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Advancing Trimble RTX Technology by adding BeiDou and Galileo

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Abstract: The Trimble® CenterPoint™ RTX™ correction service provides real-time GNSS positioning with global coverage and fast initialization. The service is transmitted via six geostationary satellite L-band links and via Networked Transport of RTCM via Internet Protocol (NTRIP). The accuracy of kinematic positioning is better than 4 cm in horizontal (95%) at anytime, anywhere. This accuracy is achieved after a typical convergence time of 30 minutes or less.

Utilizing Trimble® RTX™ technology, the CenterPoint RTX correction service is based on the generation of precise orbit and clock information for GNSS satellites. The CenterPoint RTX satellite corrections are generated in real time using data streams from approximately 100 globally distributed reference stations of Trimble's RTX tracking network.

Since its introduction in 2011 the Trimble RTX has undergone two major releases, the first in spring 2012 and then again in spring 2013. In addition to the general performance improvement with respect to convergence time, the support of QZSS, and the introduction of additional services like Trimble® RangePoint™ RTX™ and features like Trimble® xFill™. Recently the BeiDou system was included in the service. The Trimble CenterPoint RTX correction service today supports GPS, GLONASS, QZSS and BeiDou signals.

In this work we will describe performance improvements using the BeiDou satellites in the latest CenterPoint RTX service release. Results show considerable improvement in convergence time but also in positioning accuracy, especially for users in the Asia Pacific region.

We will also include results from using Galileo satellites, although those satellites are currently not declared operational by the Galileo system, results of our research on the inclusion of those satellites demonstrate the ability to improve the RTX convergence and positioning accuracy.

BIOGRAPHIES

M. Brandl is a software development engineer since 2006 at Trimble TerraSat GmbH. Since 2011 he is part of the Trimble CenterPoint RTX R&D team. He graduated 2006 with a diploma in Computer Science from the University of Applied Sciences Regensburg, Germany.

X. Chen is a senior engineer at Trimble TerraSat responsible for R&D in the area of network solutions. He holds a Ph.D. in Geodesy from Wuhan Technical University of Surveying and Mapping. His primary interests are in the field of network solutions for RTK positioning systems, troposphere and ionosphere modeling.

R. Drescher graduated from Technical University of Darmstadt with a diploma in Geodesy. He joined the GNSS R&D team of Trimble TerraSat GmbH in 2010 and holds a Ph.D. in Geodesy from Technical University of Darmstadt since 2013.

M. Glocker received a Ph.D. in computer sciences from the Technical University of Darmstadt in 2005. He started in 2006 to work as a software engineer for Trimble TerraSat GmbH and is acting as an engineering manager since 2013.

H. Landau received a Ph.D. in Satellite Geodesy from the University FAF Munich, Germany in 1988. At Trimble he is acting as General Manager of Trimble TerraSat GmbH, Munich, Germany and as Engineering Director for Precision GNSS Positioning at Trimble.

A. Nardo joined Trimble in 2013. He graduated in Astronomy in 2004 from the University of Padova and holds a Ph. D. in Astronautics from the same university. From 2010 to 2013 he served as a research fellow in the GNSS Research Centre at Curtin University, Perth, WA.

M. Nitschke is a GNSS R&D engineer at Trimble TerraSat since 2004. He served as project scientist at GFZ Potsdam (German Research Centre for Geosciences) from 1998 to 2004. He graduated from Technical University of Munich with a diploma in Geodesy. His current research interest is on precise orbit determination for GNSS satellites.

D. Salazar is a GNSS R&D engineer at Trimble TerraSat since 2012. Previously he worked as lecturer and researcher at Universitat Politecnica de Catalunya (UPC, Spain), as lecturer at Universidad Simon Bolivar (USB, Venezuela), and as an Aeronautical Engineer in Venezuela. He holds an Aeronautical Engineer degree from IUPFAN, Venezuela, and a Ph.D. on Aerospace Science and Technology from UPC.

S. Seeger is a GNSS R&D engineer at Trimble TerraSat since 2007. He graduated from the University of Erlangen-Nuremberg in 1995 with a diploma in theoretical physics. From 1996 to 2003 he served as a research assistant in the optical 3D metrology group at the University of Erlangen-Nuremberg which is now part of the Max Planck Institute for the science of light. From 2003 to 2007 he worked as a network GNSS R&D engineer at Leica Geosystems. His current research interests range from GNSS receiver RTK & PPP algorithms to network GNSS algorithms with a special emphasis on integer ambiguity resolution.

U. Weinbach joined the Trimble Terrasat R&D team in 2012. He graduated from the Technische Universität Berlin in 2008 with a diploma in Geodesy and holds a Ph.D. in Geodesy from Leibniz Universität Hannover. His research interests include GNSS clock modelling and carrier phase ambiguity resolution.

F. Zhang is a GNSS R&D engineer at Trimble TerraSat since 2008. He served as associate research fellow in the precision orbit determination team at Shanghai Astronomical Observatory from 2000 to 2002, as project scientist at IGS Analysis Center at GFZ Potsdam (German Research Centre for Geosciences) from 2002 to 2008. He graduated from Wuhan Technical University of Surveying and Mapping (nowadays part of Wuhan University) with a M.S. degree in Geodesy and obtained a Ph.D. degree from Shanghai Astronomical Observatory in Celestial Mechanics. His current research interest is on precise orbit determination for GNSS satellites.

1 INTRODUCTION

The CenterPoint RTX service was introduced in mid-2011, providing centimeter-accurate positions for real-time applications in static or kinematic applications (Chen et al. 2011). It broadcasts satellite orbit and clock corrections via multiple media to the client receivers, which carry out a PPP-like position estimation without assistance of other ground reference stations. Corrections are broadcast by six L-band satellite beams from geostationary satellites covering most of the main continents, as shown in figure 1.

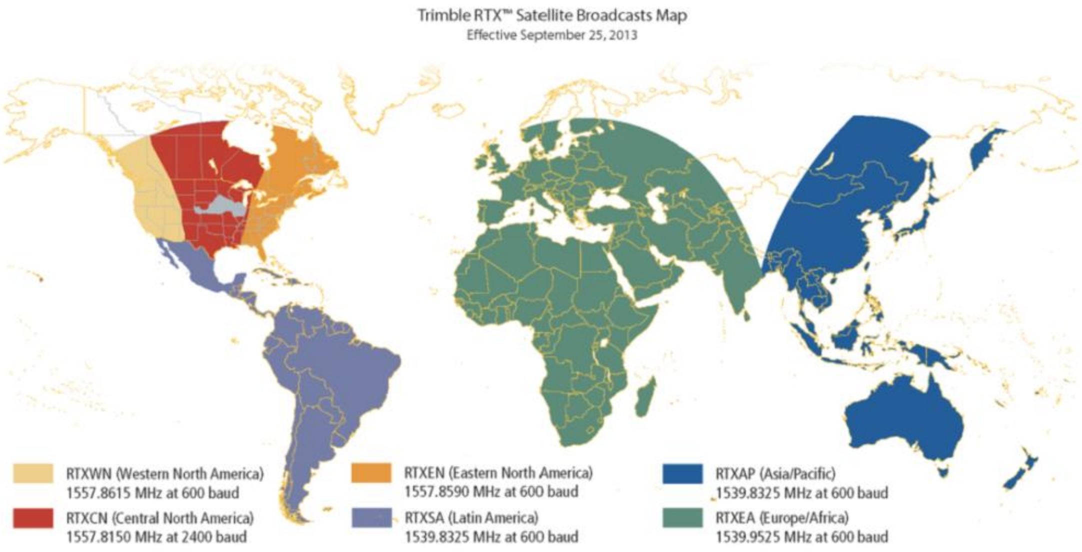

Figure 1. Trimble CenterPoint RTX service L-band corrections coverage.

