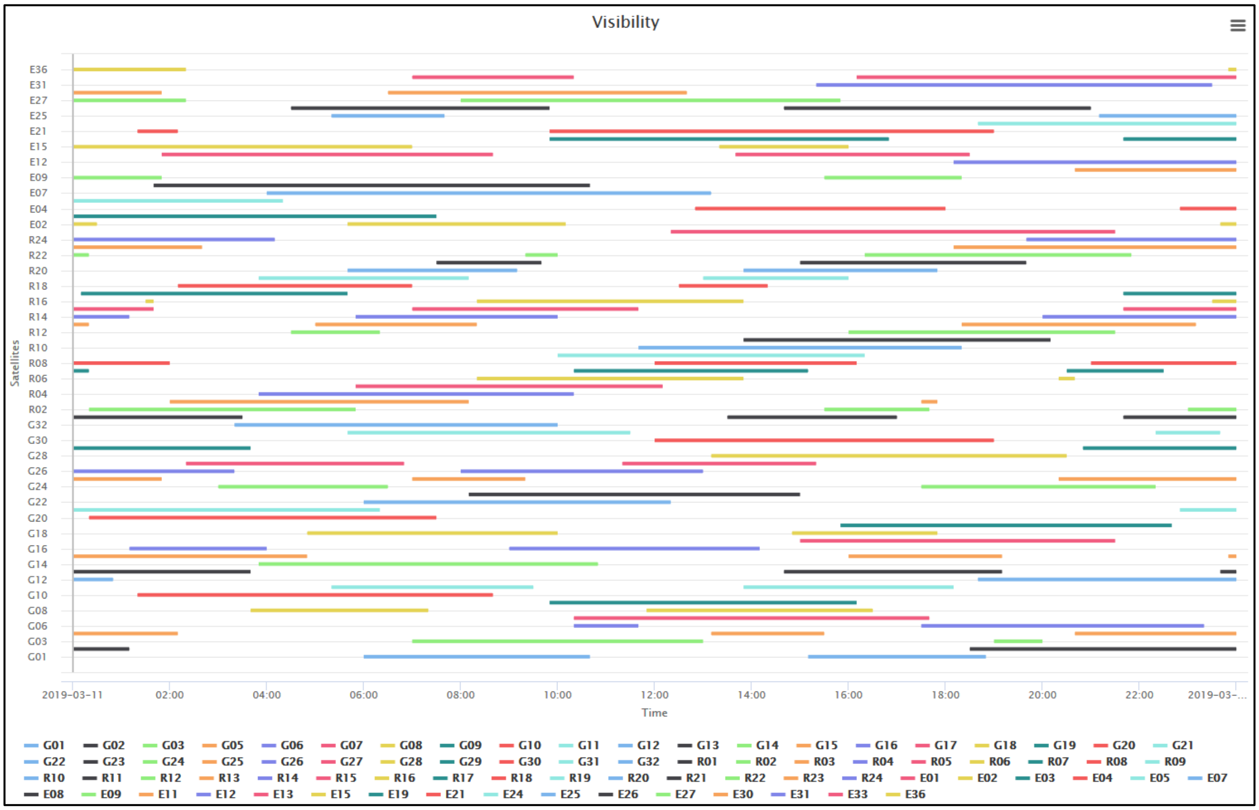


Figure 48. Number of satellites visible with a 5° satellite elevation cutoff and a 2 m antenna height during Initial Monitoring Campaign B for March 10 to 12, 2019, panels A to C, respectively, from 0000 to 2400 hours using GPS, GLONASS, and Galileo satellites (Trimble, 2019).

A



B



Visibility
Satellites
E36
E31
E27
E25
E21
E15
E12
E09
E07
E04
E02
R24
R22
R20
R18
R16
R14
R12
R10
R08
R06
R04
R02
G32
G30
G28
G26
G24
G22
G20
G18
G16
G14
G12
G10
G08
G06
G03
G01
2019-03-11
02:00
04:00
06:00
08:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
2019-03-...
Time
G01 G02 G03 G05 G06 G07 G08 G09 G10 G11 G12 G13 G14 G15 G16 G17 G18 G19 G20 G21
G22 G23 G24 G25 G26 G27 G28 G29 G30 G31 G32 R01 R02 R03 R04 R05 R06 R07 R08 R09
R10 R11 R12 R13 R14 R15 R16 R17 R18 R19 R20 R21 R22 R23 R24 E01 E02 E03 E04 E05 E07
E08 E09 E11 E12 E13 E15 E19 E21 E24 E25 E26 E27 E30 E31 E33 E36

C

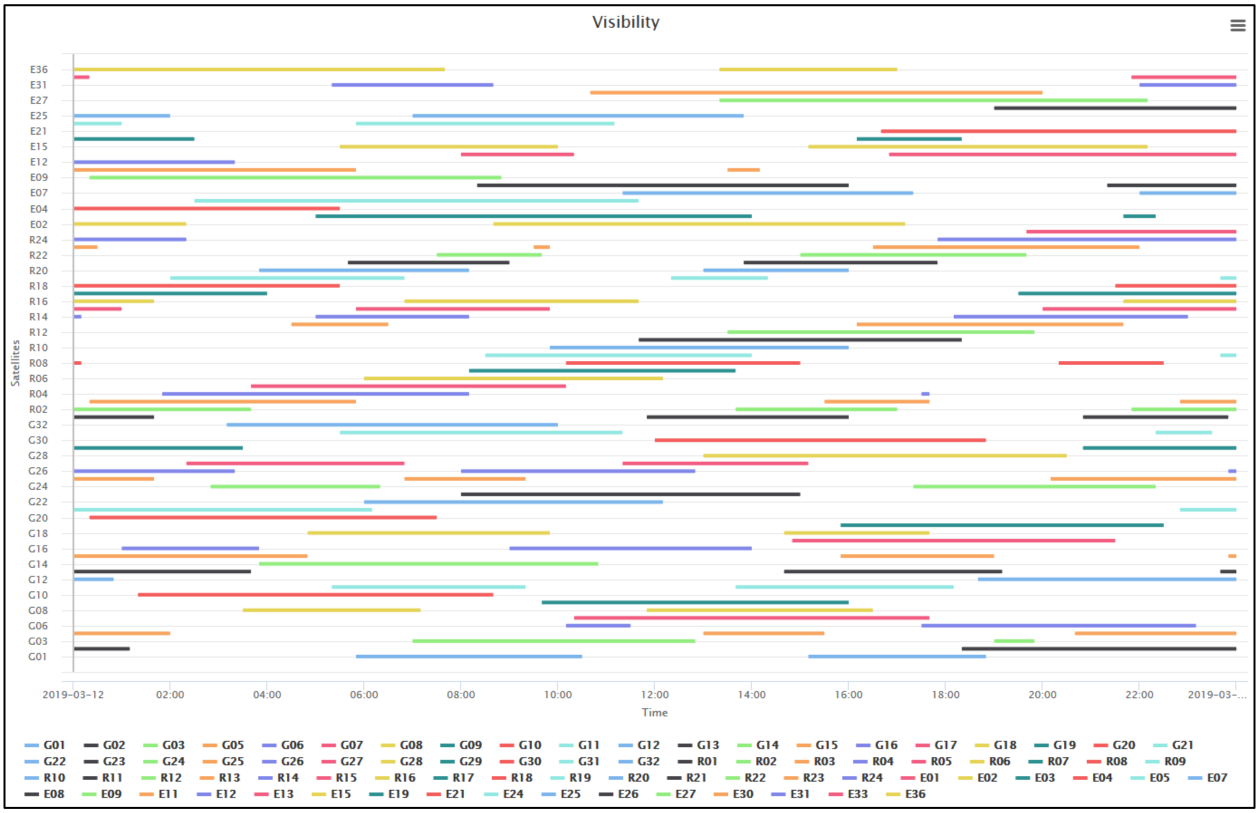
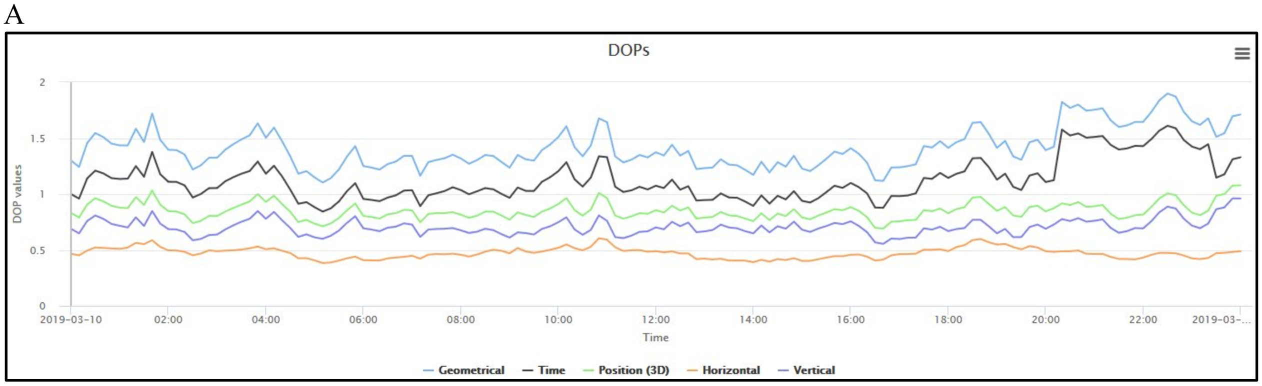


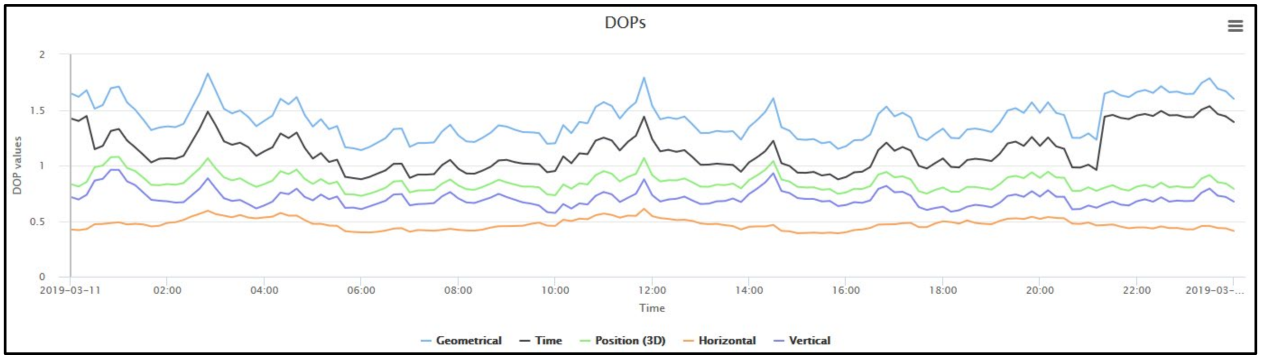
Figure 49. Individual satellite visibility with a 5° satellite elevation cutoff and a 2 m antenna height during Initial Monitoring Campaign B for March 10 to 12, 2019, panels A to C, respectively, from 0000 to 2400 hours using GPS (Gxx), GLONASS (Rxx), and Galileo (Exx) satellites (Trimble, 2019).

R10 and Alloy Receivers

A



B



C

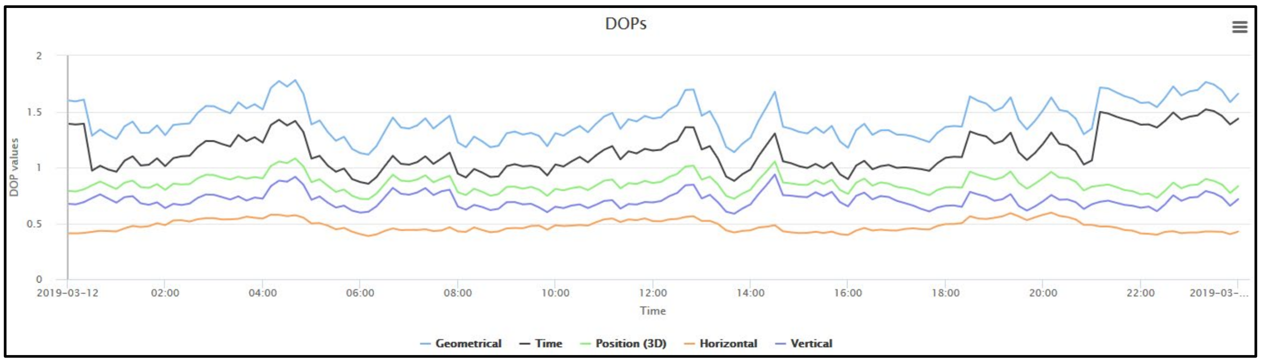
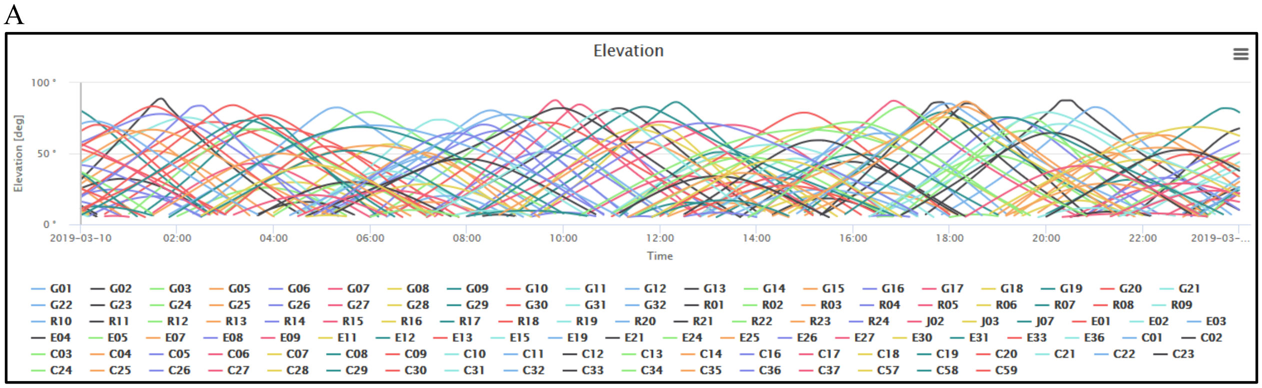
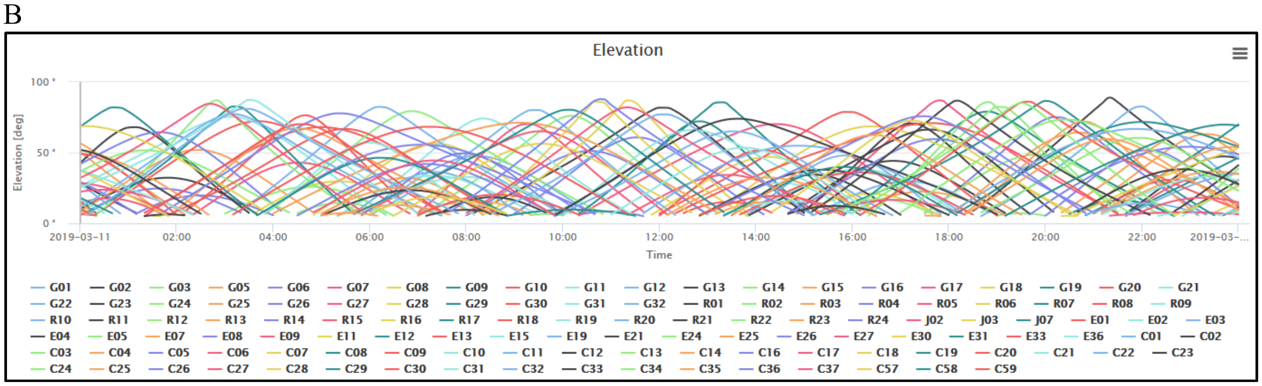


Figure 50. PDOP (green), HDOP (orange), and VDOP (dark blue) values during Initial Monitoring Campaign B for March 10 to 12, 2019, panels A to C, respectively, from 0000 to 2400 hours using GPS, GLONASS, Galileo, BeiDou, and QZSS satellites (Trimble, 2019).

A



B



C

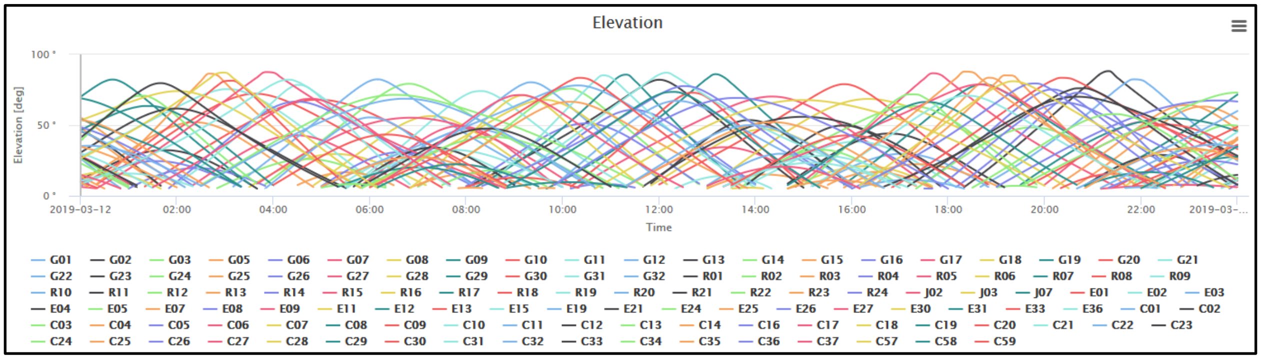
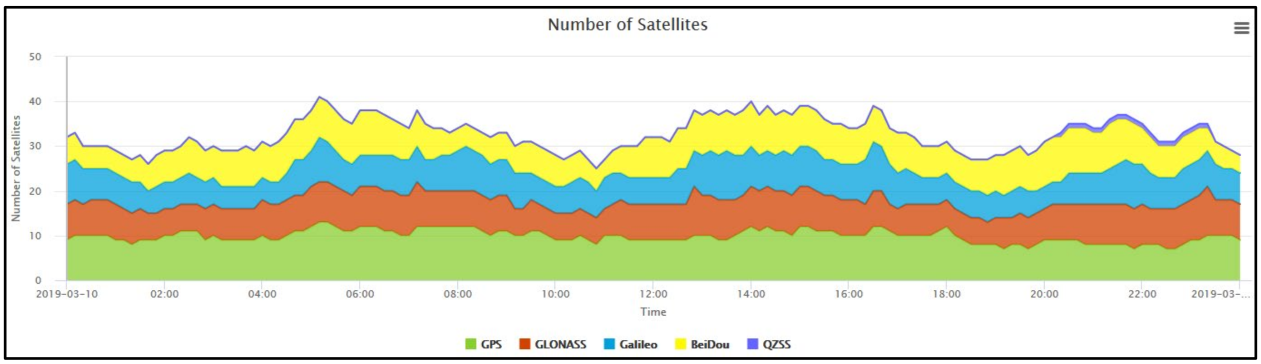
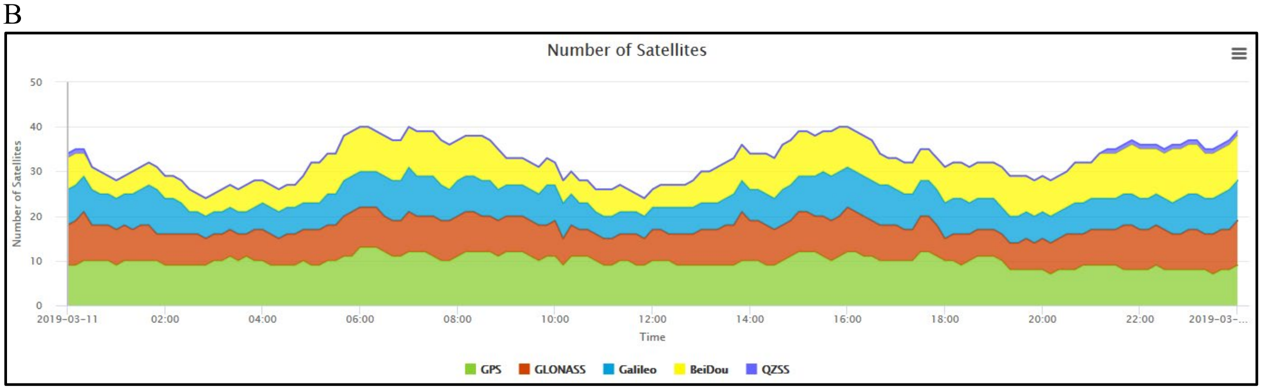


Figure 51. Monitoring line-of-sight satellite tracks and horizon elevations with a 5° satellite elevation cutoff and a 2 m antenna height during Initial Monitoring Campaign B for March 10 to 12, 2019, panels A to C, respectively, from 0000 to 2400 hours using GPS (Gxx), GLONASS (Rxx), Galileo (Exx), BeiDou (Cxx), and QZSS (Jxx) satellites (Trimble, 2019).

A



B



C

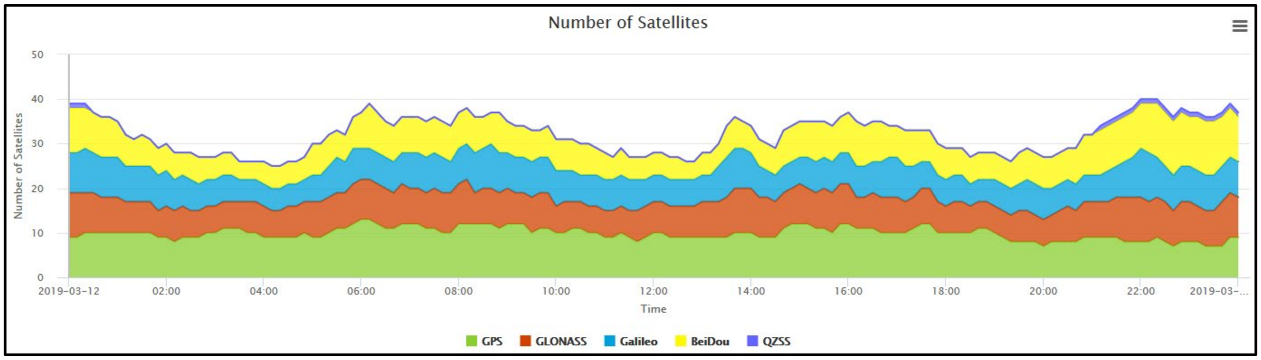
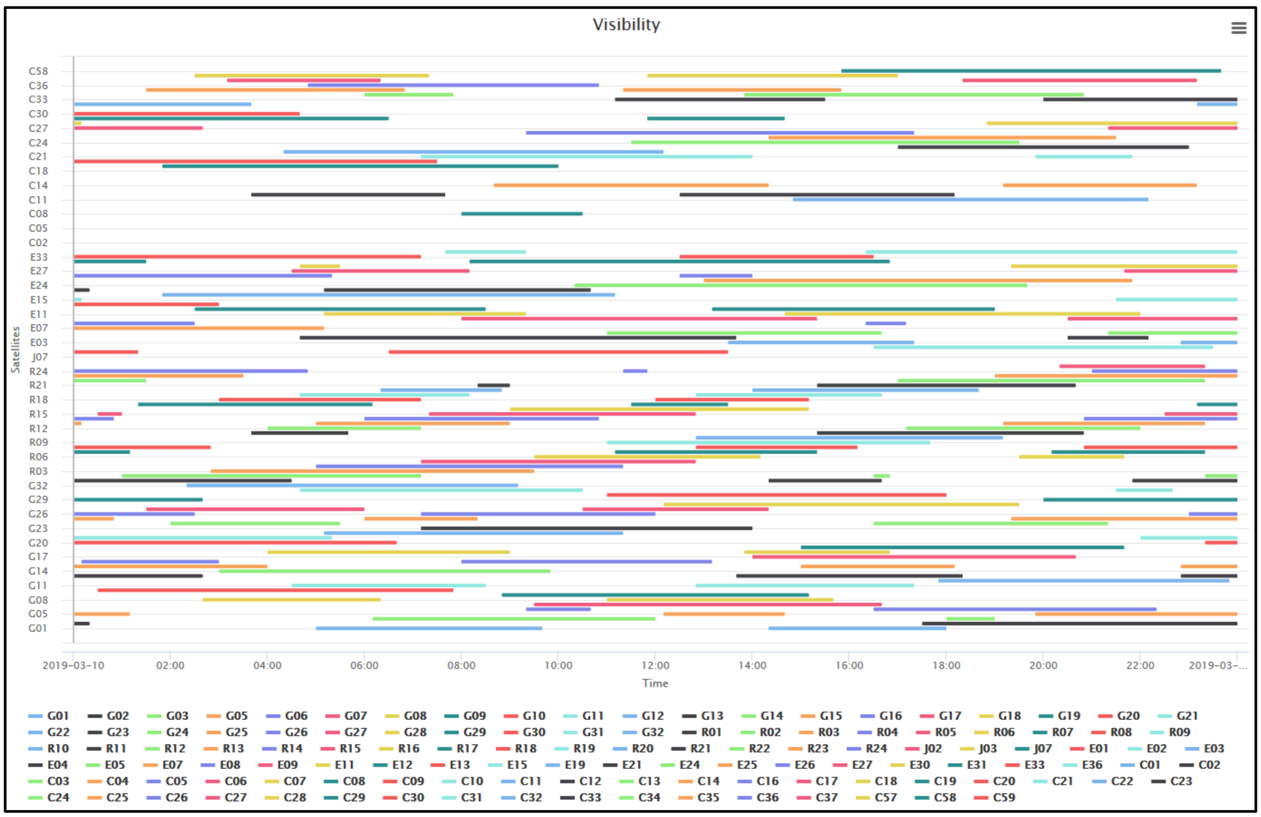
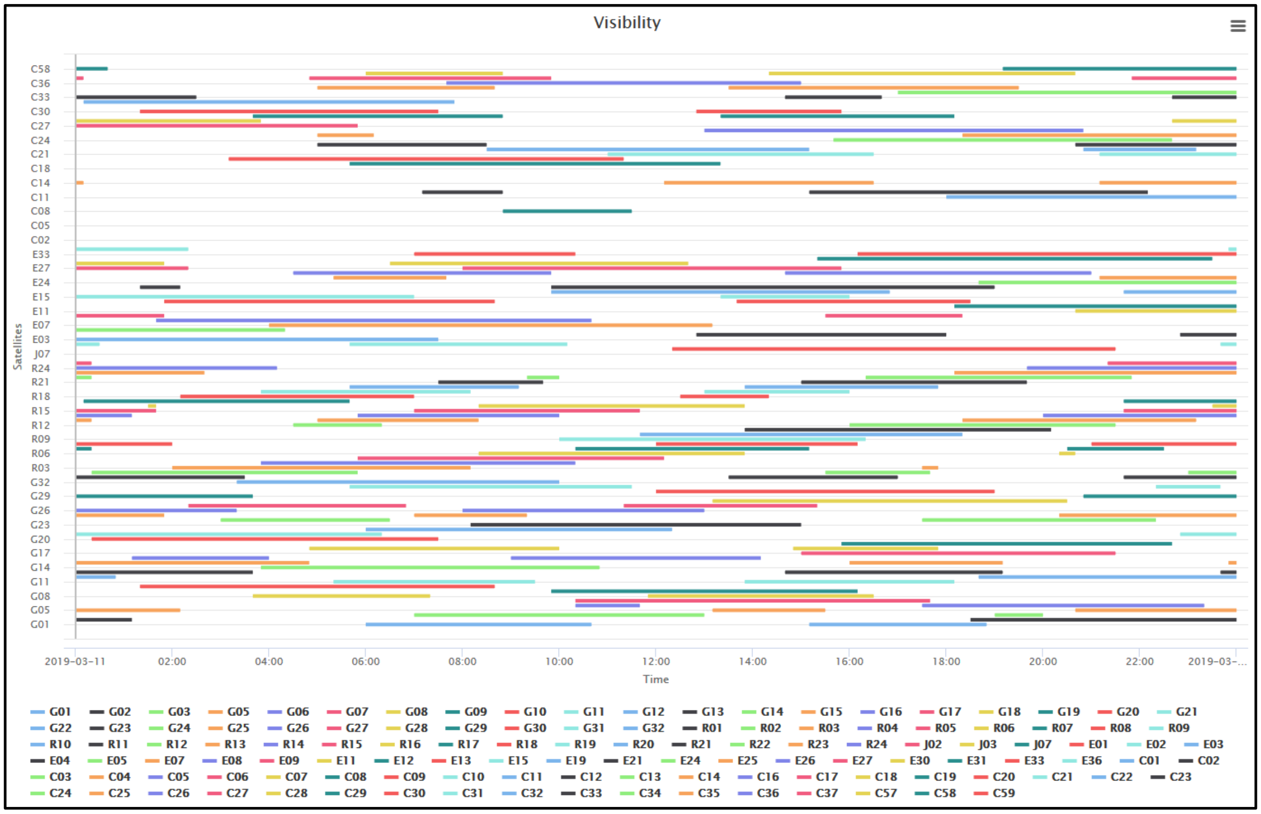


Figure 52. Number of satellites visible with a 5° satellite elevation cutoff and a 2 m antenna height during Initial Monitoring Campaign B for March 10 to 12, 2019, panels A to C, respectively, from 0000 to 2400 hours using GPS, GLONASS, Galileo, BeiDou, and QZSS satellites (Trimble, 2019).

