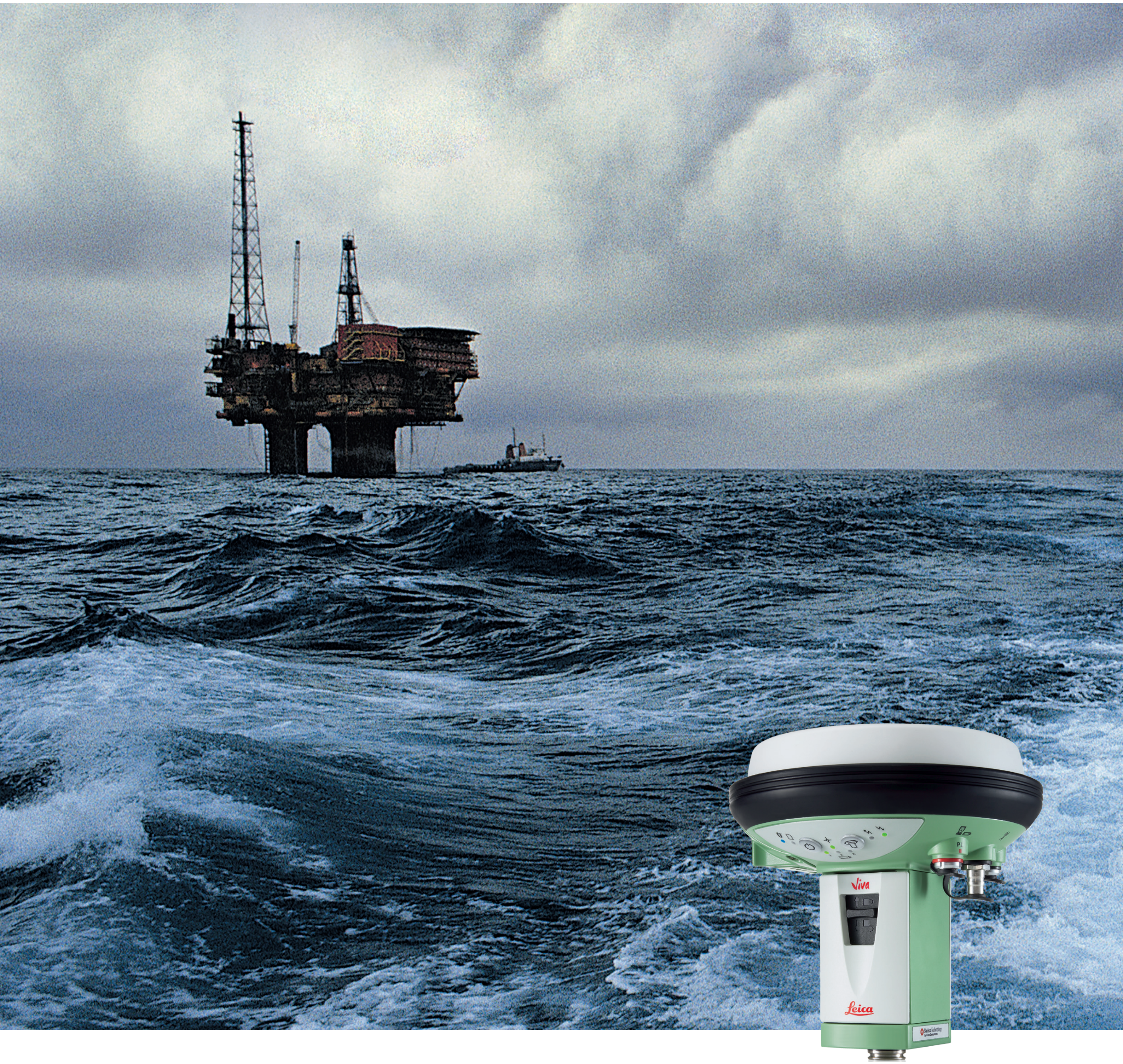
GLONASS only and BeiDou only RTK Positioning

Technical literature



PART OF
HEXAGON

- when it has to be **right**

Leica
Geosystems

October 2014

X. Luo, B. Richter, A. Cole,
Leica Geosystems AG Switzerland
Heerbrugg, Schweiz

GLONASS only and BeiDou only RTK Positioning

ABSTRACT

As a world leader in GNSS positioning, Leica Geosystems attaches great importance not only to combined GNSS solutions, but also to individual system performance. After successfully dealing with GLONASS inter-frequency biases in terms of ambiguity resolution (Takac, 2009) and GNSS interoperability (Takac et al., 2012), it is possible for the first time to provide reliable GLONASS only RTK solutions. In addition, considering that the BeiDou system allows operational positioning services over the Asia-Pacific region, it is reasonable to assess the quality of BeiDou only RTK positioning with the latest SmartWorx 5.50 firmware of Leica Viva GNSS.

This paper analyzes the performance of the individual systems in the measurement and position domains. The measurement domain analysis focuses on satellite geometry and signal strength, whereas the position domain analysis is performed at three accuracy levels, namely, navigation position, differential code position and high precision position with fixed ambiguities. Moreover, different observational environments such as open sky and canopy are taken into account.

Compared with GPS only and combined GNSS solutions, the performance of GLONASS only and BeiDou only RTK positioning is assessed with respect to availability, accuracy, reliability of coordinate quality (CQ) indicator and time to fix. The presented results serve as an informative basis for applications where GLONASS only or BeiDou only positioning is required or desired. Using technologically innovative approaches, Leica Geosystems provides the most reliable GNSS position solution to meet the demands of RTK applications in all environments.

INTRODUCTION

In addition to the well-known U. S. Global Positioning System (GPS), other Global Navigation Satellite Systems (GNSS) are in use or under development. The Russian GNSS, known as GLONASS, was developed in parallel to GPS. After a short Full Operational Capability (FOC) phase in 1996 the system degraded rapidly due to financial problems. In 2011, GLONASS reached the FOC again with the full orbital constellation of 24 satellites (Sośnica, 2014, p. 26). China has started the initiative of its own navigation satellite system BeiDou from 1985 to 1994. On December 27, 2012, BeiDou was officially announced to provide positioning, navigation and timing services over the Asia-Pacific region, whereas global services are expected by 2020 (Ge, 2013; Li et al., 2014).

