Comparison of GNSS Combinations within California Department of Transportation Real Time Network

Contributors

Scott M Peterson Ph.D, PLS (Corresponding Author)
Department of Civil and Geomatics Engineering, California State University, Fresno
2320 E. San Ramon Avenue M/S EE94
Fresno, CA 93740
scpeterson@mail.fresnostate.edu
office: 559-278-1602

Yushin Ahn, Ph.D
Department of Civil and Geomatics Engineering, California State University, Fresno
2320 E. San Ramon Avenue M/S EE94
Fresno, CA 93740
yahn@mail.fresnostate.edu
office: 559-278-8312

Mike Berber, Ph.D
Department of Civil and Geomatics Engineering, California State University, Fresno
2320 E. San Ramon Avenue M/S EE94
Fresno, CA 93740
yahn@mail.fresnostate.edu
office: 559-278-2974

Chris Thornton, PLS
Chief, New Technology Systems
Caltrans
1727 30th Street, MS #35
Sacramento, CA 95816
chris.thornton@dot.ca.gov

Erik Zamora
Department of Civil and Geomatics Engineering, California State University, Fresno
2320 E. San Ramon Avenue M/S EE94
Fresno, CA 93740
erik_zamora_1@mail.fresnostate.edu

Abstract

Network Real-Time Kinematic (NRTK) surveys are in traditional boundary and construction surveys. However, legacy standards do not address NRTK surveys. With advancement in Global Navigation Satellite System (GNSS) technology, standards have not kept pace with providing guidance regarding GNSS constellation pairings.

California Department of Transportation (Caltrans) currently operates the Caltrans Spatial Reference Network (CTSRN) with more than 200 Continuous Global Navigation Satellite System (cGNSS) Stations, providing precise positioning services to various programs, without knowing what satellite constellation pairings are optimal.

Within the CTSRN, two networks of different sizes, along with 3 testing sites yielding various baseline lengths, are used to determine the most optimal pairings of GNSS constellations. At each of the three test sites, all possible combinations of GPS, GLONASS, GALILEO, and BEIDOU (15 total combinations) were tested every 40 minutes over multiple continuous 24-hour periods.

CTSRN performance results show that the GPS constellation is the only constellation able to initialize on its own during the whole 24-hour period. GPS proves foundational to any constellation pairing and should always be used for optimal precision. Further testing shows that any triplet pairings with GPS are optimal to achieve the highest precision.

Introduction

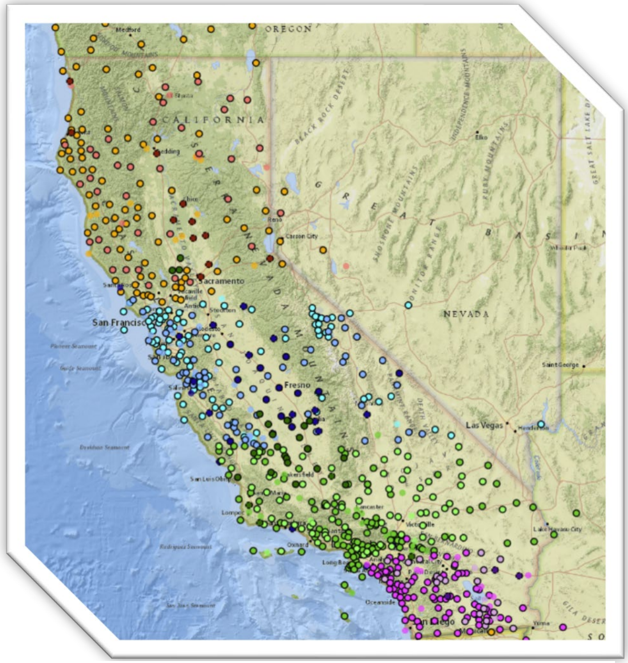

Figure 1 - CTSRN

In California, there are 3 main NRTK service providers, Leica SmartNet, Trimble VRS, and Caltrans with their own independent Trimble VRS called CTSRN. With technological advancements in GNSS, NRTK surveys tied to the CTSRN have increased, greatly improving productivity and time efficiency which support a variety of Caltrans survey applications, including surveys, construction, inspections, as-builts, automated machine guidance, and building information management. To save the taxpayer money, Caltrans needs to be efficient in its time and use of resources and equipment. NRTK eliminates the use of additional setup and equipment (Allahyari, et al. 2018). The end user only needs to set up a rover and connect to the CTSRN to receive real-time updates and corrections without the constraint of distance from a base station (Edwards, Clark and Penna 2010). Caltrans currently relies on legacy standards that do not address NRTK designs, namely baseline spacing of the cGNSS, occupation time, constellation pairings, time of day, tropospheric interaction, ionospheric interaction, and seasonal measurements. Any combination of all NRTK settings will influence the accuracy and precision of any given measurement at any given time and location.

There are currently four usable GNSS satellite constellations that the CTSRN has the ability to connect to: United States GPS, Russia's Globalnaya Navigazionnaya Sputnikovaya Sistema (GLONASS), China's BeiDou, and the European Union's Galileo. The expansion of satellite constellations introduces new opportunities for potentially improving positional stability, repeatability, and accuracy. In 2018, previous studies utilized only GPS and GLONASS which had global coverage (Allahyari, et al. 2018). With advancements from other agencies globally, currently all four constellations, GPS, GLONASS, Galileo and BeiDou, provide global coverage. Past studies have evaluated the accuracy and precision of GPS and GLONASS constellations. But, with the addition of Galileo and BeiDou as newly developed global constellations, no study has explored the optimal pairing amongst the four (GPS, GLONASS, Galileo, and BeiDou). Although Henning (Henning 2014) suggests that dilution of precision nor the number of satellite vehicles does not contribute significantly to the precision of the measurement, this study was done in 2014 and only had global constellations of GPS+GLONASS. With a lack of understanding, typical users will want to use all constellations or a combination with the hopes that they all jointly provide greater redundancy and to safeguard the precision of the work performed.

The CTSRN is a Trimble Based network utilizing virtual reference stations (VRS) method running on the Trimble Pivot software. Trimble Pivot models the ionosphere and troposphere and transmits the corrections to the rover. Janssen (Janssen 2009) and Petovello (Petovello 2011) describe how networks model the ionosphere and troposphere to provide a pseudo single base station result for seamless and reliable work, which is what the VRS represents. The Trimble Pivot modeling of the ionosphere and troposphere allow for the rover within the CTSRN to go greater distances which greatly benefits an organization like Caltrans that covers a vast network of roads and infrastructure.

This study explores the performance of the CTSRN with regards to all possible combinations of pairings of GPS, GLONASS, Galileo and BeiDou while working within the CTSRN evaluating the precision of occupations at three sights over the course of a 24-hour period. Each of the three test sites will each vary in character within the network. This study will provide recommendations of optimal constellation pairings, and optimal time to make NRTK measurements within the CTSRN. From the collected data and presented data, further insights can be concluded with reference to baseline lengths, accuracies, interaction with the ionosphere and troposphere, although only constellation pairing will be addressed in this report. Although baselines will provide differing results (Henning 2014), each site will be independently evaluated so as to only compare constellation pairings. Further studies will evaluate other influencing factors.

This research fills the gap in literature where it will expand across all current combinations of constellations across a consecutive period of 24 hours. As presented herein, GPS is foundational to any constellation pairing for optimal results. An orbital period for GPS satellites is roughly 12 hours. This study used two GPS periods (24 hours) for redundancy and to provide the most varied data with all other pairings with different orbital periods.