A



B



Visibility
Satellites
Time
2019-03-11
02:00
04:00
06:00
08:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00

C

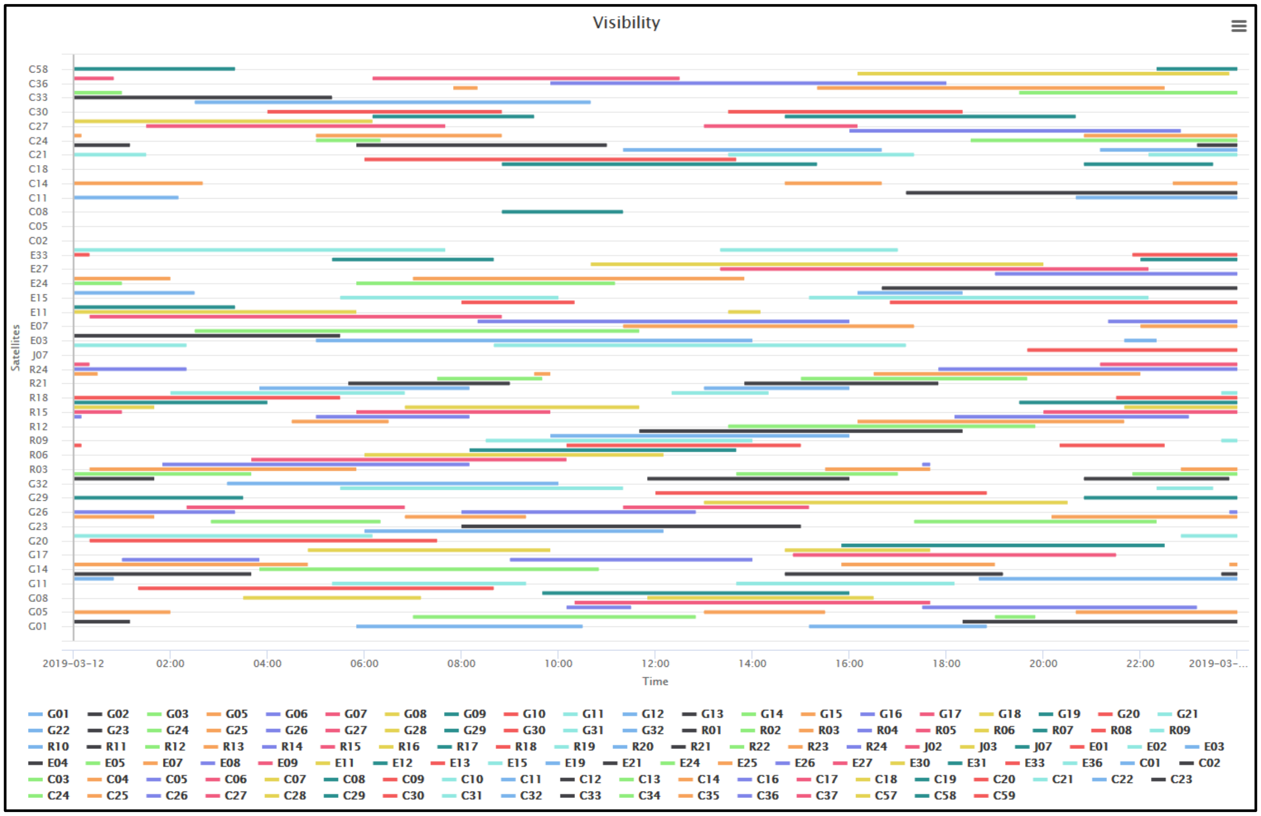


Figure 53. Individual satellite visibility with a 5° satellite elevation cutoff and a 2 m antenna height during Initial Monitoring Campaign B for March 10 to 12, 2019, panels A to C, respectively, from 0000 to 2400 hours using GPS (Gxx), GLONASS (Rxx), Galileo (Exx), BeiDou (Cxx), and QZSS (Jxx) satellites (Trimble, 2019).

Monitoring Campaign 1

Monitoring parameters for monitoring campaign 1 on April 30, 2019, are summarized in table 18 with details in figures 54 to 63. During the entire campaign, PDOP, HDOP, VDOP, and Kp values were below threshold values. The Trimble R8 GNSS receivers correctly recorded Galileo signals during this campaign.

Table 18. *Monitoring campaign 1 GNSS parameters.*

Dilution of Precision			Kp	Tripod Calibration
Precision (PDOP)	Horizontal (HDOP)	Vertical (VDOP)		
1.182 – 1.752	--	--	0 to 2	Yes

```
Product: Daily Geomagnetic Data      quar_DGD.txt
Issued: 2130 UT 07 Jul 2019
#
#  Prepared by the U.S. Dept. of Commerce, NOAA, Space Weather Prediction Center
#  Please send comment and suggestions to SWPC.Webmaster@noaa.gov
#
#              Current Quarter Daily Geomagnetic Data
#
#                 Middle Latitude        High Latitude             Estimated
#               - Fredericksburg -     ---- College ----       --- Planetary ---
#  Date          A     K-indices        A     K-indices          A     K-indices
2019 04 29      6   2 2 0 1 3 2 1 1    3   1 1 0 1 2 2 0 0      5   2 2 0 1 1 2 1 1
2019 04 30      4   1 1 0 1 3 1 1 1    5   1 1 0 1 3 2 1 1      5   2 1 0 1 2 1 2 1
2019 05 01      8   0 2 2 1 3 1 3 3   10   1 2 2 3 3 2 2 3     11   1 2 2 2 2 2 3 4
```
Figure 54. 3-hour Kp values during Monitoring Campaign 1 for April 30, 2019 (bold text), and the day before and the day after (NOAA, 2019).

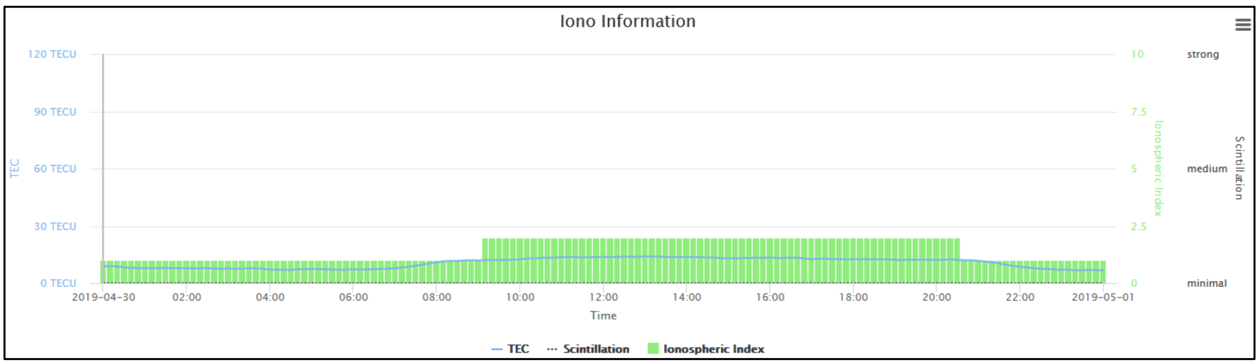


Figure 55. Ionospheric index values during Monitoring Campaign 1 for April 30, 2019 (Trimble, 2019).

R8 Receivers

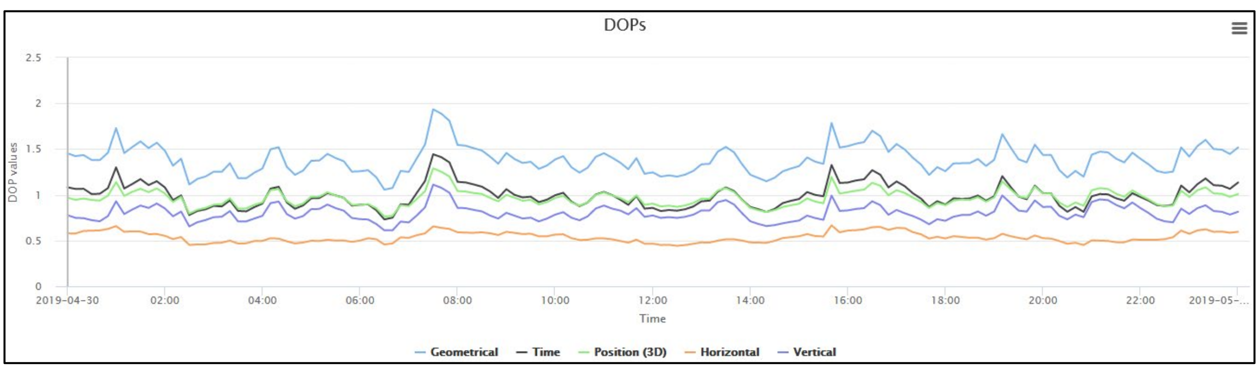


Figure 56. PDOP (green), HDOP (orange), and VDOP (dark blue) values during Monitoring Campaign 1 for April 30, 2019, from 0000 to 2400 hours using GPS, GLONASS, and Galileo satellites (Trimble, 2019).

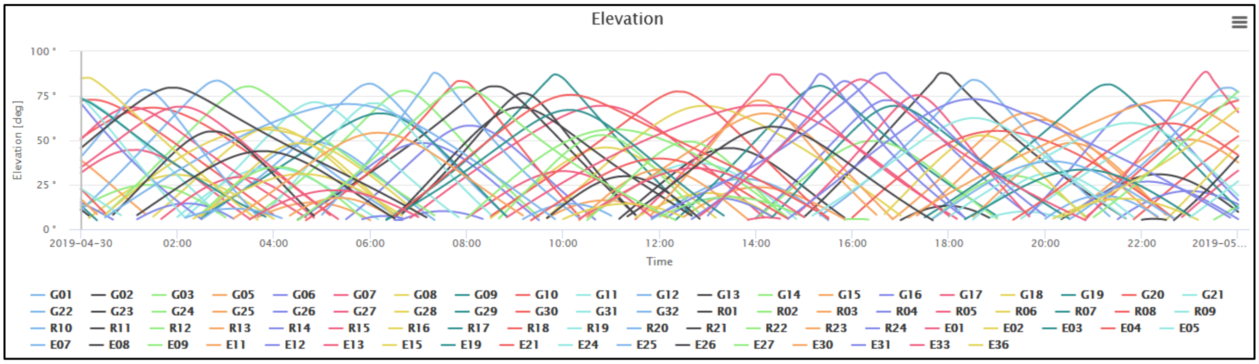


Figure 57. Monitoring line-of-sight satellite tracks and horizon elevations with a 5° satellite elevation cutoff and a 2 m antenna height during Monitoring Campaign 1 for April 30, 2019, from 0000 to 2400 hours using GPS (Gxx), GLONASS (Rxx), and Galileo (Exx) satellites (Trimble, 2019).

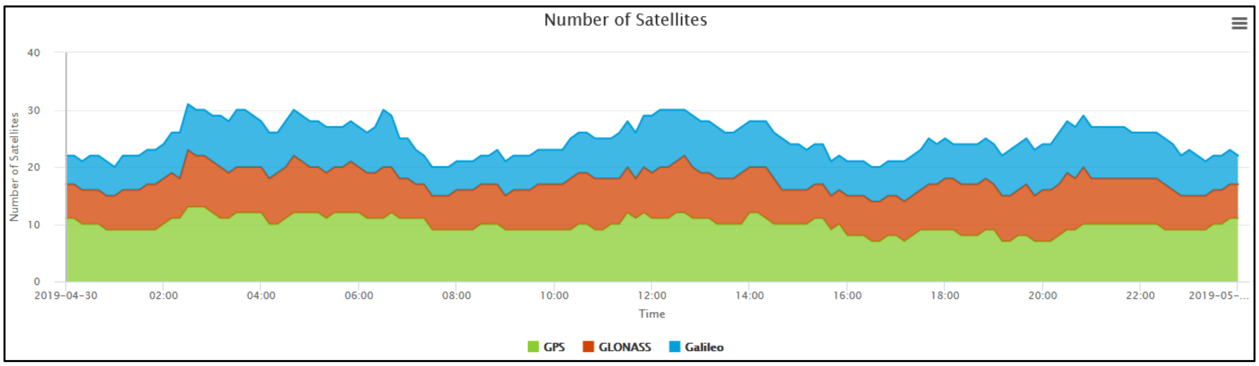


Figure 58. Number of satellites visible with a 5° satellite elevation cutoff and a 2 m antenna height during Monitoring Campaign 1 for April 30, 2019, from 0000 to 2400 hours using GPS, GLONASS, and Galileo satellites (Trimble, 2019).

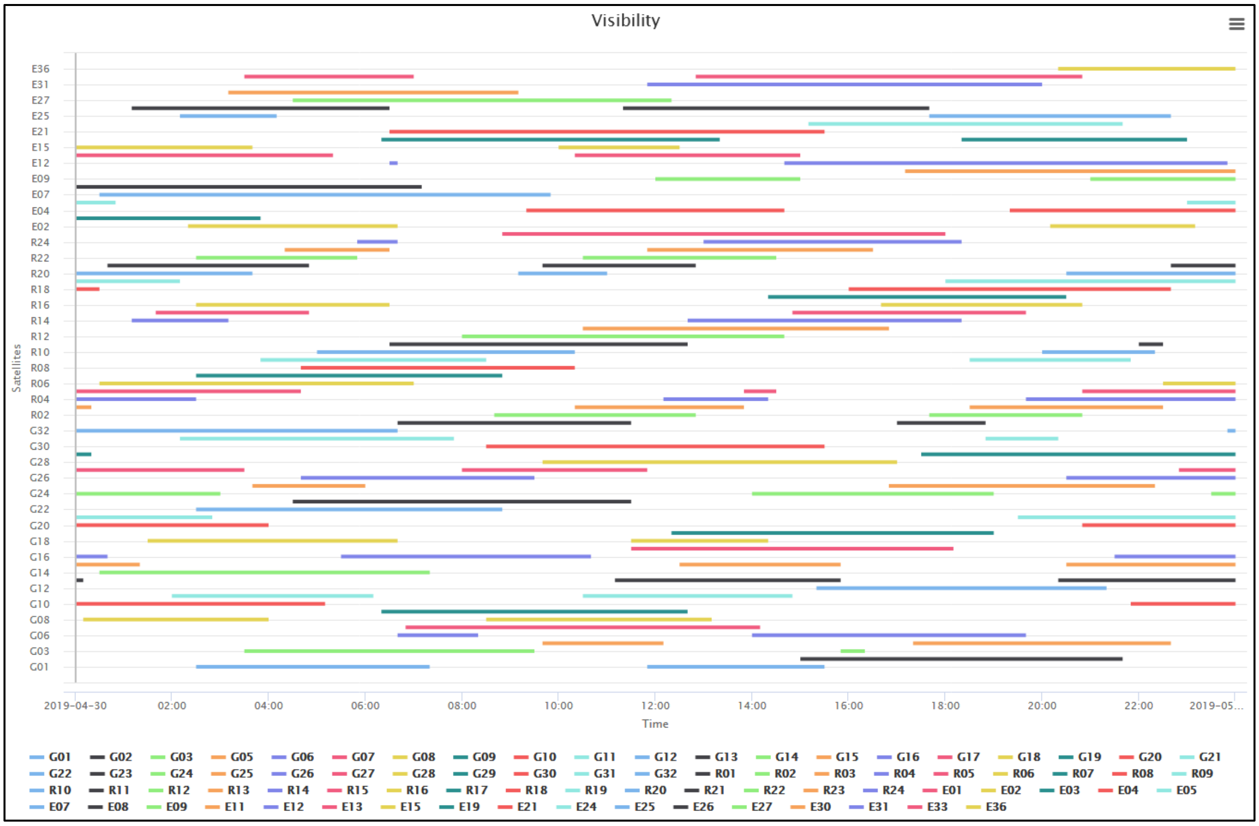


Figure 59. Individual satellite visibility with a 5° satellite elevation cutoff and a 2 m antenna height during Monitoring Campaign 1 for April 30, 2019, panels A to C, respectively, from to 2400 hours using GPS (Gxx), GLONASS (Rxx), and Galileo (Exx) satellites (Trimble, 2019).

R10 and Alloy Receivers

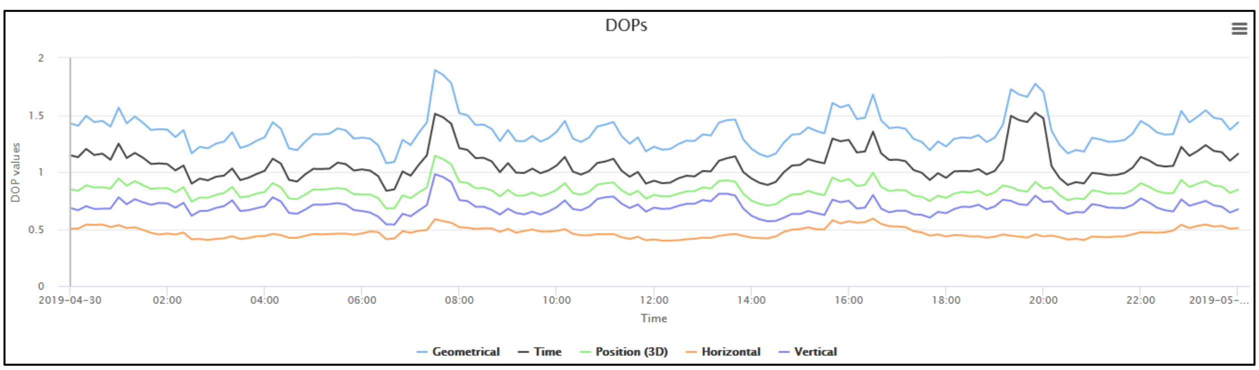


Figure 60. PDOP (green), HDOP (orange), and VDOP (dark blue) values during Monitoring Campaign 1 for April 30, 2019, from 0000 to 2400 hours using GPS, GLONASS, Galileo, BeiDou, and QZSS satellites (Trimble, 2019).

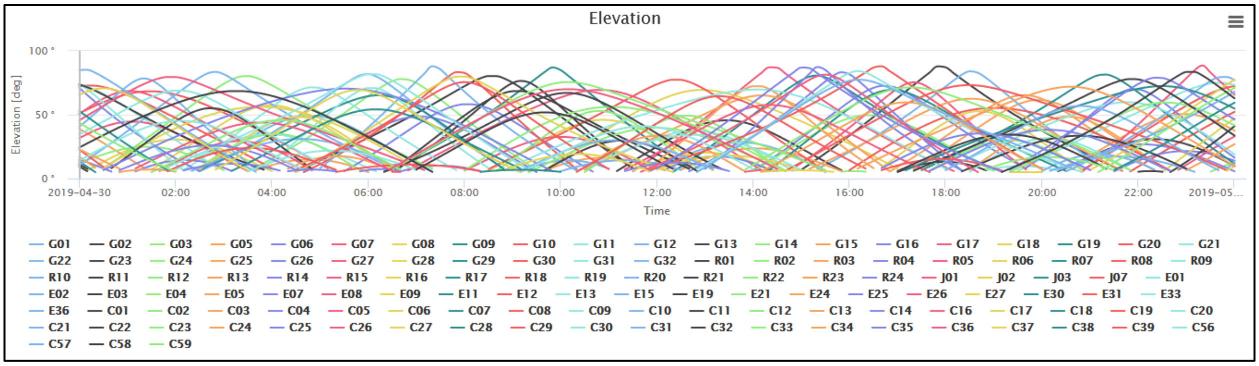


Figure 61. Monitoring line-of-sight satellite tracks and horizon elevations with a 5° satellite elevation cutoff and a 2 m antenna height during Monitoring Campaign 1 for April 30, 2019, from 0000 to 2400 hours using GPS (Gxx), GLONASS (Rxx), Galileo (Exx), BeiDou (Cxx), and QZSS (Jxx) satellites (Trimble, 2019).

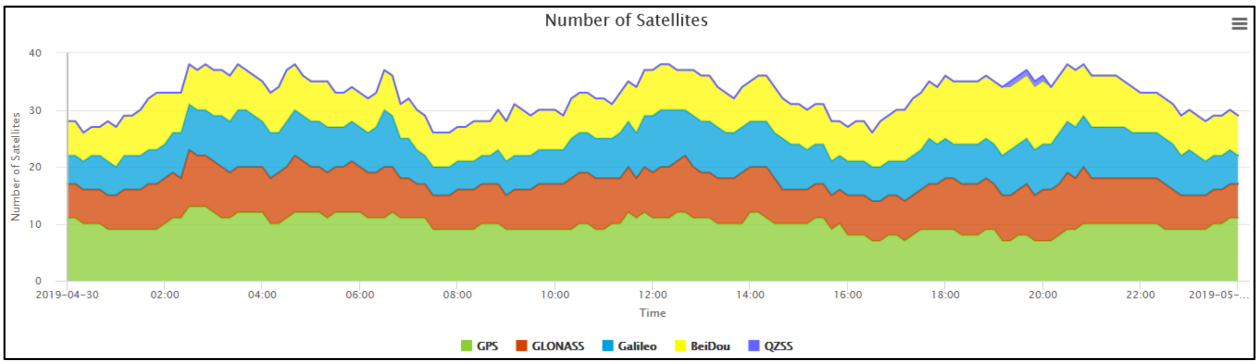


Figure 62. Number of satellites visible with a 5° satellite elevation cutoff and a 2 m antenna height during Monitoring Campaign 1 for April 30, 2019, from 0000 to 2400 hours using GPS, GLONASS, Galileo, BeiDou, and QZSS satellites (Trimble, 2019).

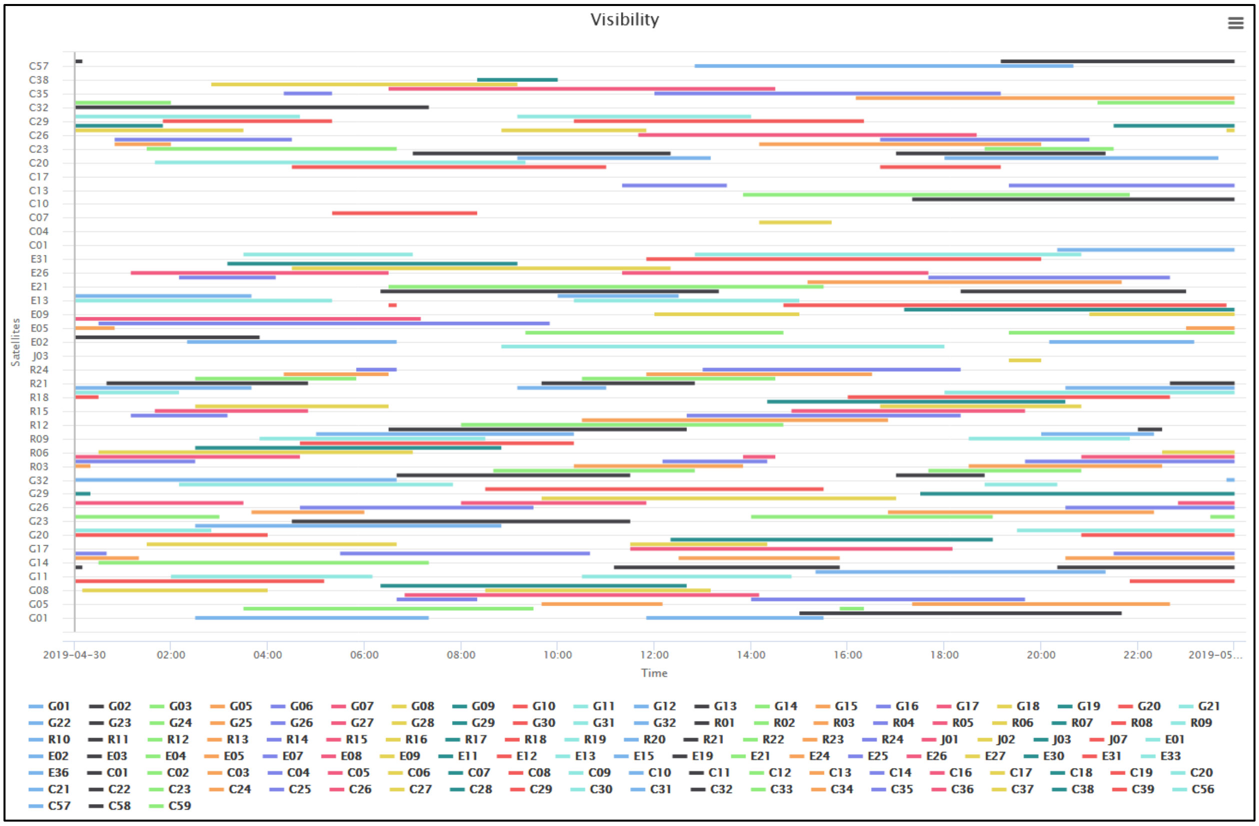


Figure 63. Individual satellite visibility with a 5° satellite elevation cutoff and a 2 m antenna height during Monitoring Campaign 1 for April 30, 2019, from 0000 to 2400 hours using GPS (Gxx), GLONASS (Rxx), Galileo (Exx), BeiDou (Cxx), and QZSS (Jxx) satellites (Trimble, 2019).

Monitoring Campaign 2

Monitoring parameters for monitoring campaign 2 on June 4, 2019, are summarized in table 19 with details in figures 64 to 73. During the entire campaign, PDOP, HDOP, VDOP, and Kp values were below threshold values. The Trimble R8 GNSS receivers correctly recorded Galileo signals during this campaign.