The coexistence of GPS, GLONASS and BeiDou either results in a combination of the services and signals or in an alternative use of each system individually. An increasing number of systems and signals produce an increasing number of observations, and thus an increasing level of redundancy in the adjustment process. This will improve the position availability, accuracy, integrity and continuity (Hofmann-Wellenhof et al., 2008, p. 400). For example, Takac and Walford (2006) showed the advantages of a combined GPS and GLONASS solution in terms of position continuity, time-to-fix behavior, reliability of ambiguity resolution and precision of RTK fixed position. In addition, Fairhurst et al. (2013) found that the integration of BeiDou into RTK positioning can improve the high precision position availability by up to 30% in dense canopy.

In order to optimize the performance of combined GNSS solutions, the individual systems need to be fully understood and mastered, particularly in difficult observing environments. Moreover, the combined use of GNSS may suffer from a complete disruption of one of the contributing systems. Taking the GLONASS outage on April 1, 2014 as an example, at 21:15 UTC, all GLONASS satellites started to transmit wrong broadcast messages, which resulted in significant position errors and satellite tracking problems, particularly for GPS/GLONASS receivers (Beutler et al., 2014). Such an event could conceivably occur with GPS and BeiDou. Therefore, a reliable RTK positioning system should provide backups for combined GNSS solutions, such as GPS only, GLONASS only and BeiDou only positioning. Indeed, most RTK GNSS receivers support GPS only, whereas less than a handful of products allow GLONASS only and BeiDou only RTK solutions. This prompted Leica Geosystems to release SmartWorx Viva 5.50, which fully supports the BeiDou system and enables GLONASS only and BeiDou only high precision RTK positioning. Additionally, this new feature aims at improving position availability in areas of low GPS visibility. It also enables more GLONASS only and BeiDou only investigations for research and teaching. Finally, this functionality accommodates possible upcoming governmental regulations.

The precondition for GLONASS only high precision RTK positioning is that the GLONASS ambiguities are fixed to integers. This requires appropriate handling of inter-frequency biases if different receiver brands are involved (Takac, 2009; Wanninger, 2012). Analyzing RTK data from baselines with different lengths (13 km, 40 km, 160 km), Veytsel (2011) showed similar performance patterns of the GPS only and GLONASS only solutions regarding accuracy and time to fix. Based on the results from long-term (175 days) network solutions, Zheng et al. (2012) found that the average coordinate repeatability of GLONASS only is worse than that of GPS only. Such a difference in system performance was also reported by Alcay et al. (2012). In terms of BeiDou only RTK positioning, Li et al. (2013) presented reliable single epoch ambiguity resolution results which are comparable to those of GPS. The accuracy of BeiDou only RTK positioning is slightly worse than that of GPS, but it reaches the mm–cm level over very short (4.2 m) and short (8.2 km) baselines. Applying the improved LAMBDA ambiguity resolution method to short baseline (10 m) RTK, Odolinski et al. (2014) showed 100% successful fixes for both GPS and BeiDou, where the standard deviations of position errors are also at the mm–cm level. In addition, the combined use of GPS and BeiDou reduces the position standard deviations by 22% and 53% when compared to GPS only and BeiDou only solutions, respectively. He et al. (2014) confirmed that the availability and reliability of dual-frequency BeiDou RTK positioning are comparable to those of GPS. The combination of GPS and BeiDou enhances the performance of ambiguity resolution when compared to GPS only, especially for high elevation cut-off angles. Apart from single-baseline RTK, Li et al. (2014) performed BeiDou only precise point positioning in kinematic mode. The resulting horizontal precision is better than 3.0 cm and the vertical is better than 6.0 cm.

The encouraging findings summarized above indicate that GLONASS and BeiDou should not be considered as GPS augmentation systems, but as stand-alone constellations that are able to provide high precision RTK solutions. Starting with an overview of Leica Viva GNSS technology, the following sections present the results from GLONASS only and BeiDou only RTK positioning at different accuracy levels. Compared with GPS only and combined GNSS solutions, the RTK performance is assessed with respect to availability, accuracy, CQ reliability and time to fix.

LEICA VIVA GNSS TECHNOLOY

Leica Viva GNSS provides highly accurate and reliable RTK positions thanks to a series of innovative technologies such as

- Leica SmartTrack
- Leica SmartCheck
- Leica xRTK
- Leica SmartLink

These technologies are involved in the whole process of RTK positioning, from signal tracking to data processing as illustrated in Fig. 1. Using advanced GNSS measurement engines, Leica SmartTrack technology guarantees low-noise and highly sensitive signal tracking, even in strong multipath environments. It is future proof and ensures compatibility with all GNSS systems today and tomorrow. The resulting high-quality observations are processed by the RTK processing kernel together with correction data either from a single base station or from a network. Leica SmartCheck technology automatically and constantly evaluates the quality of RTK solutions to ensure high position reliability. At a slightly lower accuracy level than a standard RTK fix, Leica xRTK technology provides reliable, ambiguity-fixed positions with highest availability in difficult measuring environments such as urban canyons and dense canopy (Fairhurst et al., 2011). The SmartTrack, SmartCheck and xRTK technologies have been extended to fully support BeiDou.

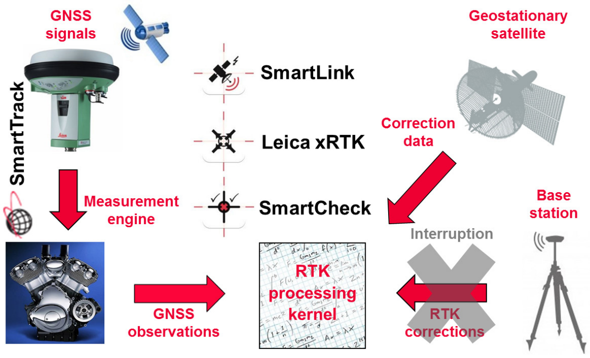


Figure 1 Innovative technologies of Leica Viva GNSS involved in the process of RTK positioning.

