Experiences with Trimble CenterPoint RTX with Fast Convergence

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Experiences with Trimble CenterPoint RTX with Fast Convergence

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Abstract: The Trimble CenterPoint RTX service was introduced in 2011. It provides real-time GNSS positioning with global coverage and fast convergence.

In 2013 a global ionospheric model was added to the RTX service, which is based on a spherical harmonic expansion. This has led to a significant reduction in convergence time.

In spring 2014 the BeiDou system was included in the Trimble CenterPoint RTX service. Today it supports GPS, GLONASS, QZSS and BeiDou signals. Earlier publications have shown the benefits of using Galileo, BeiDou and QZSS in the RTX positioning service.

This presentation will introduce improvements achieved with regional augmentation systems using the Trimble RTX approach. Experiences made in the last years and the recent achievements are shown demonstrating the possibility of reliable initialization using carrier phase ambiguity resolution in a couple of minutes using a correction signal from a geostationary L-band satellite. This new regional service provides centimeter accurate positioning results of 4 cm in horizontal (95%) with convergence times of less than 5 minutes.

1 INTRODUCTION

The CenterPoint RTX service was introduced in mid-2011, providing centimeter-accurate positions for real-time applications in static or kinematic applications [1], [2]. 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 local 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.
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 an open post-processing service, available via a web interface [3]. 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.

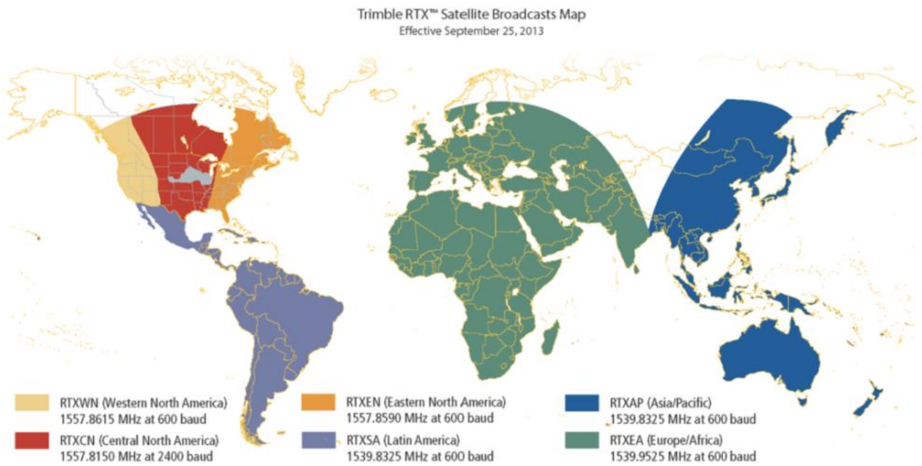

Figure 1. **Trimble CenterPoint RTX L-band Corrections coverage**

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, BeiDou, and QZSS.

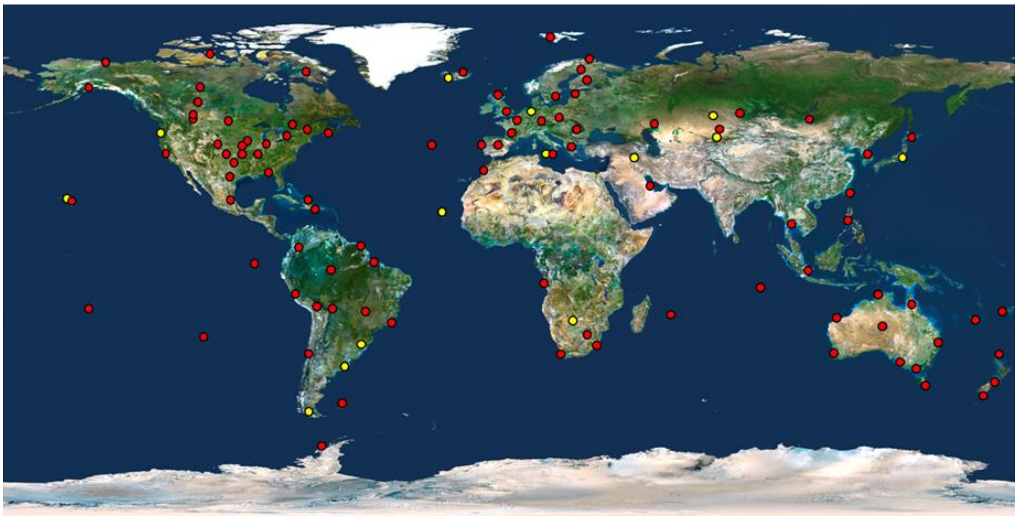

Figure 2. Trimble CenterPoint RTX worldwide tracking network

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 [4]. The third release improved the overall performance and significantly reduced the initialization time by introducing a Global Ionosphere model and applying new algorithms [5].