Background

The primary goal of the CTSRN is to provide a simple procedure for all programs with the California Department of Transportation, to be efficient in their time management, use of equipment, and ability to provide accurate and precise results on all observed data. Caltrans desires to know the performance capabilities of the CTSRN with respect to constellation pairings, baseline length, occupation time, and seasonal changes.

Repeatable real-time positioning is critical for transportation infrastructure development, asset management, and construction surveying. The CTSRN delivers NRTK positioning across California using a statewide array of Continuously Operating Reference Stations (CORS). While GPS forms the core of this service, modern receivers increasingly support additional constellations, including GLONASS, Galileo, and BeiDou. This expansion introduces new opportunities for improving positioning stability, particularly in challenging geometries or degraded environments. Traditional practice is to enable all constellations, or those that are available without understanding why, only with the assumption that more constellations mean better quality.

Both legacy standards, the Federal Geographic Data Committee (FGDC) defined horizontal positional precision at the 95% confidence level (FGDC 1998), and the Caltrans Survey Manual Chapter 5 (Caltrans 2015) reinforces this requirement by recommending that internal precision be expressed using confidence circle methods when error ellipses are unavailable. Although many CORS networks continue to rely on GPS-only solutions, the increased availability of multi-constellation signals invites a re-evaluation of NRTK performance under real-world field conditions.

This study was conducted through a partnership between Caltrans and the Fresno State Department of Geomatics Engineering to assess how various constellation combinations affect internal horizontal precision in a NRTK environment. Caltrans maintains a CORS network with some operating with all constellations and others operating and a reduced amount, many older CORS running with only GPS and GLONASS. Caltrans desires to know

1. Given the cost of ~$1500 connection fees to each individual constellation, and given that Caltrans has over 200 CORS within the CTSRN, are all constellations needed at each CORS
2. which subset of constellation pairing can achieve the highest precision and accuracy. Can Caltrans continue to use legacy standards of GPS+GLONASS
3. what is the capability of the CTSRN amongst all pairs of constellations

4. when is the optimal time to achieve the highest degree of precision and accuracy

This portion of the study evaluates the constellation pairings. Although studied previously by Henning (Henning 2014), it is determined that for this procedure the effects of baseline length, will not contribute to the analysis of deciding which pairs of constellations are optimal. The results will show the effects of baselines, however, a future report will address baseline length with respect to the CTSRN. This process will mimic any random location and outline the process to best test the set of constellations. Each site will act independently, while measuring the reported precision and accuracy at that given location.

Utilizing Trimble Pivot, two dedicated Caltrans networks were constructed to support this analysis. Baselines are given as a reference to show the expanse of the project areas:

- **Main-net**: A 6-station network with a ~312 km perimeter,
- **Sub-net**: A 5-station network with a ~151 km perimeter.

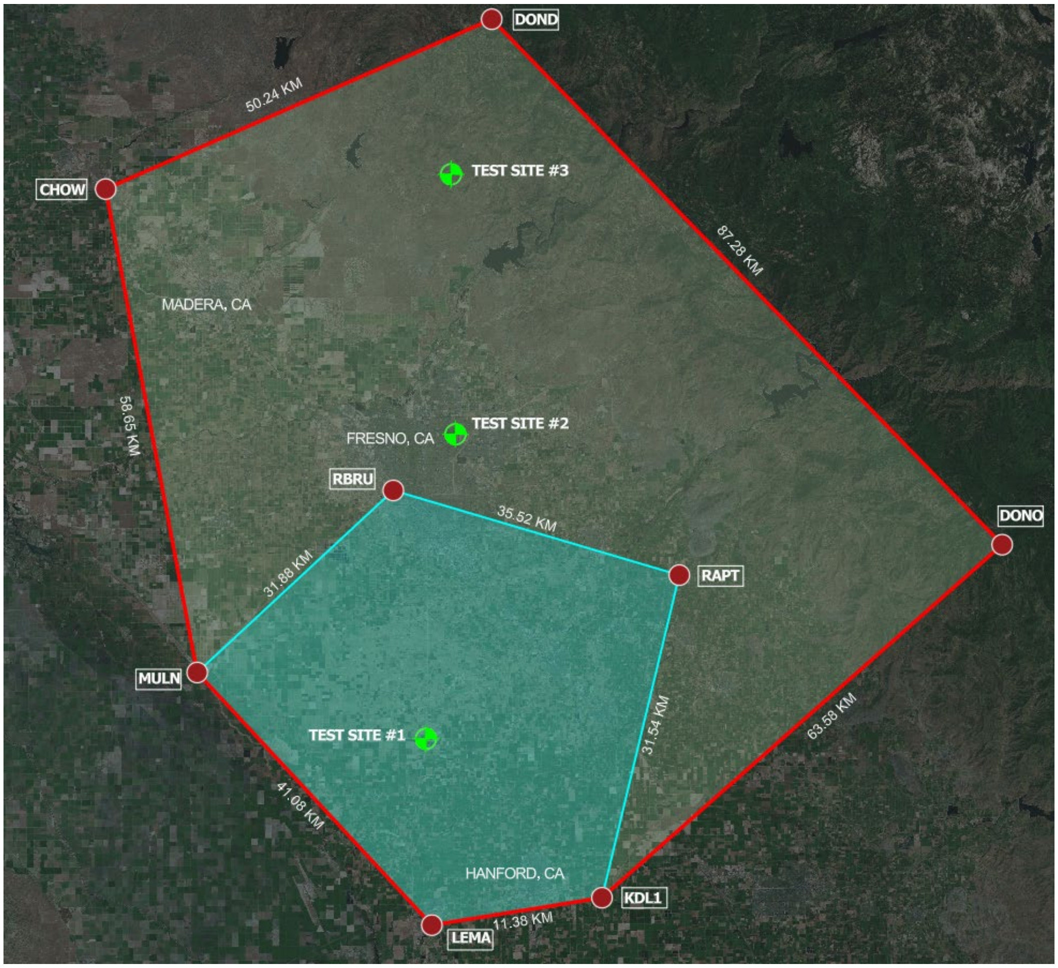

Figure 2 - Main-net and Sub-net within CTSRN

Three test sites were strategically selected to represent a range of geographic conditions:

- **Site 1** (Sub-net center): ~28.9 km average baseline length (22.2-35.9 km range), central to the sub-net COR stations, and within Caltrans right-of-way for easy and permittable access, with an average orthometric elevation of 110m.