In addition to the L-band transmission, the RTX corrections are globally available for Trimble customers via Internet using the NTRIP protocol and can be used for real-time applications. Trimble also offers a post-processing service, available via a web interface (Doucet et al. 2012). Since its introduction, Trimble CenterPoint RTX has been well accepted by customers in precision agriculture due to its high accuracy, high reliability, easy access and fast convergence. Trimble RTX based positioning services are also available on infrastructure and survey devices since 2012.

The CenterPoint RTX system is based on the real-time generation of precise orbit and clock corrections for GNSS satellites. Part of the quality and strength of the service stems from Trimble's RTX tracking network (shown in Figure 2), a set of about 100 globally distributed reference stations streaming real-time data to CenterPoint RTX computing centers. The precise corrections created in the computing centers then allow customer rovers to carry out a sophisticated PPP-like positioning with ambiguity fixing, currently supporting GPS, GLONASS and QZSS systems.

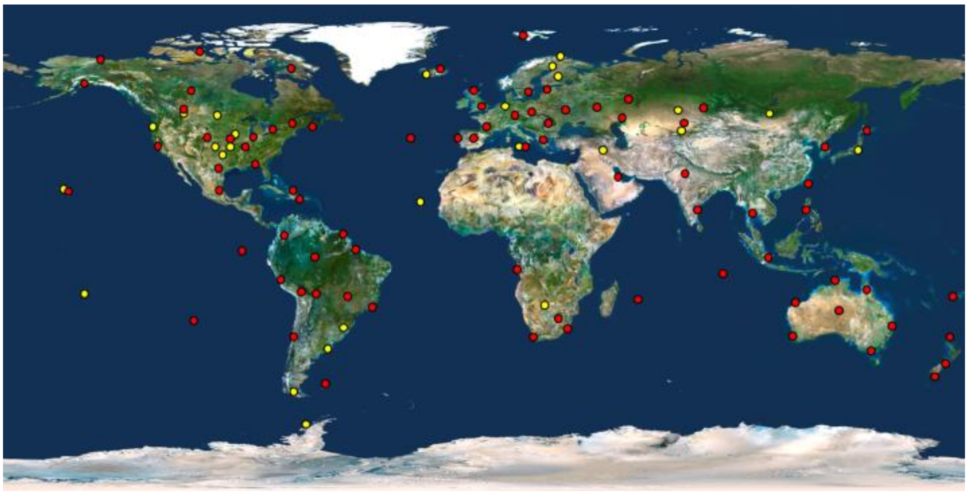

Figure 2. Trimble CenterPoint RTX worldwide tracking network.

Trimble actively pursues the continuous expansion of CenterPoint RTX system capabilities. For instance, the inclusion of QZSS to the system in the second release at early 2012 has demonstrated around 20% reductions in convergence time in the Asia Pacific region (Landau et al. 2012). The third release improved the overall performance and significantly reduced the initialization time (see Figure 3) by introducing a global ionospheric model and applying new algorithms (Drescher et al. 2013).

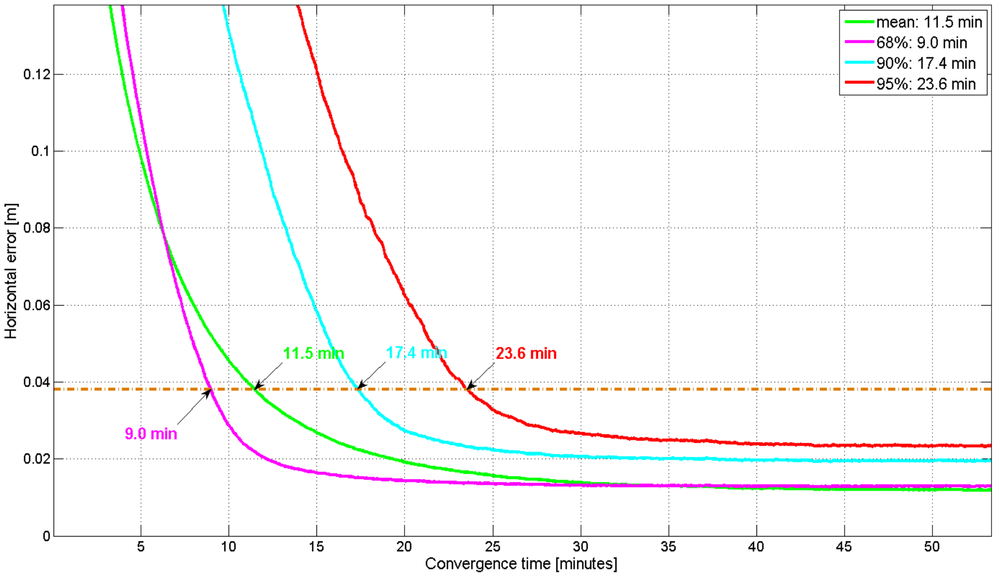

Figure 3. Trimble CenterPoint RTX worldwide initialization times.

The potential of using both BeiDou and Galileo in addition to GPS, GLONASS and QZSS in a prototype CenterPoint RTX correction stream has already been demonstrated (Zhang et al. 2013, Salazar et al. 2013). Including BeiDou reduced convergence time by 12% and adding Galileo by 28% compared to standard RTX processing are the remarkable results of early system tests carried out in August 2013 with 10 stations in the Asia Pacific region and with a prototype version of the CenterPoint RTX system (Landau et al. 2013).

With the latest major release of the Trimble RTX technology in spring 2014 the support of BeiDou satellites is now available in the commercial CenterPoint RTX system. In this paper the performance improvements in respect to convergence time and positioning accuracy achieved with the next generation of CenterPoint RTX by utilizing BeiDou satellites are presented. It shows additional improvements compared to the preliminary results of early prototype testing. In addition this work includes recent research results from using Galileo satellites in CenterPoint RTX, although Galileo satellites are currently still in their in-orbit-validation phase and therefore not part of the CenterPoint RTX service at this point of time. The presented Galileo test results confirm the results of the earlier tests with respect to improvements of convergence time and positioning accuracy.

2 SATELLITE ORBIT ESTIMATION

Precise satellite orbit information is a fundamental precondition for RTX GNSS positioning. The computed satellite orbits produced by the RTX system in real-time have a typical overall accuracy (RMS) of around 3cm for GPS satellites and of around 6cm for GLONASS, when considering IGS rapid products as the reference (Glocker et al. 2012).

In order to assess the quality of orbit results, especially for systems where a good reference is not readily available, post-processed overlap periods of different orbital arcs are used. Every sample in this analysis is based on RMS values computed from a 24 hour overlap time period of two consecutive three-day arcs, as illustrated in Figure 4.