In the case that RTK communication links, for example, UHF radio and cell phone, are interrupted, Leica SmartLink technology uses L-band correction data from one of the seven geostationary satellites 98W, AORW, AORE, 25E, IOR, 143.5E and POR to bridge RTK link outages for up to 10 minutes. During this time, fixed integer ambiguities can be maintained reliably in order to avoid work interruptions. The position accuracy during SmartLink service is slightly reduced compared to a standard RTK fixed solution with an approximate 2D accuracy of ±5 cm. Currently, GPS and GLONASS are supported by SmartLink.

DATA COLLECTION

In order to perform BeiDou only RTK positioning, two GNSS data sets were collected from Shanghai test sites. A Leica Viva GS10 unit was connected to a Leica AS10 antenna at the base, whereas a Leica GS15 sensor was used at the rover. In the canopy test, 3 hours of 1-Hz GNSS data were collected from a short baseline of 245 m. In the open sky test, 24 hours of 1-Hz GNSS data were recorded from a very short baseline of 1.5 m. Short baselines were used in both tests to additionally reflect the expected field performance of the sensors (Richter and Green, 2004). The RTK data format was RTCM v3 MSM which represents an extension to RTCM v3 with Multi System Messages (MSM). The RTCM v3 MSM fully supports GPS, GLONASS, Galileo and BeiDou in the new message structure.

Satellite Geometry

Fig. 2 shows the GNSS skyplots for the rover sites. Fig. 2a–c are related to the short-term canopy data, and Fig. 2d–f are generated using the long-term open sky data. In the canopy test, a total of 12 GPS, 11 GLONASS and 7 BeiDou (4 GEO and 3 IGSO) satellites were tracked by the GS15. In comparison to GPS and GLONASS, the BeiDou satellites illustrate an unfavorable distribution with less variability. Except for the GEO satellite C1, all the BeiDou satellites are located in the third and fourth quadrants (Fig. 2c). Table 1 provides the mean values of geometric dilution of precision (GDOP; Hofmann-Wellenhof et al., 2008, p. 264). In general, the smaller the GDOP, the better the satellite geometry. It can be seen that despite canopy GPS and GLONASS provide good satellite geometry with GDOP values less than 5. The mean GDOP of BeiDou is larger than 10, indicating a low confidence level of position estimates. The combination of GPS, GLONASS

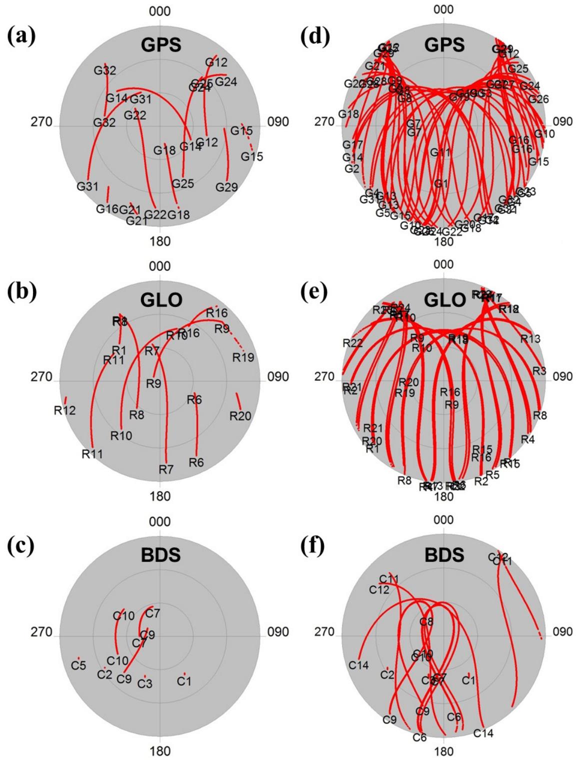


Figure 2 Skyplots of the GNSS satellites tracked by a Leica Viva GS15 at Shanghai (GLO: GLONASS, BDS: BeiDou) (a–c) 3-hour canopy data collected on May 9, 2014, (d–f) 24-hour open sky data collected on May 12–13, 2014.

Table 1 Mean geometric dilution of precision (GDOP) for different GNSS systems (GGB: GPS/GLO/BDS; cf. Fig. 2).

RTK test	GPS	GLO	BDS	GGB
Canopy	2.3	3.7	13.4	1.8
Open sky	2.1	4.5	5.3	1.3

and BeiDou (GGB) produces excellent satellite geometry, where the mean GDOP is smaller than 2. Analyzing the open sky data set, 30 GPS, 24 GLONASS and 11 BeiDou (3 GEO, 5 IGSO and 3 MEO) satellites were observed at the rover. Since more IGSO and MEO satellites are available in this case the BeiDou satellite geometry is significantly improved when compared to the canopy data (Fig. 2f). Accordingly, the mean GDOP is reduced from 13.4 to 5.3, being similar to that of GLONASS (Table 1).

Signal Strength

The quality of signal tracking is analyzed by examining the measured signal strength. Based on the 24 hours of open sky data, Fig. 3 depicts signal-to-noise ratio (SNR) over elevation for GPS, GLONASS and BeiDou signals. Using Leica SmartTrack technology, GNSS signals from elevation angles lower than 5° can be received with reasonable SNR values of up to 45 dB-Hz, 40 dB-Hz and 43 dB-Hz for the L1, L2 and L5/B2 bands, respectively. As can be seen in Fig. 3a, GLO L1 is about 1 dB-Hz weaker than GPS L1, and 5 dB-Hz stronger than BeiDou B1. This was also observed in Fairhurst et al. (2013) and corresponds to the different minimum received power levels of these GNSS signals. Such a systematic difference in signal strength is absent for the L2 band (Fig. 3b). In Fig. 3c, GPS L5 shows not only higher signal strength than BDS B2, but also smaller variations over the whole elevation range. Currently, there are seven GPS IIF satellites transmitting the L5 signal. All 12 satellites in the GPS IIF series are expected to be available for RTK positioning by 2016. Furthermore, larger SNR values are visible in Fig. 3c at lower elevation angles, and smaller SNR values are present in Fig. 3b at higher elevation angles. The latter case is especially observable in the canopy data set for the GLO L2, GPS L2 and L5 signals. This indicates that SNR is a more realistic quality indicator for GNSS measurements than the satellite elevation angle. Its incorporation into the stochastic model enables a more realistic characterization of GNSS observation quality (Brunner et al. 1999; Luo et al., 2008, 2014).