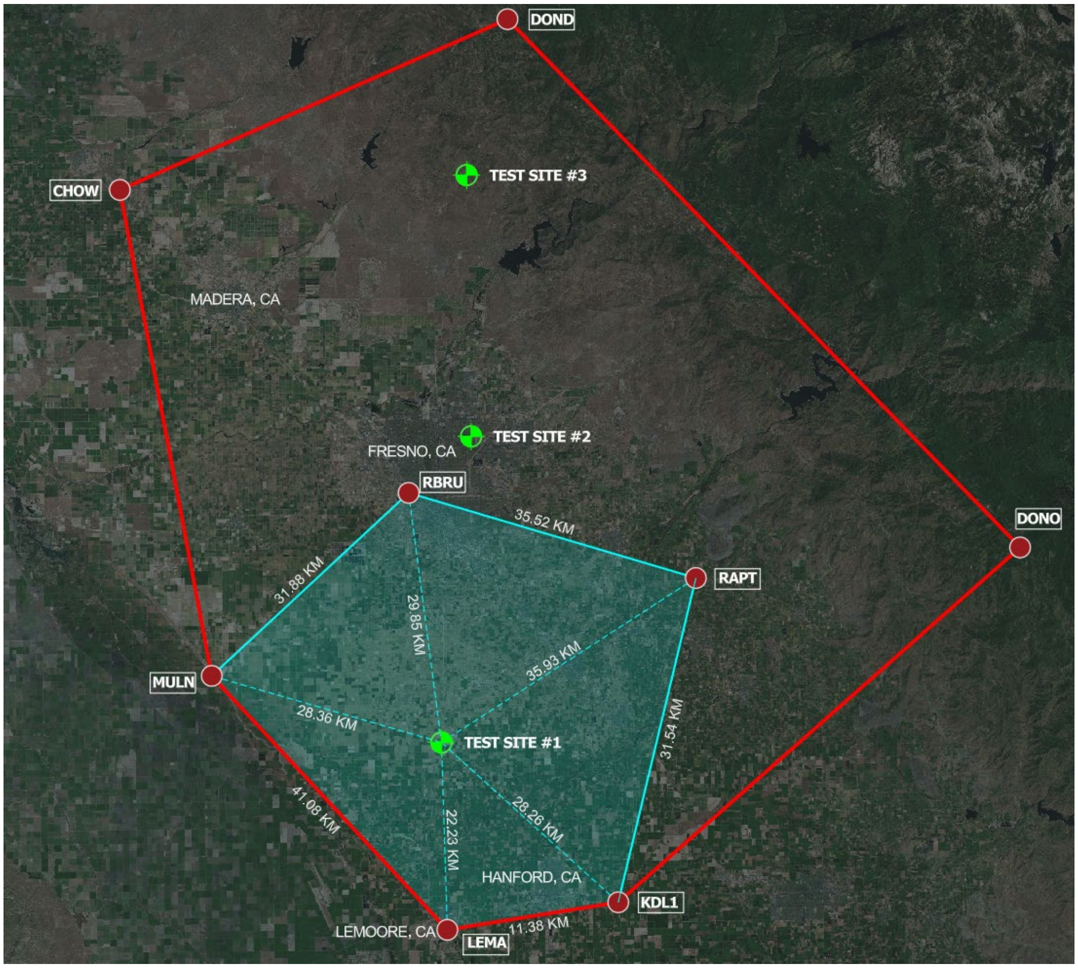

Figure 3 - Subnet showing Location of Test Site #1

- **Site 2** (Main-net center): ~54.2 km average baseline length (41.9-66.4 km range, located on Fresno State Campus, central to the main-net. It too has an average orthometric elevation of 100m.

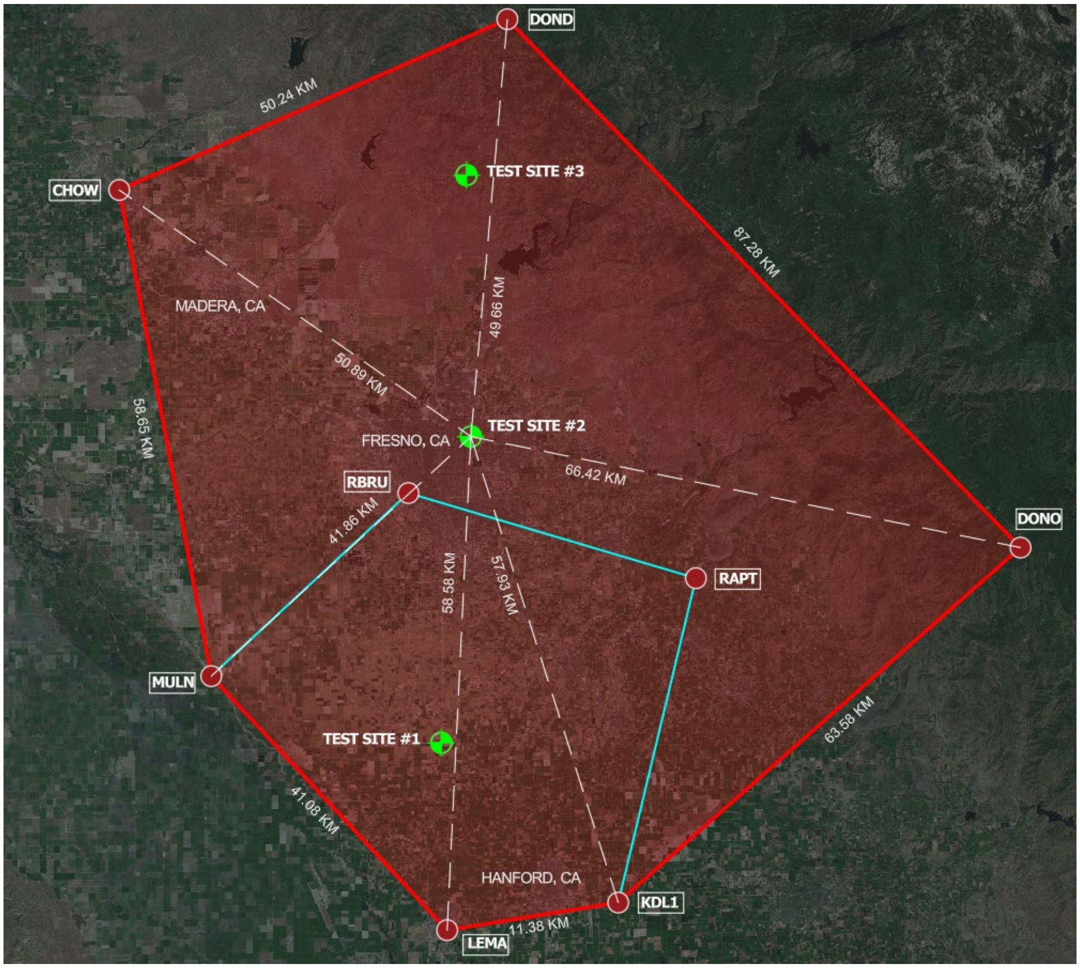

Figure 4 - Main-net showing location of Test site #2

- **Site 3** (Main-net edge): ~63.9 km average baseline length (19.1–89.5 km range), located roughly 25 north of Fresno State at a shared research area with the Forest Service named the San Joaquin Experimental Range. It has an average orthometric elevation of 330m.