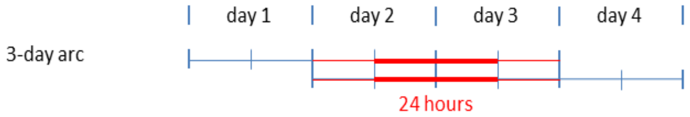

Figure 4. Orbit overlap scheme for Trimble post-processed orbit analysis.

Figures 5 to 7 show the typical orbit overlap discrepancies of the tangential (along-track), normal (cross-track) and radial components of a ten month period from end of April 2013 to February 2014 of one BeiDou IGSO (C06), one BeiDou MEO (C12) and one Galileo (E12) satellite.

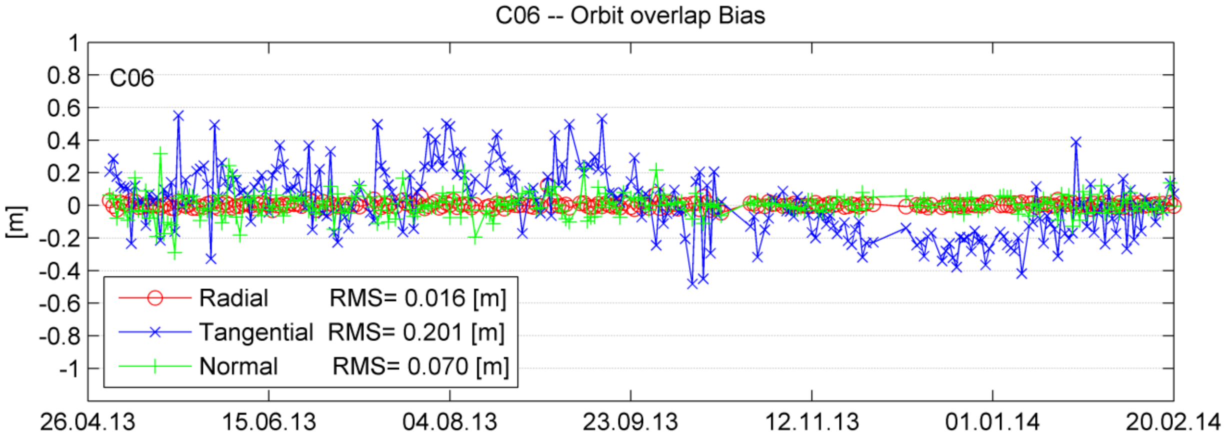

Figure 5. Orbit overlap biases for BeiDou IGSO C06 satellite.

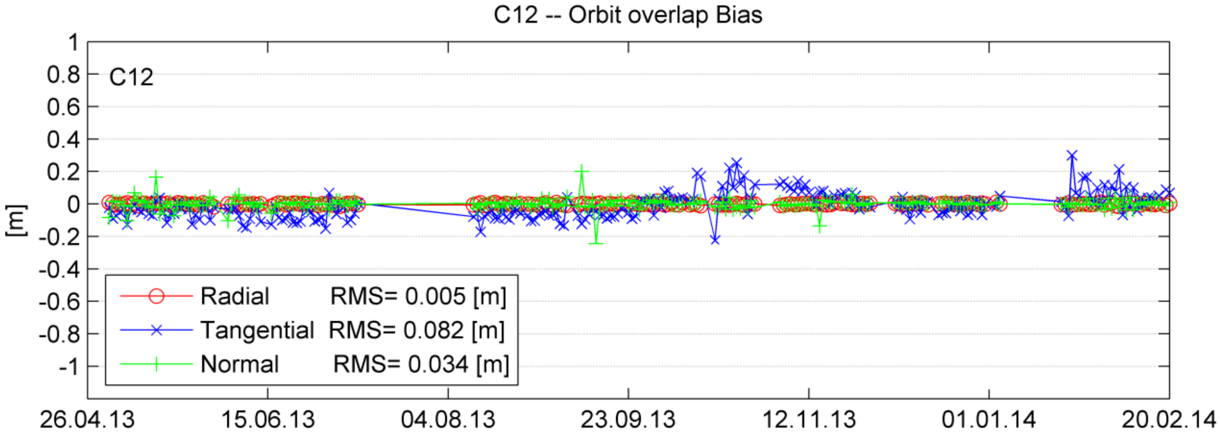

Figure 6. Orbit overlap biases for BeiDou MEO C12 satellite.

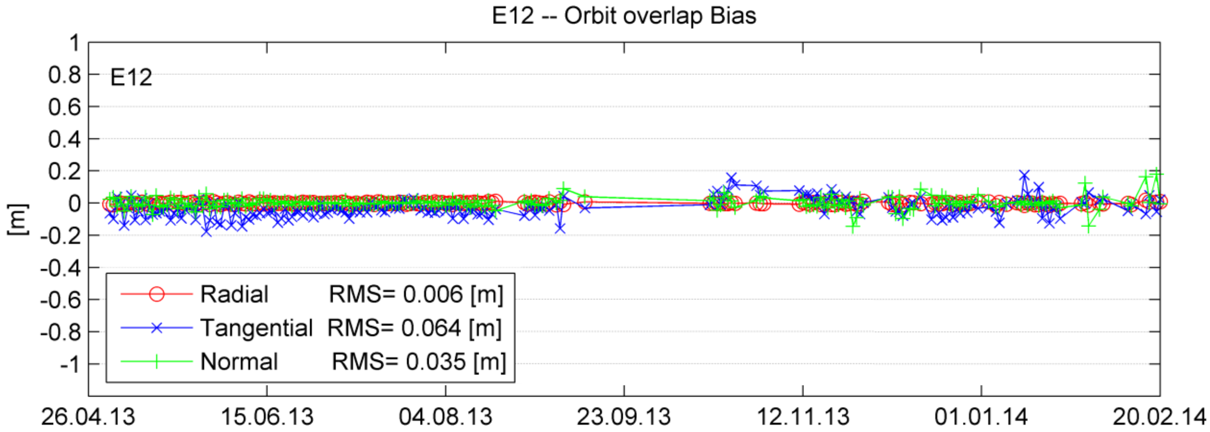

Figure 7. Orbit overlap biases for Galileo E12 satellite.

Figure 8 shows the RMS for all BeiDou IGSO, BeiDou MEO and Galileo satellites within the ten-month overlap analysis. The plot shows comparable results for the four BeiDou MEO satellites (C11 to C14) and the four Galileo satellites. The larger discrepancies for the five BeiDou satellites (C06 to C10) with Inclined Geosynchronous Orbits (IGSO) are expected due to the relatively poorer geometric configuration of this type of satellite orbits.

The geometry configuration of Geostationary Orbits (GEO) is even more challenging for orbit determination, especially for the along-track component. Orbit determination for BeiDou geostationary satellites is an open research topic of the Trimble RTX development team; therefore no results are shown in figure 8 for this type of satellites.