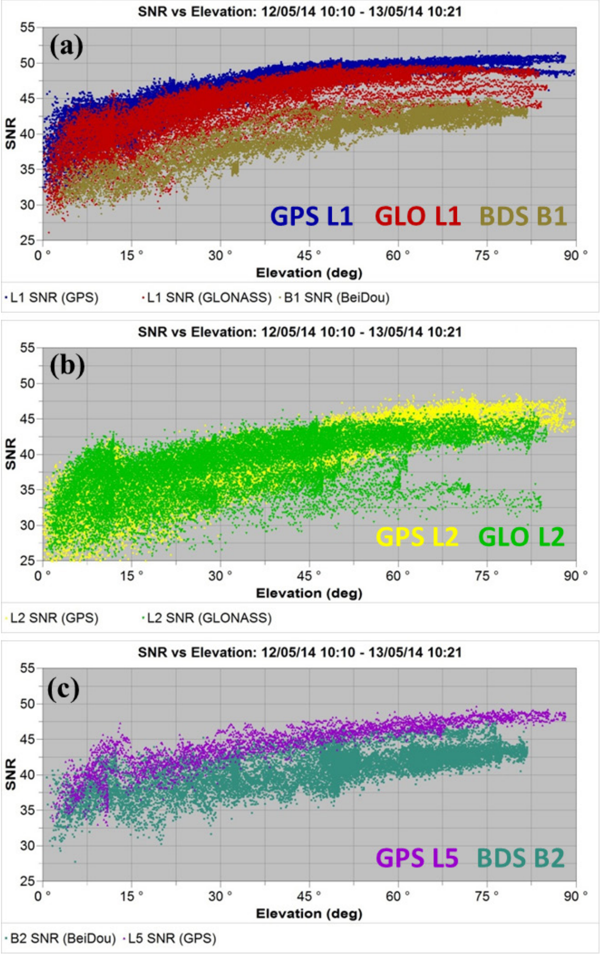


Figure 3 Signal-to-noise ratio (SNR in dB-Hz) for GPS, GLONASS and BeiDou signals (Leica Viva GS15, Shanghai, 24-hour open sky data, May 12–13, 2014) (a) SNR vs. elevation for GPS L1/GLO L1/BDS B1, (b) SNR vs. elevation for GPS L2/GLO L2, (c) SNR vs. elevation for GPS L5/BDS B2.

RTK PERFORMANCE ANALYSIS

The performance of GLONASS only and BeiDou only RTK positioning is analyzed at different accuracy levels such as navigation position (Nav), differential code position (DGNSS) and high precision position with fixed ambiguities (RTK fixed). The results are compared with GPS only and combined GNSS (GPS/GLO/BDS) solutions regarding position availability, accuracy, CQ reliability and time to fix.

Availability

Within the framework of this study, availability is defined as the percentage of the RTK solutions at different accuracy levels (Feng and Wang, 2008). Mathematically, it can be expressed as

$$\text{Availability}_l = \frac{(\#Pos)_l}{\#Pos_{all}} \times 100\%, \qquad (1)$$

where $(\#Pos)_l$ is the number of positions for the RTK solution type $l \in \{\text{Nav,DGNSS,RTK fixed}\}$, and $\#Pos_{all}$ denotes the number of all positions measured. In general, high availability of RTK fixed positions is desirable.

Table 2 and 3 present the position availability as computed using Eq. (1) for the canopy and open sky RTK tests, respectively. The number of all positions measured ($\#Pos_{all}$) is the same for GPS, GLO and GGB, whereas BDS delivers fewer positions due to its limited satellite geometry (Fig. 2 and Table 1). In the canopy test (Table 2), GPS and GGB produce about 10% more RTK fixed positions than GLO, and 30% more than BDS. This demonstrates the best performance of GPS and the advantage of the combined solution GGB in ambiguity resolution. As a whole, GLO and BDS provide approximately 11% and 31% non-fixed solutions, where DGNSS plays a dominant role. Regarding the results from the open sky test (Table 3), GLO and BDS show comparable performance to GPS and GGB, with more than 98% RTK fixed positions. Despite the low availability of non-fixed solutions, it can be seen that more DGNSS positions are produced. Considering the small numbers of navigation positions, the following investigations focus on DGNSS and RTK fixed solutions.

Table 2 Position availability [%] achieved in the 3-hour canopy RTK test [see Eq. (1)].

GNSS	$\#Pos_{all}$	Nav	DGNSS	RTK fixed
GPS	11111	0.00	0.30	99.70
GLO	11111	2.23	8.93	88.84
BDS	11074	14.02	17.07	68.91
GGB	11111	0.00	0.04	99.96

Table 3 Position availability [%] achieved in the 24-hour open sky RTK test [see Eq. (1)].

GNSS	$\#Pos_{all}$	Nav	DGNSS	RTK fixed
GPS	87094	0.02	0.04	99.94
GLO	87094	0.42	0.63	98.95
BDS	84226	0.89	1.08	98.03
GGB	87094	0.00	0.01	99.99

Accuracy

For both RTK tests, the ground truth coordinates are available. This enables an accuracy assessment by comparing the estimated RTK positions with the true rover coordinates. In this study, accuracy is represented by the 3D position error

$$[e_i]_l = \left[\sqrt{(x_i - x_0)^2 + (y_i - y_0)^2 + (z_i - z_0)^2)}\right]_l, \qquad (2)$$

where $i = 1,\ldots,n$, l denotes the RTK solution type, and (x_0, y_0, z_0) are the true coordinates for point i. Generally, the smaller the 3D position error, the better the accuracy. Table 4 shows the mean 3D position error of DGNSS solutions for different GNSS constellations. In the canopy test, GPS and GGB show larger position errors than GLO. This is due to the extremely low availability of DGNSS positions for GPS (0.3%) and GGB (0.04%), which leads to inaccurate estimates of mean position error. In the open sky test, the DGNSS solutions reach an accuracy of 0.3 m. In both tests, BDS provides meter-level DGNSS accuracy.