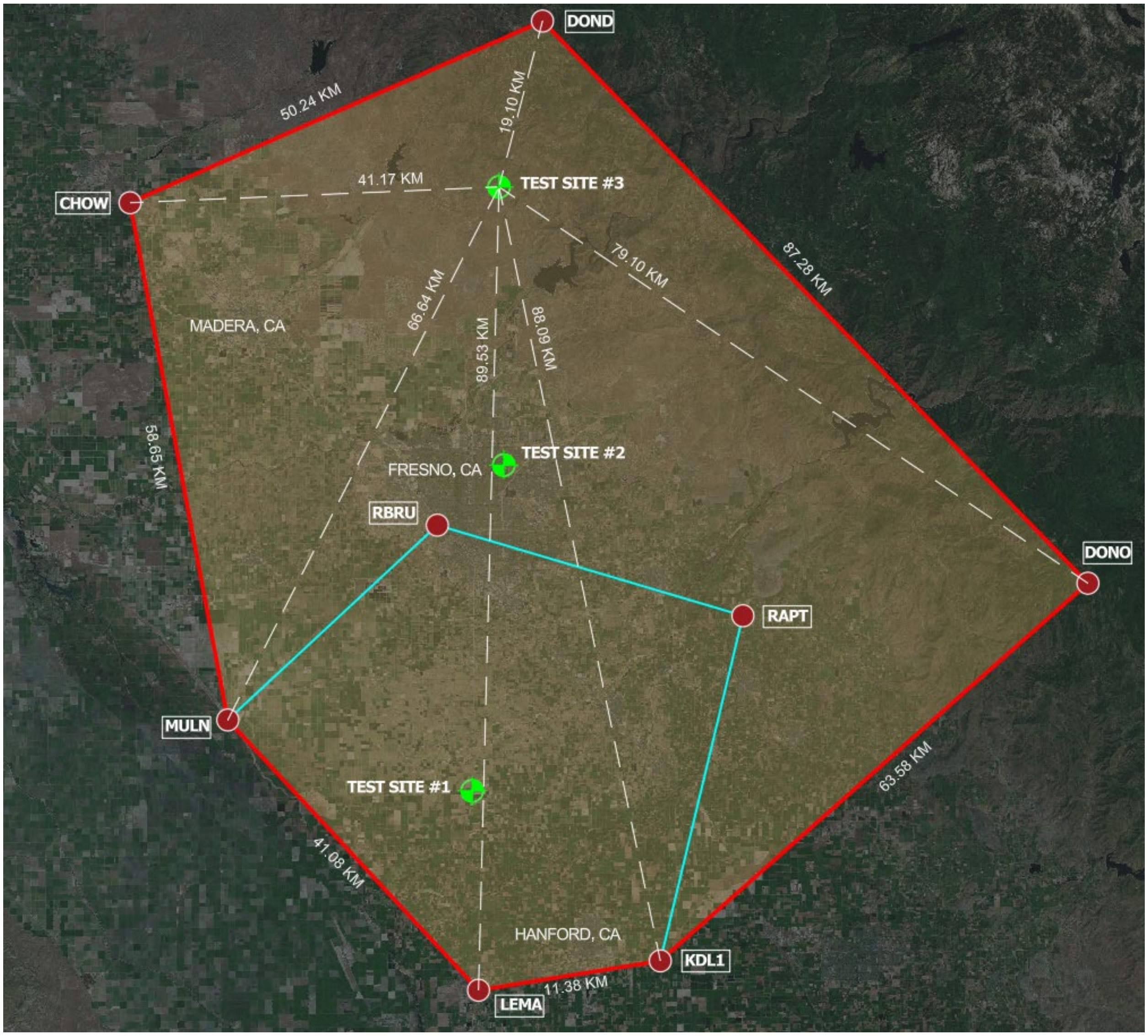

Figure 5 - Main-net showing location of Test Site #3

The goal of this research was to evaluate and compare the reported precision from Trimble Business Center (Trimble Buisness Center n.d.) reported by each constellation group, compute the observed standard deviation at the 95% confidence level, and then to identify the top four performing configurations for further evaluation in future phases. Special emphasis was placed on adherence to Caltrans and FGDC standards, with mean precision values at the 95% confidence level, and the S95 values computed using the Caltrans-approved method for circular horizontal accuracy.

Methodology

Site Construction and Equipment Setup

Three permanent test sites were established across the Central Valley of California. At each site, two fixed 7.6cm - diameter steel posts, 3.048 meters in length, were installed to ensure structural integrity and repeatability. Each post was embedded in a 0.3048m diameter borehole, with approximately 1.52 meters encased in concrete below ground and approximately 1.52 meters exposed above ground. The interior of each post was fully filled with concrete to maximize rigidity. Each post was placed approximately 6 meters apart.

Figure 6 - Permanent Mounting Post for GNSS Receiver

A 3-inch SECO Tilt Mount Adapter was installed at the top of each post and paired with a Trimble Quick Release system, maintaining a consistent 0.050-meter vertical offset. All mount hardware was sealed and secured using industrial-grade Loctite to ensure permanence throughout the study. Only the GNSS receiver was removed between sessions, guaranteeing consistent antenna orientation and geometry.

Each observation session used a Trimble R12i GNSS receiver connected to a TSC5 data collector via Bluetooth. The survey type was configured as RTK using broadcast corrections from the Caltrans Spatial Reference Network (CTSRN) in Virtual Reference Station (VRS) format. The tilt function and the xFill feature was disabled to ensure all positioning was based strictly on real-time corrections provided by CTSRN.

Observation Protocol and Constellation Configurations

A total of 15 GNSS constellation combinations were evaluated, covering all practical permutations of GPS (G), GLONASS (R), Galileo (E), and BeiDou (C). These combinations were grouped into two categories:

1. Post #1: GPS-Inclusive Combinations – using GPS with one or more additional constellations, reflecting standard compatibility across CTSRN base stations.
2. Post #2: Non-GPS Combinations – excluding GPS, to analyze the independent performance of alternative constellations and the value of GPS in multi-constellation NRTK.

At 40-minute intervals, the receiver was re-initialized to start a new 60-second NRTK session. This process was repeated across a 24-hour period, yielding 36 observations per constellation combination per site. The total observation campaign produced a large, time-distributed dataset under uniform hardware and environmental conditions.

Data Processing and Statistical Analysis

Horizontal precision metrics were extracted using TBC (Trimble Buisness Center n.d.), specifically from the Trimble QC3 quality reports. The reported horizontal DRMS values were scaled using a 1.9599 multiplier to represent 95% internal confidence level.

To further evaluate local precision, the S95 value was calculated for each constellation group using actual observables. This method follows the Caltrans Surveys Manual (Caltrans 2015) which approximates the 95% confidence circle without requiring a covariance matrix. Only groups with 30 or more valid observations were included in S95 analysis to maintain statistical reliability.

All numerical processing and visualization were conducted in MATLAB and Microsoft Excel. Mean precision, S95, minimum, maximum, and range values were calculated for each constellation group, and the top four performers at each site were highlighted for further consideration in subsequent phases.

Results

Horizontal precision statistics were calculated for each GNSS constellation group across the three test sites. Results include the reported horizontal precision at the 95% confidence level and the S95 (observed standard deviation at the 95% confidence level) positional precision. S95 was calculated per Caltrans Chapter 5 (Caltrans 2015), using deviations from the mean northing and easting to estimate a 95% confidence radius. S95 values are only reported for groups with at least 30 valid observations.

Site 1

Constellation	Reported Precision Min (m)	Max (m)	Range (m)	2-sigma (m)	Observed Precision S95 (m)	Constellation
G1	0.007	0.023	0.016	0.016	0.012	G1
G2	0.011	0.034	0.023	0.017	0.010	G2
R	0.016	0.040	0.024	0.025	N/A	R
E	0.010	0.028	0.018	0.016	0.012	E
C	0.012	0.067	0.055	0.024	0.019	C
RE	0.009	0.026	0.017	0.014	0.011	RE
RC	0.011	0.079	0.068	0.021	0.019	RC
EC	0.008	0.020	0.012	0.012	0.012	EC
REC	0.007	0.023	0.016	0.012	0.016	REC
GR	0.010	0.021	0.012	0.014	0.011	GR
GE	0.007	0.016	0.009	0.010	0.009	GE
GC	0.008	0.018	0.011	0.012	0.012	GC
GRE	0.007	0.014	0.007	0.010	0.009	GRE
GRC	0.006	0.019	0.013	0.011	0.012	GRC
GEC	0.006	0.014	0.008	0.009	0.013	GEC
GREC	0.006	0.016	0.009	0.009	0.012	GREC

Table 1 - Site #1 Precision Statistics for all 15 possible combinations of constellations