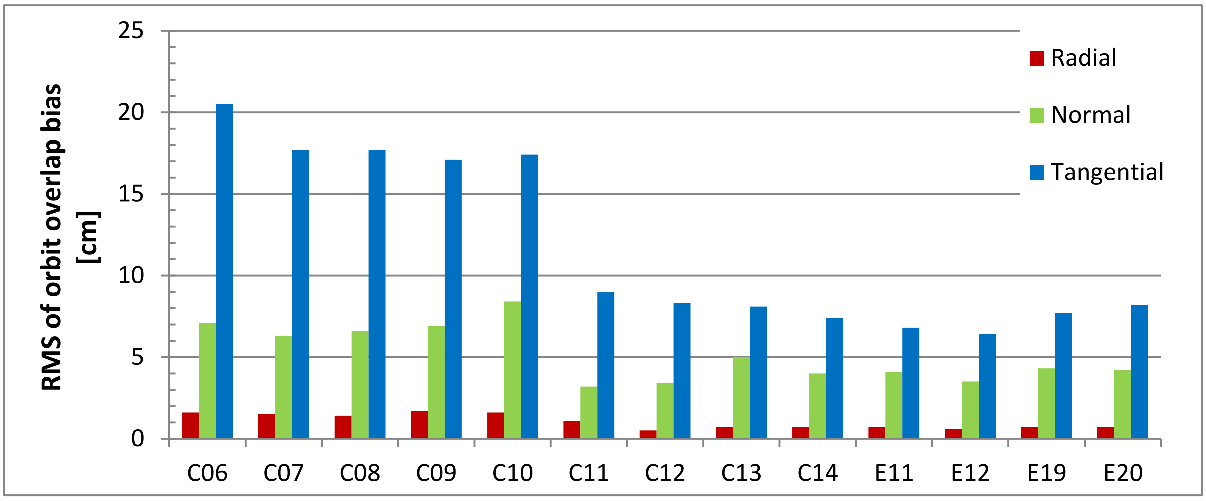

Figure 8. RMS of 10 month orbit overlaps for BeiDou and Galileo satellites.

3 SATELLITE CLOCK ESTIMATION

Accurate satellite clock corrections are a critical element for precise absolute RTX GNSS positioning. Due to the insufficient stability of the atomic clocks on board of the GNSS satellites, when dealing with the precise carrier phase observations, the satellite clock corrections have to be computed and transmitted with a high update rate. Furthermore, the estimation of satellite clocks based on ambiguity-fixed carrier phase observations is the key for absolute positioning with ambiguity fixing for an isolated receiver. Only with this approach the convergence time of the positioning solution can be reduced to the values accomplished with the Trimble CenterPoint RTX service.

The clock estimation in the RTX server software is based on a two-step approach. In a first step, pseudorange-leveled low-rate clocks are estimated, and in a second step, high-rate (1 Hz) phase clock corrections that can be used for ambiguity fixing are computed. In the following section, the integer property of the narrowlane ambiguities that is required for ionosphere free ambiguity fixing is demonstrated using the BeiDou and Galileo correction data stream from two independent RTX servers. It must be emphasized that the Galileo corrections are currently only used in Trimble development systems, i.e. they are not yet available in any commercial product.

3.1 Consistency of RTX-Server solutions

The integer nature of the ambiguities when using the RTX correction data becomes visible when the orbit, the Melbourne-Wuebbena widelane bias and the phase clock corrections of two independent server solutions are compared. Figure 9 shows the combined differences of real-time phase clock, Melbourne-Wuebbena widelane bias and orbit corrections from two different RTX servers for 3 BeiDou IGSO and 3 MEO satellites with respect to the reference satellite C08 on February 11, 2014 expressed in B1-B2 narrowlane cycles with a wavelength of 10.8 cm. The integer levels of the ambiguity differences are evident as well as some gaps, especially for the MEO satellites, C11, C12 and C14. They cannot be reliably estimated consistent to the IGSO satellites when they are all on the opposite side of the globe, i.e. above North and South America. The integer-valued differences are expected and caused by the fact that different sets of biases were fixed on the two servers.

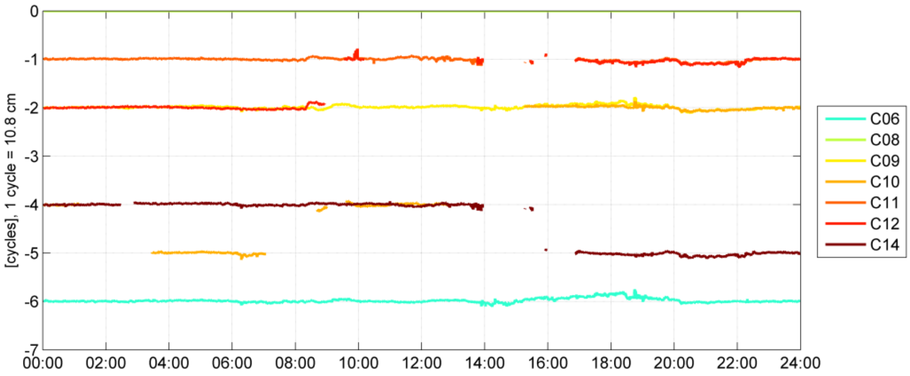

Figure 9. Combined differences of real-time phase clock, Melbourne-Wuebbena widelane bias and orbit corrections from two different RTX servers for 3 BeiDou IGSO and 3 MEO satellites with respect to the reference satellite C08 on February 11, 2014.

Figure 10 shows the combined differences of real-time phase clock, Melbourne-Wuebbena biases and orbit corrections for two Galileo satellites with respect to the reference satellite E19 on February 11, 2014 expressed in E1-E5 narrowlane cycles with a wavelength of 10.8 cm. The fourth satellite E11 was not in the solution on this day because it was not transmitting navigation signals (NAGU 2014005). Due to the limited number of satellites in the Galileo constellation, phase clocks corrections over regions with scarce receiver coverage may not pass the built-in reliability checks, and hence they would not be broadcast to CenterPoint RTX users.

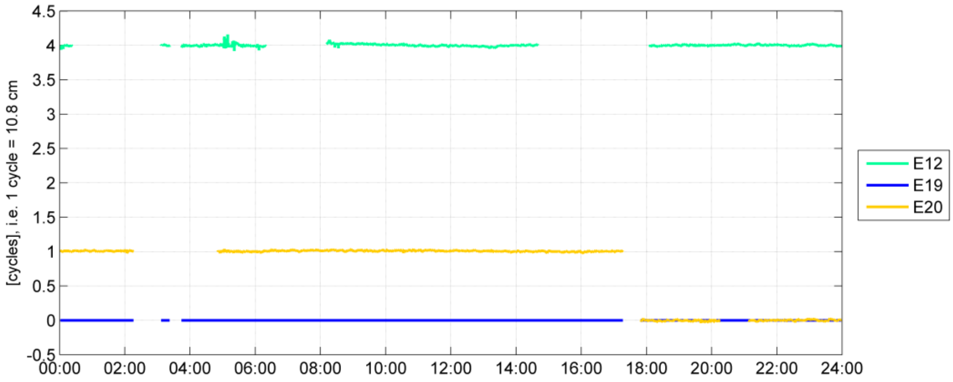

Figure 10. Combined differences of real-time phase clock, Melbourne-Wuebbena widelane bias and orbit corrections from two different RTX servers for 2 Galileo satellites with respect to the reference satellite E19 on Feb. 11, 2014.