With the fourth release of the CenterPoint RTX service in spring 2014 the support of BeiDou satellites was added to the service. It could be shown that the addition of the BeiDou system to GPS and GLONASS provides a 25% improvement of the convergence time w.r.t. GPS+GLONASS, while the prepared addition of GALILEO provides a 20% improvement w.r.t. GPS+GLONASS [6].

From the development of the CenterPoint RTX service it is seen, that the convergence time can mainly be reduced by supporting additional GNSS or by providing ionosphere correction models. Currently all available satellite systems are supported (GPS, GLONASS, QZSS, BeiDou). The Galileo support is prepared and can be activated when the Galileo early service is specified and released. Therefore the main potential to further reduce the convergence time – and to improve single frequency positioning solutions – are improved ionosphere correction models. In this contribution we focus on the recently released regional ionosphere model for Europe, which provides enhanced ionosphere corrections by reference network densification and model refinement.

The performance improvements in terms of convergence time and positioning accuracy achieved with the new regional augmentation of CenterPoint RTX deployed in Europe are presented. The description of the properties of Trimble Ionosphere Models, namely the Global Ionosphere Model (GIM) and the Regional Ionosphere Model (RIM), are discussed in section 2. Their effect on convergence and positioning error for the dual frequency and single frequency case is discussed in section 3. A final summary is provided in section 4.

2 CENTERPOINT RTX IONOSPHERE CORRECTION MODELS

2.1 The role of the ionosphere

Fast and precise point positioning depends on the efficiency to resolve the phase ambiguities to their integer values. This resolution is not possible instantaneously because in the GNSS observation equations the ambiguities are highly correlated with other unknown parameters. Hence it is essential to collect observations from multiple epochs to make the positioning solution stabilized and the parameters decorrelated. By providing external ionosphere corrections the initial parameter correlation is reduced significantly. Therefore also the ambiguity resolution is sped up significantly.

2.2 Models used by Trimble CenterPoint RTX

The CenterPoint RTX worldwide tracking network is depicted in figure 2. It is made of 106 reference stations tracking GPS, GLONASS, QZSS, BeiDou and Galileo, and supports a Global Ionosphere Model based on the assumption of isotropic ionosphere. Under such an assumption, the slant total electron content can be mapped to the vertical and the ionosphere can be spatially represented by a single layer model based on spherical harmonics expansion [7]. The Total Electron Content (TEC) is then expressed as:

$$TEC(\varphi,\lambda) = \sum_{n=0}^{nmax} \sum_{m=0}^{n} P_{nm}(\sin\varphi)(C_{nm}\cos(m\lambda) + C_{nm}\sin(m\lambda))$$

Where the latitude φ and the longitude λ refer to the Ionosphere Pierce Point, defined by the intersection between the line of sight and the thin shell, and $P_{nm}(\sin\varphi)$ are the Legendre functions.
This quite simple approach constitutes a tradeoff between the L-band transmission constraints and the accuracy of the model. As a result, this model provides the slant ionosphere with decreased accuracy at low elevation angles, which is a clear indication that the isotropic assumption is not correct. Although the Global Ionosphere Model is useful for reducing convergence time in dual frequency mode and for supporting single frequency mode, a new approach is needed to further reduce convergence time down to a few minutes. Moreover, the spatial resolution should be improved by network densification. Therefore, a new Regional Ionosphere Model has been introduced, based on a different approach: the single satellite ionosphere slant delay is modeled, thus overcoming the isotropic assumption, and the spatial resolution is increased through a tracking network densification. The network supporting the Regional Ionosphere Model in Europe is currently using 257 stations and it is shown in figure 3. The average station spacing is approximately 200 km.