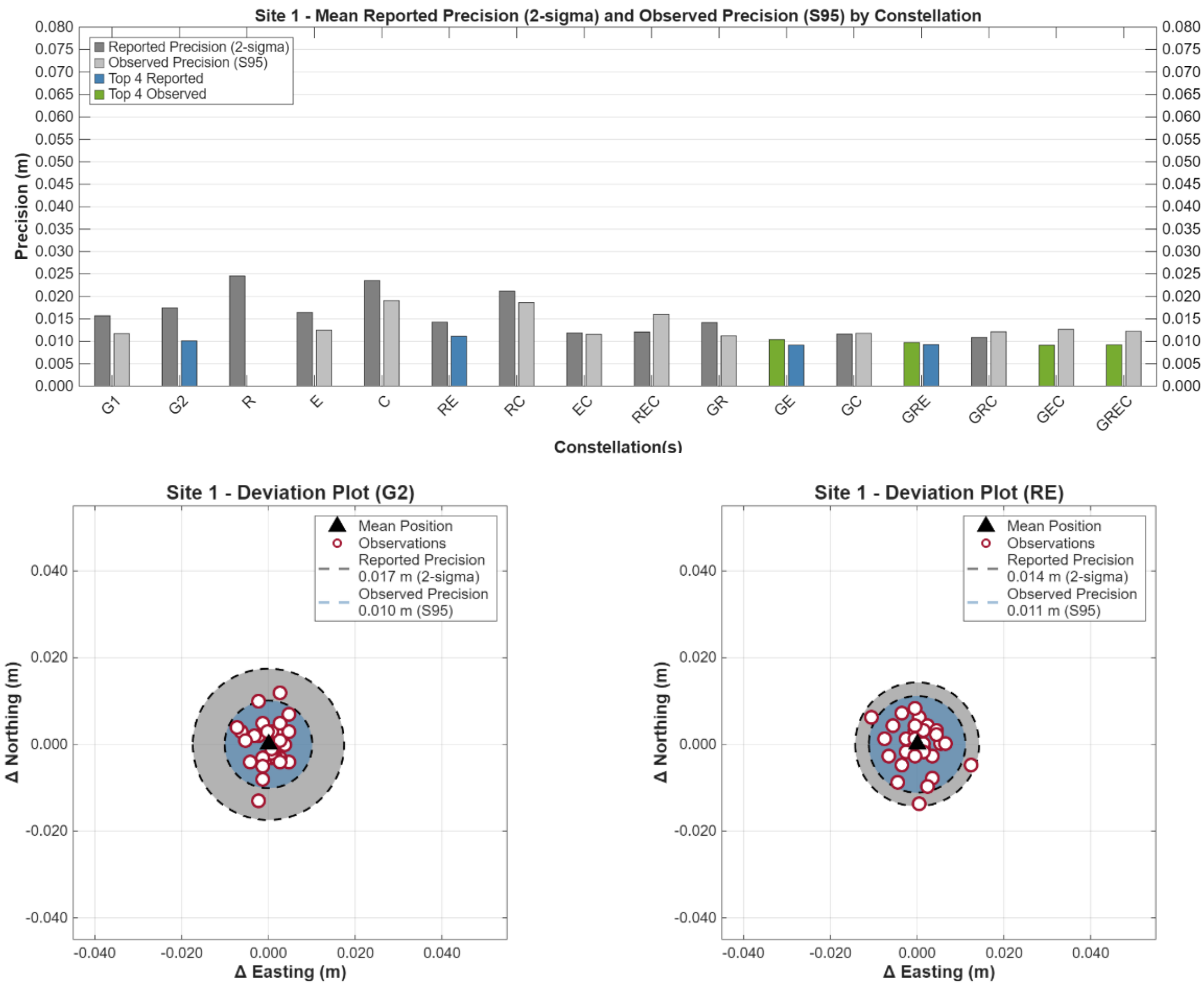

Figure 7 – Top = Overall results of 15 Constellation combinations at Site #1, Bottom Left = Scatter plot showing actual observations with respect to the mean from Post #2 @ site #1 with GPS only constellation, Bottom Right = Scatter plot showing actual observations with respect to the mean with GLONASS + Galileo

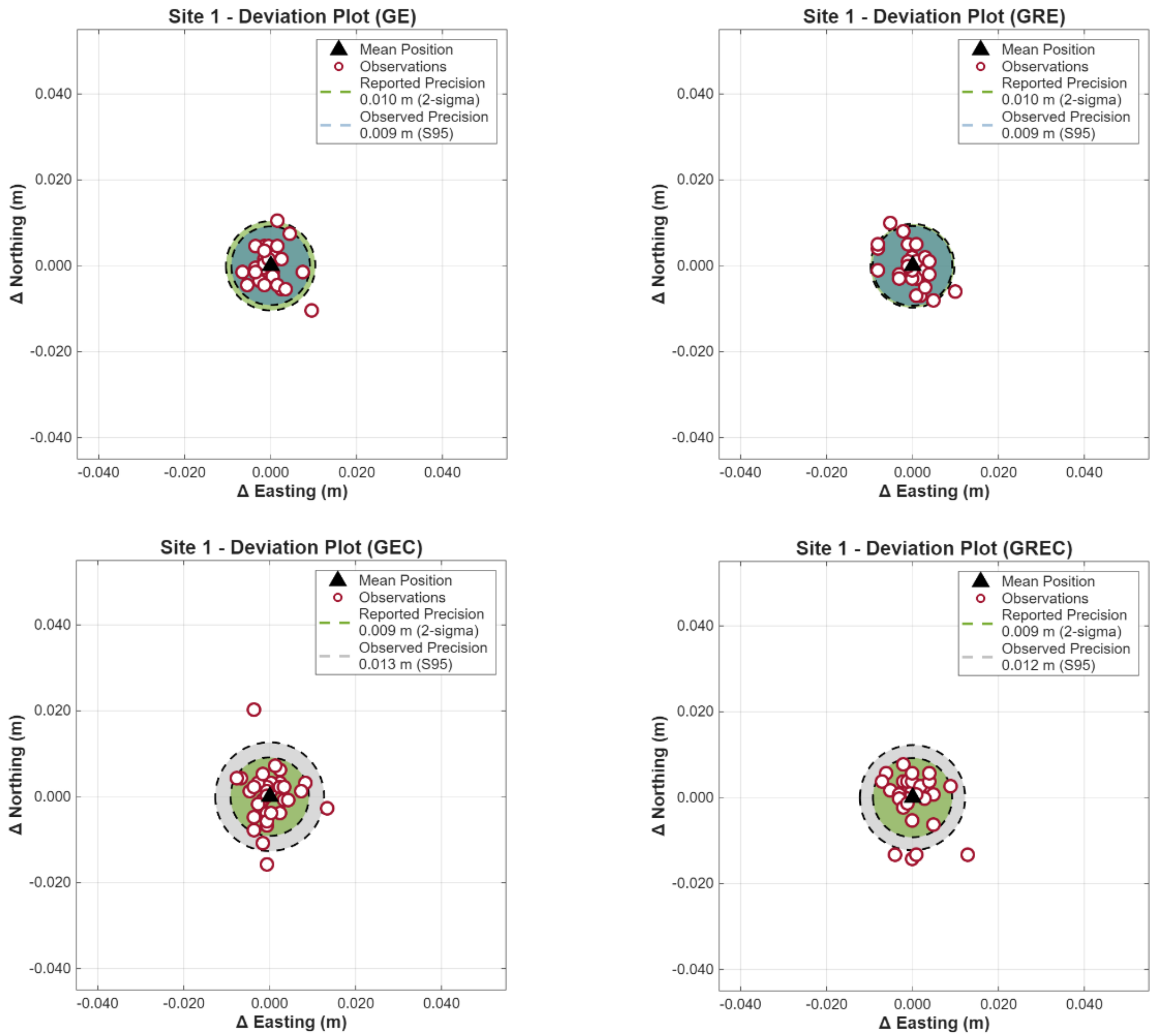

Figure 8 - Scatter plots showing actual observations with respect to the mean Site #1 – GPS + Galileo (GE), GPS + GLONASS + Galileo (GRE), GPS + Galileo + BeiDou (GEC), GPS + GLONASS + Galileo + BeiDou (GREC)