3.2 Galileo and BeiDou satellite clocks

Two types of Rubidium (Rb) frequency standards are used in the BeiDou satellites, a European type and a Chinese product.

Figure 11 shows the differences of the real-time CenterPoint RTX satellite clock corrections for the BeiDou IGSO and MEO satellites with respect to the reference satellite C11 on March 23, 2014. Apart from the IGSO satellite C08 which exhibits slightly lower frequency stability, the performance of the BeiDou clocks is very homogeneous.

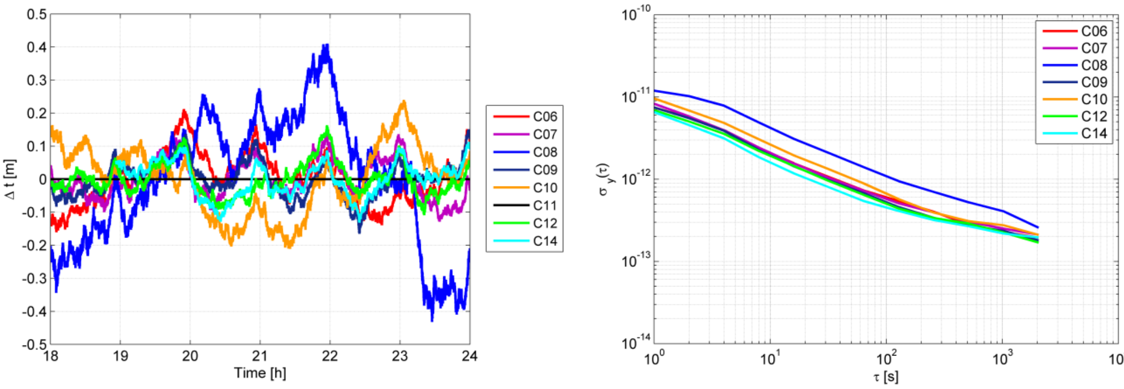

Figure 11. Differences of real-time ambiguity-fixed RTX phase clock corrections with respect to C11 on March 23, 2014, after removing a linear trend, and the corresponding Allan deviation for the BeiDou IGSO and MEO satellites.

Each Galileo IOV satellite is equipped with two highly stable passive hydrogen maser (PHM) frequency standards, as well as with two additional Rb frequency standards of lower stability. Together with the latest generation of GPS Rb oscillators that are used on board of the GPS Block IIF satellites and the Japanese QZSS satellite, the Galileo PHM are the most stable GNSS clocks ever flown into space.

Figure 12 shows the differences of the real-time CenterPoint RTX satellite clock corrections for the Galileo IOV satellites with respect to the reference satellite E11 on March 24, 2014. On this day, 3 satellites (E11, E12, E19) were using a hydrogen maser clock and one satellite (E20) was using a Rubidium clock. The difference between the frequency stability of the different oscillator types is clearly visible in the Allan deviation shown in Figure 12.

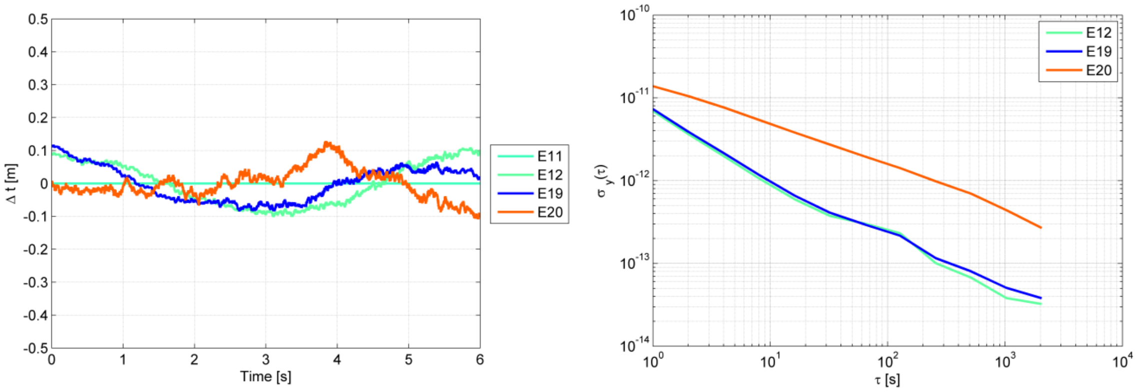

Figure 12. Differences of real-time ambiguity-fixed RTX phase clock corrections with respect to E11 on March 24, 2014 after removing a linear trend and the corresponding Allan deviation for the Galileo IOV satellites.

4 POSITIONING RESULTS

The correction data estimated by the CenterPoint RTX positioning service is transmitted via Trimble compressed data format (CMRx) to the user receiver. The CenterPoint RTX user receiver applies the transmitted data to correct its observations for geometric ranges, satellite clock errors and satellite biases. The ionospheric effect is eliminated via “ionospheric free” carrier and code-carrier combinations on L1 and L2. The CenterPoint RTX ionosphere information is most beneficial for GLONASS processing by avoiding to rely on code-carrier observation with their larger GLONASS satellite-dependent receiver code biases. The troposphere is handled via an a-priori model plus additional unknowns for the vertical wet delay, and two gradients in north-south and east-west directions.

In the following we present an evaluation of the user receiver performance with CenterPoint RTX orbit, clock and bias information derived from Trimble’s CenterPoint RTX worldwide tracking network. Then, those corrections were used to estimate the positions of 50 Trimble NetR9 reference stations distributed around the earth in kinematic mode from February 10, 2014 to February 13, 2014. The location of stations used in this experiment is depicted in Figure 13.

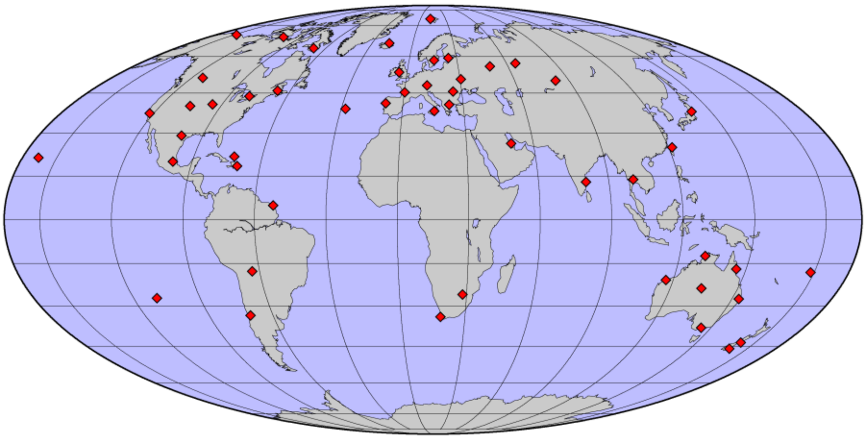

Figure 13. Set of Trimble NetR9 receivers used to evaluate the new CenterPoint RTX corrections.

In this study, the main variable to consider was the convergence time, which has been estimated at each reference station by restarting the receiver positioning algorithm every hour during the aforementioned time period, and then leaving it running for 60 minutes.