To analyze the accuracy of RTK fixed solutions, Fig. 4 illustrates the time series of 3D position error and the number of used satellites. Fig. 4a and b are related to the canopy test, whereas Fig. 4c and d depict the results from the open sky test. As can be seen in Fig. 4a, GLO constantly provides cm-level RTK fixed positions in the canopy test. However, when compared to GPS, larger variations are visible for the time interval 2.5–3 h. This can be primarily explained by the smaller number of used satellites during this time (Fig. 4b) and secondly by the higher noise level. In contrast, BDS produces highly variable position errors of up to 3 dm, which is attributed to the satellite geometry problem rather than the number of used satellites. A maximum of 19 satellites are involved in GGB, which delivers the most accurate and consistent RTK fixed positions. In the open sky test, the position errors from GLO are

Table 4 Mean 3D position error [m] of DGNSS solutions for different GNSS constellations [see Eq. (2)].

GNSS	Canopy (3h)	Open sky (24h)
GPS	1.59	0.35
GLO	0.53	0.83
BDS	3.25	1.50
GGB	1.44	0.32

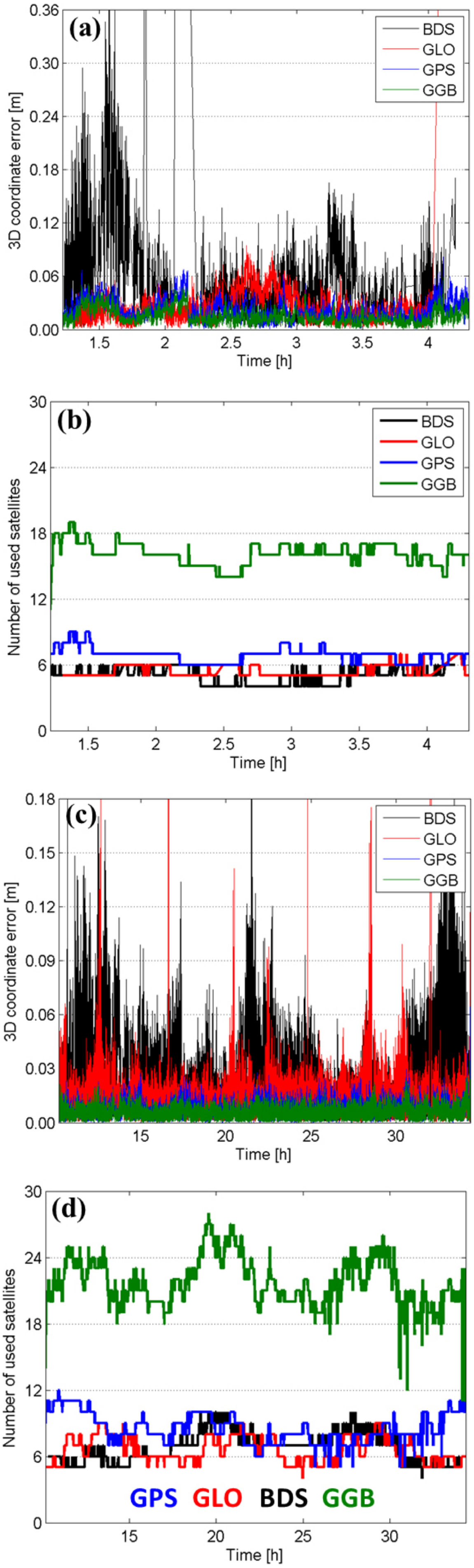


Figure 4 Time series of 3D position error of RTK fixed solutions and the associated number of used satellites (a–b) 3-hour canopy RTK test (baseline length: 245 m), (c–d) 24-hour open sky RTK test (baseline length: 1.5 m). Note the different scale of the y-axis in (a) and (c).

Table 5 Mean 3D position error [m] of RTK fixed solutions for different GNSS constellations [see Eq. (2)].

GNSS	Canopy (3h)	Open sky (24h)
GPS	0.022	0.007
GLO	0.025	0.014
BDS	0.058	0.024
GGB	0.015	0.005

below 3 cm and are insignificantly affected by the varying number of used satellites (Fig. 4c and d). However, the position errors from BDS vary strongly over time and illustrate a negative correlation with the number of used satellites. In other words, the more BeiDou satellites contribute to a RTK fixed solution, the smaller the position error will be. In comparison to GPS, GGB shows mm-level improvements in position accuracy and consistency, achieved by using a maximum of 28 satellites simultaneously.

Table 5 presents the mean 3D position error of RTK fixed solutions. In the canopy test, the mean position error of GLO is smaller than 3 cm, which is comparable to that of GPS. Due to the limited satellite geometry, BDS delivers a considerably larger position error of about 6 cm. In the open sky test, GLO is less accurate than GPS, but more accurate than BDS. As expected, the combined solution GGB provides the most accurate positions in both tests. Its benefits seem to increase with increasing canopy and baseline length.

CQ reliability

Leica Viva GNSS provides the so-called coordinate quality (CQ) indicator to represent the accuracy of the current RTK position. A realistic CQ should reflect the position error defined by Eq. (2). Fig. 5 depicts the mean 3D CQ of RTK fixed solutions. In both tests, except for BDS, the mean 3D CQ values are below 3 cm. In the canopy test, the mean 3D CQ (GPS: 0.026 m, GLO: 0.028 m, GGB: 0.019 m) and position error agree at the millimeter level (cf. Table 5). In the open sky test, the mean CQ

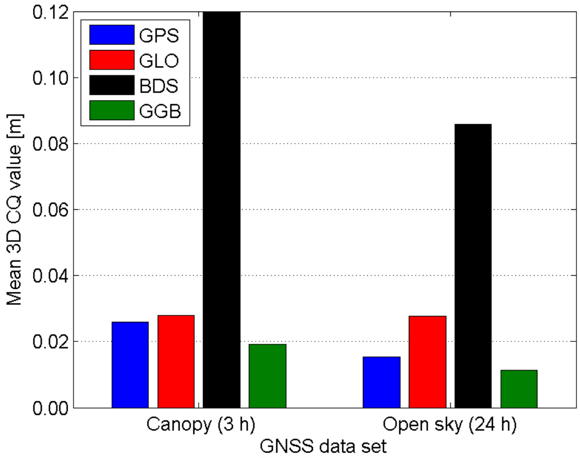


Figure 5 Mean 3D CQ of RTK fixed solutions for different GNSS systems (GGB: GPS/GLO/BDS; cf. Table 5).