Site 2

Constellation	Reported Precision Min (m)	Max (m)	Range (m)	2-sigma (m)	Observed Precision S95 (m)	Constellation
G1	0.015	0.095	0.080	0.031	0.041	**G1**
G2	0.013	0.072	0.059	0.030	0.024	**G2**
R	0.023	0.031	0.007	0.027	N/A	**R**
E	0.016	0.097	0.081	0.034	N/A	**E**
C	0.012	0.081	0.069	0.028	N/A	**C**
RE	0.013	0.069	0.056	0.027	0.039	**RE**
RC	0.011	0.073	0.062	0.026	0.062	**RC**
EC	0.011	0.055	0.044	0.022	0.029	**EC**
REC	0.009	0.055	0.046	0.021	0.071	**REC**
GR	0.015	0.081	0.065	0.030	0.034	**GR**
GE	0.011	0.063	0.052	0.022	0.022	**GE**
GC	0.009	0.053	0.044	0.022	0.032	**GC**
GRE	0.011	0.056	0.045	0.021	0.027	**GRE**
GRC	0.009	0.057	0.047	0.021	0.044	**GRC**
GEC	0.008	0.036	0.027	0.017	0.026	**GEC**
GREC	0.008	0.055	0.047	0.019	0.028	**GREC**

Table 2 - Site #2 Precision Statistics for all 15 possible combinations of constellations

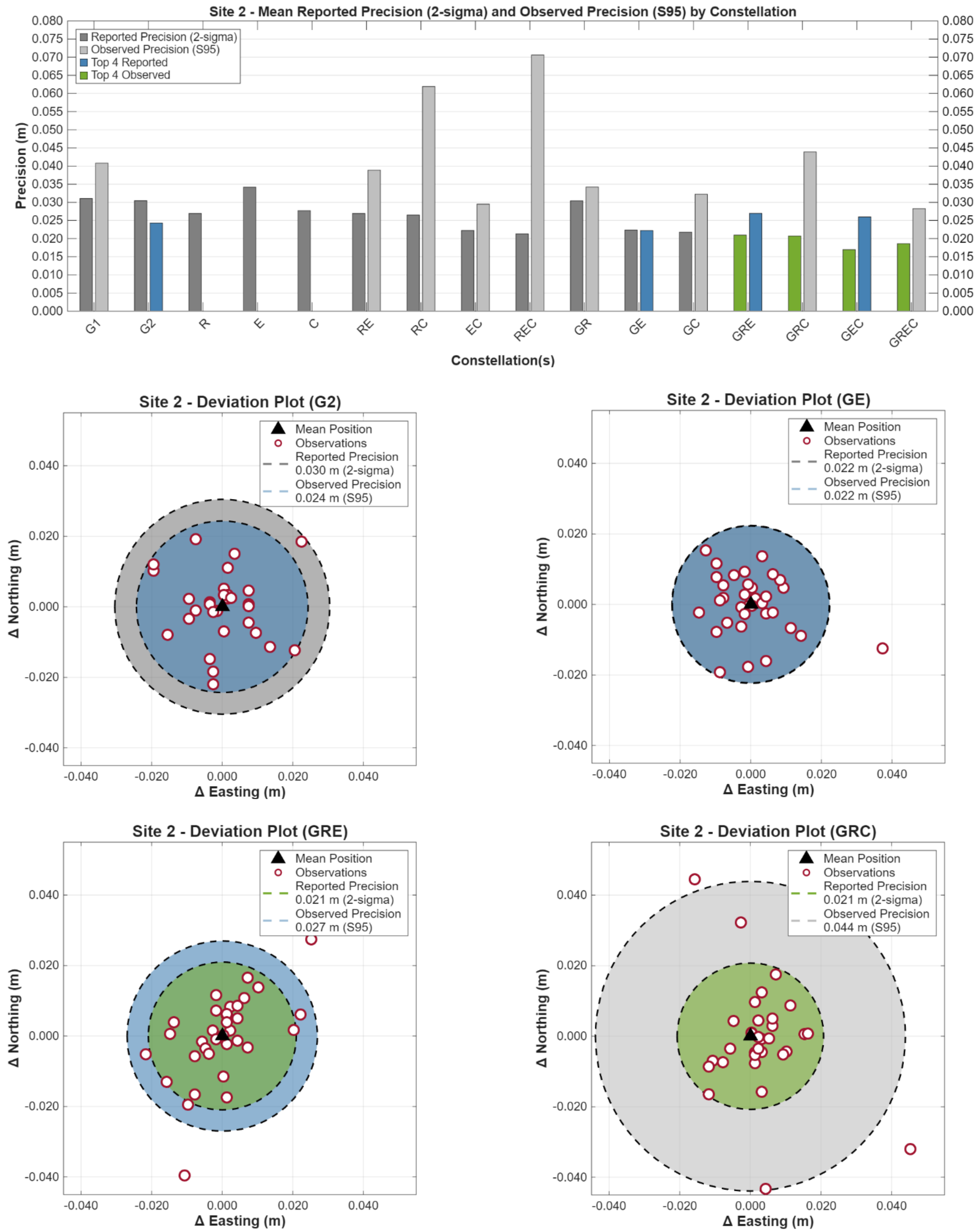

Figure 9 - Top = Overall results of 15 Constellation combinations at Site #2, Middle Left = Scatter plot showing actual observations with respect to the mean from Post #2 @ site #2 with GPS only constellation, Middle Right = Scatter plot showing actual observations with respect to the mean - GPS + Galileo, Bottom Left = Scatter plot showing actual observations with respect to the mean - GPS + GLONASS + Galileo (GRE), Bottom Right = Scatter plot showing actual observations with respect to the mean - GPS + GLONASS + BeiDou (GRC)

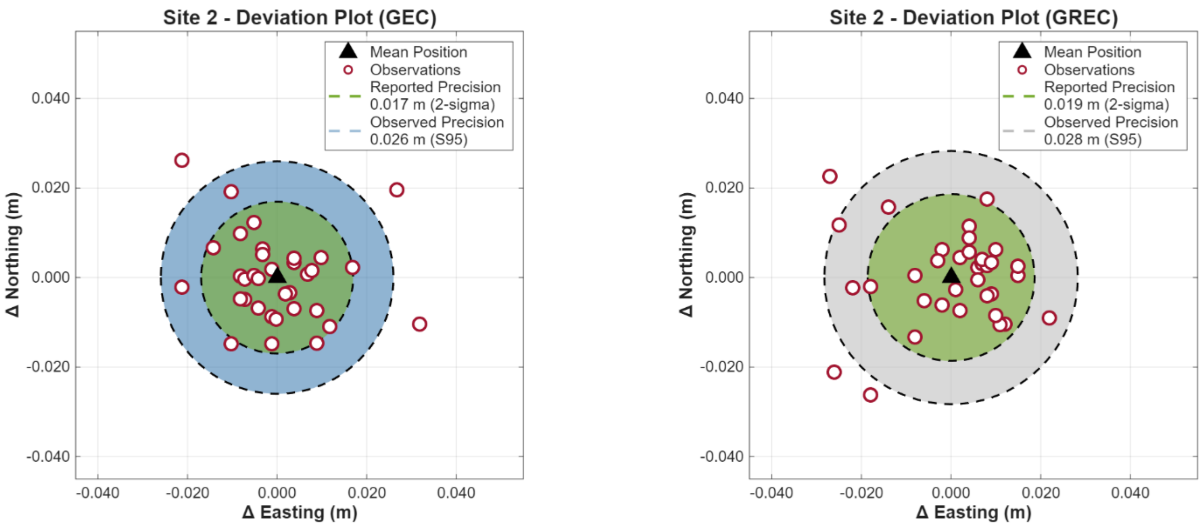

Figure 10 – Left = Scatter plot showing actual observations with respect to the mean Site #2 - GPS + Galileo + BeiDou (GEC), Right = Scatter plot showing actual observations with respect to the mean Site #2 - GPS + GLONASS + Galileo + BeiDou (GREC)