Table 19. *Monitoring campaign 2 GNSS parameters.*

Dilution of Precision			Kp	Tripod Calibration
Precision (PDOP)	**Horizontal (HDOP)**	**Vertical (VDOP)**		
1.30 – 1.94	--	--	2	Yes

```
Product: Daily Geomagnetic Data     quar_DGD.txt
Issued: 2130 UT 07 Jul 2019
#
#  Prepared by the U.S. Dept. of Commerce, NOAA, Space Weather Prediction Center
#  Please send comment and suggestions to SWPC.Webmaster@noaa.gov
#
#              Current Quarter Daily Geomagnetic Data
#
#                 Middle Latitude        High Latitude            Estimated
#               - Fredericksburg -     ---- College ----      --- Planetary ---
#  Date         A     K-indices        A     K-indices        A     K-indices
2019 06 03      5  1 0 1 2 2 2 2 2     3  1 0 0 2 2 1 0 1     4  1 1 0 2 1 1 1 1
2019 06 04      8  2 1 2 2 2 2 3 2    11  2 2 4 3 2 3 2 1     7  2 2 2 2 2 2 2 2
2019 06 05      5  2 1 1 1 2 1 2 1     2  2 1 1 1 0 0 0 0     4  2 1 1 0 1 1 1 1
```
Figure 64. 3-hour Kp values during Monitoring Campaign 2 for June 4, 2019 (bold text), and the day before and the day after (NOAA, 2019).

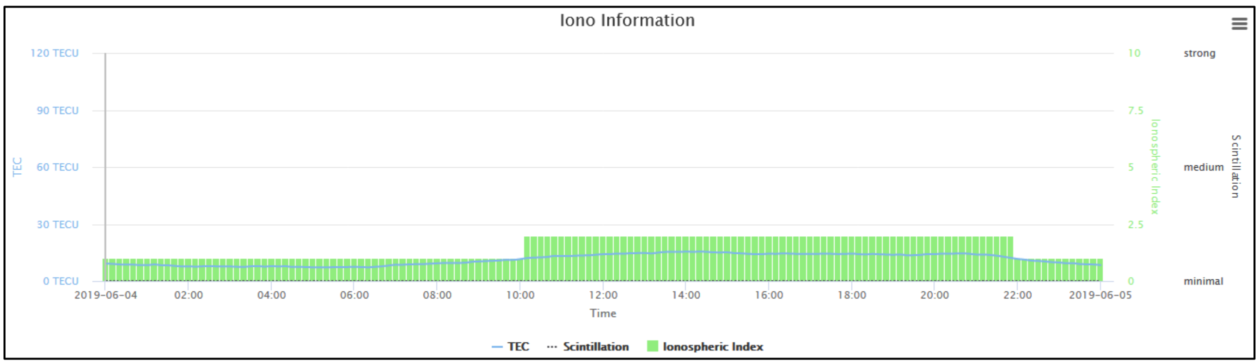


Figure 65. Ionospheric index values during Monitoring Campaign 2 for June 4, 2019 (Trimble, 2019).

R8 Receivers

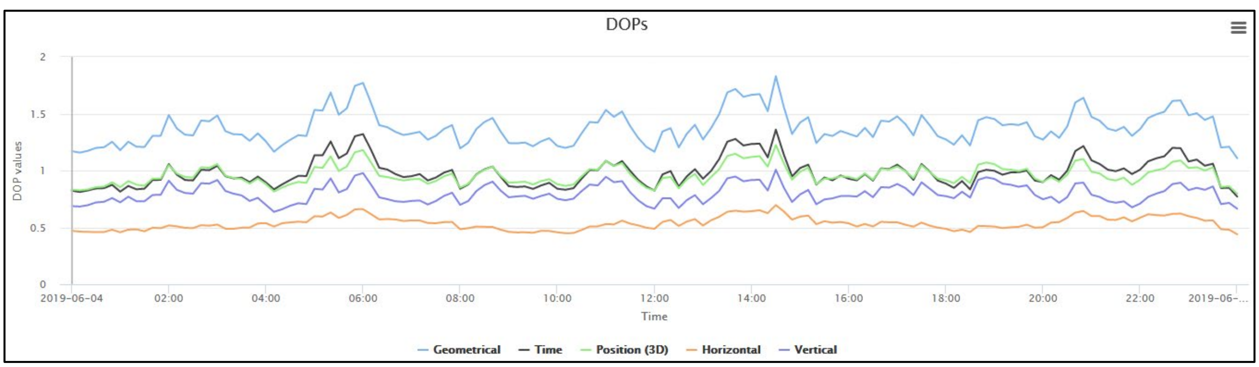


Figure 66. PDOP (green), HDOP (orange), and VDOP (dark blue) values during Monitoring Campaign 2 for June 4, 2019, from 0000 to 2400 hours using GPS, GLONASS, and Galileo satellites (Trimble, 2019).

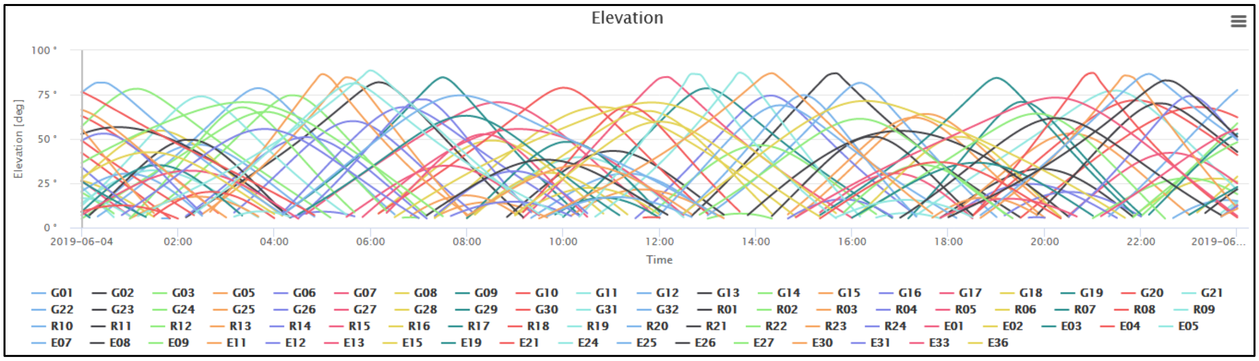


Figure 67. Monitoring line-of-sight satellite tracks and horizon elevations with a 5° satellite elevation cutoff and a 2 m antenna height during Monitoring Campaign 2 for June 4, 2019, from 0000 to 2400 hours using GPS (Gxx), GLONASS (Rxx), and Galileo (Exx) satellites (Trimble, 2019).

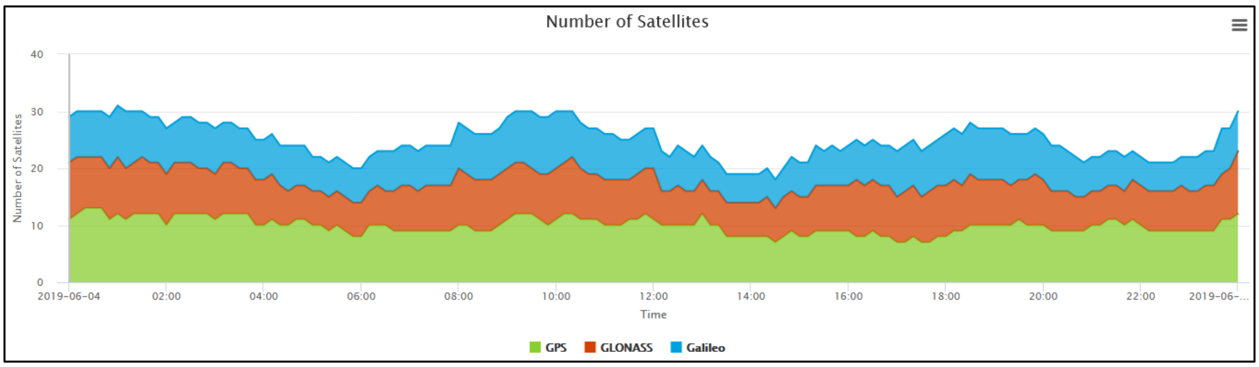


Figure 68. Number of satellites visible with a 5° satellite elevation cutoff and a 2 m antenna height during Monitoring Campaign 2 for June 4, 2019, from 0000 to 2400 hours using GPS, GLONASS, and Galileo satellites (Trimble, 2019).

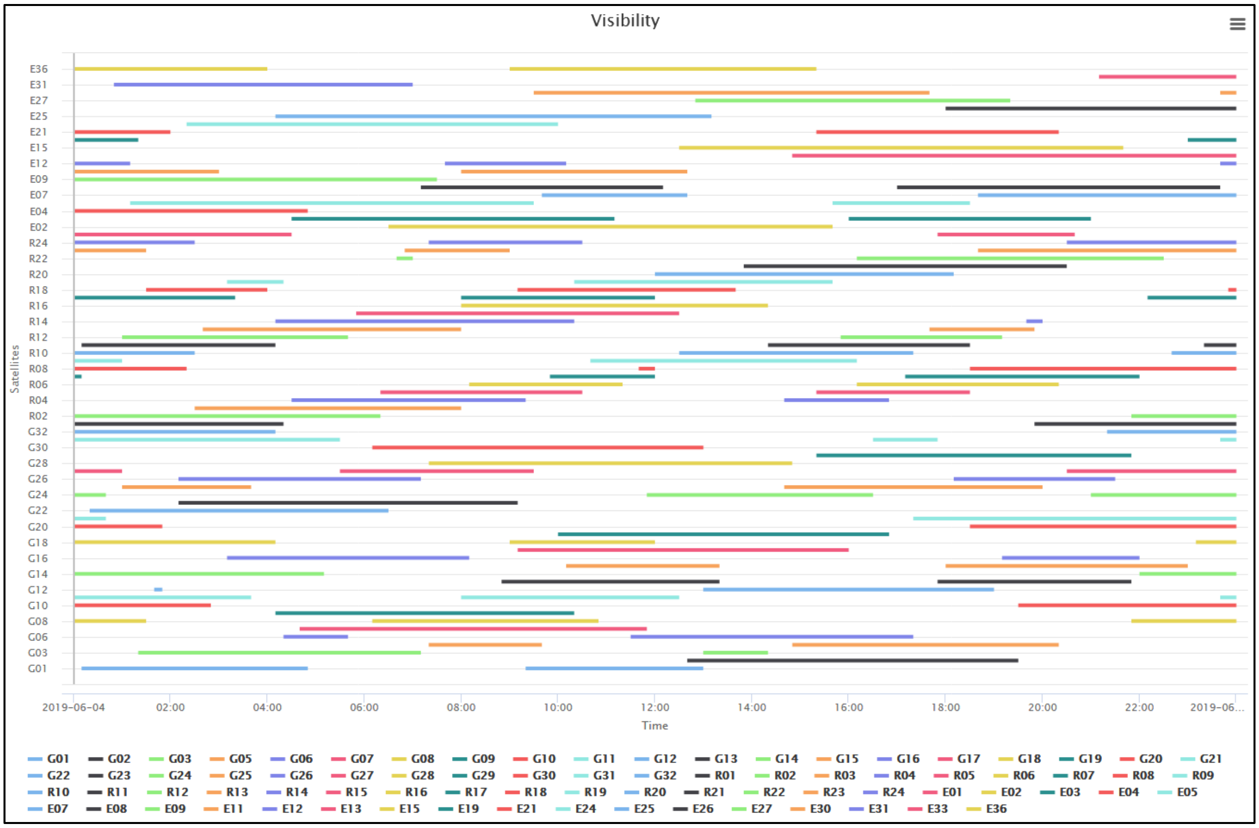


Figure 69. Individual satellite visibility with a 5° satellite elevation cutoff and a 2 m antenna height during Monitoring Campaign 2 for June 4, 2019, from to 2400 hours using GPS (Gxx), GLONASS (Rxx), and Galileo (Exx) satellites (Trimble, 2019).

R10 and Alloy Receivers

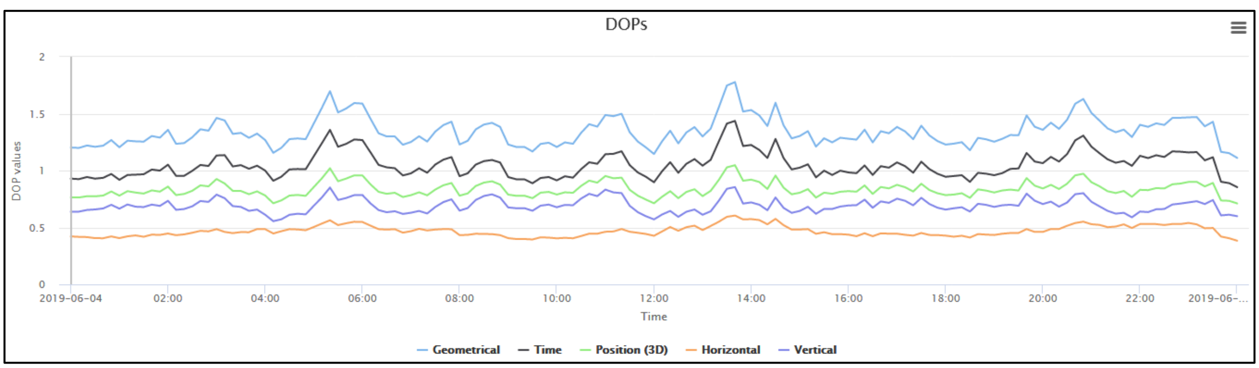


Figure 70. PDOP (green), HDOP (orange), and VDOP (dark blue) values Monitoring Campaign 2 for June 4, 2019, from 0000 to 2400 hours using GPS, GLONASS, Galileo, BeiDou, and QZSS satellites (Trimble, 2019).

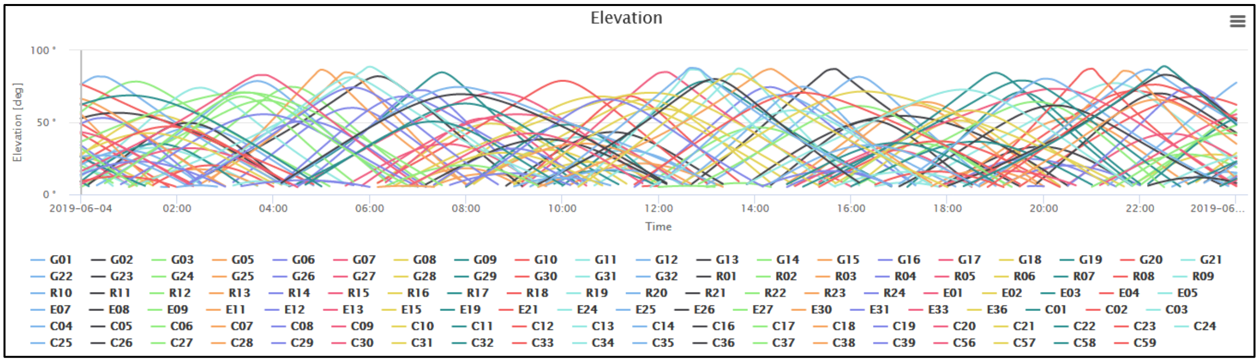


Figure 71. Monitoring line-of-sight satellite tracks and horizon elevations with a 5° satellite elevation cutoff and a 2 m antenna height during Monitoring Campaign 2 for June 4, 2019, from 0000 to 2400 hours using GPS (Gxx), GLONASS (Rxx), Galileo (Exx), BeiDou (Cxx), and QZSS (Jxx) satellites (Trimble, 2019).

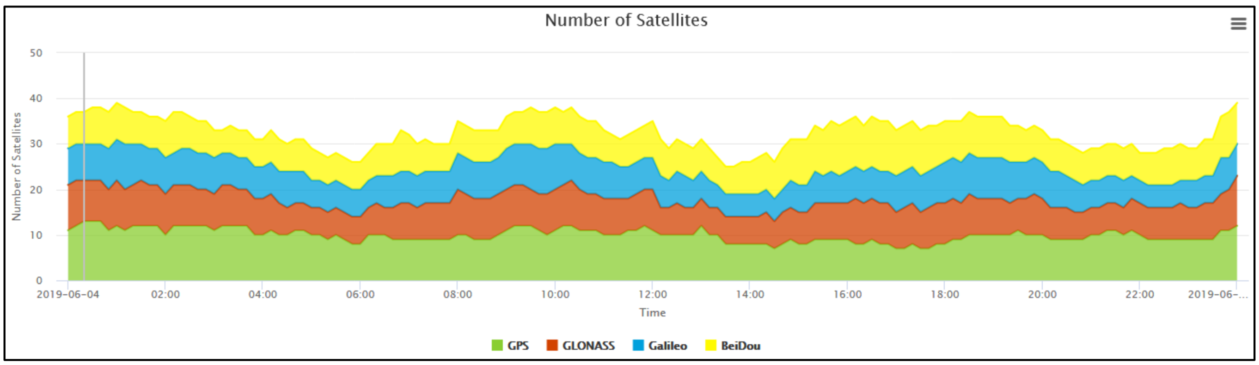


Figure 72. Number of satellites visible with a 5° satellite elevation cutoff and a 2 m antenna height during Monitoring Campaign 2 for June 4, 2019, from 0000 to 2400 hours using GPS, GLONASS, Galileo, BeiDou, and QZSS satellites (Trimble, 2019).

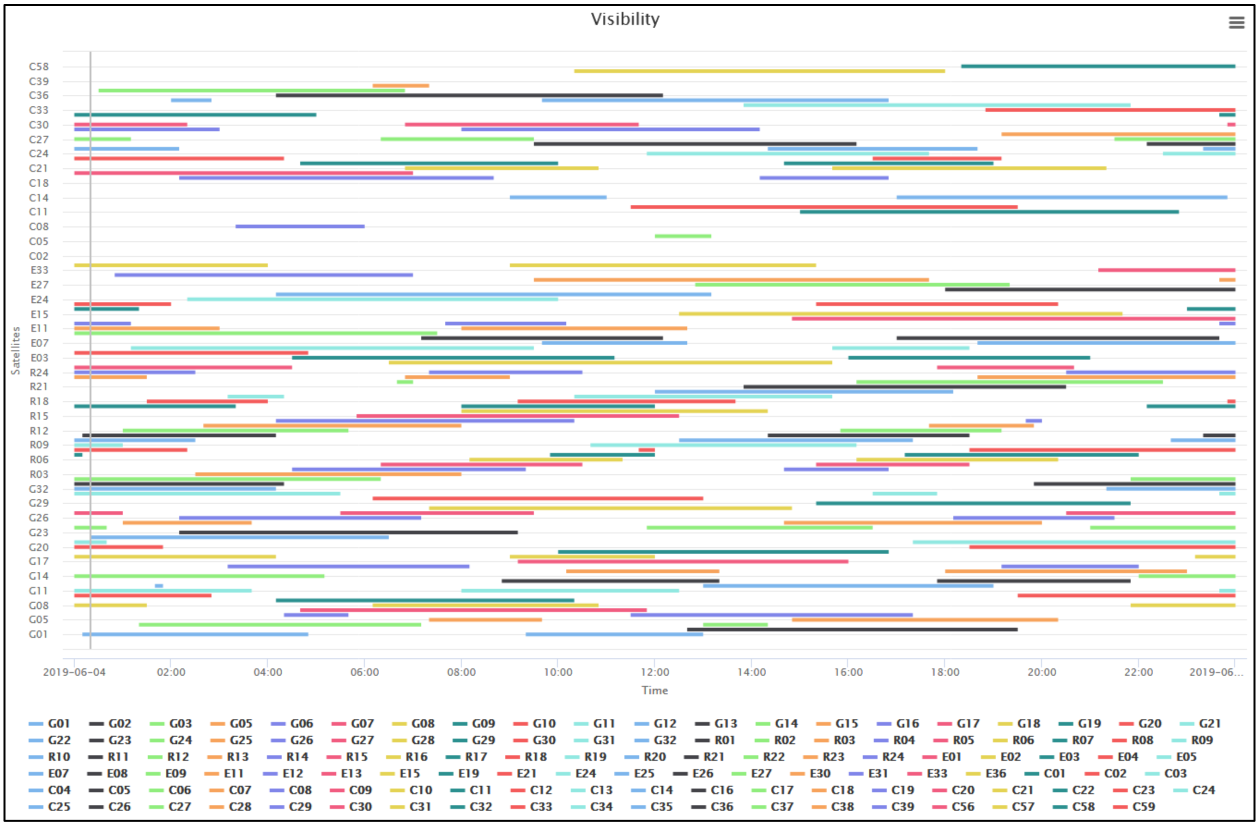


Figure 73. Individual satellite visibility with a 5° satellite elevation cutoff and a 2 m antenna height Monitoring Campaign 2 for June 4, 2019, from 0000 to 2400 hours using GPS (Gxx), GLONASS (Rxx), Galileo (Exx), BeiDou (Cxx), and QZSS (Jxx) satellites (Trimble, 2019).

Monitoring Campaign 3

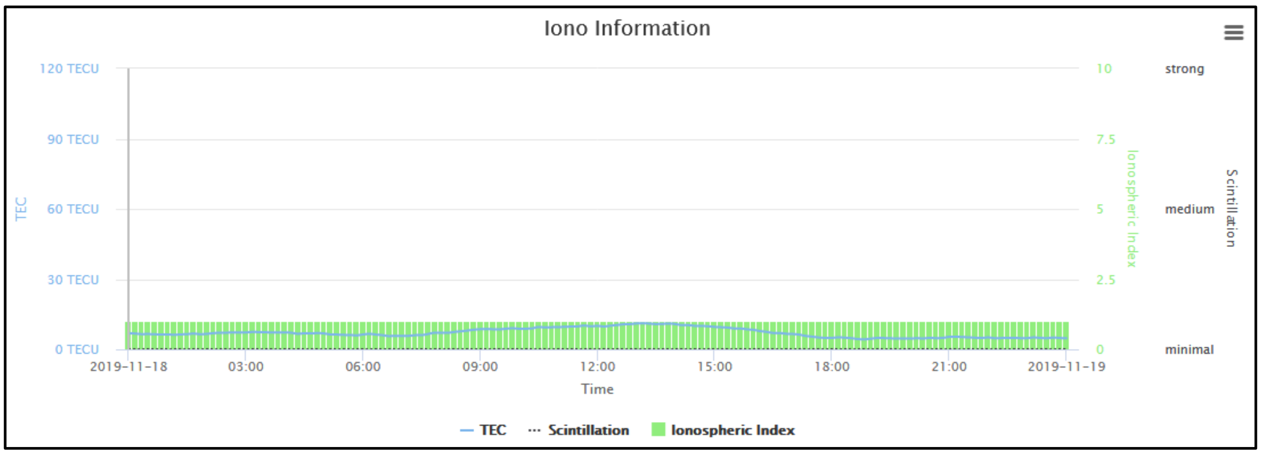
Monitoring parameters for monitoring campaign 3 on November 18-19, 2019, are summarized in table 20 with details in figures 74 to 83. During the entire campaign, PDOP, HDOP, VDOP, and Kp values were below threshold values. The Trimble R8 GNSS receivers correctly recorded Galileo signals during this campaign.

Table 20. *Monitoring campaign 3 GNSS parameters.*

Dilution of Precision			Kp	Tripod Calibration
Precision (PDOP)	**Horizontal (HDOP)**	**Vertical (VDOP)**		
1.14 – 2.31	--	--	0 – 2	Yes

```
Product: Daily Geomagnetic Data     quar_DGD.txt
Issued: 1530 UT 25 Nov 2019
#
#  Prepared by the U.S. Dept. of Commerce, NOAA, Space Weather Prediction Center
#  Please send comment and suggestions to SWPC.Webmaster@noaa.gov
#
#              Current Quarter Daily Geomagnetic Data
#
#                 Middle Latitude        High Latitude            Estimated
#               - Fredericksburg -     ---- College ----      --- Planetary ---
#  Date         A     K-indices        A     K-indices        A     K-indices
2019 10 17      4  2 1 1 1 1 1 1 1     6  1 0 3 3 3 1 0 0     6  2 2 2 2 1 1 1 1
2019 10 18      4  1 2 1 1 2 1 1 1     5  0 1 3 3 2 1 0 0     6  1 2 2 2 2 1 1 2
2019 10 19      3  1 0 1 1 2 1 1 0     8  0 0 2 4 3 2 1 2     5  1 1 1 2 2 2 2 1
2019 10 20      4  1 2 1 1 1 1 1 2     8  1 0 3 3 3 1 1 2     6  2 2 2 1 1 1 1 3
```
Figure 74. 3-hour Kp values during Monitoring Campaign 3 for November 18-19, 2019 (bold text), and the day before and the day after (NOAA, 2019).

A



B

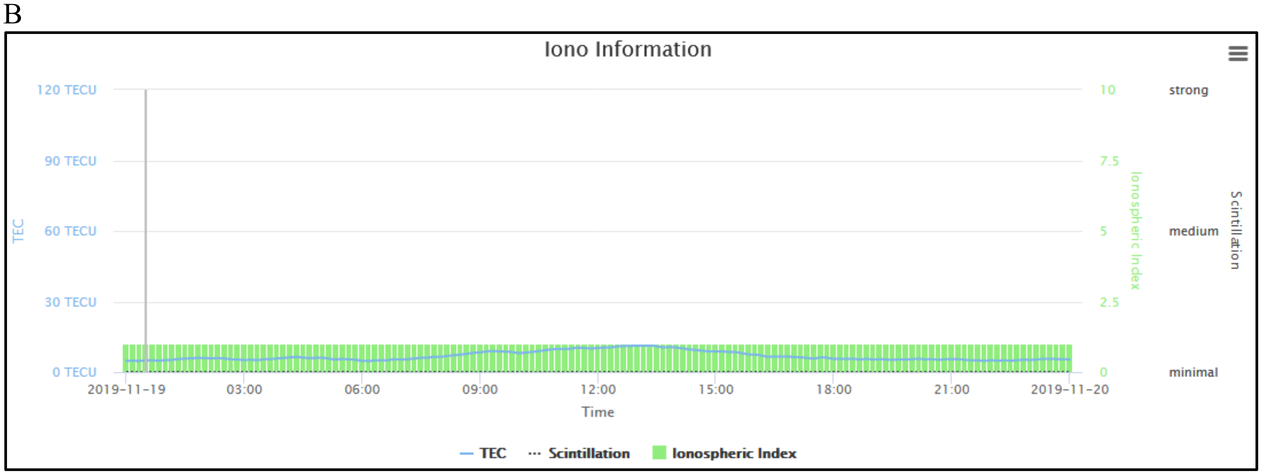
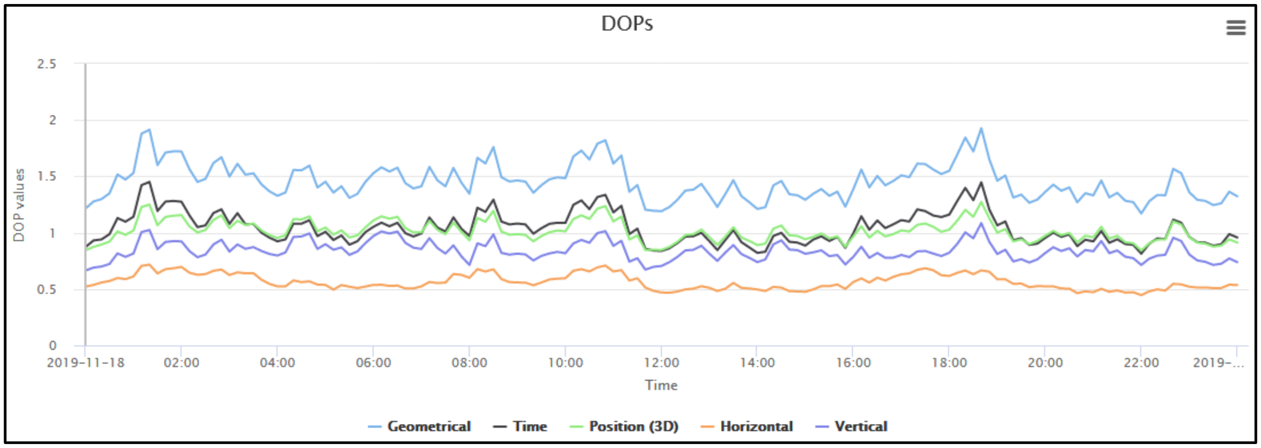


Figure 75. Ionospheric index values during Monitoring Campaign 3 for November 18-19, 2019, panels A and B, respectively (Trimble, 2019).