An additional condition has been imposed on the number of satellites: for each 1-hour sample, the number of Galileo or BeiDou satellites must be 3 or more. The BeiDou satellites contributed to this analysis were C06, C07, C08, C09, C10, C11, C12 and C14. The geostationary BeiDou satellites were not used, nor was BeiDou C13 used, which was flagged unhealthy during the investigated time period. With respect to Galileo, E12, E13 and E14 were used. E11 was flagged unhealthy and was not used in this analysis.

Although Trimble RTX corrections contain a global ionosphere model the level of ionosphere activity cannot be fully ignored in convergence analysis of PPP-like positioning approaches. During periods of strong ionosphere activity not only the estimated ionosphere delay is increased, also ionosphere disturbances are more frequent, which have a negative effect on GNSS signals and its use in various GNSS positioning techniques, including Trimble RTX positioning.

Figure 14 shows a time series of the global mean ionosphere activity over the past two years as computed by the RTX system. During the 4-day test period in February 2014 the global mean ionosphere activity, estimated by the RTX system was 33.1 TECU, which indicates a strong ionosphere activity. Therefore, besides the analysis on BeiDou and Galileo influence in RTX positioning, this experiment is also giving an indication how well the CenterPoint RTX correction service works under challenging ionospheric conditions.

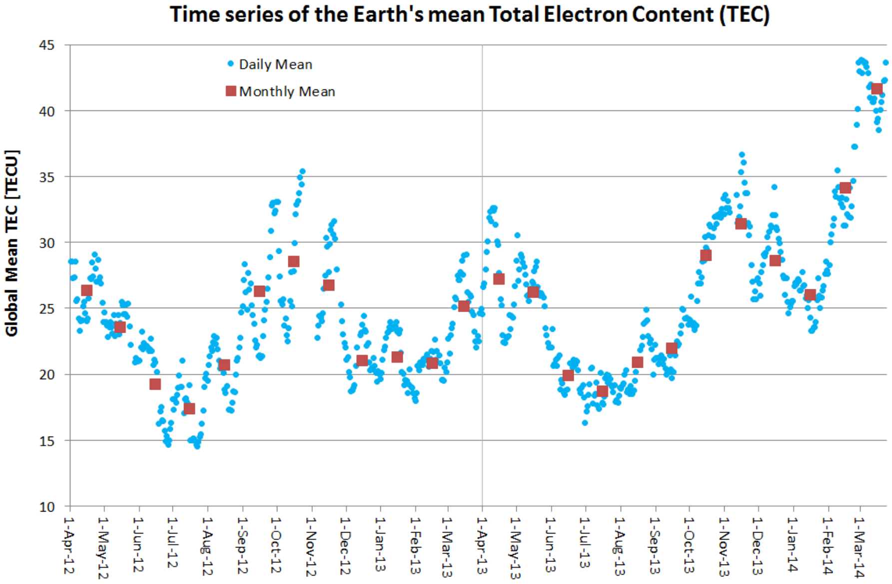

Figure 14. Time Series of Earth’s mean Total Electron Content (TEC).

Four scenarios were considered in the analysis of the convergence performance. The “reference scenario” was chosen to be the GPS and GLONASS constellation, and hereinafter denoted as “GG”. This reference scenario was compared with the GPS+GLONASS+BeiDou case (“GGB”) and the GPS+GLONASS+Galileo case (“GGG”).

In the absence of a production CenterPoint RTX service, which included BeiDou support, the performance and position accuracy results we present in the following were derived by simulating real-time RTX positioning in a kind of post-processed way. RTX correction data latency was not simulated.

BeiDou and Galileo satellites are not providing global coverage yet. Therefore we have used only time periods with at least three visible BeiDou, respectively three Galileo satellites, in the convergence analysis and compared it against the reference scenario “GG”. This leads to the situation that the set of analyzed convergence runs in the two scenarios “GGB” and “GGG” varies, which is caused by diverse visibility of BeiDou respectively Galileo satellites at the involved test receivers. This reduces the number of convergence runs in this analysis to 1515 in the “GGB” scenario and to 406 in the “GGG” scenario.

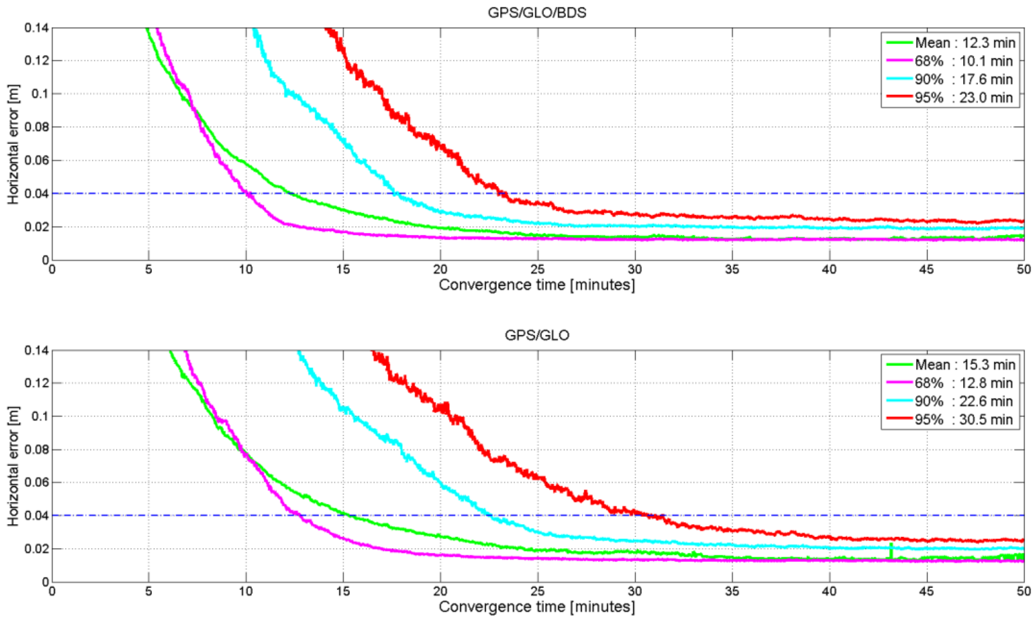

Figure 15. RTX convergence performance for horizontal error. Scenario: GPS+GLO+BDS.