210 ## Site 3

Constellation	Reported Precision				Observed Precision	Constellation
	Min (m)	Max (m)	Range (m)	2-sigma (m)	S95 (m)	
G1	0.009	0.050	0.041	0.027	0.022	G1
G2	0.014	0.062	0.047	0.027	0.019	G2
R	N/A	N/A	N/A	N/A	N/A	R
E	0.014	0.065	0.052	0.026	N/A	E
C	0.017	0.071	0.054	0.031	N/A	C
RE	0.013	0.047	0.034	0.023	0.015	RE
RC	0.011	0.048	0.036	0.022	0.020	RC
EC	0.010	0.042	0.032	0.018	0.014	EC
REC	0.009	0.053	0.044	0.017	0.023	REC
GR	0.013	0.037	0.024	0.021	0.014	GR
GE	0.010	0.028	0.018	0.017	0.012	GE
GC	0.010	0.037	0.027	0.017	0.024	GC
GRE	0.009	0.026	0.017	0.016	0.013	GRE
GRC	0.009	0.027	0.017	0.016	0.012	GRC
GEC	0.008	0.044	0.036	0.014	0.015	GEC
GREC	0.007	0.023	0.016	0.013	0.011	GREC

Table 3 - Site #3 Precision Statistics for all 15 possible combinations of constellations