R8 Receivers

A



B

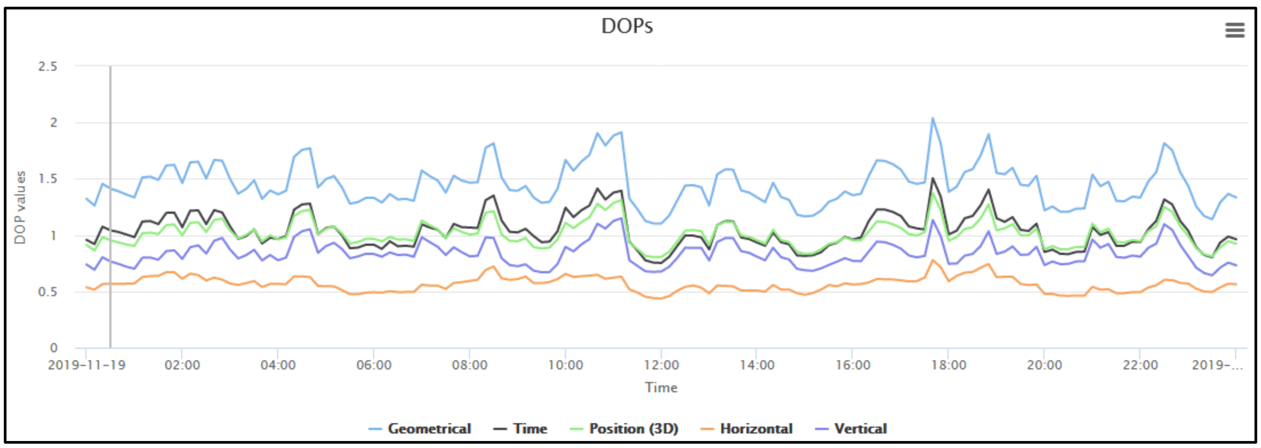
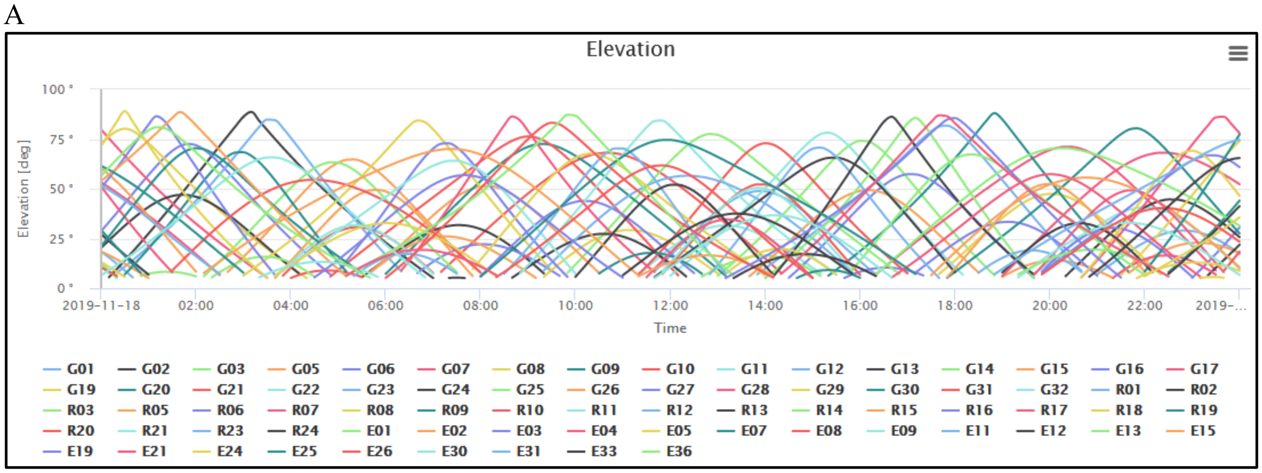


Figure 76. PDOP (green), HDOP (orange), and VDOP (dark blue) values during Monitoring Campaign 3 for November 18-19, 2019, from 0000 to 2400 hours using GPS, GLONASS, and Galileo satellites, panels A and B, respectively (Trimble, 2019).

A



B

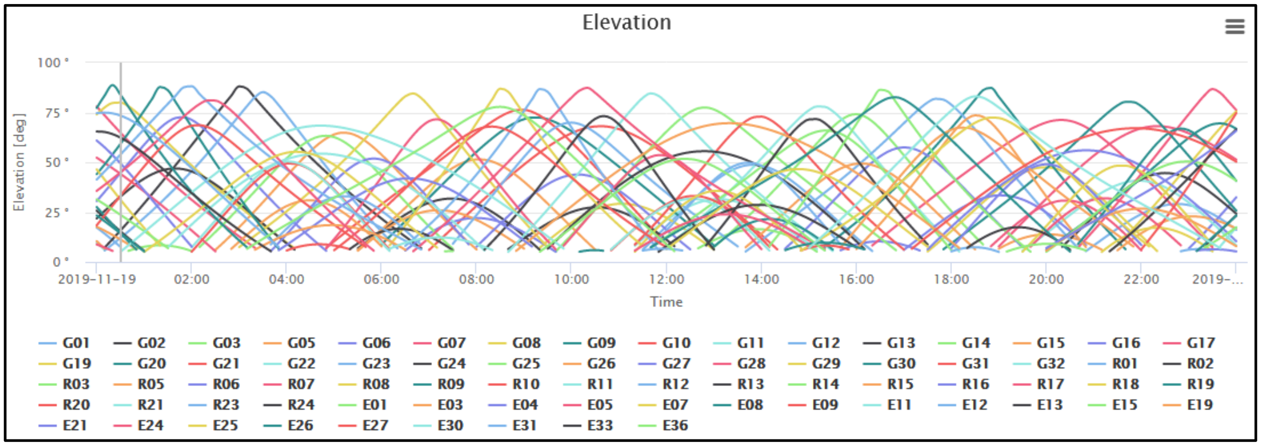
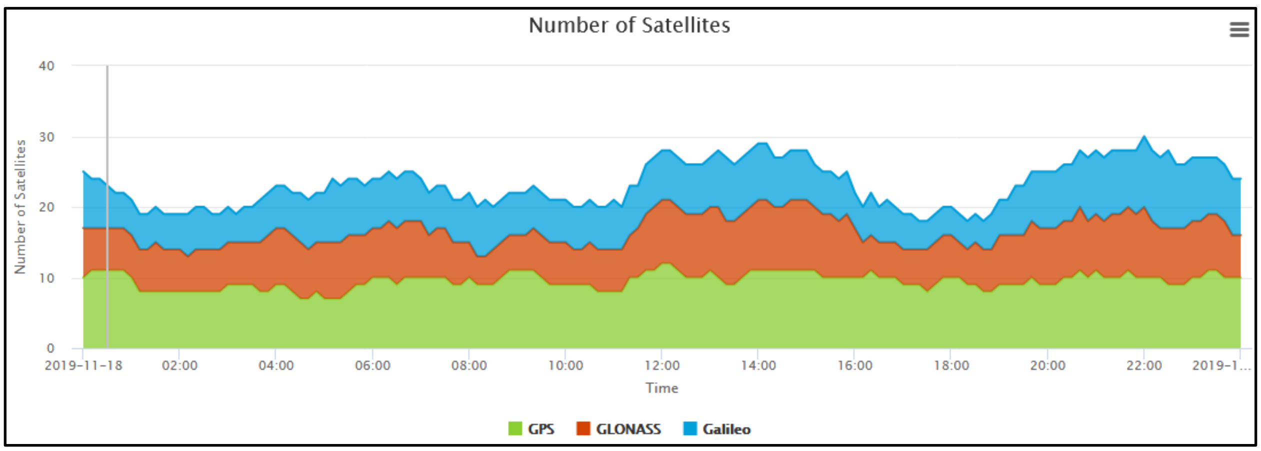


Figure 77. Monitoring line-of-sight satellite tracks and horizon elevations with a 5° satellite elevation cutoff and a 1 m antenna height during Monitoring Campaign 3 for November 18-19, 2019, from 0000 to 2400 hours using GPS (Gxx), GLONASS (Rxx), and Galileo (Exx) satellites, panels A and B, respectively (Trimble, 2019).

A



B

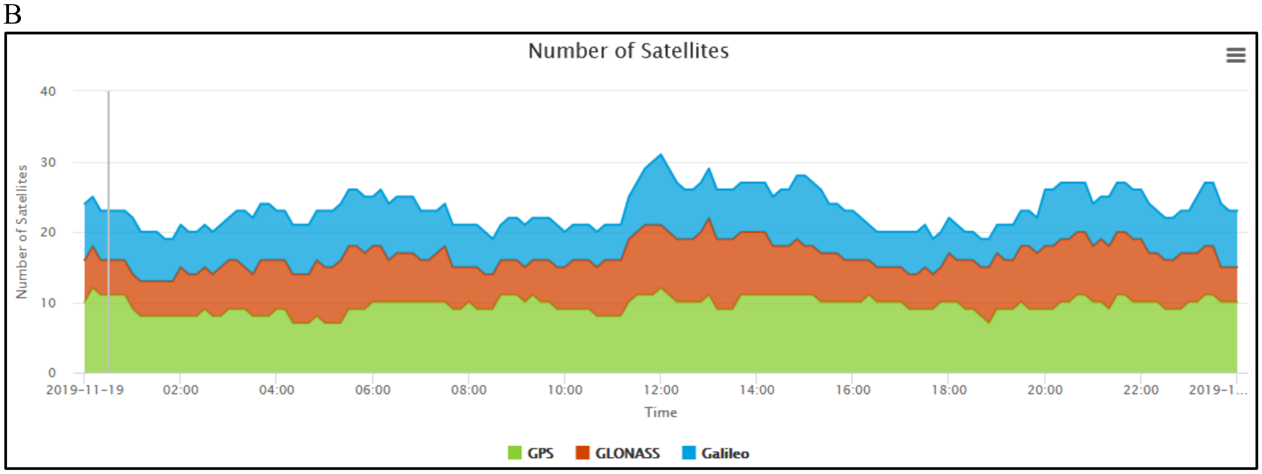
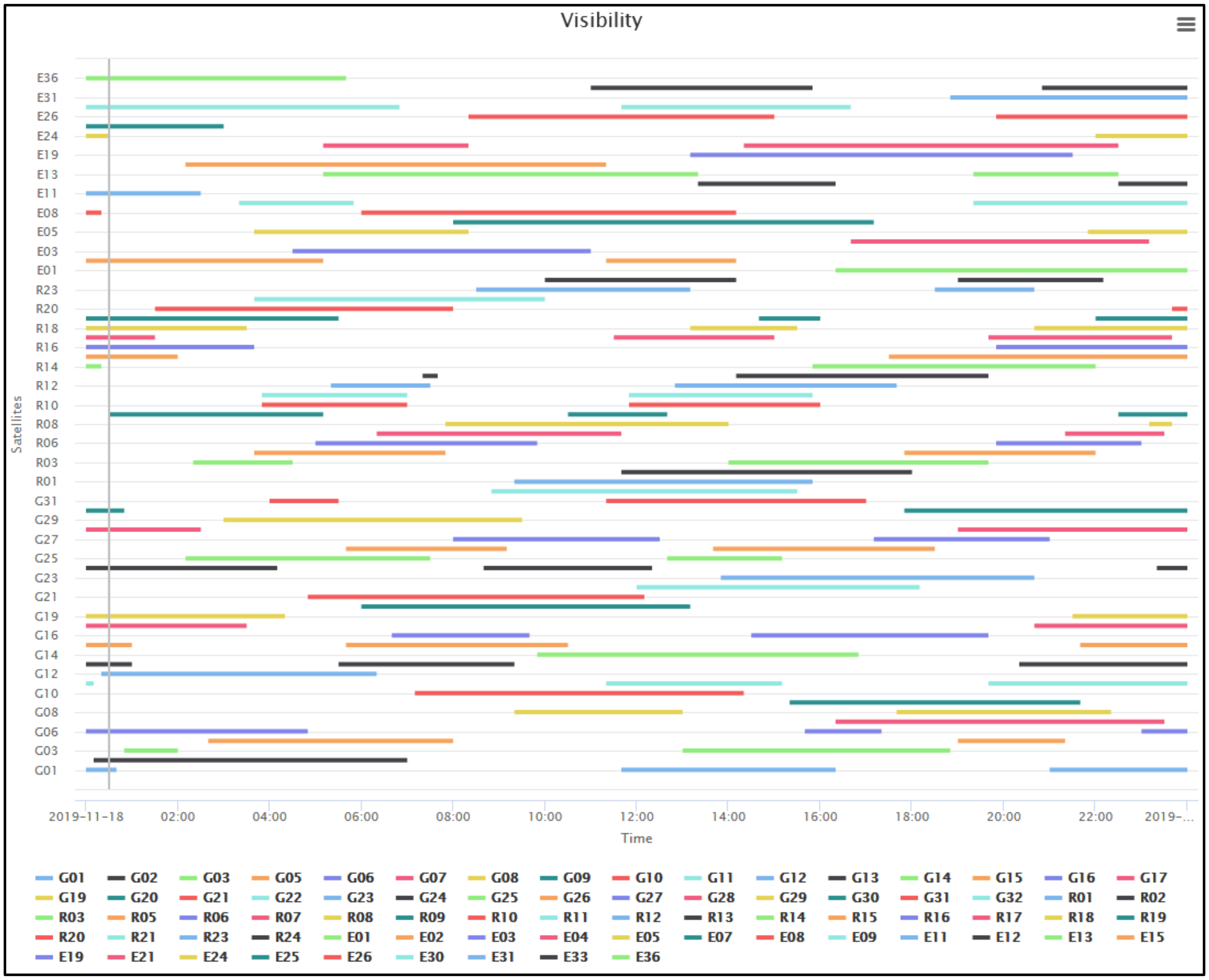


Figure 78. Number of satellites visible with a 5° satellite elevation cutoff and a 1 m antenna height during Monitoring Campaign 3 for November 18-19, 2019, from 0000 to 2400 hours using GPS, GLONASS, and Galileo satellites, panels A and B, respectively (Trimble, 2019).

A



Visibility
Satellites
E36
E31
E26
E24
E19
E13
E11
E08
E05
E03
E01
R23
R20
R18
R16
R14
R12
R10
R08
R06
R03
R01
G31
G29
G27
G25
G23
G21
G19
G16
G14
G12
G10
G08
G06
G03
G01
2019-11-18
02:00
04:00
06:00
08:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
2019-...
Time
G01 G02 G03 G05 G06 G07 G08 G09 G10 G11 G12 G13 G14 G15 G16 G17
G19 G20 G21 G22 G23 G24 G25 G26 G27 G28 G29 G30 G31 G32 R01 R02
R03 R05 R06 R07 R08 R09 R10 R11 R12 R13 R14 R15 R16 R17 R18 R19
R20 R21 R23 R24 E01 E02 E03 E04 E05 E07 E08 E09 E11 E12 E13 E15
E19 E21 E24 E25 E26 E30 E31 E33 E36

B

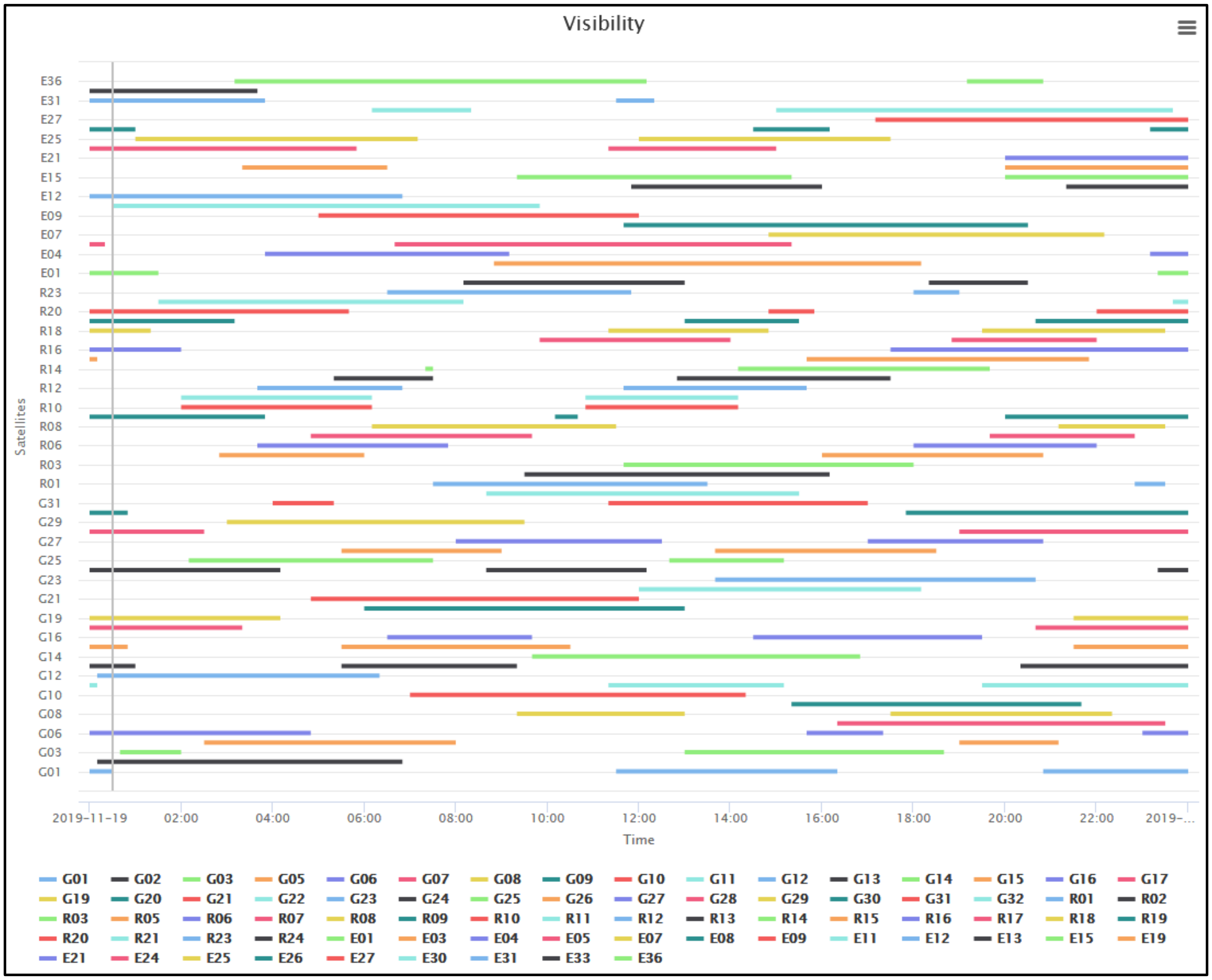
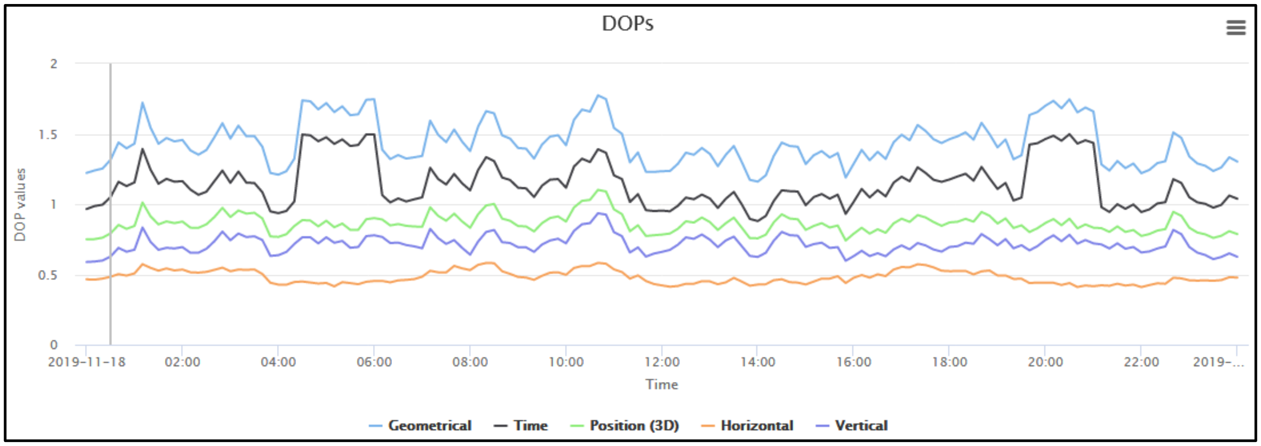


Figure 79. Individual satellite visibility with a 5° satellite elevation cutoff and a 1 m antenna height during Monitoring Campaign 3 for November 18-19, 2019, from 0000 to 2400 hours using GPS (Gxx), GLONASS (Rxx), and Galileo (Exx) satellites, panels A and B, respectively (Trimble, 2019).

R10 and Alloy Receivers

A



B

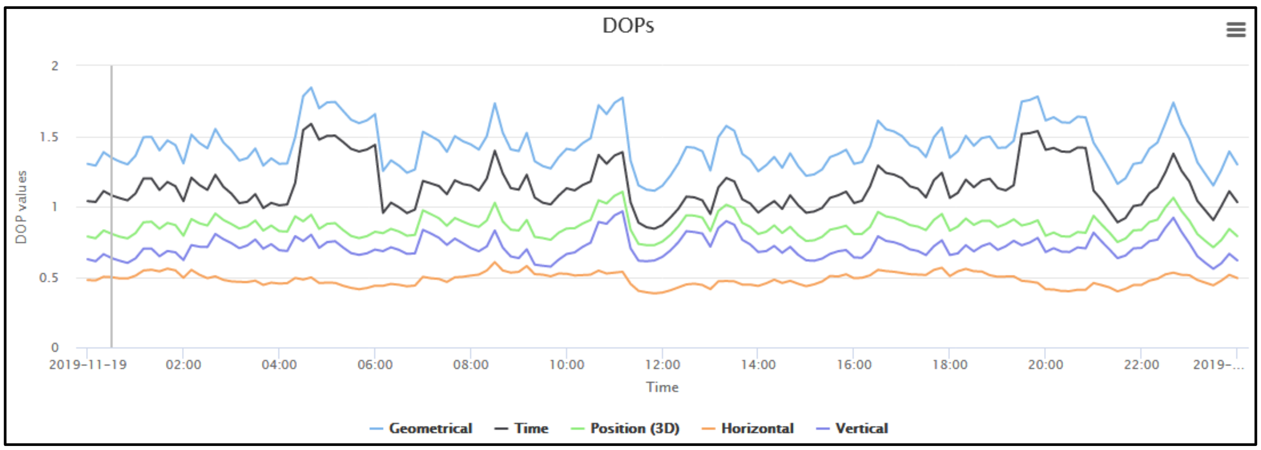
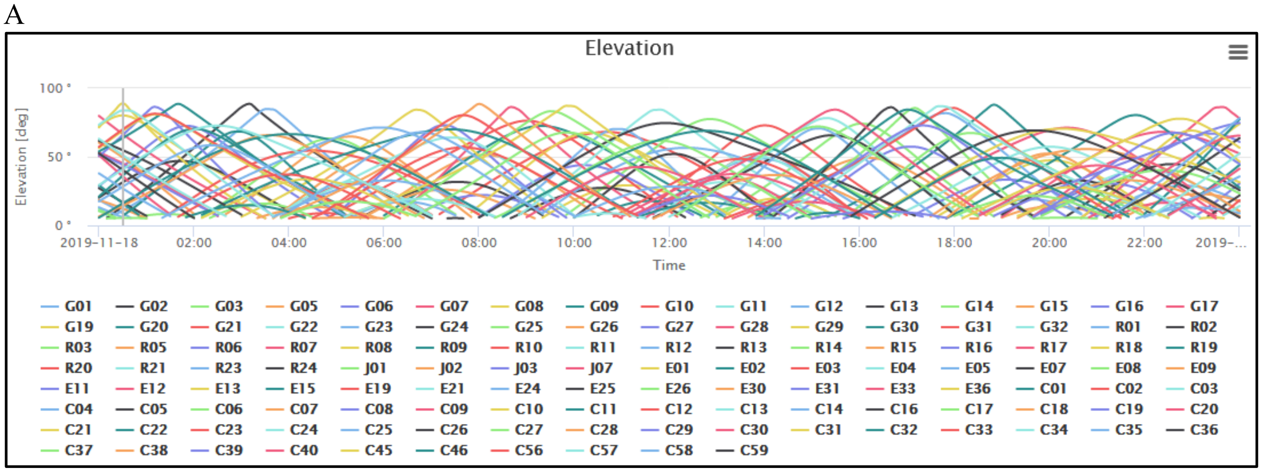


Figure 80. PDOP (green), HDOP (orange), and VDOP (dark blue) values Monitoring Campaign 3 for November 18-19, 2019, from 0000 to 2400 hours using GPS, GLONASS, Galileo, BeiDou, and QZSS satellites, panels A and B, respectively (Trimble, 2019).