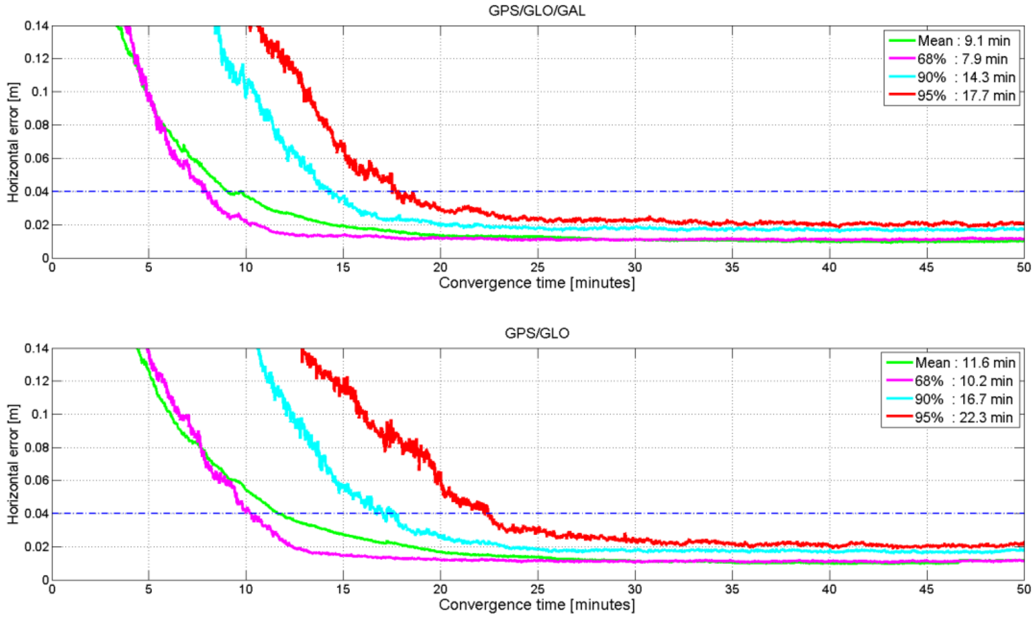

Figure 16. RTX convergence performance for horizontal error. Scenario: GPS+GLO+GAL.

The figures 15 and 16 show the results for the described scenarios. It can be seen that at the 95-percentile level (Trimble's commonly used performance metric), the improvement in the GGB case (adding BeiDou) is 25% with respect to the reference, GPS+GLONASS (GG) case. The convergence time improvement for the GGG scenario (adding Galileo) is 21%. The difference of the performance of the reference GPS+GLONASS run can be explained by the different set of analyzed convergence runs which is dependent on the visibility of the analyzed satellite systems at the reference stations involved in this experiment.

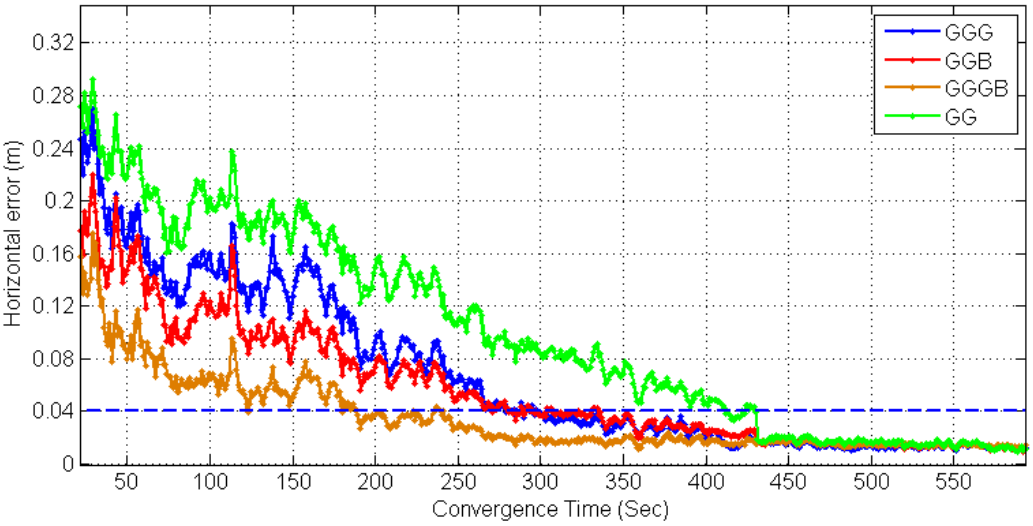

Figure 17. RTX horizontal convergence performances at station SEOU for 4 scenarios (GG/GGG/GGB/GGGB).

While the figures 15 and 16 show the overall statistical performance from many stations the individual improvement might not be really visible. This is why we would like to show at least one individual convergence run. Figure 17 shows such an example at station SEOU in the Asia-Pacific region for 4 scenarios: GPS/GLONASS (GG), GPS/GLONASS/GALILEO (GGG), GPS/GLONASS/BeiDou (GGB) and GPS/GLONASS/GALILEO/BeiDou (GGGB) on Feb. 10, 2014. 4 BeiDou Satellites and 3 GALILEO satellites were observed during this time. As shown in the figure, the horizontal convergence time for scenario GG is around 430 seconds, where the convergence time for scenario GGG and GGB are around 270 seconds. With satellites from all 4 satellite systems, the convergence time is even shorter, which is around 200 seconds.

Regarding the accuracy performance, the error with respect to the true coordinates is computed after the convergence has been achieved (considering minute 30.5 to 60), i.e. by averaging the values of the tails of the curves previously shown. It is reassuring that, as expected, the accuracy slightly improves when the functional model gets stronger, as shown in Figure 18.

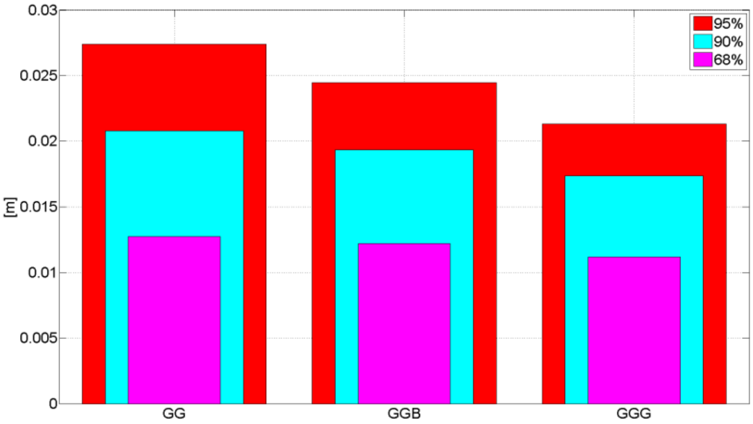

Figure 18. Horizontal positioning accuracy values after convergence.

The figure 18 shows, at 95-percentile levels, a horizontal accuracy value of 2.7cm for the reference case GG compared to 2.4cm for the GGB scenario. In the GGG case the achieved horizontal accuracy is 2.1cm.