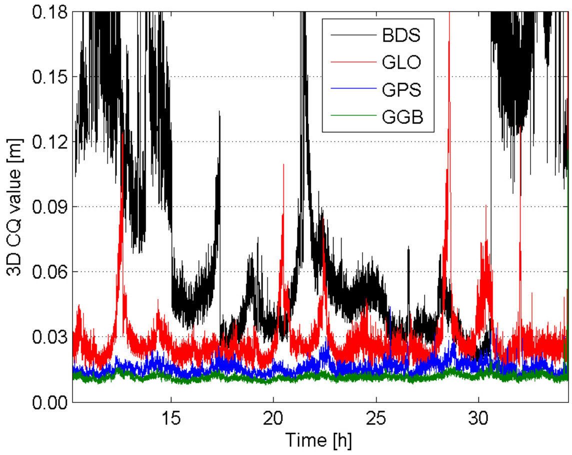


Figure 6 Time series of 3D CQ of RTK fixed solutions (24-hour open sky RTK test, baseline length: 1.5 m; cf. Fig. 4c)

values of GPS (0.015 m), GLO (0.028 m) and GGB (0.011 m) are approximately twice as large as the associated position errors. This avoids providing overly optimistic CQ and guarantees the high reliability of RTK fixed positions.

Realistic CQ estimates should reflect the RTK position quality instantaneously. To verify this, Fig. 6 illustrates the time series of 3D CQ of RTK fixed solutions resulting from the open sky test. Comparing Fig. 4c and Fig. 6 with each other, it can be seen that the large peaks in the GLO position errors are well reflected in the corresponding CQ values. In the case of BDS, the 3D CQ and position error show similar variation patterns, where the CQ values are considerably larger than the actual position errors at the both ends of the time series. This is due to a strong contribution of the GEO satellites, which have invariant satellite geometry and result in larger position uncertainty. By comparing the CQ values of GPS and GGB, the combined use of GNSS leads to not only smaller (cf. Fig. 5), but also more consistent CQ estimates.

Time to fix

The time to fix (TTF) is here defined as the time required to regain a RTK fixed solution after losing it by resetting the ambiguity filter. The TTF can be computed using

$$TTF = t_i - t_j \quad \text{with} \quad t_i > t_j, \qquad (3)$$

where t_j is the time when losing ambiguity fix, and t_i is the time when achieving an ambiguity-fixed solution again. A key requirement for high precision RTK positioning is providing fast and reliable ambiguity resolution, even in difficult observational environments. However, the time to resolve integer ambiguities is always a trade-off between speed, performance and reliability of the entire system (Kotthoff et al., 2003).

For different GNSS constellations, Fig. 7 illustrates the TTF obtained from Eq. (3) and the associated cumulative distribution function (CDF). Fig. 7a and b are related to the canopy test, whereas Fig. 7c and d correspond to the open sky test. In canopy conditions, it takes at least 5 s to resolve the phase ambiguities (Fig. 7a). This minimum time can be reached by both GLO and BDS. However, they produce fewer TTF estimates with larger variations than GPS and GGB (cf. Table 2). Regarding the CDF in Fig. 7b, GLO and BDS need considerably more time for ambiguity resolution. The advantage of GGB over GPS in reducing TTF is clearly visible. In open sky environments, it is encouraging to see that the minimum of TTF reaches 4 s (Fig. 7c). Although the results from GLO and BDS vary strongly over time, they are highly consistent regarding the probability distribution (Fig. 7d). In 90% of the cases, GLO and BDS allow ambiguity resolution within 10 s. For GPS and GGB, an ambiguity-fixed solution can be regained in 5 s with 99% probability.

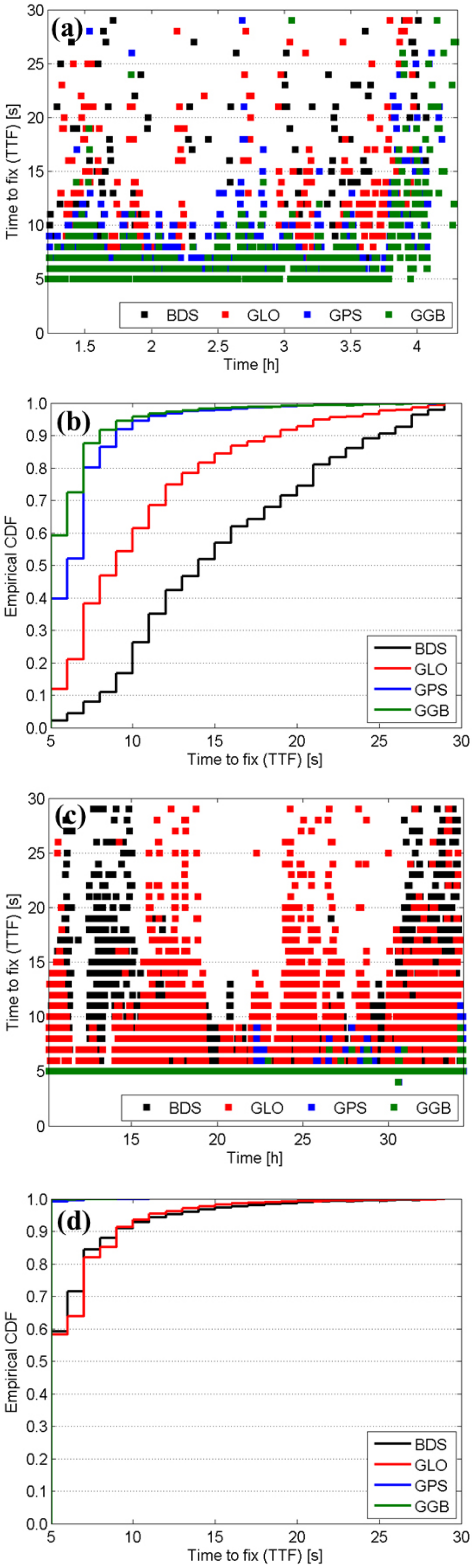


Figure 7 Time to fix (TTF) calculated by means of Eq. (3) and the associated cumulative distribution function (CDF) (a–b) 3-hour canopy RTK test (baseline length: 245 m), (c–d) 24-hour open sky RTK test (baseline length: 1.5 m).