A



B

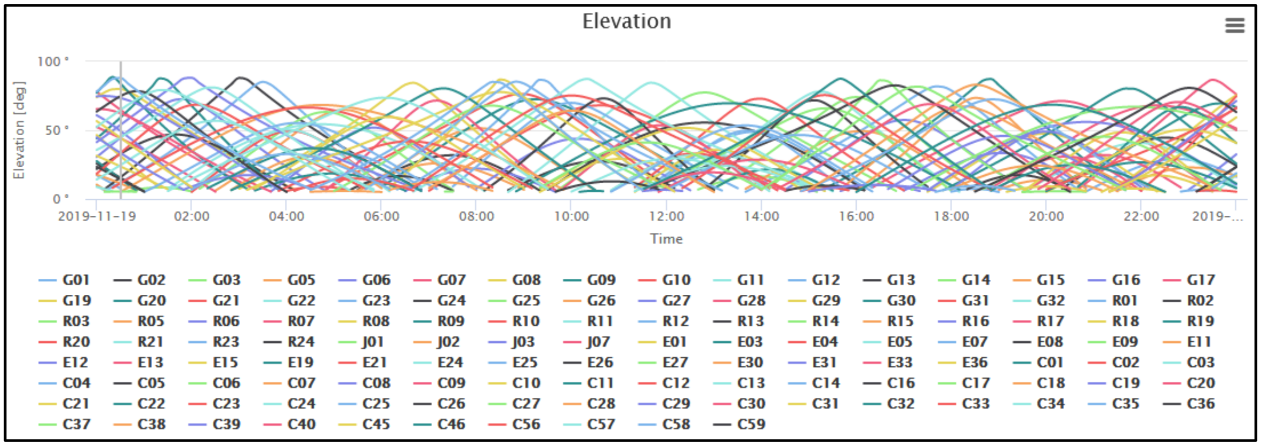
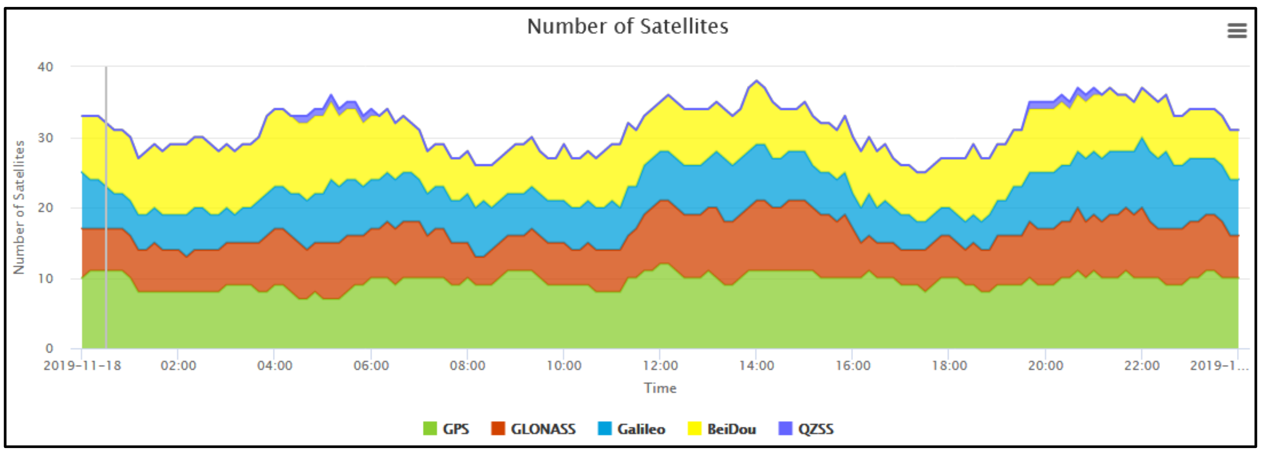


Figure 81. Monitoring line-of-sight satellite tracks and horizon elevations with a 5° satellite elevation cutoff and a 1 m antenna height during Monitoring Campaign 3 for November 18-19, 2019, from 0000 to 2400 hours using GPS (Gxx), GLONASS (Rxx), Galileo (Exx), BeiDou (Cxx), and QZSS (Jxx) satellites, panels A and B, respectively (Trimble, 2019).

A



B

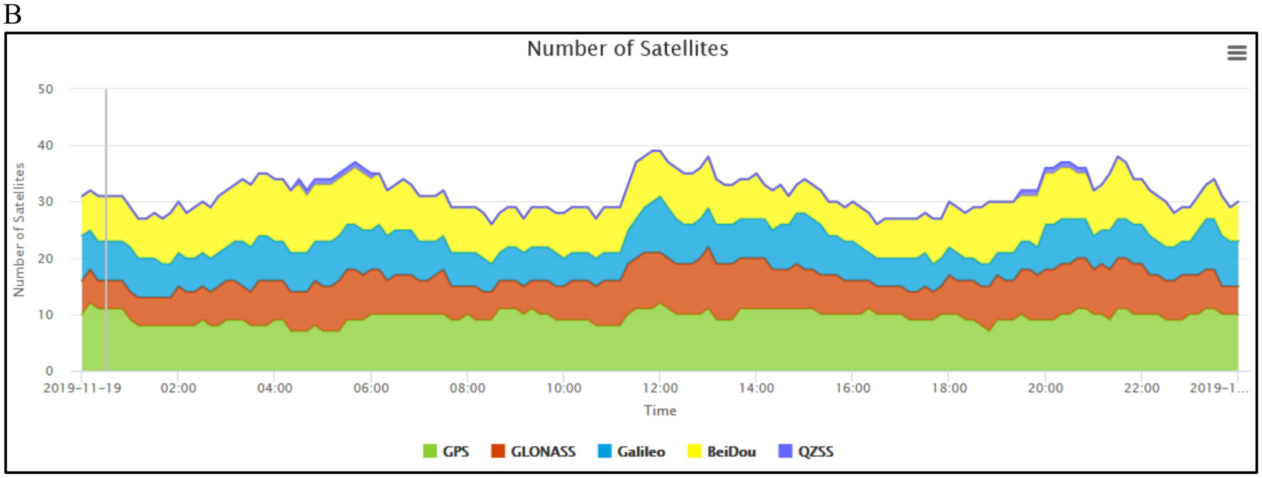
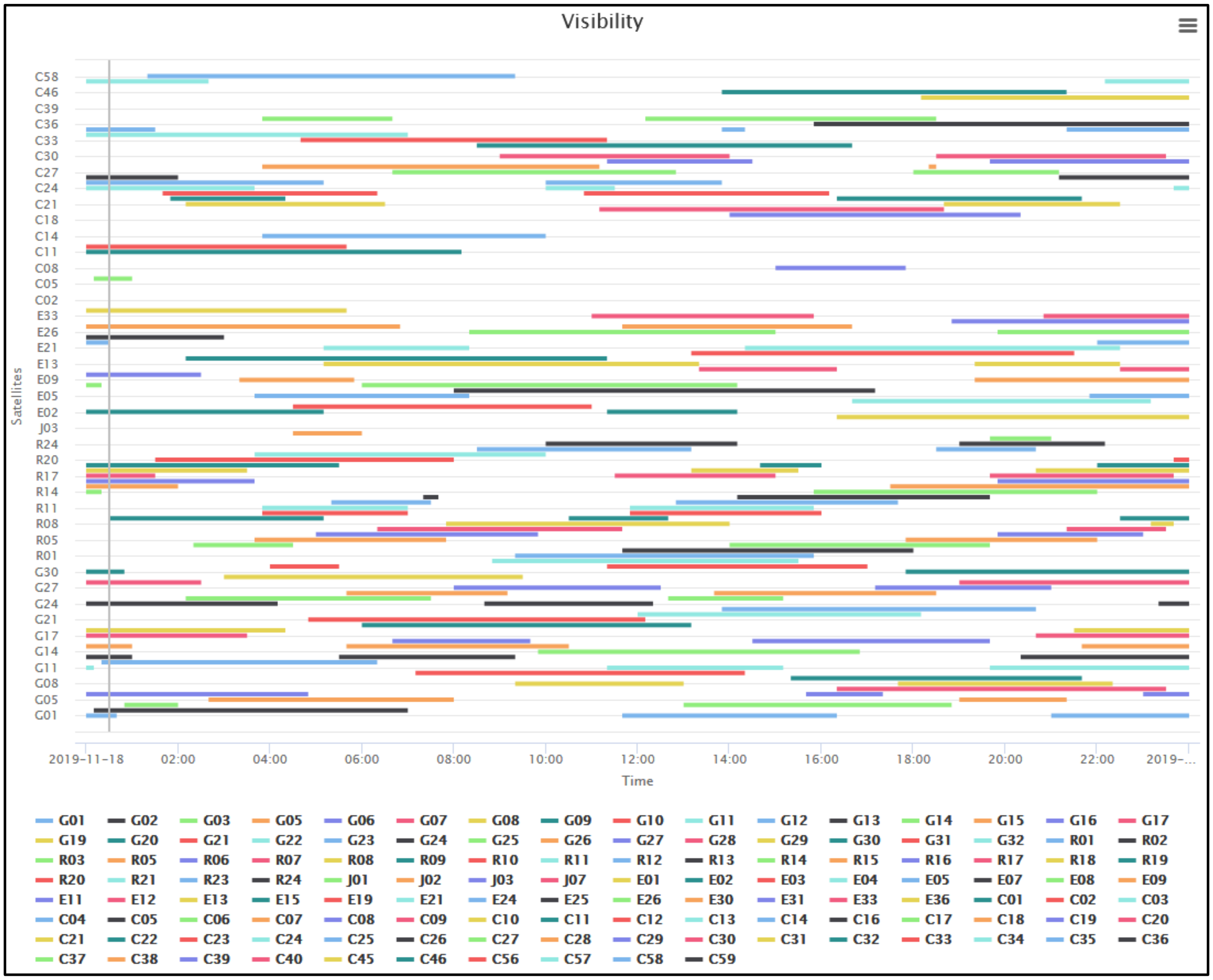


Figure 82. Number of satellites visible with a 5° satellite elevation cutoff and a 1 m antenna height during Monitoring Campaign 3 for November 18-19, 2019, from 0000 to 2400 hours using GPS, GLONASS, Galileo, BeiDou, and QZSS satellites, panels A and B, respectively (Trimble, 2019).

A


Visibility
Satellites
Time
2019-11-18
02:00
04:00
06:00
08:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
2019-...
C58
C46
C39
C36
C33
C30
C27
C24
C21
C18
C14
C11
C08
C05
C02
E33
E26
E21
E13
E09
E05
E02
J03
R24
R20
R17
R14
R11
R08
R05
R01
G30
G27
G24
G21
G17
G14
G11
G08
G05
G01
G01 G02 G03 G05 G06 G07 G08 G09 G10 G11 G12 G13 G14 G15 G16 G17
G19 G20 G21 G22 G23 G24 G25 G26 G27 G28 G29 G30 G31 G32 R01 R02
R03 R05 R06 R07 R08 R09 R10 R11 R12 R13 R14 R15 R16 R17 R18 R19
R20 R21 R23 R24 J01 J02 J03 J07 E01 E02 E03 E04 E05 E07 E08 E09
E11 E12 E13 E15 E19 E21 E24 E25 E26 E30 E31 E33 E36 C01 C02 C03
C04 C05 C06 C07 C08 C09 C10 C11 C12 C13 C14 C16 C17 C18 C19 C20
C21 C22 C23 C24 C25 C26 C27 C28 C29 C30 C31 C32 C33 C34 C35 C36
C37 C38 C39 C40 C45 C46 C56 C57 C58 C59

B

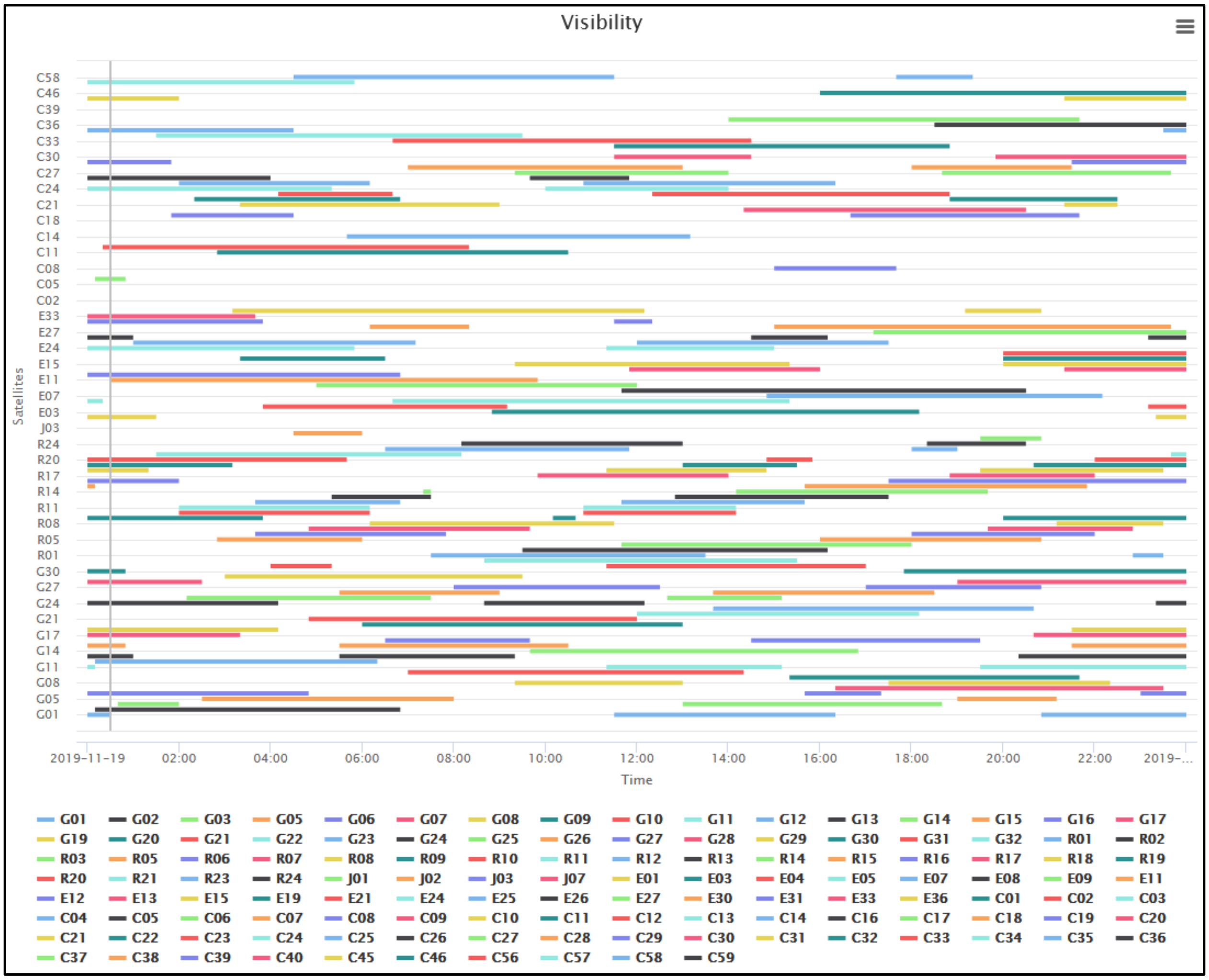


Figure 83. Individual satellite visibility with a 5° satellite elevation cutoff and a 1 m antenna height Monitoring Campaign 3 for November 18-19, 2019, from 0000 to 2400 hours using GPS (Gxx), GLONASS (Rxx), Galileo (Exx), BeiDou (Cxx), and QZSS (Jxx) satellites, panels A and B, respectively (Trimble, 2019).

Monitoring Campaign Data

Monitoring campaign data for each station in the ground deformation monitoring network is shown below in each station section. For each station and campaign, the date, occupation time, cap temperature, change in rod length based on the temperature change from the initial campaign (ΔL_{Rod}), the minimum and maximum number of satellites received during the occupation time being correlated with other receivers, the number of individual GNSS observations during the observation time, and any special notes were determined and recorded in the tables below. Parameters in each table are defined as:

- Temp Probe – UGS-assigned code for each individual temperature probe and instrument.
- GNSS/Tripod – UGS-assigned code for each individual GNSS receiver and tripod.
- Rod Temp – temperature of the datum point at the time of GNSS monitoring.
- ΔL_{Rod} – change in length of the rod, based on the initial and current temperature.
- Datum Depth – depth of the datum point below the existing ground surface.

- Height – height of the GNSS antenna above the datum point.
- Measured To – location where the height was measured on the GNSS receiver.
- Occupation Time – total data collection time of the GNSS receiver.
- Satellites – the minimum and maximum number of satellites received over the occupation time correlating with other receivers.
- Adjusted Elevation – within the campaign position measurement table, an adjustment correction of the thermal change of the driven rod (ΔL_{Rod}) from the measured elevation.

To reduce coordinate system transformation errors, all data is reported in one system: the North American Datum of 1983 (NAD83, 2011, Epoch:2010.0000) for horizontal coordinates and the North American Vertical Datum of 1988 (NAVD88, Geoid12A) ellipsoidal for vertical coordinates.

Base Station GDB-B1

Monitoring parameters are shown in table 21 for each monitoring campaign for ground deformation monitoring base station GDM-B1.

Table 21. *Base station GDM-B1 monitoring parameters.*

Campaign		GNSS Monitoring				
			Antenna			
#	**Date**	**GNSS\ Tripod**	**Height (m)**	**Measured To**	**Occupation Time (hrs:min)**	**Satellites (min/max)**
Initial A	12/18/2018	1/1	1.930	Center Bumper	25:03.75	13/19
Initial B	3/10-12/2019	R10/3	1.948	Phase Center	64:43:18	13/18
1	4/30/2019	R10/1	2.047	Phase Center	39:38:15	12/18
2	6/4/2019	R10/2	1.750	Phase Center	42:06:38	12/18
3	11/18-19/2019	R10-2/5	1.752	Phase Center	4:50:50	10/10

Base Station GDB-B2

Monitoring parameters are shown in table 22 for each monitoring campaign for ground deformation monitoring base station GDM-B2.

Table 22. *Base station GDM-B2 monitoring parameters.*

Campaign		GNSS Monitoring				
			Antenna			
#	**Date**	**GNSS\ Tripod**	**Height (m)**	**Measured To**	**Occupation Time (hrs:min)**	**Satellites (min/max)**
Initial A	12/18/2018	2/2	1.930	Center Bumper	25:52.25	13/19
Initial B	3/10-12/2019	R10/NF	1.295	Phase Center	59:22:29	13/17
1	4/30/2019	2/2	1.930	Center Bumper	23:45:48	NA
2	6/4/2019	2/2	1.630	Center Bumper	32:22:08	18/18
3	11/18-19/2019	1/1	1.632	Center Bumper	26:43:48	8/8

Base Station UTMI

Monitoring parameters are shown in table 23 for each monitoring campaign for ground deformation monitoring base station Milford TURN (UTMI).

Table 23. *Base station UTMI monitoring parameters.*

Campaign			
#	Date	Occupation Time (hrs:min)	Satellites (min/max)
Initial A	Not used	--	--
Initial B	Not used	--	--
1	4/30/2019	10:30:00	12/18
2	6/4/2019	42:00:00	12/18
3	11/18-19/2019	27:00:00	8/14

Station GDM-1

Monitoring parameters are shown in table 24 and position measurements for each monitoring campaign are shown in table 25 for ground deformation monitoring station GDM-1.

Table 24. *Station GDM-1 monitoring parameters.*

Campaign		UGS Code		Monument			GNSS Monitoring			
							Antenna			
#	Date	Temp Probe	GNSS\ Tripod	Rod Temp (°C)	ΔL_{Rod} (mm)	Datum Depth (m)	Height (m)	Measured To	Occupation Time (h:m:s)	Satellites (min/max)
Initial A	12/18/2018	2	4/4	3.5	--	0.069	1.930	Center Bumper	0:39:50	13/14
Initial B	3/10/2019	2	3/5	5.0	0	0.069	1.930	Center Bumper	1:56:53	17/17
1	4/30/2019	1	3/3	13.4	2.4	0.076	1.930	Center Bumper	1:00:23	17/17
2	6/5/2019	1	3/3	26.3	6.1	0.068	1.930	Center Bumper	0:59:37	12/14
3	11/18-19/2019	2	2/2	9.15	1.2	0.070	1.930	Center Bumper	15:25:53	8/10

Table 25. *Station GDM-1 position measurements.*

Campaign	Station Position NAD83 (2011, Epoch:2010.0000), UTM Zone 12 North – NAVD88 (Geoid12B) Ellipsoidal Coordinates					
	Latitude	Longitude	Northing	Easting	Elevation	Adjusted Elevation
Initial A	38.51362101	-112.916968506	4264546.6726	332867.9677	1584.0057	--
Initial B	38.51362096	-112.916968571	4264546.6671	332867.9618	1584.0142	--
1	38.513620848	-112.916968559	4264546.6547	332867.9627	1584.0224	1584.0200
2	38.513620861	-112.91696868	4264546.6561	332867.9619	1584.0660	1584.0599
3	38.513620951	-112.916968390	4264546.6658	332867.9777	1584.0470	1584.0458

Station GDM-2

Monitoring parameters are shown in table 26 and position measurements for each monitoring campaign are shown in table 27 for ground deformation monitoring station GDM-2.

Table 26. *Station GDM-2 monitoring parameters.*

Campaign		UGS Code		Monument			GNSS Monitoring			
							Antenna			
#	Date	Temp Probe	GNSS\ Tripod	Rod Temp (°C)	ΔL_{Rod} (mm)	Datum Depth (m)	Height (m)	Measured To	Occupation Time (h:m:s)	Satellites (min/max)
Initial A	12/18/2018	1	3/3	9.9	--	0.081	1.930	Center Bumper	0:41:25	13/13
Initial B	3/10/2019	2	4/4	4.2	0	0.079	1.930	Center Bumper	1:31:42	12/13
1	4/30/2019	1	4/4	12.9	2.4	0.087	1.930	Center Bumper	0:53:44	16/16
2	6/5/2019	1	4/4	26.25	5.8	0.079	1.930	Center Bumper	1:05:06	12/12
3	11/18-19/2019	2	3/3	9.35	1.6	0.076	1.930	Center Bumper	17:35:07	8/10

Table 27. *Station GDM-2 position measurements.*

Campaign	Station Position NAD83 (2011, Epoch:2010.0000), UTM Zone 12 North – NAVD88 (Geoid12B) Ellipsoidal Coordinates					
	Latitude	Longitude	Northing	Easting	Elevation	Adjusted Elevation
Initial A	38.514039278	-112.896964780	4264556.9317	334613.6707	1630.5360	--
Initial B	38.514039268	-112.896964744	4264556.9304	334613.6737	1630.5523	--
1	38.514039125	-112.896964663	4264556.9144	334613.6804	1630.5464	1630.5440
2	38.514039131	-112.896964668	4264556.9151	334613.6800	1630.5964	1630.5906
3	38.514039215	-112.896964507	4264556.9242	334613.6943	1630.5765	1630.5749

Station GDM-3

Monitoring parameters are shown in table 28 and position measurements for each monitoring campaign are shown in table 29 for ground deformation monitoring station GDM-3.

Table 28. *Station GDM-3 monitoring parameters.*

Campaign		UGS Code		Monument			GNSS Monitoring			
							Antenna			
#	Date	Temp Probe	GNSS\ Tripod	Rod Temp (°C)	ΔL_{Rod} (mm)	Datum Depth (m)	Height (m)	Measured To	Occupation Time (h:m:s)	Satellites (min-max)
Initial A	12/18/2018	1	5/5	8.8	--	0.090	1.948	Phase Center	0:42:25	12/13
Initial B	3/10-12/2019	2	3/5	3.4	0	0.094	1.930	Center Bumper	1:39:17	14/14
1	4/30/2019	1	3/3	13.1	2.6	0.092	1.930	Center Bumper	0:51:51	16/16
2	6/5/2019	2	1/5	22.8	5.5	0.092	1.930	Center Bumper	1:02:14	13/14
3	11/19/2019	2	3/3	9.7	1.8	0.092	1.930	Center Bumper	1:22:41	10/11

Table 29. *Station GDM-3 position measurements.*

Campaign	Station Position NAD83 (2011, Epoch:2010.0000), UTM Zone 12 North – NAVD88 (Geoid12B) Ellipsoidal Coordinates					
	Latitude	Longitude	Northing	Easting	Elevation	Adjusted Elevation
Initial A	38.513138676	-112.880039556	4264426.6440	336087.8502	1700.5939	--
Initial B	38.513138613	-112.880039628	4264426.6371	336087.8438	1700.5682	--
1	38.513138487	-112.880039626	4264426.6232	336087.8437	1700.5608	1700.5582
2	38.513138521	-112.880039558	4264426.6268	336087.8497	1700.6093	1700.6038
3	38.513138645	-112.880039411	4264426.6403	336087.8627	1700.5927	1700.5909

Station GDM-4

Monitoring parameters are shown in table 30 and position measurements for each monitoring campaign are shown in table 31 for ground deformation monitoring station GDM-4.

Table 30. *Station GDM-4 monitoring parameters.*

Campaign		UGS Code		Monument			GNSS Monitoring			
							Antenna			
#	Date	Temp Probe	GNSS\ Tripod	Rod Temp (°C)	ΔL_{Rod} (mm)	Datum Depth (m)	Height (m)	Measured To	Occupation Time (h:m:s)	Satellites (min/max)
Initial A	12/18/2018	2	4/4	6.5	--	0.058	1.930	Center Bumper	0:39:50	14/16
Initial B	3/10-12/2019	2	4/4	6.0	0	0.058	1.930	Center Bumper	1:33:08	14/15
1	4/30/2019	2	1/5	13.7	2.2	0.055	1.930	Center Bumper	0:47:13	12/14
2	6/5/2019	1	4/4	26.65	5.9	0.061	1.930	Center Bumper	1:10:04	14/15
3	11/19/2019	2	2/2	11.3	1.6	0.051	1.930	Center Bumper	1:04:52	10/10

Table 31. *Station GDM-4 position measurements.*

Campaign	Station Position NAD83 (2011, Epoch:2010.0000), UTM Zone 12 North – NAVD88 (Geoid12B) Ellipsoidal Coordinates					
	Latitude	Longitude	Northing	Easting	Elevation	Adjusted Elevation
Initial A	38.508181273	-112.905131025	4263921.3437	333887.9380	1615.4529	--
Initial B	38.508181188	-112.905131065	4263921.3344	333887.9343	1615.4730	--
1	38.508181210	-112.905131050	4263921.3368	333887.9356	1615.4794	1615.4772
2	38.508181119	-112.905131163	4263921.3269	333887.9257	1615.4961	1615.4902
3	38.508181156	-112.905130914	4263921.3305	333887.9474	1615.5039	1615.5023

Station GDM-5

Monitoring parameters are shown in table 32 and position measurements for each monitoring campaign are shown in table 33 for ground deformation monitoring station GDM-5.

Table 32. *Station GDM-5 monitoring parameters.*

Campaign		UGS Code		Monument			GNSS Monitoring			
							Antenna			
#	Date	Temp Probe	GNSS\ Tripod	Rod Temp (°C)	ΔL_{Rod} (mm)	Datum Depth (m)	Height (m)	Measured To	Occupation Time (min)	Satellites (min/max)
Initial A	12/18/2018	1	5/5	10.8	--	0.054	1.948	Phase Center	0:44:25	15/16
Initial B	3/10-12/2019	2	4/4	4.4	0	0.050	1.930	Center Bumper	1:31:29	12/16
1	4/30/2019	1	4/4	9.5	2.0	0.059	1.930	Center Bumper	0:45:24	13/13
2	6/5/2019	2	3/3	24.6	7.3	0.053	1.930	Center Bumper	1:00:20	12/15
3	11/19/2019	2	3/3	10.1	2.2	0.050	1.930	Center Bumper	1:04:13	13/16

Table 33. *Station GDM-5 position measurements.*

Campaign	Station Position NAD83 (2011, Epoch:2010.0000), UTM Zone 12 North – NAVD88 (Geoid12B) Ellipsoidal Coordinates					
	Latitude	Longitude	Northing	Easting	Elevation	Adjusted Elevation
Initial A	38.507715253	-112.891249725	4263844.6245	335097.7053	1662.2748	--
Initial B	38.507715211	-112.891249842	4263844.6201	335097.6950	1662.2369	--
1	38.507715099	-112.891249814	4263844.6076	335097.6972	1662.2355	1662.2334
2	38.507715114	-112.891249696	4263844.6090	335097.7075	1662.2785	1662.2712
3	38.507715206	-112.891249619	4263844.6191	335097.7145	1662.2589	1662.2567

Station GDM-6

Monitoring parameters are shown in table 34 and position measurements for each monitoring campaign are shown in table 35 for ground deformation monitoring station GDM-6.