211

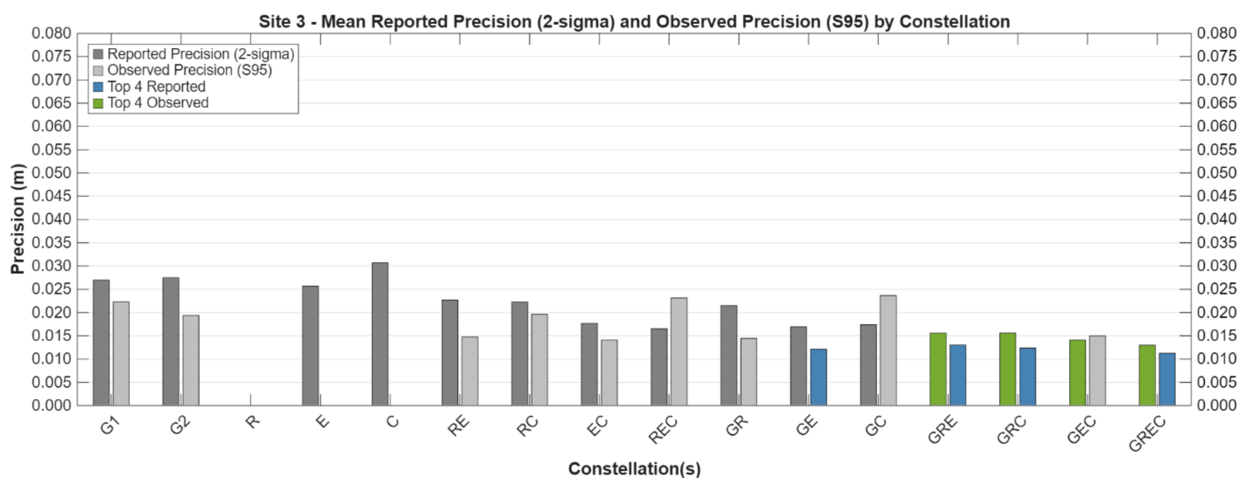

Figure 11 – Overall results of 15 Constellation combinations at Site #3

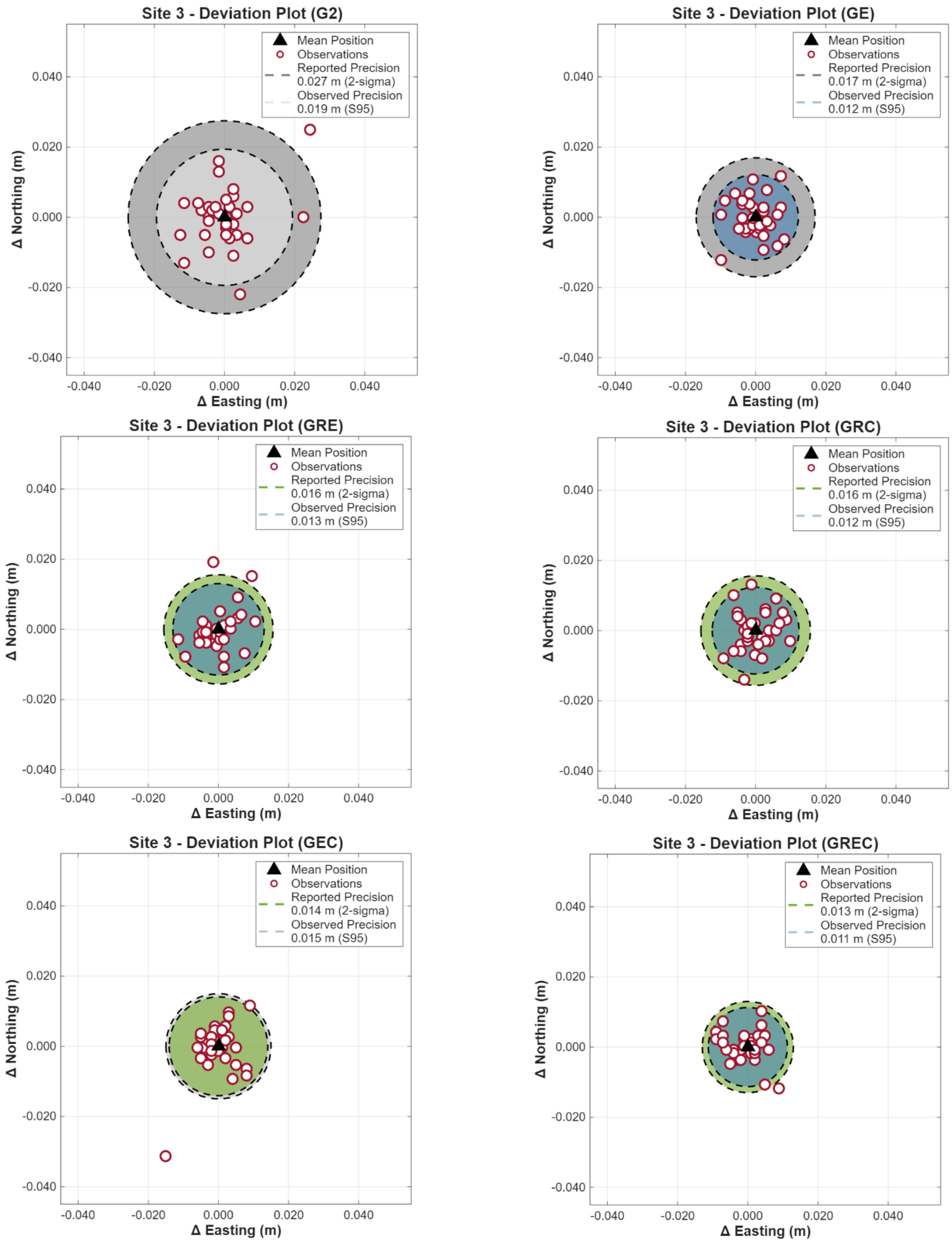

Figure 12 – Scatter plot showing actual observations with respect to the mean Site #3 – GPS only at Post #2 @ Site #3, GPS + Galileo (GE), GPS + GLONASS + Galileo (GRE), GPS + GLONASS + BeiDou (GRC), GPS + Galileo + BeiDou (GEC), GPS + GLONASS + Galileo + BeiDou (GREC)

Discussion

The results of this precision evaluation support several important conclusions regarding GNSS constellation selection in NRTK surveying, particularly under Caltrans network configurations. The findings align with Caltrans and FGDC (FGDC 1998) positional accuracy standards, which define 95% confidence as the reporting baseline for both internal precision and external positional uncertainty.

According to the Caltrans Surveys Manual (Caltrans 2015) horizontal accuracy must be reported as a 95% confidence circle. This study applied that requirement using the Caltrans-recommended method for deriving a confidence radius from observed deviations in northing and easting, allowing meaningful comparison across test sites and configurations.

1. Full-constellation (GREC) superiority

The GREC configuration (GPS + GLONASS + Galileo + BeiDou) consistently achieved the highest precision across all test sites. Its mean horizontal precision remained below 0.020 m at every site, with S95 values consistently in the lowest quartile. GREC's superior performance is attributed to satellite redundancy, improved geometry, and signal diversity. These results affirm current best practices of enabling all available constellations in high-precision NRTK work, especially when consistent reliability is required.

2. GPS-based combinations outperform non-GPS

Every configuration that excluded GPS (e.g., R, E, C) performed poorly, either due to insufficient valid observations or consistently higher mean values. In contrast, GPS-inclusive configurations—particularly those combining GPS with Galileo and BeiDou—consistently ranked in the top tier. This reinforces the importance of GPS as a foundational system within the CTSRN and supports policies that require GPS compatibility for baseline station networks.

3. Multi-constellation configurations mitigate baseline effects

Test Site 3, with longer and more irregular baseline geometry, predictably showed increased positional variance. However, top-performing configurations (such as GREC, GEC, and GRE) maintained sub-0.020 m precision across all metrics. This suggests that signal diversity, rather than just satellite count, plays a key role in preserving NRTK quality in marginal conditions—such as when operating at the network edge.

4. Practical limitations of GLONASS and BeiDou alone

GLONASS-only and BeiDou-only groups underperformed and often failed to meet the minimum 30-epoch threshold for confidence estimation. This outcome may reflect the limited constellation health or satellite geometry when used in isolation. For this reason, reliance on any single non-GPS constellation is not recommended for standalone NRTK operations in Caltrans field conditions.

5. Implications for Caltrans RTK operations

Based on this study, enabling full-constellation tracking (GREC) on compatible equipment is strongly recommended. If technical or policy constraints limit constellation inclusion, GPS combined with Galileo and BeiDou (e.g., GEC, GRE) still provides robust sub-2 cm performance. In contrast, restricting receivers to only GPS or GLONASS should be avoided unless supported by extremely short baselines and favorable environmental conditions.

Conclusion

In the early 2000s, GLONASS emerged as an additional global aid to GPS to increase satellite count, and to decrease the need for GNSS planning, which resulted in overnight campaigns in many instances. GPS + GLONASS was and has maintained as a legacy standard until today. The results show that it is time to move on from the Legacy standards and move forward with different pairings of constellations within the CTSRN.

This study evaluated the horizontal precision of various GNSS constellation configurations using NRTK within two Caltrans real-time networks. Through the analysis of over 1,600 observations across three test sites, consistent trends emerged regarding constellation performance under standardized operational conditions.

For the CTSRN, the results clearly demonstrate that multi-constellation configurations yield superior internal positional confidence, as reflected in both mean horizontal precision and 95% confidence circle metrics (S95). The most stable and precise results were consistently produced by triple- and quad-constellation combinations.

Based on these findings, the following operational recommendations are made:

- Preferred Configuration: Use all four constellations (GREC – GPS, GLONASS, Galileo, BeiDou) whenever possible. This full configuration provides the highest overall precision and resilience across varied baseline lengths and network geometries.
- If limited to three constellations: Prioritize GEC (GPS, Galileo, BeiDou), which ranked consistently among the top performers at all sites and offered sub-2 cm mean precision in every test.
- If limited to two constellations: Use GE (GPS + Galileo). This pairing balances redundancy and geometric diversity, and outperformed most other dual-constellation options.
- If restricted to one constellation: Use GPS (G) as the sole source. While not optimal alone, GPS remains the most reliable and stable core system within the CTSRN and should be enabled at minimum.

The next steps for the evaluation of the CTSRN is to evaluate the effects of baselines, observation time, accuracy, and seasonal measurements. Moving forward, only GREC, GRE, GRC, and GEC configurations will be retained for future testing phases. These groups demonstrated the most consistent and precise horizontal positioning results across the board. They will now undergo additional validation under varied temporal and geographic conditions to assess long-term network robustness.

Acknowledgments

The California Department of Transportation funded this research as per agreement 2660-65A1054. The authors express gratitude for other Caltrans employees, Kevin Maxwell and Eric Adney, who contributed their understanding and expertise to discussions on this project. The authors acknowledge the response of Trimble in providing feedback on their PIVOT software. The lead author gives a special thanks to Erik Zamora, an undergraduate student in the Geomatics Engineering program at Fresno State for his dedication to working on this project. Additional thanks to all the Geomatics engineering students who spent time throughout the night during our 24 hour occupation times.

References

Allahyari, Mahsa, Micahel J. Olsen, Daniel T. Gillins, and Michael L. Dennis. 2018. "Tale of Two RTNs: Rigorous Evaluation of Real-Time Network GNSS Observations." *J. Surv. Eng.* 1-15.

Caltrans. 2015. "Chapter 5: Clasification of Accuracy Standards."

Edwards, Stuart John, Peter J Clark, and Nigel Penna. 2010. "An Examination of network RTK GPS services in great Britain." *Survey Review* 107-121.

FGDC, Federal Geographic Data Committee. 1998. "Geospatial Positioning Accuracy Standards Part 3: National Standard for Spatial Data Accuracy."

Henning, William. 2014. *User Guidelines for Single Base Real Time GNSS Positioning*. https://www.ngs.noaa.gov/PUBS_LIB/UserGuidelinesForSingleBaseRealTimeGNSSPositioningv.3.1APR2014-1.pdf, National Geodetic Survey.

Janssen, Volker. 2009. "A Comparison of the VRS and MAC principles for network RTK." *International Global Nagication Satellite Systems Society.* IGNSS Symposium 2009. 1-13.

Petovello, Mark. 2011. "GNSS Solutions: Virtual Reference Stations." *InsideGNSS* 28-31.

Trimble Buisness Center. n.d. *[computer software]*. Trimble.