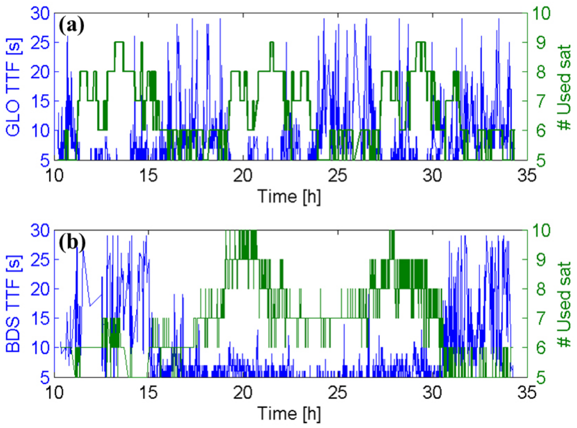


Figure 8 Time to fix (TTF) computed using Eq. (3) and the associated number of used satellites (24-hour open sky RTK test) (a) GLONASS only solution, (b) BeiDou only solution.

Table 6 Mean time to fix (TTF) [s] achieved using different GNSS constellations (see Eq. (3), cf. Fig. 7).

RTK test	GPS	GLO	BDS	GGB
Canopy	6.8	10.5	15.4	6.2
Open sky	5.0	6.5	6.5	5.0

In order to understand the large variations in the TTF of GLO and BDS (Fig. 7c), the number of used satellites is illustrated together with the TTF in Fig. 8. As can be seen in both plots, larger TTF values with higher variability are present if a small number of satellites (e.g., 5–6) are used for ambiguity resolution. Not only the number of satellites, but also the geometry plays an important role in fast and reliable ambiguity resolution. In Table 6, the mean results of TTF are summarized for different GNSS constellations. In the canopy test, GLO and BDS need about 4 s and 9 s more for fixing ambiguities than GPS and GGB. However, in the open sky test, GLO and BDS are on average only 1.5 s slower in resolving ambiguities than GPS and GGB. A comparison between Table 6 and Table 1 confirms the strong impact of satellite geometry upon the TTF performance, particularly in difficult observational environments.

CONCLUSIONS

Always pushing the boundaries on GNSS performance, Leica Geosystems provides for the first time a product that fully supports GLONASS only and BeiDou only high precision RTK positioning. In addition, the individual satellite systems can be easily configured by users themselves. Analyzing representative GNSS data sets, this paper evaluates the performance of GLONASS only and BeiDou only RTK positioning at different accuracy levels. In comparison with GPS only and combined GNSS solutions, the results were presented considering position availability, accuracy, CQ reliability and time to fix ambiguities. The main results from the RTK tests in canopy and open sky environments can be summarized as follows:

1. Due to the limited variability of the GEO and IGSO satellites, the BeiDou satellite geometry is worse than GPS and GLONASS. This is particularly true under heavy canopy.

2. In the L1 band, the signal strength of GLONASS is approximately 1 dB-Hz weaker than GPS, and 5 dB-Hz stronger than BeiDou. The latter magnitude of difference also applies to the GPS L5 and BeiDou B2 signals.

3. In the canopy test, GPS provides about 10% and 30% more RTK fixed solutions than GLONASS and BeiDou, respectively. However, in the open sky test, the availability of ambiguity-fixed solutions is larger than 98% for all three constellations.

4. GLONASS and BeiDou enable sub-meter and meter level DGNSS positioning, respectively. Regarding RTK fixed solutions, both GPS and GLONASS reach 3 cm accuracy in the canopy test. This is also achieved by BeiDou in the open sky test. The combined use of GNSS delivers mm-level accuracy and consistency.

5. The CQ indicator reflects the actual position error in a realistic manner. The larger BeiDou CQ is due to the limited satellite geometry, resulting in larger position uncertainty.

6. The TTF of GLONASS and BeiDou strongly depends on the prevailing satellite geometry. In the canopy test, GLONASS and BeiDou need about 10 s and 15 s for ambiguity resolution, respectively. These times are significantly reduced to 6.5 s in the open sky test, being only 1.5 s longer when compared to GPS.

As shown in this study, GPS is still the system of first choice (Jewell, 2014), and plays the most important role in RTK positioning. Nevertheless, GLONASS can already be used in stand-alone mode. The BeiDou only RTK is feasible, providing cm-level accuracy in open sky environments. Leica Viva GNSS technology is fully future proof, which will enable a straightforward integration of future systems such as Galileo and will immediately allow Galileo only RTK positioning once the system is operational.

ACKNOWLEDGMENTS

The staffs of Leica Geosystems (Shanghai), Ye Meng, Yujie Jin and Dengyong Rao, are gratefully acknowledged for providing the GNSS data.

REFERENCES

Alcay, S., Inal, C., Yigit, C. O., Yetkin, M. (2012) Comparing GLONASS only with GPS only and hybrid positioning in various length of baselines. Acta Geodaetica et Geophysica, 47(1), 1–12. doi: 10.1556/AGeod.47.2012.1.1

Beutler, G., Dach, R., Hugentobler, U., Montenbruck, O., Weber, G., Brockmann, E. (2014) GLONASS April: What went wrong. GPS World, 25(7), 14–16.