Table 34. *Station GDM-6 monitoring parameters.*

Campaign		UGS Code		Monument			GNSS Monitoring			
							Antenna			
#	Date	Temp Probe	GNSS\ Tripod	Rod Temp (°C)	ΔL_{Rod} (mm)	Datum Depth (m)	Height (m)	Measured To	Occupation Time (h:m:s)	Satellites (min/max)
Initial A	12/18/2018	1	3/3	10.5	--	0.102	1.930	Center Bumper	0:49:00	15/15
Initial B	3/10-12/2019	2	3/5	4.5	0	0.102	1.930	Center Bumper	1:35:10	16/16
1	4/30/2019	1	4/4	12.1	2.7	0.103	1.930	Center Bumper	0:45:27	13/15
2	6/5/2019	1	1/5	22.1	8.2	0.103	1.930	Center Bumper	1:03:15	12/13
3	11/19/2019	2	3/3	10.2	2.1	0.100	1.930	Center Bumper	1:04:40	13/16

Table 35. *Station GDM-6 position measurements.*

Campaign	Station Position NAD83 (2011, Epoch:2010.0000), UTM Zone 12 North – NAVD88 (Geoid12B) Ellipsoidal Coordinates					
	Latitude	Longitude	Northing	Easting	Elevation	Adjusted Elevation
Initial A	38.507448579	-112.880350525	4263795.5310	336047.8146	1707.6473	--
Initial B	38.507448498	-112.880350374	4263795.5217	336047.8276	1707.6632	--
1	38.507448388	-112.880350417	4263795.5095	336047.8236	1707.6634	1707.6607
2	38.507448368	-112.880350391	4263795.5073	336047.8258	1707.7014	1707.6932
3	38.507448470	-112.880350180	4263795.5182	336047.8445	1707.6931	1707.6910

Station GDM-7

Monitoring parameters are shown in table 36 and position measurements for each monitoring campaign are shown in table 37 for ground deformation monitoring station GDM-7.

Table 36. *Station GDM-7 monitoring parameters.*

Campaign		UGS Code		Monument			GNSS Monitoring			
							Antenna			
#	Date	Temp Probe	GNSS\ Tripod	Rod Temp (°C)	ΔL_{Rod} (mm)	Datum Depth (m)	Height (m)	Measured To	Occupation Time (h:m:s)	Satellites (min/max)
Initial A	12/18/2018	2	4/4	6.4	--	0.201	1.930	Center Bumper	0:39:75	18/19
Initial B	3/10-12/2019	1	1/1	4.7	0	0.200	1.930	Center Bumper	1:39:48	17/17
1	4/30/2019	2	1/5	13.9	2.5	0.202	1.930	Center Bumper	0:45:50	16/18
2	6/5/2019	1	4/4	22.1	5.0	0.203	1.930	Center Bumper	1:00:20	12/15
3	11/18-19/2019	2	4/4	9.5	1.4	0.202	1.930	Center Bumper	16:49:05	8/10

Table 37. *Station GDM-7 position measurements.*

Campaign	Station Position NAD83 (2011, Epoch:2010.0000), UTM Zone 12 North – NAVD88 (Geoid12B) Ellipsoidal Coordinates					
	Latitude	Longitude	Northing	Easting	Elevation	Adjusted Elevation
Initial A	38.502981335	-112.908037368	4263349.3424	333622.4519	1611.6136	--
Initial B	38.502981283	-112.908037332	4263349.3365	333622.4549	1611.6191	--
1	38.502981198	-112.908037375	4263349.3272	333622.4510	1611.6264	1611.6239
2	38.502981198	-112.908037283	4263349.3270	333622.4590	1611.6714	1611.6664
3	38.502981284	-112.908037190	4263349.3364	333622.4673	1611.6515	1611.6501

Station GDM-8

Monitoring parameters are shown in table 38 and position measurements for each monitoring campaign are shown in table 39 for ground deformation monitoring station GDM-8.

Table 38. *Station GDM-8 monitoring parameters.*

Campaign		UGS Code		Monument			GNSS Monitoring			
							Antenna			
#	Date	Temp Probe	GNSS\ Tripod	Rod Temp (°C)	ΔL_{Rod} (mm)	Datum Depth (m)	Height (m)	Measured To	Occupation Time (h:m:s)	Satellites (min/max)
Initial A	12/18/2018	2	4/4	9.2	--	0.117	1.930	Center Bumper	0:43:50	13/14
Initial B	3/10-12/2019	2	4/4	5.0	0	0.116	1.930	Center Bumper	1:33:46	13/13
1	4/30/2019	2	1/5	13.0	2.5	0.112	1.930	Center Bumper	0:49:01	14/16
2	6/5/2019	1	4/4	24.9	5.7	0.113	1.930	Center Bumper	1:03:49	16/16
3	11/19/2019	2	4/4	9.9	1.5	0.113	1.930	Center Bumper	1:09:12	14/14

Table 39. *Station GDM-8 position measurements.*

Campaign	Station Position NAD83 (2011, Epoch:2010.0000), UTM Zone 12 North – NAVD88 (Geoid12B) Ellipsoidal Coordinates					
	Latitude	Longitude	Northing	Easting	Elevation	Adjusted Elevation
Initial A	38.503765815	-112.897612416	4263417.6195	334533.6566	1645.231	--
Initial B	38.503765787	-112.897612497	4263417.6167	334533.6494	1645.2537	--
1	38.503765718	-112.897612371	4263417.6087	334533.6603	1645.2557	1645.2533
2	38.503765725	-112.897612466	4263417.6097	334533.6521	1645.2742	1645.2685
3	38.503765717	-112.897612251	4263417.6084	334533.6708	1645.2702	1645.2687

Station GDM-9

Monitoring parameters are shown in table 40 and position measurements for each monitoring campaign are shown in table 41 for ground deformation monitoring station GDM-9.

Table 40. *Station GDM-9 monitoring parameters.*

Campaign		UGS Code		Monument			GNSS Monitoring			
							Antenna			
#	Date	Temp Probe	GNSS\ Tripod	Rod Temp (°C)	ΔL_{Rod} (mm)	Datum Depth (m)	Height (m)	Measured To	Occupation Time (h:m:s)	Satellites (min/max)
Initial A	12/18/2018	1	5/5	9.3	--	0.075	1.948	Phase Center	0:43:50	18/18
Initial B	3/10-12/2019	2	3/5	4.1	0	0.071	1.930	Center Bumper	1:38:20	12/14
1	4/30/2019	2	1/5	13.7	2.7	0.069	1.930	Center Bumper	0:53:25	12/12
2	6/5/2019	2	4/4	22.3	5.2	0.075	1.930	Center Bumper	1:01:37	13/13
3	11/19/2019	2	4/4	9.5	1.5	0.070	1.930	Center Bumper	1:08:41	13/14

Table 41. *Station GDM-9 position measurements.*

Campaign	Station Position NAD83 (2011, Epoch:2010.0000), UTM Zone 12 North – NAVD88 (Geoid12B) Ellipsoidal Coordinates					
	Latitude	Longitude	Northing	Easting	Elevation	Adjusted Elevation
Initial A	38.502157580	-112.892248296	4263229.4484	334997.9117	1663.2728	--
Initial B	38.502157492	-112.892248399	4263229.4388	334997.9024	1663.2438	--
1	38.502157370	-112.892248321	4263229.4251	334997.9090	1663.2514	1663.2487
2	38.502157436	-112.892248475	4263229.4328	334997.8957	1663.2423	1663.2371
3	38.502157478	-112.892248157	4263229.4368	334997.9235	1663.2602	1663.2587

Station GDM-10

Monitoring parameters are shown in table 42 and position measurements for each monitoring campaign are shown in table 43 for ground deformation monitoring station GDM-10.

Table 42. *Station GDM-10 monitoring parameters.*

Campaign		UGS Code		Monument			GNSS Monitoring			
							Antenna			
#	Date	Temp Probe	GNSS\ Tripod	Rod Temp (°C)	ΔL_{Rod} (mm)	Datum Depth (m)	Height (m)	Measured To	Occupation Time (h:m:s)	Satellites (min/max)
Initial A	12/18/2018	1	3/3	11.4	--	0.076	1.930	Center Bumper	0:47:50	18/18
Initial B	3/10-12/2019	2	4/4	5.7	0	0.073	1.930	Center Bumper	1:38:18	16/17
1	4/30/2019	1	3/3	9.4	1.7	0.079	1.930	Center Bumper	1:01:35	14/14
2	6/5/2019	1	1/5	24.9	8.3	0.076	1.930	Center Bumper	1:01:11	14/16
3	11/19/2019	2	3/3	12.7	3.1	0.073	1.930	Center Bumper	1:15:20	11/12

Table 43. *Station GDM-10 position measurements.*

Campaign	Station Position NAD83 (2011, Epoch:2010.0000), UTM Zone 12 North – NAVD88 (Geoid12B) Ellipsoidal Coordinates					
	Latitude	Longitude	Northing	Easting	Elevation	Adjusted Elevation
Initial A	38.504320158	-112.888539039	4263462.8712	335326.4156	1654.1710	--
Initial B	38.504320092	-112.888538911	4263462.8637	335326.4266	1654.1798	--
1	38.504319972	-112.888538876	4263462.8503	335326.4294	1654.1831	1654.1814
2	38.504320014	-112.888538924	4263462.8550	335326.4253	1654.2154	1654.2071
3	38.504320047	-112.888538720	4263462.8583	335326.4432	1654.2064	1654.2033

Station GDM-11

Monitoring parameters are shown in table 44 and position measurements for each monitoring campaign are shown in table 45 for ground deformation monitoring station GDM-11.

Table 44. *Station GDM-11 monitoring parameters.*

Campaign		UGS Code		Monument			GNSS Monitoring			
							Antenna			
#	Date	Temp Probe	GNSS\ Tripod	Rod Temp (°C)	ΔL_{Rod} (mm)	Datum Depth (m)	Height (m)	Measured To	Occupation Time (h:m:s)	Satellites (min/max)
Initial A	12/18/2018	1	3/3	8.3	--	0.104	1.930	Center Bumper	0:43:00	16/17
Initial B	3/10-12/2019	2	3/5	4.2	0	0.105	1.930	Center Bumper	1:33:25	13/14
1	4/30/2019	1	3/3	14.1	2.8	0.106	1.930	Center Bumper	1:11:15	12/12
2	6/5/2019	1	3/3	19.6	4.4	0.102	1.930	Center Bumper	1:07:12	17/17
3	11/19/2019	2	4/4	11.0	1.9	0.102	1.930	Center Bumper	1:04:07	10/10

Table 45. *Station GDM-11 position measurements.*

Campaign	Station Position NAD83 (2011, Epoch:2010.0000), UTM Zone 12 North – NAVD88 (Geoid12B) Ellipsoidal Coordinates					
	Latitude	Longitude	Northing	Easting	Elevation	Adjusted Elevation
Initial A	38.501218759	-112.886397478	4263114.7469	335506.1689	1686.9261	--
Initial B	38.501218705	-112.886397316	4263114.7407	335506.1829	1686.9422	--
1	38.501218588	-112.886397271	4263114.7275	335506.1865	1686.9461	1686.9433
2	38.501218664	-112.886397416	4263114.7363	335506.1741	1686.9457	1686.9413
3	38.501218679	-112.886397112	4263114.7374	335506.2006	1686.9723	1686.9704

Station GDM-12

Monitoring parameters are shown in table 46 and position measurements for each monitoring campaign are shown in table 47 for ground deformation monitoring station GDM-12.

Table 46. *Station GDM-12 monitoring parameters.*

Campaign		UGS Code		Monument			GNSS Monitoring			
							Antenna			
#	Date	Temp Probe	GNSS\ Tripod	Rod Temp (°C)	ΔL_{Rod} (mm)	Datum Depth (m)	Height (m)	Measured To	Occupation Time (h:m:s)	Satellites (min/max)
Initial A	12/18/2018	1	3/3	8.8	--	0.111	1.930	Center Bumper	0:45:75	17/17
Initial B	3/10-12/2019	1	2/2	4.6	0	0.115	1.930	Center Bumper	1:39:59	15/15
1	4/30/2019	1	4/4	13.0	2.3	0.116	1.930	Center Bumper	1:00:54	15/15
2	6/5/2019	1	4/4	18.2	3.8	0.113	1.930	Center Bumper	0:50:31	17/17
3	11/19/2019	2	4/4	9.2	1.3	0.114	1.930	Center Bumper	1:02:10	12/17

Table 47. *Station GDM-12 position measurements.*

Campaign	Station Position NAD83 (2011, Epoch:2010.0000), UTM Zone 12 North – NAVD88 (Geoid12B) Ellipsoidal Coordinates					
	Latitude	Longitude	Northing	Easting	Elevation	Adjusted Elevation
Initial A	38.499825427	-112.881079943	4262950.5731	335966.8855	1711.5546	--
Initial B	38.499825250	-112.881079725	4262950.5531	335966.9041	1711.5758	--
1	38.499825201	-112.881079653	4262950.5476	335966.9103	1711.5772	1711.5748
2	38.499825200	-112.881079744	4262950.5477	335966.9024	1711.5703	1711.5665
3	38.499825259	-112.881079446	4262950.5536	335966.9284	1711.5953	1711.5940

Station GDM-13

Monitoring parameters are shown in table 48 and position measurements for each monitoring campaign are shown in table 49 for ground deformation monitoring station GDM-13.

Table 48. *Station GDM-13 monitoring parameters.*

Campaign		UGS Code		Monument			GNSS Monitoring			
							Antenna			
#	Date	Temp Probe	GNSS\ Tripod	Rod Temp (°C)	ΔL_{Rod} (mm)	Datum Depth (m)	Height (m)	Measured To	Occupation Time (h:m:s)	Satellites (min/max)
Initial A	12/18/2018	1	3/3	7.1	--	0.140	1.930	Center Bumper	0:44:75	14/14
Initial B	3/10-12/2019	1	1/1	5.1	0	0.140	1.930	Center Bumper	1:36:47	11/14
1	4/30/2019	1	3/3	13.2	2.3	0.142	1.930	Center Bumper	0:46:09	15/16
2	6/6/2019	1	1/4	19.4	4.1	0.136	1.930	Center Bumper	1:01:13	16/16
3	11/19/2019	2	4/4	10.4	1.6	0.137	1.930	Center Bumper	2:11:02	9/10

Table 49. *Station GDM-13 position measurements.*

Campaign	Station Position NAD83 (2011, Epoch:2010.0000), UTM Zone 12 North – NAVD88 (Geoid12B) Ellipsoidal Coordinates					
	Latitude	Longitude	Northing	Easting	Elevation	Adjusted Elevation
Initial A	38.499729299	-112.864158120	4262909.8564	337442.8833	1796.1919	--
Initial B	38.499729143	-112.864157962	4262909.8388	337442.8967	1796.2181	--
1	38.499729075	-112.864157901	4262909.8311	337442.9019	1796.2106	1796.2083
2	38.499729090	-112.864157999	4262909.8329	337442.8934	1796.2171	1796.2130
3	38.499729104	-112.864157723	4262909.8340	337442.9174	1796.2425	1796.2409

Station GDM-14

Monitoring parameters are shown in table 50 and position measurements for each monitoring campaign are shown in table 51 for ground deformation monitoring station GDM-14.

Table 50. *Station GDM-14 monitoring parameters.*

Campaign		UGS Code		Monument			GNSS Monitoring			
							Antenna			
#	Date	Temp Probe	GNSS\ Tripod	Rod Temp (°C)	ΔL_{Rod} (mm)	Datum Depth (m)	Height (m)	Measured To	Occupation Time (h:m:s)	Satellites (min/max)
Initial A	12/18/2018	2	4/4	5.3	--	0.162	1.930	Center Bumper	0:40:50	17/17
Initial B	3/10-12/2019	1	2/2	5.0	0	0.155	1.930	Center Bumper	1:32:25	16/17
1	4/30/2019	2	1/5	12.7	0.9	0.157	1.930	Center Bumper	0:47:25	16/16
2	6/5/2019	2	4/4	20.3	1.8	0.157	1.930	Center Bumper	1:00:16	12/12
3	11/19/2019	2	4/4	9.6	0.6	0.156	1.930	Center Bumper	1:07:02	9/12

Table 51. *Station GDM-14 position measurements.*

Campaign	Station Position NAD83 (2011, Epoch:2010.0000), UTM Zone 12 North – NAVD88 (Geoid12B) Ellipsoidal Coordinates					
	Latitude	Longitude	Northing	Easting	Elevation	Adjusted Elevation
Initial A	38.495145552	-112.905791997	4262475.4172	333800.3063	1625.5426	--
Initial B	38.495145524	-112.905791991	4262475.4140	333800.3067	1625.5534	--
1	38.495145413	-112.905791891	4262475.4015	333800.3152	1625.5581	1625.5572
2	38.495145408	-112.905791958	4262475.4011	333800.3094	1625.5618	1625.5600
3	38.495145512	-112.905791832	4262475.4124	333800.3206	1625.5804	1625.5798

Station GDM-15

Monitoring parameters are shown in table 52 and position measurements for each monitoring campaign are shown in table 53 for ground deformation monitoring station GDM-15.

Table 52. *Station GDM-15 monitoring parameters.*

Campaign		UGS Code		Monument			GNSS Monitoring			
							Antenna			
#	Date	Temp Probe	GNSS\ Tripod	Rod Temp (°C)	ΔL_{Rod} (mm)	Datum Depth (m)	Height (m)	Measured To	Occupation Time (h:m:s)	Satellites (min/max)
Initial A	12/18/2018	2	4/4	12.4	--	0.123	1.930	Center Bumper	0:40:50	17/17
Initial B	3/10-12/2019	1	2/2	3.9		0.125	1.930	Center Bumper	1:34:47	14/15
1	4/30/2019	2	1/5	12.9	2.5	0.124	1.930	Center Bumper	0:46:02	16/16
2	6/5/2019	2	4/4	21.8	5.1	0.123	1.930	Center Bumper	1:00:26	14/14
3	11/19/2019	2	2/2	10.2	1.8	0.122	1.930	Center Bumper	1:10:06	11/12

Table 53. *Station GDM-15 position measurements.*

Campaign	Station Position NAD83 (2011, Epoch:2010.0000), UTM Zone 12 North – NAVD88 (Geoid12B) Ellipsoidal Coordinates					
	Latitude	Longitude	Northing	Easting	Elevation	Adjusted Elevation
Initial A	38.494111522	-112.897409195	4262345.5136	334529.2823	1656.2462	--
Initial B	38.494111503	-112.897409271	4262345.5116	334529.2756	1656.2578	--
1	38.494111400	-112.897409198	4262345.5001	334529.2818	1656.2582	1656.2557
2	38.494111407	-112.897409411	4262345.5013	334529.2632	1656.2754	1656.2703
3	38.494111501	-112.897409047	4262345.5110	334529.2952	1656.2858	1656.2840

Station GDM-16

Monitoring parameters are shown in table 54 and position measurements for each monitoring campaign are shown in table 55 for ground deformation monitoring station GDM-16.

Table 54. Station GDM-16 monitoring parameters.

Campaign		UGS Code		Monument			GNSS Monitoring			
							Antenna			
#	Date	Temp Probe	GNSS\ Tripod	Rod Temp (°C)	ΔL_{Rod} (mm)	Datum Depth (m)	Height (m)	Measured To	Occupation Time (h:m:s)	Satellites (min/max)
Initial A	12/18/2018	1	5/5	8.2	--	0.091	1.948	Phase Center	0:41:50	17/17
Initial B	3/10-12/2019	1	2/2	3.7	0	0.095	1.930	Center Bumper	1:34:50	12/13
1	4/30/2019	2	1/5	11.4	2.3	0.090	1.930	Center Bumper	0:46:53	13/14
2	6/5/2019	2	4/4	18.0	4.1	0.094	1.930	Center Bumper	1:02:18	17/17
3	11/19/2019	2	2/2	9.9	1.8	0.091	1.930	Center Bumper	1:09:31	13/13

Table 55. Station GDM-16 position measurements.

Campaign	Station Position NAD83 (2011, Epoch:2010.0000), UTM Zone 12 North – NAVD88 (Geoid12B) Ellipsoidal Coordinates					
	Latitude	Longitude	Northing	Easting	Elevation	Adjusted Elevation
Initial A	38.498181940	-112.889340884	4262782.8934	335242.4757	1679.2361	--
Initial B	38.498181837	-112.889340935	4262782.8820	335242.4711	1679.1962	--
1	38.498181743	-112.889340914	4262782.8715	335242.4727	1679.1976	1679.1953
2	38.498181785	-112.889341069	4262782.8765	335242.4592	1679.2030	1679.1989
3	38.498181845	-112.889340721	4262782.8825	335242.4897	1679.2210	1679.2192

Station GDM-17

Monitoring parameters are shown in table 56 and position measurements for each monitoring campaign are shown in table 57 for ground deformation monitoring station GDM-17.

Table 56. Station GDM-17 monitoring parameters.

Campaign		UGS Code		Monument			GNSS Monitoring			
							Antenna			
#	Date	Temp Probe	GNSS\ Tripod	Rod Temp (°C)	ΔL_{Rod} (mm)	Datum Depth (m)	Height (m)	Measured To	Occupation Time (h:m:s)	Satellites (min/max)
Initial A	12/18/2018	1	5/5	8.6	--	0.103	1.948	Phase Center	0:42:75	18/19
Initial B	3/10-12/2019	1	1/1	3.6	0	0.095	1.930	Center Bumper	1:50:00	14/14
1	4/30/2019	1	4/4	13.7	2.7	0.097	1.930	Center Bumper	1:05:28	18/18
2	6/5/2019	2	1/5	24.3	5.9	0.100	1.930	Center Bumper	1:11:46	14/14
3	11/19/2019	2	2/2	10.5	2.0	0.099	1.930	Center Bumper	1:05:11	13/15

Table 57. Station GDM-17 position measurements.

Campaign	Station Position NAD83 (2011, Epoch:2010.0000), UTM Zone 12 North – NAVD88 (Geoid12B) Ellipsoidal Coordinates					
	Latitude	Longitude	Northing	Easting	Elevation	Adjusted Elevation
Initial A	38.495794771	-112.878265366	4262498.1078	336203.2877	1731.1650	--
Initial B	38.495794677	-112.878265423	4262498.0975	336203.2826	1731.1309	--
1	38.495794608	-112.878265407	4262498.0898	336203.2838	1731.1195	1731.1168
2	38.495794635	-112.878265487	4262498.0929	336203.2769	1731.1277	1731.1218
3	38.495794637	-112.878265218	4262498.0926	336203.3003	1731.1572	1731.1552

Station GDM-18

Monitoring parameters are shown in table 58 and position measurements for each monitoring campaign are shown in table 59 for ground deformation monitoring station GDM-18.

Table 58. *Station GDM-18 monitoring parameters.*

Campaign		UGS Code		Monument			GNSS Monitoring			
							Antenna			
#	Date	Temp Probe	GNSS\ Tripod	Rod Temp (°C)	ΔL_{Rod} (mm)	Datum Depth (m)	Height (m)	Measured To	Occupation Time (h:m:s)	Satellites (min/max)
Initial A	12/18/2018	1	3/3	7.9	--	0.116	1.930	Center Bumper	0:46:75	18/19
Initial B	3/10-12/2019	1	2/2	4.6	0	0.120	1.930	Center Bumper	1:49:07	13/13
1	4/30/2019	1	3/3	13.7	1.0	0.114	1.930	Center Bumper	1:07:21	15/15
2	6/6/2019	2	4/5	19.5	1.8	0.115	1.930	Center Bumper	2:10:54	16/17
3	11/19/2019	2	3/3	10.5	0.7	0.115	1.930	Center Bumper	3:03:15	8/9

Table 59. *Station GDM-18 position measurements.*

Campaign	Station Position NAD83 (2011, Epoch:2010.0000), UTM Zone 12 North – NAVD88 (Geoid12B) Ellipsoidal Coordinates					
	Latitude	Longitude	Northing	Easting	Elevation	Adjusted Elevation
Initial A	38.493626138	-112.866940089	4262237.2573	337186.4449	1792.9159	--
Initial B	38.493625977	-112.866939897	4262237.2391	337186.4613	1792.9380	--
1	38.493625916	-112.866939868	4262237.2322	337186.4637	1792.9373	1792.9363
2	38.493625920	-112.866939926	4262237.2328	337186.4586	1792.9333	1792.9315
3	38.493625939	-112.866939666	4262237.2344	337186.4813	1792.9646	1792.9639

Station GDM-19

Monitoring parameters are shown in table 60 and position measurements for each monitoring campaign are shown in table 61 for ground deformation monitoring station GDM-19.

Table 60. *Station GDM-19 monitoring parameters.*

Campaign		UGS Code		Monument			GNSS Monitoring			
							Antenna			
#	Date	Temp Probe	GNSS\ Tripod	Rod Temp (°C)	ΔL_{Rod} (mm)	Datum Depth (m)	Height (m)	Measured To	Occupation Time (h:m:s)	Satellites (min/max)
Initial A	12/18/2018	2	4/4	9.9	--	0.091	1.930	Center Bumper	0:42:00	16/17
Initial B	3/10-12/2019	1	1/1	3.8	0	0.090	1.930	Center Bumper	1:38:40	16/16
1	4/30/2019	2	1/5	11.4	2.2	0.091	1.930	Center Bumper	0:45:25	14/15
2	6/5/2019	2	4/4	19.8	4.5	0.089	1.930	Center Bumper	1:01:38	15/15
3	11/19/2019	2	2/2	9.4	1.6	0.091	1.930	Center Bumper	1:21:01	9/11

Table 61. *Station GDM-19 position measurements.*

Campaign	Station Position NAD83 (2011, Epoch:2010.0000), UTM Zone 12 North – NAVD88 (Geoid12B) Ellipsoidal Coordinates					
	Latitude	Longitude	Northing	Easting	Elevation	Adjusted Elevation
Initial A	38.488516839	-112.893162642	4261716.8079	334886.9934	1683.1787	--
Initial B	38.488516793	-112.893162701	4261716.8030	334886.9881	1683.1877	--
1	38.488516711	-112.893162707	4261716.7939	334886.9874	1683.1921	1683.1899
2	38.488516747	-112.893162821	4261716.7980	334886.9775	1683.2094	1683.2049
3	38.488516802	-112.893162527	4261716.8036	334887.0032	1683.2205	1683.2189

Station GDM-20

Monitoring parameters are shown in table 62 and position measurements for each monitoring campaign are shown in table 63 for ground deformation monitoring station GDM-20.

Table 62. Station GDM-20 monitoring parameters.