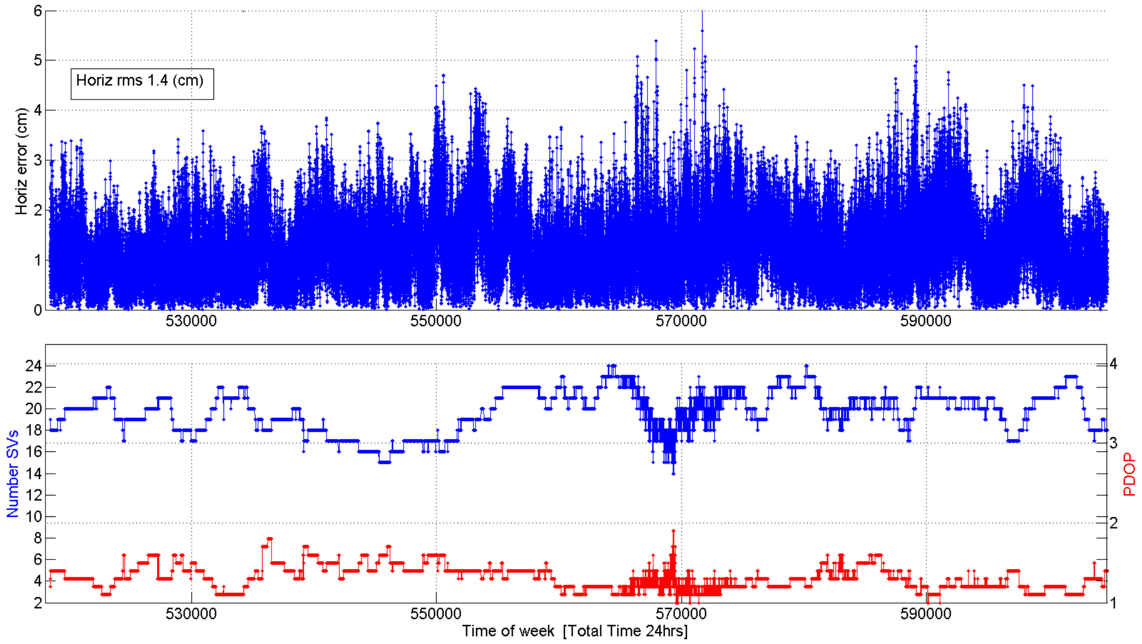

Figure 19. Example of 24 hours RTX horizontal error at station Bangkok.

Figure 19 shows an example of 24 hours RTX horizontal positioning performance at station Bangkok on March 1, 2014. The horizontal RMS is 1.4 cm, and the 95 percentile positioning error is 2.2 cm. From the figure, you can see the positioning performance is reasonably good even during ionosphere scintillations (around time of week 570000 seconds), which can be seen clearly from the rapid change of number of tracked satellites and PDOP from the lower panel. Up to 24 satellites are used in the position solution including GPS, GLONASS, Galileo and BeiDou.

5 CONCLUSIONS

Trimble's CenterPoint RTX worldwide, real-time, ambiguity-fixing precise positioning service has been delivering top-of-class performance for its users since its introduction to the market, providing high quality bias, orbits and clock corrections for the currently supported GNSS (GPS, GLONASS and QZSS). In the past, the addition of new GNSS systems has yielded improvements in CenterPoint RTX key metrics, and therefore Trimble's R&D team had a keen interest in also adding BeiDou and Galileo support. Encouraging results of early prototype tests and further improvements thereafter have resulted in a new generation of the CenterPoint RTX service, which now includes BeiDou corrections in the commercial real-time service and the post-processing service. At the moment, while the Galileo satellites are still in the in-orbit validation phase, Galileo is not part of the commercial real-time service, but the constellation is already in this current phase able to demonstrate future performance improvement for the CenterPoint RTX service.

The orbit estimation for both BeiDou and Galileo show good stability in the latest release of CenterPoint RTX, which has added innovative ways to robustly cope with the quirks associated with non-standard (or still-in-development) constellation arrangements, although the BeiDou geostationary satellites exhibit specific problems that have not been fully solved yet.

Regarding the satellite clocks, BeiDou results are very good, but Galileo ones are simply extraordinary. Again, the problems related with BeiDou GEOs remain currently unsolved but actively pursued.

In this work, a prototype “all-GNSS” engine was used to estimate the positions of 50 fixedly installed monitoring receivers around the globe in kinematic mode, during a period of 4 days in February 2014, yielding very impressive results.

The addition of BeiDou to the standard RTX processing reduced the convergence time at the 95-percentile level by 25%, while horizontal positions improved by 10%.

The former values represent extraordinary improvements on top of what currently is an outstanding product. Especially RTX users in the Asia Pacific region are going to benefit from the available BeiDou satellites and their inclusion into the CenterPoint RTX commercial real-time service.

The current research and development work carried out by the Trimble RTX team suggests that, in the near future Galileo may be quickly and successfully added to the Trimble products portfolio, improving both the convergence and the positioning performance even more for RTX users around the globe.

REFERENCES

Chen X., Allison T., Cao W., Ferguson K., Grünig S., Gomez V., Kipka A., Kohler J., Landau H., Leandro R., Lu G., Stolz R., Talbot N. (2011) *“Trimble RTX, an Innovative New Approach for Network RTK”*, Proceedings of the 24th International Technical Meeting of The Satellite Division of the Institute of Navigation (ION GNSS 2011), Portland, OR, 2214-2219.

Chen X., Landau H., Feipeng Z., Nitschke M., Glocker M., Kipka A., Weinbach U., Salazar D. (2013) *“Towards a Precise Multi-GNSS Positioning System Enhanced for the Asia-Pacific Region”*, China Satellite Navigation Conference (CSNC) 2013 Proceedings, Lecture Notes in Electrical Engineering, Vol. 245, 277-290.

Drescher R., Chen X., Landau H., Kipka A., Glocker M., Gomez V. (2013) *“Accelerating the Convergence of Trimble CenterPoint RTX Positioning by using a Global Ionospheric Model”*, GNSS PPP Workshop: Reaching Full Potential, Ottawa, Canada.

Doucet K., Herwig M., Kipka A., Kreikenbohm P., Landau H., Leandro R., Moessmer M., Pagels C. (2012) *“Introducing Ambiguity Resolution in Web-hosted Global Multi-GNSS Precise Positioning with Trimble RTX-PP”*, Proceedings of the 25th International Technical Meeting of The Satellite Division of the Institute of Navigation (ION GNSS 2012), Nashville, Tennessee, 1115-1125.

Glocker M., Landau H., Leandro R., Nitschke M. (2012) *“Global Precise Multi-GNSS Positioning with Trimble CenterPoint RTX”*, Proceedings of NAVITEC 2012 - European Workshop on GNSS Signals and Signal Processing, Noordwijk, The Netherlands.

Landau H., Glocker M., Kipka A., Leandro R., Nitschke M., Stolz R., Zhang F. (2012) *“Aspects of using the QZSS Satellites in the Trimble CenterPoint™ RTX™ Service: QZSS Orbit and Clock Accuracy, RTX Positioning Performance Improvements”*, Proceedings of the 25th International Technical Meeting of The Satellite Division of the Institute of Navigation (ION GNSS 2012), Nashville, Tennessee, 3038-3045.

Landau H., Brandl M., Chen X., Drescher R., Nardo A., Nitschke M., Salazar D., Weinbach U., Zhang F. (2013) *“Towards the Inclusion of Galileo and BeiDou/Compass Satellites in CenterPoint RTX”*, Proceedings of the 26th International Technical Meeting of The Satellite Division of the Institute of Navigation (ION GNSS+ 2013), Nashville, Tennessee, 1215-1223.

Salazar D., Brandl M., Chen X., Drescher R., Glocker M., Landau H., Nitschke M., Weinbach U., Zhang F. (2013) *“CenterPoint RTX: Towards A Worldwide, Real-Time, Commercially Available All-GNSS Ambiguity-Fixing Precise Positioning Service”*, Proceedings of the International Global Navigation Satellite Systems Society, IGNSS Symposium 2013, Outrigger Gold Coast, Queensland, Australia.

Zhang F., Brandl M., Chen X., Drescher R., Glocker M., Landau H., Leandro R., Nitschke M., Salazar D., Weinbach U. (2013) *“Trimble CenterPoint RTX – A First Study on Supporting Galileo”*, Proceedings of the European Navigation Conference (ENC) 2013, Vienna, Austria.