Brunner, F. K., Hartinger, H., Troyer, L. (1999) GPS signal diffraction modelling: the stochastic SIGMA-Δ model. Journal of Geodesy, 73(5), 259–267. doi:10.1007/s001900050242

Fairhurst, P., Glueckert, U., Richter, B. (2011) Leica Viva GNSS receivers. White Paper, Leica Geosystems AG, Heerbrugg, Switzerland.

Fairhurst, P., Luo, X., Aponte, J. (2013) New systems, new signals, new positions – Providing BeiDou integration. In: Proceedings of ION GNSS+ 2013, Nashville, TN, September 16–20, 2013, pp. 3214–3220.

Feng, Y., Wang, J. (2008) GPS RTK performance characteristics and analysis. Journal of Global Positioning Systems, 7(1), 1–8.

Ge, M. (2013) BeiDou Navigation Satellite System and its potential precise positioning service. In: GNSS 2013 – Schneller. Genauer. Effizienter. 124. DVW-Seminar, Karlsruhe, March 14–15, 2013, DVW-Schriftenreihe, Band 70/2013, Wißner-Verlag, Augsburg, pp. 3–30.

He, H., Li, J., Yang, Y., Xu, J., Guo, H., Wang, A. (2014) Performance assessment of single- and dual-frequency BeiDou/GPS single-epoch kinematic positioning. GPS Solutions, 18(3), 393–403. doi:10.1007/s10291-013-0339-3

Hofmann-Wellenhof, B., Lichtenegger, H., Wasle, E. (2008) GNSS – Global Navigation Satellite Systems: GPS, GLONASS, Galileo & more. Springer-Verlag, Wien, 516 pp.

Jewell, D. (2014) The Gold Standard: What's in a name? GPS World, 25(3), p. 4.

Kotthoff, H., Hilker, C., Ziegler, C. (2003) Strategy of reliable ambiguity resolution for static and kinematic applications. In: Proceedings ION GPS/GNSS 2003, Portland, OR, September 9–12, 2003, pp. 2611–2616.

Li, M., Qu, L., Zhao, Q., Guo, J., Su, X., Li, X. (2014) Precise Point Positioning with the BeiDou Navigation Satellite System. Sensors, 14(1), 927–943. doi:10.3390/s140100927

Li, J., Yang, Y., Xu, J., He, H., Guo, H., Wang, A. (2013) Performance analysis of single-epoch dual-frequency RTK by BeiDou Navigation Satellite System. In: J. Sun et al. (Eds.), Proceedings of China Satellite Navigation Conference (CSNC) 2013, Wuhan, China, May 15–17, Lecture Notes in Electrical Engineering, vol. 245, Springer-Verlag, Berlin Heidelberg, pp. 133–143. doi:10.1007/978-3-642-37407-4_12

Luo, X., Mayer, M., Heck, B. (2008) Improving the stochastic model of GNSS observations by means of SNR-based weighting. In: M. G. Sideris (Ed.), Observing our changing Earth, Proceedings of the 2007 IAG Symposia, vol. 133, Springer-Verlag, Berlin Heidelberg, pp. 725–734. doi:10.1007/978-3-540-85426-5_83

Luo, X., Mayer, M., Heck, B., Awange, J. L. (2014) A realistic and easy-to-implement weighting model for GPS phase observations. IEEE Transactions on Geoscience and Remote Sensing, 52(10), 6110–6118. doi:10.1109/TGRS.2013.2294946

Odolinski, R., Odijk, D., Teunissen, P. J. G. (2014) Combined GPS and BeiDou instantaneous RTK positioning. NAVIGATION, 61(2), 135–148. doi:10.1002/navi.61

Richter, B., Green, A. (2004) Relevance of dual frequency surveying system tests for real time field performance. In: Proceedings of ION GNSS 2004, Long Beach, CA, September 21–24, pp. 1367–1373.

Sośnica, K. J. (2014) Determination of Precise Satellite Orbits and Geodetic Parameters using Satellite Laser Ranging. Astronomical Institute, University of Bern, Bern, 253 pp.

Takac, F. (2009) GLONASS inter-frequency biases and ambiguity resolution, Inside GNSS, 2(4), 24–28.

Takac, F., Cole, A., Carrera, M., Alves, P., Wübbena, G., Sleewaegen, J.-M., Simsky, A., De Wilde, W. (2012) A proposed industry solution to realize universal GLONASS observation interoperability for precise positioning. Presented at ION GNSS 2012, Nashville, TN, September 17–21, 2012.

Takac, F., Walford, J. (2006) Leica System 1200 – High performance GNSS technology for RTK applications. In: Proceedings of ION GNSS 2006, Fort Worth, TX, September 26–29, 2006, pp. 217–225.

Veytsel A. V. (2011) Using multi-system receivers for accuracy positioning. Presented at the Sixth Meeting of the International Committee on Global Navigation Satellite Systems (ICG), Tokyo, Japan, September 4–9, 2011.

Wanninger, L. (2012) Carrier-phase inter-frequency biases of GLONASS receivers. Journal of Geodesy, 86(2), 139–148. doi:10.1007/s00190-011-0502-y

Zheng, Y., Nie, G., Fang, R., Yin, Q., Yi, W., Liu, J. (2012) Investigation of GLONASS performance in differential positioning. Earth Science Informatics, 5(3–4), 189–199. doi:10.1007/s12145-012-0108-9

Whether you want to stake-out an object on a construction site or you need accurate measurements of a tunnel or a bridge; whether you want to determine the area of a parcel of land or need the position of a power pole or to capture objects for as-built maps – you need reliable and precise data.

Leica Viva combines a wide range of innovative products designed to meet the daily challenges for all positioning tasks. The simple yet powerful and versatile Leica Viva hardware and software innovations are redefining state-of-the-art technology to deliver maximum performance and productivity. Leica Viva gives you the inspiration to make your ambitious visions come true.

When it has to be right.

Swiss Technology
by Leica Geosystems

10.14 – INT

Leica Geosystems AG
Heerbrugg, Schweiz

www.leica-geosystems.com

- when it has to be **right**

Leica
Geosystems