Campaign		UGS Code		Monument			GNSS Monitoring			
							Antenna			
#	Date	Temp Probe	GNSS\ Tripod	Rod Temp (°C)	ΔL_{Rod} (mm)	Datum Depth (m)	Height (m)	Measured To	Occupation Time (h:m:s)	Satellites (min/max)
Initial A	12/18/2018	1	5/5	4.8	--	0.088	1.948	Phase Center	0:44:25	14/16
Initial B	3/10-12/2019	1	1/1	5.1	0	0.085	1.930	Center Bumper	1:34:02	13/13
1	4/30/2019	1	4/4	13.7	2.4	0.083	1.930	Center Bumper	0:48:12	12/14
2	6/6/2019	1	1/5	20.2	4.3	0.089	1.930	Center Bumper	1:09:24	16/16
3	11/19/2019	2	2/2	9.9	1.3	0.084	1.930	Center Bumper	1:02:55	10/14

Table 63. Station GDM-20 position measurements.

Campaign	Station Position NAD83 (2011, Epoch:2010.0000), UTM Zone 12 North – NAVD88 (Geoid12B) Ellipsoidal Coordinates					
	Latitude	Longitude	Northing	Easting	Elevation	Adjusted Elevation
Initial A	38.487775386	-112.869599067	4261592.4680	336941.2677	1786.7156	--
Initial B	38.487775304	-112.869599186	4261592.4591	336941.2572	1786.6867	--
1	38.487775196	-112.869599122	4261592.4470	336941.2626	1786.6927	1786.6903
2	38.487775307	-112.869599255	4261592.4595	336941.2512	1786.6891	1786.6848
3	38.487775269	-112.869598946	4261592.4548	336941.2780	1786.7127	1786.7114

GROUND DEFORMATION NETWORK DATA COMMENTARY

A discussion about the data from each monitoring campaign is found in the following sections.

Initial Monitoring Campaign A

Due to the Trimble R8 GNSS receivers not recording Galileo signals, we decided to perform an additional monitoring campaign (Initial B) that will be considered the start of ground deformation monitoring at the FORGE site. This will result in higher quality data and overall lower horizontal and vertical errors. Data from Initial Monitoring Campaign A is included in this report but was not used in the determination of ground deformation.

Initial Monitoring Campaign B

GNSS data quality was good for Initial Monitoring Campaign B and data will be used as the initial measurement for ground deformation monitoring for the Utah FORGE Project. Satellite network error is provided in table 64.

Table 64. Satellite error results for Initial Monitoring Campaign B.

Station	Measurement Date	X ± Error (mm)	Y ± Error (mm)	Z ± Error (mm)
GDM-01	3/11/2019	±5.9	±3.5	±5.0
GDM-02	3/11/2019	±5.8	±3.6	±5.1
GDM-03	3/11/2019	±5.4	±3.4	±4.9
GDM-04	3/12/2019	±6.2	±3.7	±5.7
GDM-05	3/11/2019	±5.4	±3.3	±4.7
GDM-06	3/11/2019	±5.2	±3.1	±4.4
GDM-07	3/11/2019	±5.8	±3.5	±4.9
GDM-08	3/12/2019	±5.8	±3.5	±5.3
GDM-09	3/12/2019	±5.7	±3.5	±5.3
GDM-10	3/11/2019	±5.4	±3.2	±4.5
GDM-11	3/12/2019	±6.3	±3.7	±5.7

Station	Measurement Date	X ± Error (mm)	Y ± Error (mm)	Z ± Error (mm)
GDM-12	3/12/2019	±6.2	±3.8	±5.7
GDM-13	3/12/2019	±5.7	±3.5	±5.3
GDM-14	3/11/2019	±5.3	±3.1	±4.4
GDM-15	3/11/2019	±5.0	±3.1	±4.4
GDM-16	3/11/2019	±6.2	±3.9	±5.5
GDM-17	3/11/2019	±5.7	±3.6	±5.1
GDM-18	3/12/2019	±5.7	±3.4	±5.1
GDM-19	3/11/2019	±5.2	±3.2	±4.4
GDM-20	3/12/2019	±6.2	±3.7	±5.6

Monitoring Campaign 1

Data from Base Station GDM-B2 was not used for processing of Monitoring Campaign 1 positions. The tripod setup at Base Station GDM-B2 experienced ground detachment due to strong, gusty winds and the recorded data was not usable for this campaign. Instead, base station UTMI, located in Milford, Utah, was used as the second base station to substitute for Base Station GDM-B2. The comparative results of Monitoring Campaign Initial B to 1 show little movement between the two campaigns. A vector movement map from Monitoring Campaign Initial B to 1 is shown in figure 84, and change values and network error are shown in table 65.

Table 65. *Monitoring results for Monitoring Campaign 1.*

Station	Monitoring Date		ΔX ± Error (mm)	ΔY ± Error (mm)	ΔZ ± Error (mm)
	Initial	Campaign			
GDM-01	3/11/2019	4/30/2019	0.9 ± 8.1	-12.4 ± 5.0	8.1 ± 6.9
GDM-02	3/11/2019	4/30/2019	6.7 ± 7.6	-16.0 ± 4.8	-5.9 ± 6.4
GDM-03	3/11/2019	4/30/2019	-0.1 ± 8.0	-13.9 ± 5.1	-7.3 ± 6.9
GDM-04	3/12/2019	4/30/2019	1.3 ± 8.9	2.4 ± 5.4	6.3 ± 7.5
GDM-05	3/11/2019	4/30/2019	2.2 ± 8.3	-12.5 ± 5.1	-1.4 ± 7.7
GDM-06	3/11/2019	4/30/2019	-4.0 ± 7.4	-12.2 ± 4.6	0.1 ± 6.6
GDM-07	3/11/2019	4/30/2019	-3.9 ± 8.4	-9.3 ± 5.1	7.3 ± 7.1
GDM-08	3/12/2019	4/30/2019	10.9 ± 7.8	-8.0 ± 5.0	1.9 ± 7.0
GDM-09	3/12/2019	4/30/2019	6.6 ± 12.2	-13.7 ± 7.5	7.6 ± 11.1
GDM-10	3/11/2019	4/30/2019	2.8 ± 7.9	-13.4 ± 5.0	3.3 ± 7.4
GDM-11	3/12/2019	4/30/2019	3.6 ± 10.0	-13.2 ± 6.1	3.8 ± 8.6
GDM-12	3/12/2019	4/30/2019	6.2 ± 7.8	-5.5 ± 4.9	1.3 ± 6.7
GDM-13	3/12/2019	4/30/2019	5.2 ± 7.4	-7.7 ± 4.6	-7.4 ± 6.4
GDM-14	3/11/2019	4/30/2019	8.5 ± 8.2	-12.5 ± 5.0	4.6 ± 6.9
GDM-15	3/11/2019	4/30/2019	6.2 ± 8.3	-11.5 ± 5.2	0.3 ± 7.2
GDM-16	3/11/2019	4/30/2019	1.6 ± 8.7	-10.5 ± 5.7	1.3 ± 8.3
GDM-17	3/11/2019	4/30/2019	1.2 ± 7.8	-7.7 ± 4.8	-11.4 ± 6.7
GDM-18	3/12/2019	4/30/2019	2.4 ± 8.0	-6.9 ± 5.2	-0.7 ± 7.1
GDM-19	3/11/2019	4/30/2019	-0.7 ± 8.1	-9.1 ± 5.0	4.4 ± 7.5
GDM-20	3/12/2019	4/30/2019	5.4 ± 8.4	-12.1 ± 5.2	6.0 ± 7.2

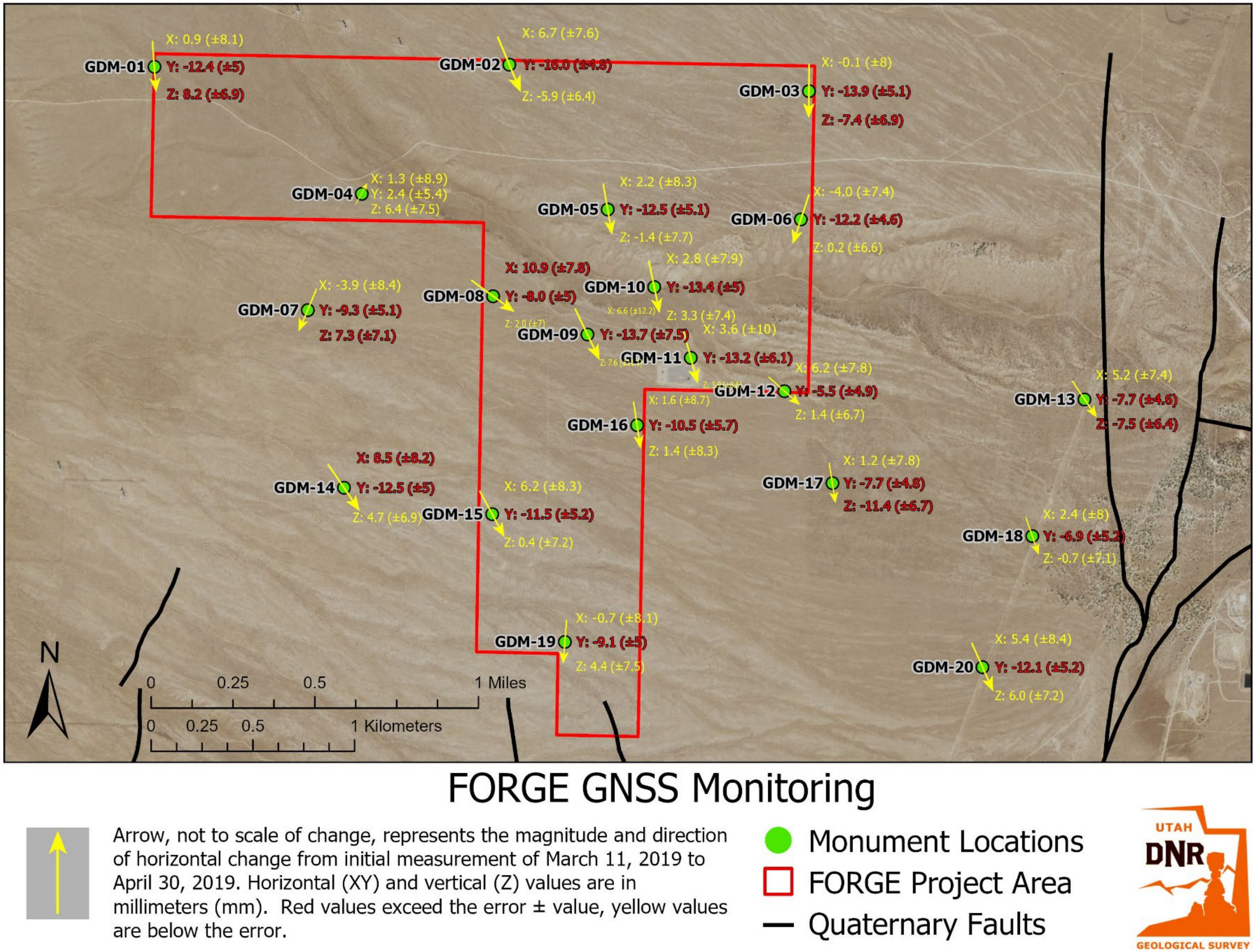


Figure 84. Vector map of monument movements measured between Monitoring Campaigns Initial B and 1.

Monitoring Campaign 2

Adjustments in methodology were made for Monitoring Campaign 2 that included base tripod height and transporting equipment throughout occupation. In an effort in preventing metrological interference with base positions, as experienced in Monitoring Campaign 1, the fixed height tripod was lowered 30 cm, which increased anchor leg reach and lowered the overall profile of the instrument. It was discovered as the monitoring equipment was transported, the tripod length would extend, due to vibrations caused by the rough, off-road terrain. Previously, measured monuments were remeasured, except for Station GDM-05 that extended 1.50 cm, which was corrected in the processing of data and that the raw data for this monument would need correction. Future occupations will adjust transportation methodology to prevent vibration lengthening by resetting the tripod length for each measurement and minimize the use of ATV transport.

The results of Monitoring Campaign 2 compared to Initial Monitoring Campaign B generally show an increase in elevation to the north and west of the FORGE site. Values increased approximately 46 mm at Station GDM-01 to the northwest, 47 mm at Station GDM-07 to the west, 38 mm at Station GDM-02 to the upper north, 34 mm at Station GDM-05 at the mid-north, 27 mm at Station GDM-10 to the lower north, and 36 mm at Station GDM-03 to the northeast. The change in elevation decreases towards the drilling site, with elevations normalizing immediately around the drill site. The monitoring stations with the somewhat large vertical deformation are mostly located adjacent to Negro Mag Wash and an unnamed wash to the south that channel water flowing westward from the Mineral Mountains.

Due to the lack of data for annual groundwater level variations, ground response to thermal change, and the operations of the Blundell Geothermal Plant to the east, it is unknown how these factors may influence each station's elevation. Elevation values slightly increased to the south reaching 17 mm at Station GDM-19. Figure 85 shows a vector movement map from Monitoring Campaign Initial B to 2, and change values and network error are shown in table 66. The horizontal vectors show a general movement trend to the south/southwest. Figure 86 shows a vector movement map from Monitoring Campaign 1 to 2.

Table 66. *Monitoring results for Monitoring Campaign 2.*

Station	Monitoring Date		ΔX ± Error (mm)	ΔY ± Error (mm)	ΔZ ± Error (mm)
	Initial	Campaign			
GDM-01	3/11/2019	6/5/2019	0.1 ± 8.5	-11.0 ± 5.2	45.7 ± 8.0
GDM-02	3/11/2019	6/5/2019	6.3 ± 8.6	-15.3 ± 5.1	38.3 ± 8.0
GDM-03	3/11/2019	6/5/2019	5.9 ± 8.5	-10.3 ± 5.2	35.6 ± 8.0
GDM-04	3/12/2019	6/5/2019	-8.6 ± 8.8	-7.5 ± 5.2	17.2 ± 7.8
GDM-05	3/11/2019	6/5/2019	12.5 ± 9.7	-11.1 ± 6.0	34.3 ± 9.1
GDM-06	3/11/2019	6/5/2019	-1.8 ± 10.7	-14.4 ± 5.9	30.0 ± 9.7
GDM-07	3/11/2019	6/5/2019	4.1 ± 10.0	-9.5 ± 5.9	47.3 ± 9.2
GDM-08	3/12/2019	6/5/2019	2.7 ± 10.1	-7.0 ± 6.2	14.8 ± 9.2
GDM-09	3/12/2019	6/5/2019	-6.7 ± 16.8	-6.0 ± 8.2	-6.7 ± 13.8
GDM-10	3/11/2019	6/5/2019	-1.3 ± 9.1	-8.7 ± 5.6	27.3 ± 8.2
GDM-11	3/12/2019	6/5/2019	-8.8 ± 10.9	-4.4 ± 6.0	-0.9 ± 9.1
GDM-12	3/12/2019	6/5/2019	-1.7 ± 10.5	-5.4 ± 5.8	-9.3 ± 8.7
GDM-13	3/12/2019	6/6/2019	-3.3 ± 13.4	-5.9 ± 7.4	-5.1 ± 11.0
GDM-14	3/11/2019	6/5/2019	2.7 ± 26.8	-12.9 ± 13.9	6.6 ± 25.9
GDM-15	3/11/2019	6/5/2019	-12.4 ± 21.4	-10.3 ± 9.4	12.5 ± 16.8
GDM-16	3/11/2019	6/5/2019	-11.9 ± 11.0	-5.5 ± 6.1	2.7 ± 9.2
GDM-17	3/11/2019	6/5/2019	-5.7 ± 15.6	-4.6 ± 7.7	-9.1 ± 13.0
GDM-18	3/12/2019	6/6/2019	-2.7 ± 12.3	-6.3 ± 6.6	-6.5 ± 10.1
GDM-19	3/11/2019	6/5/2019	-10.6 ± 18.9	-5.0 ± 10.5	17.2 ± 16.3
GDM-20	3/12/2019	6/6/2019	-6.0 ± 13.1	0.4 ± 7.0	-1.9 ± 10.8

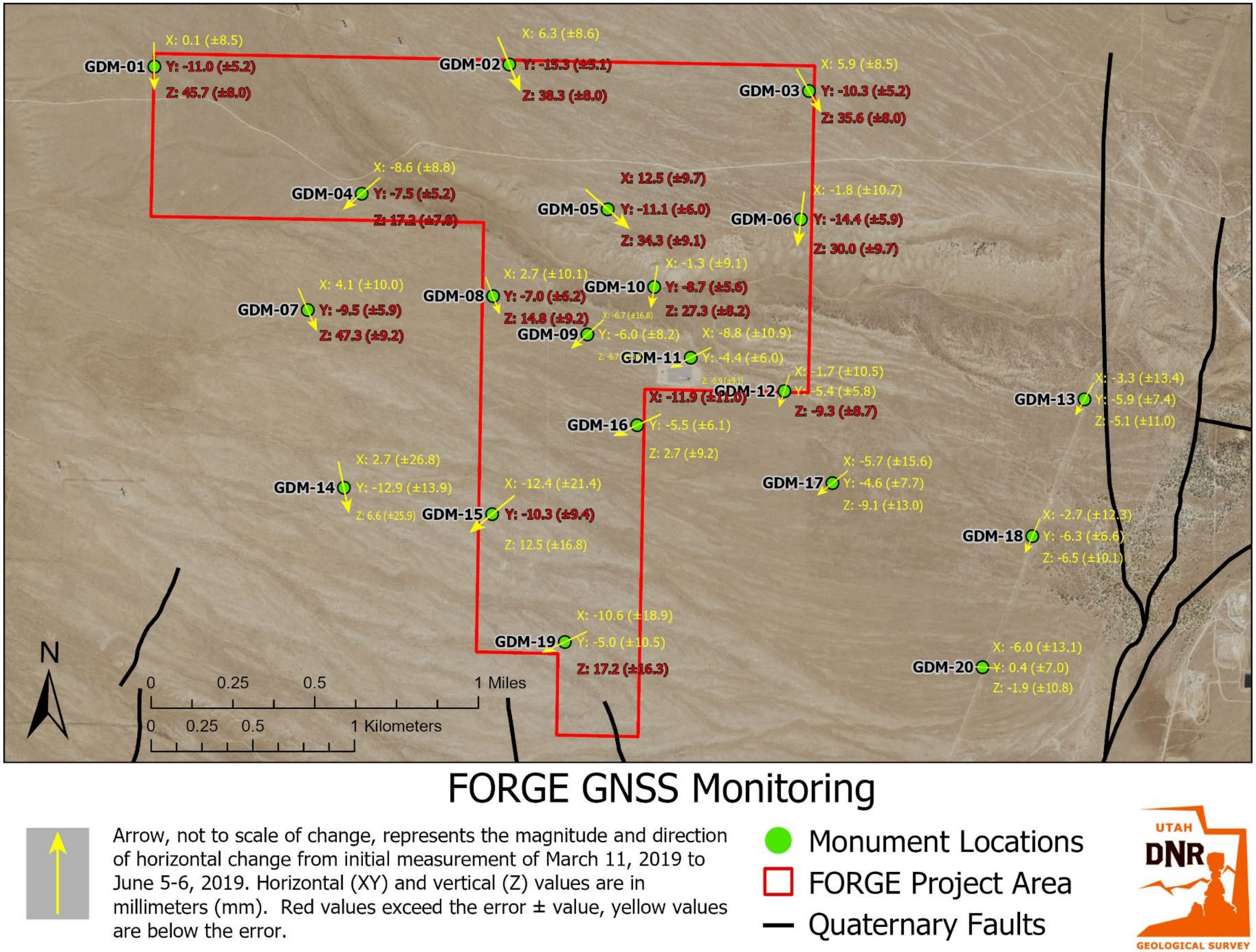


Figure 85. Vector map of monument movements measured between Monitoring Campaigns Initial B and 2.

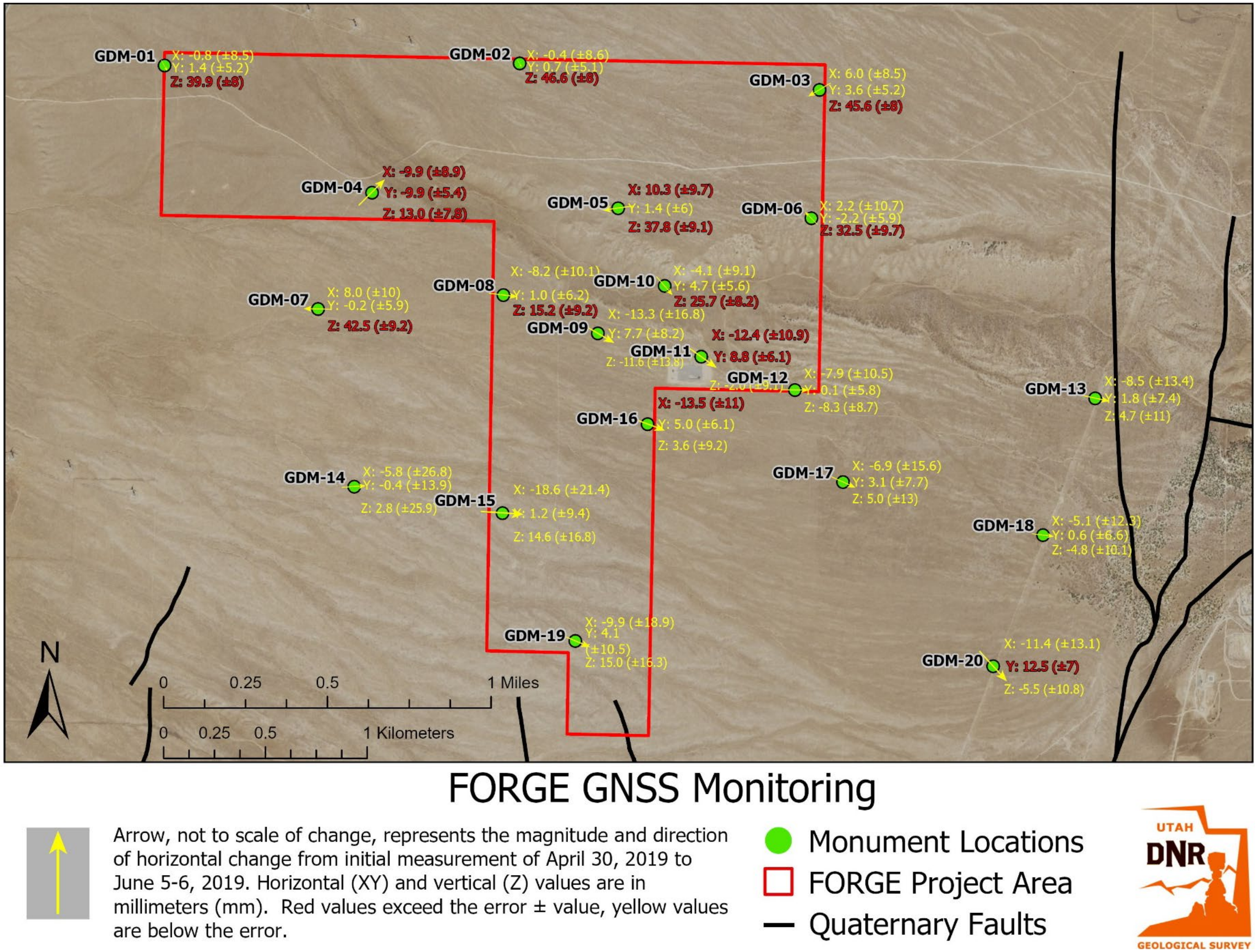


Figure 86. Vector map of monument movements measured between Monitoring Campaigns 1 and 2.

Monitoring Campaign 3

Monitoring Campaign 3 was performed using ATV and truck transport between monitoring stations. Stations GDM-B1, GDM-B2, GDM-01, GDM-02, and GDM-07 were started the night prior to the rest of the campaign, due to the high change documented in Monitoring Campaign 2 for those stations. Another overnight occupation was planned for three additional stations, but due to significant inclement weather, the overnight occupation was not performed. During Station GDM-B1 equipment retrieval, it was discovered the power supply cable connection was detached and that the receiver recorded under five hours of data as a result. No other significant issues occurred during this occupation.

The results of Monitoring Campaign 3 are summarized in figures 87 and 88 and table 67. When comparing to the Initial Monitoring Campaign B in March, there is an overall inflation throughout the FORGE site. Unlike Monitoring Campaign 2, the FORGE site shows an average vertical inflation of 24.5 mm, with a maximum of 31.6 mm and a minimum 14.9 mm, all exceeding the calculated GNSS errors for both occupations. Due to lack of long-term, seasonal data for the area, including groundwater levels and the nearby Blundell Geothermal Plant production and injection wells influence, and that no FORGE project well testing occurred during the time period between Monitoring Campaigns 2 and 3, we theorize the ground inflation is related to natural effects in the area, such as from groundwater changes. However, as further occupations add to the dataset of ground monitoring data, seasonal and other natural effects should be more discernable in developing a more accurate conclusion related to the ground deformation observed in the GNSS data. The Monitoring Campaign Initial B to 3 horizontal vectors show a general movement trend to the east/southeast. The Monitoring Campaign 2 to 3 horizontal vectors show a general movement trend to the southwest with a magnitude less than between Monitoring Campaign Initial B to 3.

Table 67. *Monitoring results for Monitoring Campaign 3.*

Station	Monitoring Date		ΔX ± Error (mm)	ΔY ± Error (mm)	ΔZ ± Error (mm)
	Initial	Campaign			
GDM-01[1]	3/11/2019	11/18/2019	15.9 ± 6.5	-1.3 ± 5.0	31.6 ± 6.0
GDM-02[1]	3/11/2019	11/18/2019	20.6 ± 6.0	-6.2 ± 4.7	22.6 ± 5.6
GDM-03	3/11/2019	11/19/2019	18.9 ± 9.4	3.2 ± 6.2	22.7 ± 8.2
GDM-04	3/12/2019	11/19/2019	13.1 ± 10.8	-3.9 ± 6.7	29.3 ± 9.7
GDM-05	3/11/2019	11/19/2019	19.5 ± 8.2	-1.0 ± 5.7	19.8 ± 7.6
GDM-06	3/11/2019	11/19/2019	16.9 ± 8.4	-3.5 ± 5.7	27.8 ± 7.5
GDM-07[1]	3/11/2019	11/18/2019	12.4 ± 6.2	-0.1 ± 4.8	31.0 ± 5.7
GDM-08	3/12/2019	11/19/2019	21.4 ± 8.7	-8.3 ± 5.8	15.0 ± 8.0
GDM-09	3/12/2019	11/19/2019	21.1 ± 8.1	-2.0 ± 5.6	14.9 ± 7.4
GDM-10	3/11/2019	11/19/2019	16.6 ± 8.9	-5.4 ± 5.8	23.5 ± 8.0
GDM-11	3/12/2019	11/19/2019	17.7 ± 10.7	-3.3 ± 6.9	28.2 ± 9.9
GDM-12	3/12/2019	11/19/2019	24.3 ± 8.3	0.5 ± 5.6	18.2 ± 7.3
GDM-13	3/12/2019	11/19/2019	20.7 ± 8.8	-4.8 ± 5.8	22.8 ± 8.0
GDM-14	3/11/2019	11/19/2019	13.9 ± 7.9	-1.6 ± 5.5	26.4 ± 7.0
GDM-15	3/11/2019	11/19/2019	19.6 ± 8.9	-0.6 ± 5.7	26.2 ± 7.8
GDM-16	3/11/2019	11/19/2019	18.6 ± 8.1	0.5 ± 5.5	23.0 ± 7.3
GDM-17	3/11/2019	11/19/2019	17.7 ± 8.3	-4.9 ± 5.8	24.3 ± 7.8
GDM-18	3/12/2019	11/19/2019	20.0 ± 8.5	-4.7 ± 5.6	25.9 ± 7.8
GDM-19	3/11/2019	11/19/2019	15.1 ± 7.6	0.6 ± 5.5	31.2 ± 7.0
GDM-20	3/12/2019	11/19/2019	20.8 ± 9.1	-4.3 ± 5.9	24.7 ± 8.0

[1] Overnight station occupation time of 15h:25m for GDM-01, 17h:35m for GDM-02, and 16h:49m for GDM-07, instead of the typical ±1-hour occupation time.

In order to determine how longer than ±1-hour station occupation times would reduce measurement error, we occupied stations GDM-01, GDM-02, and GDM-07 overnight for 15h:25m, 17h:35m, and 16h:49m, respectively. Average horizontal (X and Y) and vertical (Z) error for these stations was ±6.2, ±4.8, and ±5.8 mm, respectively. For the remaining stations, the average X, Y, and Z

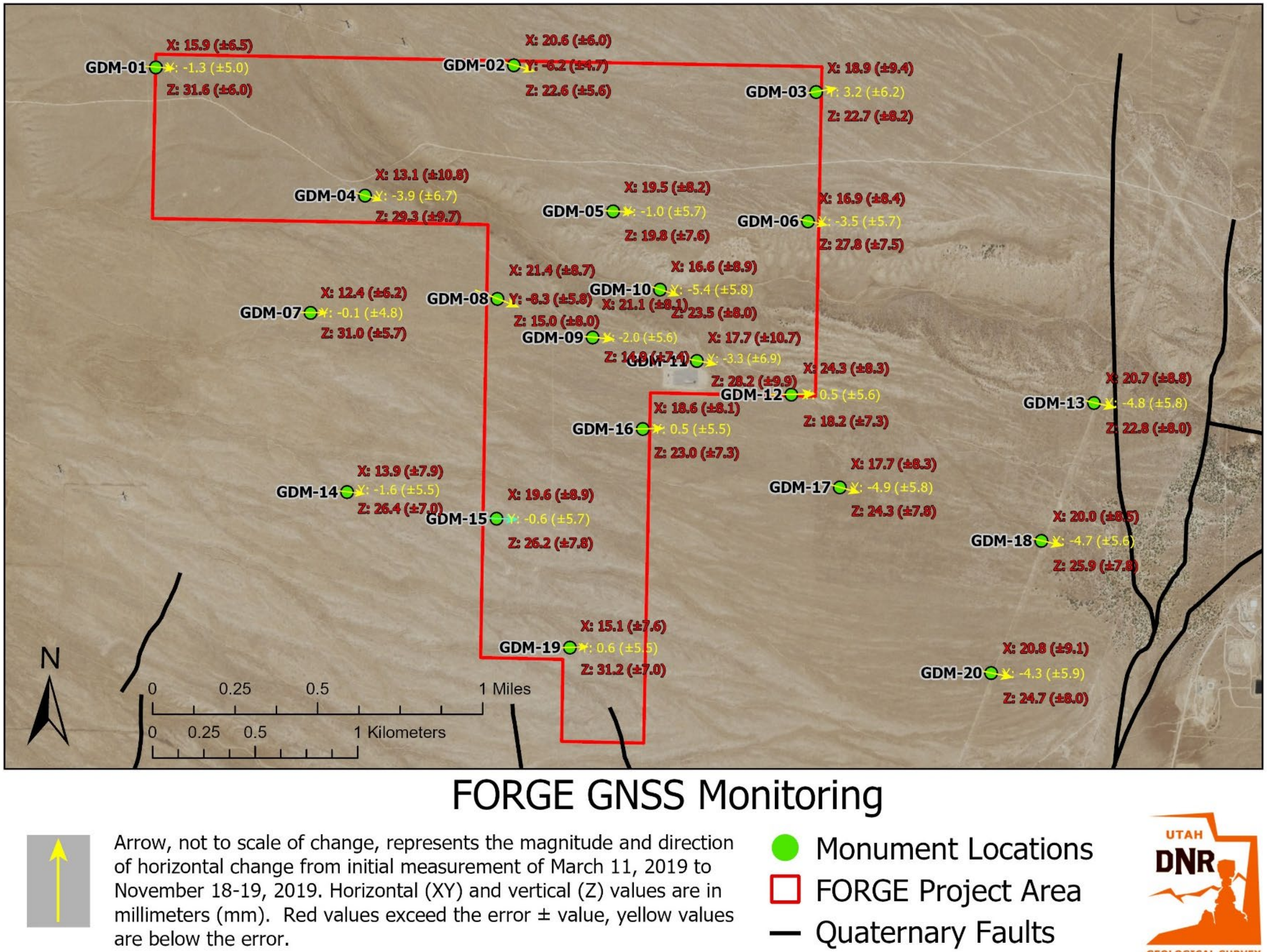


Figure 87. Vector map of monument movements measured between Monitoring Campaigns Initial B and 3.

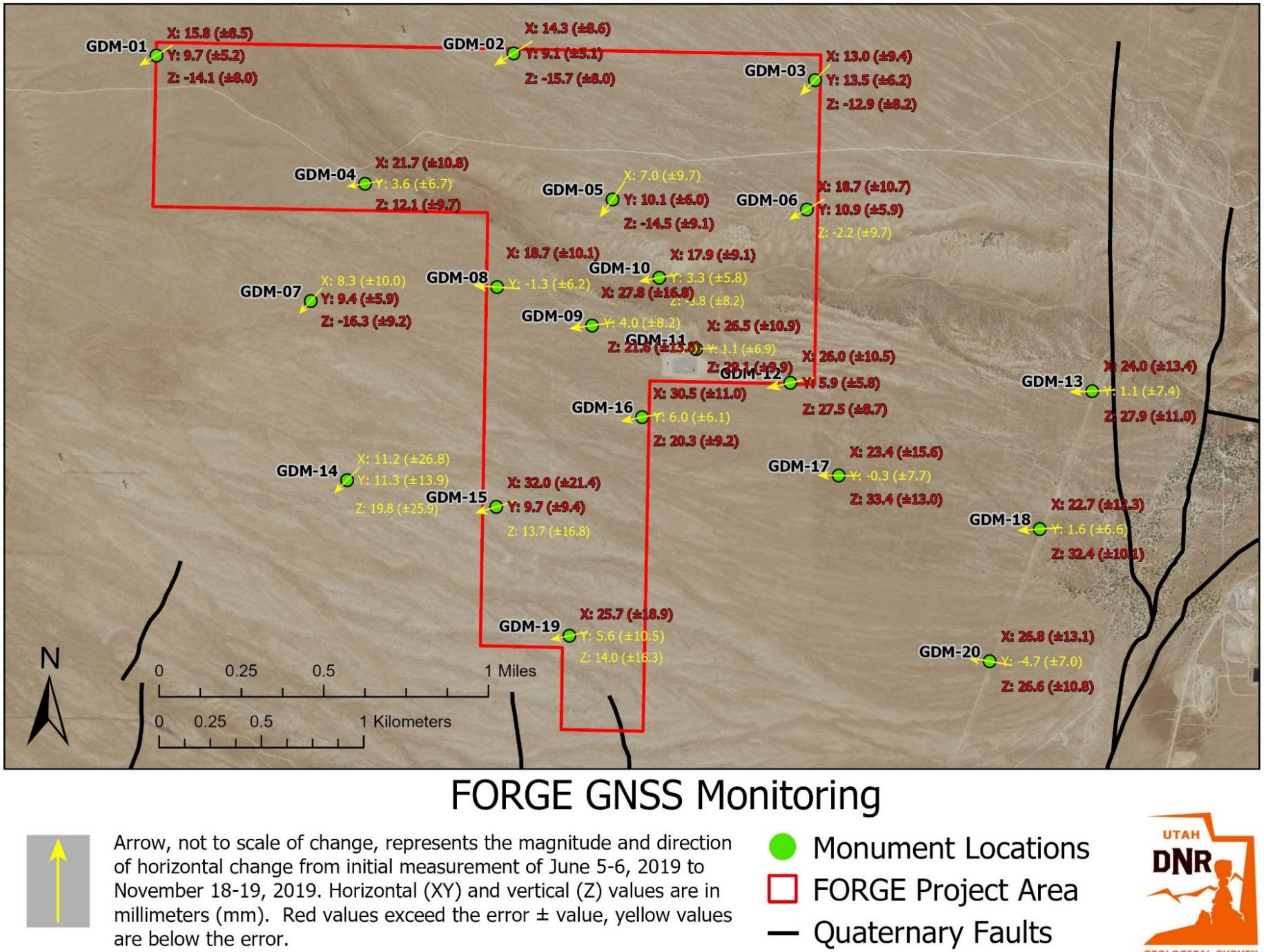


Figure 88. Vector map of monument movements measured between Monitoring Campaigns 2 and 3.

error is ±8.7, ±6.1, and ±7.9 mm, respectively. This results in a decrease in error in X, Y, and Z of ±2.5, ±1.3, and ±2.1 mm, respectively, based on an approximately 15-1/2 to 17-1/2 hour occupation time.

Monitoring Summary and Discussion

Five individual monitoring campaigns have been completed to date, including two initial and three subsequent campaigns. Due to a manufacturer firmware issue with the GNSS receivers used at the monitoring stations during the Initial Monitoring Campaign A, the start of monitoring is considered as the second or Initial Monitoring Campaign B.

Geophysical deformation monitoring station movement errors are generally within the normal range of errors for static survey methods and the complementary interferometric synthetic aperture radar (InSAR) analysis task as part of the Utah FORGE Project. The error is highly dependent on baseline lengths, which for this project, are somewhat long. However, due to the lack of closer areas known to be not spatially moving (horizontal and/or vertical movement) with high confidence, the longer baselines are necessary. A future part of this monitoring could be to identify a closer base station location on solid ground, known to not be moving with high confidence, and that is readily accessible for the GNSS equipment. There are likely several locations above the western range front of the Mineral Mountains; however, topographic shadowing of the GNSS signals will be encountered and an additional GNSS receiver will be required during data acquisition.

The effect of groundwater level variations on ground surface elevations is also unknown, due to the lack of groundwater level monitoring wells within the ground deformation network, as is the impact from operations at the Blundell Geothermal Plant (production and injection wells) to the east. However, these wells are on the east side of the Mineral Mountains West fault, and as such, are not expected to play a large role in effecting ground deformation on the west side of the fault.

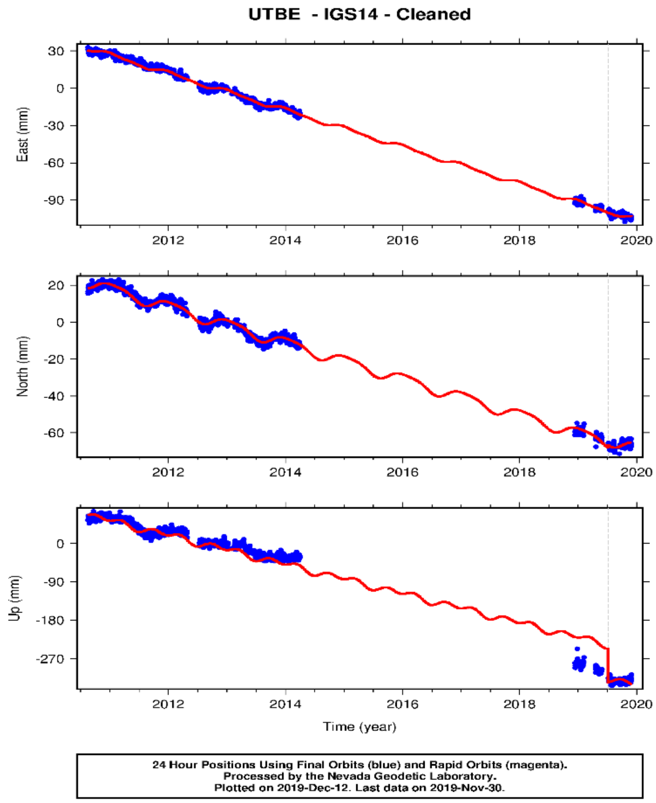


Figure 89. Plot of three-dimensional position (east [x], north [y], and up [z] from top to bottom of figure) of the TURN UTBE station at Beryl Junction, Utah (Nevada Geodetic Laboratory, 2019) showing seasonal horizontal and vertical deformational changes.

The current deformation monitoring network is quite close to the Utah FORGE site and does not include far-field stations, nor do we have a very long temporal baseline of data, as originally proposed. The far field stations and a longer time period of monitoring would help to differentiate seasonal and other deformation signals from those signals created as part of the operation of the Utah FORGE site.

As part of future planning for the Utah FORGE Project, it would be helpful to have at least one continuously operating GNSS geophysical deformation monitoring station within the existing ground deformation network footprint to lower the positional error and to help resolve seasonal and/or diurnal ground deformation changes. Our test with overnight occupation times at three stations during Monitoring Campaign 3 confirmed an approximate reduction of 2 mm average X, Y, and Z error with occupation times >15.5 hours. This station could be co-located with an existing seismometer station or located at the future office and visitor center, where it could be part of an interpretative display for the public. In addition, to reduce errors even further, the existing four GNSS receivers could be replaced with the most current technology in order to add additional satellite constellations and signals that would lower PDOP values.

We will continue to work with the JPL APPS software in processing that may result in more precise base station locations and lower monitoring station movement errors. Future monitoring campaigns during Phase 3 of the Utah FORGE Project will be performed quarterly, and are recommended more often, as drilling and/or stimulation activities proceed.

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APPENDIX A – NGS MONUMENT DATASHEETS

NGS Bailey (JO0533) Bench Mark

```
PROGRAM = datasheet95, VERSION = 8.12.5.2
1        National Geodetic Survey,   Retrieval Date = NOVEMBER 29, 2018
 JO0533 ***********************************************************************
 JO0533  DESIGNATION -  BAILEY
 JO0533  PID         -  JO0533
 JO0533  STATE/COUNTY-  UT/BEAVER
 JO0533  COUNTRY     -  US
 JO0533  USGS QUAD   -  PINNACLE PASS (1973)
 JO0533
 JO0533                         *CURRENT SURVEY CONTROL
 JO0533  ______________________________________________________________________
 JO0533* NAD 83(1994) POSITION- 38 30 47.46252(N) 112 47 53.56451(W)   ADJUSTED
 JO0533* NAVD 88 ORTHO HEIGHT -  2414.7   (meters)      7922.    (feet) VERTCON
 JO0533  ______________________________________________________________________
 JO0533  GEOID HEIGHT    -         -20.131 (meters)                     GEOID12B
 JO0533  LAPLACE CORR    -           4.72  (seconds)                    DEFLEC12B
 JO0533  HORZ ORDER      -  THIRD
 JO0533
 JO0533.The horizontal coordinates were established by classical geodetic methods
 JO0533.and adjusted by the National Geodetic Survey in June 1998.
 JO0533.
 JO0533.The NAVD 88 height was computed by applying the VERTCON shift value to
 JO0533.the NGVD 29 height (displayed under SUPERSEDED SURVEY CONTROL.)
 JO0533
 JO0533.Significant digits in the geoid height do not necessarily reflect accuracy.
 JO0533.GEOID12B height accuracy estimate available here.
 JO0533
 JO0533.The Laplace correction was computed from DEFLEC12B derived deflections.
 JO0533
 JO0533. The following values were computed from the NAD 83(1994) position.
 JO0533
 JO0533;                    North         East     Units Scale Factor Converg.
 JO0533;SPC UT S     - 3,205,728.597   386,773.981   MT  1.00003220   -0 47 43.4
 JO0533;SPC UT S     -10,517,461.24  1,268,940.97   sFT  1.00003220   -0 47 43.4
 JO0533;UTM  12      - 4,264,288.591   343,222.452   MT  0.99990269   -1 07 11.9
 JO0533
 JO0533!             -  Elev Factor  x  Scale Factor =   Combined Factor
 JO0533!SPC UT S     -   0.99962443  x   1.00003220  =   0.99965662
 JO0533!UTM  12      -   0.99962443  x   0.99990269  =   0.99952715
 JO0533
 JO0533:                Primary Azimuth Mark                       Grid Az
 JO0533:SPC UT S     -  PINEY                                      095 40 52.6
 JO0533:UTM  12      -  PINEY                                      096 00 21.1
 JO0533
 JO0533_U.S. NATIONAL GRID SPATIAL ADDRESS: 12SUH4322264288(NAD 83)
 JO0533
 JO0533|---------------------------------------------------------------------|
 JO0533| PID    Reference Object                     Distance      Geod. Az  |
 JO0533|                                                           dddmmss.s |
 JO0533| JO0531 PINEY                               APPROX.12.5 KM 0945309.2 |
 JO0533|---------------------------------------------------------------------|
 JO0533
 JO0533                         SUPERSEDED SURVEY CONTROL
 JO0533
 JO0533  NAD 83(1986)-  38 30 47.45825(N)    112 47 53.56085(W) AD(        ) 3
 JO0533  NAD 27      -  38 30 47.56831(N)    112 47 50.73926(W) AD(        ) 3
```

```
JO0533  NGVD 29 (07/19/86) 2413.4    (m)         7918.     (f) VERT ANG
JO0533
JO0533.Superseded values are not recommended for survey control.
JO0533
JO0533.NGS no longer adjusts projects to the NAD 27 or NGVD 29 datums.
JO0533.See file dsdata.pdf to determine how the superseded data were derived.
JO0533
JO0533_MARKER: DD = SURVEY DISK
JO0533_SETTING: 66 = SET IN ROCK OUTCROP
JO0533_STABILITY: A = MOST RELIABLE AND EXPECTED TO HOLD
JO0533+STABILITY: POSITION/ELEVATION WELL
JO0533_SATELLITE: THE SITE LOCATION WAS REPORTED AS SUITABLE FOR
JO0533+SATELLITE: SATELLITE OBSERVATIONS - September 19, 2011
JO0533
JO0533  HISTORY     - Date     Condition        Report By
JO0533  HISTORY     - 1957     MONUMENTED       USGS
JO0533  HISTORY     - 20110919 GOOD             GEOCAC
JO0533
JO0533                          STATION DESCRIPTION
JO0533
JO0533'DESCRIBED BY US GEOLOGICAL SURVEY 1957
JO0533'LOCATED ABOUT 15 MI. NE. OF MILFORD, 10 MI. E. OF UNION PACIFIC
JO0533'RAILROAD, 1.5 MI. NW. OF POWER LINE, 0.5 MI. N. OF HEAD OF BAILEY
JO0533'CANYON, ON SMALL TOP OF MAIN RIDGE OF MINERAL MOUNTAINS, 6 FT. S.
JO0533'AND 2 FT. LOWER THAN HIGHEST ROCK.
JO0533'
JO0533'TO REACH FROM MILFORD POST OFFICE, DRIVE N. (TOWARD DESERET) ON STATE
JO0533'HIGHWAY 257 FOR 5.5 MI. TO CURVE TO LEFT, CONTINUE STRAIGHT AHEAD ON
JO0533'SIDE RD. ACROSS RAILROAD 2.0 MI. TO FORKS, CONTINUE STRAIGHT AHEAD
JO0533'(RIGHT FORK) 6.7 MI. TO FORKS, CONTINUE STRAIGHT AHEAD (LEFT FORK)
JO0533'1.7 MI. TO SIDE RD., TURN LEFT ON SIDE RD. UP CANYON 2.0 MI. TO
JO0533'SUMMIT OF RIDGE AND DIM CROSSROADS, TURN LEFT (N.) ON DIM RD. ALONG
JO0533'RIDGE 1.5 MI. TO SHARP RIGHT TURN IN MAHOGANY THICKET.  STATION IS
JO0533'ABOUT 300 FT. SW. ON SMALL TOP.
JO0533'
JO0533'STATION MARK--STANDARD TABLET, STAMPED ---BAILEY 1957---, CEMENTED
JO0533'IN GRANITE BEDROCK.
JO0533'
JO0533'REFERENCE MARK NO. 1--STANDARD REFERENCE MARK TABLET, STAMPED ---RM
JO0533'NO 1---, CEMENTED IN BEDROCK, 2 FT. HIGHER THAN STATION MARK.
JO0533'
JO0533'REFERENCE MARK NO. 2--STANDARD REFERENCE MARK TABLET, STAMPED ---RM
JO0533'NO 2 1957---, CEMENTED IN BEDROCK, 1 FT. HIGHER THAN STATION MARK.
JO0533
JO0533                          STATION RECOVERY (2011)
JO0533
JO0533'RECOVERY NOTE BY GEOCACHING 2011 (MFM)
JO0533'RECOVERED AS DESCRIBED.

*** retrieval complete.
Elapsed Time = 00:00:06
```

APPENDIX B – NGS OPUS DATASHEETS

NGS Bailey (JO0533) Bench Mark (FORGE GDM-B1 Base Station) Reoccupation OPUS Solution

Ben Erickson <benerickson@utah.gov>

OPUS solution : 00980700_24h.19d OP1554140622352

1 message

---

opus <opus@ngs.noaa.gov>   Mon, Apr 1, 2019 at 12:11 PM
Reply-To: ngs.opus@noaa.gov
To: benerickson@utah.gov

```
 FILE: 00980700_24h.19d OP1554140622352

                  NGS OPUS SOLUTION REPORT
                  ========================

All computed coordinate accuracies are listed as peak-to-peak values.
For additional information: https://www.ngs.noaa.gov/OPUS/about.jsp#accuracy

     USER: benerickson@utah.gov                DATE: April 01, 2019
RINEX FILE: 0098070r.19o                       TIME: 18:10:44 UTC


  SOFTWARE: page5  1603.24 master73.pl 160321      START: 2019/03/11  17:00:00
 EPHEMERIS: igs20441.eph [precise]                  STOP: 2019/03/12  17:00:00
  NAV FILE: brdc0700.19n                        OBS USED: 64387 / 66212   :  97%
  ANT NAME: TRMR10          NONE               # FIXED AMB:   209 /   224   :  93%
ARP HEIGHT: 1.7989                          OVERALL RMS: 0.017(m)


 REF FRAME: NAD_83(2011)(EPOCH:2010.0000)              IGS08 (EPOCH:2019.1924)

         X:     -1937058.602(m)   0.002(m)         -1937059.518(m)   0.002(m)
         Y:     -4608483.022(m)   0.013(m)         -4608481.715(m)   0.013(m)
         Z:      3951665.231(m)   0.010(m)          3951665.110(m)   0.010(m)

       LAT:   38 30 47.46467      0.013(m)       38 30 47.47878      0.013(m)
     E LON:  247 12  6.43892      0.007(m)      247 12  6.38316      0.007(m)
     W LON:  112 47 53.56108      0.007(m)      112 47 53.61684      0.007(m)
    EL HGT:          2393.687(m)  0.009(m)              2392.946(m)  0.009(m)
 ORTHO HGT:          2413.818(m)  0.028(m) [NAVD88 (Computed using GEOID12B)]

                        UTM COORDINATES    STATE PLANE COORDINATES
                         UTM (Zone 12)         SPC (4303 UT S)
Northing (Y) [meters]     4264288.656          3205728.662
Easting (X)  [meters]      343222.537           386774.065
Convergence  [degrees]    -1.11996389          -0.79539722
Point Scale                0.99990269           1.00003220
Combined Factor            0.99952729           0.99965675

US NATIONAL GRID DESIGNATOR: 12SUH4322264288(NAD 83)


                       BASE STATIONS USED
PID      DESIGNATION                        LATITUDE    LONGITUDE DISTANCE(m)
DL6904 NVSV SPRING VALLEY CORS ARP       N385500.492 W1142409.605  146604.5
DI2242 P009 MARYSVALE_UT2006 CORS ARP    N382847.732 W1121321.725   50361.4
DM7135 NVPI PIOCHE CORS ARP              N375613.346 W1142703.101  158258.5

               NEAREST NGS PUBLISHED CONTROL POINT
JO0533      BAILEY                       N383047.462 W1124753.564       0.1
```

This position and the above vector components were computed without any knowledge by the National Geodetic Survey regarding the equipment or field operating procedures used.

Ben Erickson <benerickson@utah.gov>

OPUS solution : 01910700_24h.19d OP1554143280908

1 message

opus <opus@ngs.noaa.gov> — Mon, Apr 1, 2019 at 12:54 PM
Reply-To: ngs.opus@noaa.gov
To: benerickson@utah.gov

```
FILE: 01910700_24h.19d OP1554143280908

                   NGS OPUS SOLUTION REPORT
                   ========================

All computed coordinate accuracies are listed as peak-to-peak values.
For additional information: https://www.ngs.noaa.gov/OPUS/about.jsp#accuracy

    USER: benerickson@utah.gov              DATE: April 01, 2019
RINEX FILE: 0191070r.19o                    TIME: 18:53:22 UTC


 SOFTWARE: page5  1603.24 master74.pl 160321      START: 2019/03/11  17:00:00
EPHEMERIS: igs20441.eph [precise]                  STOP: 2019/03/12  17:00:00
 NAV FILE: brdc0700.19n                        OBS USED: 64813 / 66469   :  98%
 ANT NAME: TRMR10          NONE              # FIXED AMB:   222 /   233   :  95%
ARP HEIGHT: 1.1459                          OVERALL RMS: 0.017(m)


REF FRAME: NAD_83(2011)(EPOCH:2010.0000)              IGS08 (EPOCH:2019.1924)

      X:   -1958758.923(m)  0.005(m)          -1958759.841(m)  0.005(m)
      Y:   -4596273.612(m)  0.002(m)          -4596272.306(m)  0.002(m)
      Z:    3953845.056(m)  0.007(m)           3953844.935(m)  0.007(m)

    LAT:   38 32 39.00775      0.005(m)       38 32 39.02168      0.005(m)
  E LON:  246 55  5.23571      0.006(m)      246 55  5.17969      0.006(m)
  W LON:  113  4 54.76429      0.006(m)      113  4 54.82031      0.006(m)
 EL HGT:         1572.245(m)   0.005(m)             1571.512(m)   0.005(m)
ORTHO HGT:       1592.968(m)   0.028(m) [NAVD88 (Computed using GEOID12B)]

                   UTM COORDINATES    STATE PLANE COORDINATES
                    UTM (Zone 12)         SPC (4303 UT S)
Northing (Y) [meters]     4268248.946         3209548.717
Easting (X)  [meters]      318566.480          362093.797
Convergence  [degrees]    -1.29760833         -0.96919722
Point Scale                1.00000539          1.00003923
Combined Factor            0.99975876          0.99979259

US NATIONAL GRID DESIGNATOR: 12SUH1856668248(NAD 83)


                        BASE STATIONS USED
PID       DESIGNATION                        LATITUDE    LONGITUDE DISTANCE(m)
DM7135 NVPI PIOCHE CORS ARP                N375613.346 W1142703.101  137526.9
AI8817 ECHO ECHO_BRGN_NV1999 CORS ARP      N375455.904 W1141551.243  124873.8
DI2242 P009 MARYSVALE_UT2006 CORS ARP      N382847.732 W1121321.725   75293.7

               NEAREST NGS PUBLISHED CONTROL POINT
JO0542      SOLUS                          N383218.039 W1130706.939     3265.6
```

This position and the above vector components were computed without any knowledge by the National Geodetic Survey regarding the equipment or field operating procedures used.