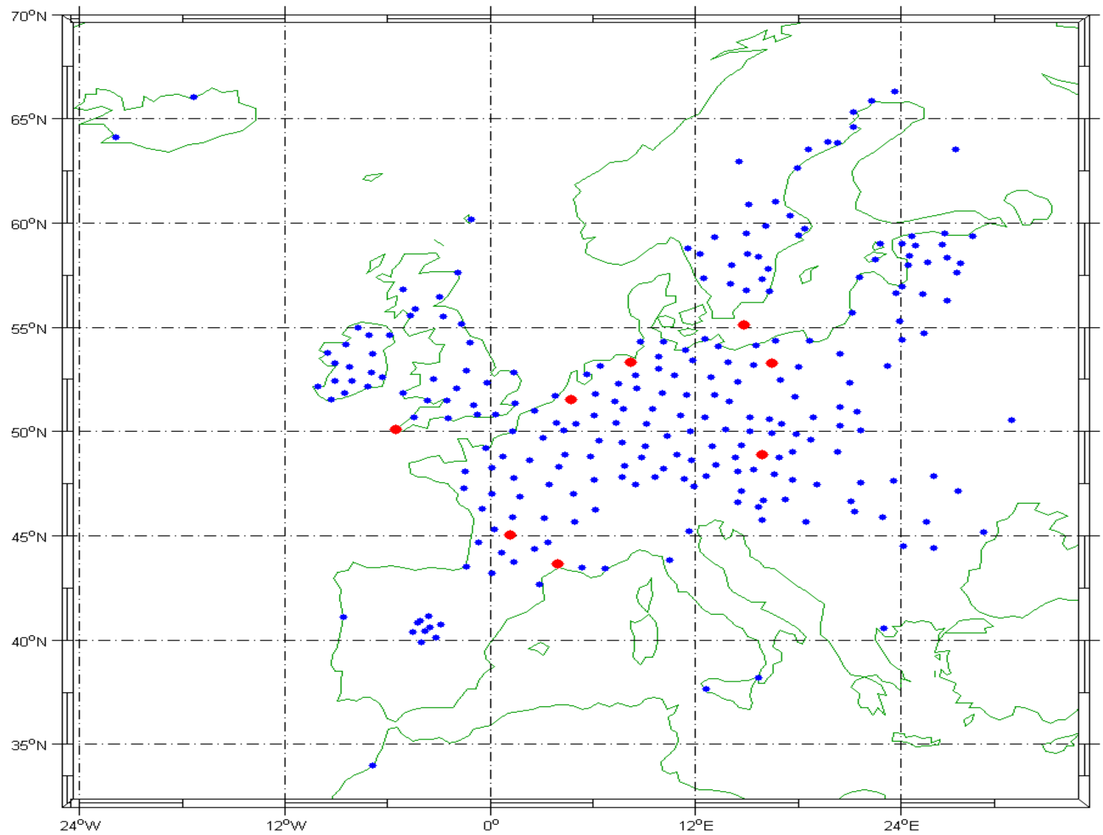

Figure 3. Regional CenterPoint RTX tracking network, red asterisks represent the stations used for ionosphere statistics computation (section 2.3)

2.3 Performance of the models in terms of residual statistics

The performance of the models is shown by the standard deviation of the residual of the ionosphere phase combination after applying the model corrections. Therefore, our performance indicator is defined as:

$$\sigma_i = \sqrt{\sum \frac{\left(L_{iono} - L_{iono,model}\right)_i^2}{n_i}}$$

Where σ_i refers to the i-th elevation bin (from 15+/- 5 deg to 85+/-5 deg), L_{iono} represents the phase ionosphere combination (in meters), $L_{iono,model}$ is the ionosphere linear combination of the modelled values used as corrections and n_i is the number of data points in the corresponding bin. To consider the initial phase ambiguities and existing hardware biases a constant shift is applied for every contributing satellite arc before computing the residuals. We report results from data collected from 8 stations on 10 March 2015. The position of the considered stations is represented by the red asterisks in figure 3.

Figure 4 shows the σ_i values of the residual slant delay (relative to L1 frequency) after applying our CenterPoint RTX ionosphere correction models to the observations. We see that the regional model provides more precise corrections in general, and especially for low elevation angles.

In the bin [10, 20] the Regional Model is more precise than the Global by 89%, in the bin [20,30] deg the improvement is 65% and for higher elevation angles it is around 50%. Such a level of correction improves greatly ambiguity fixing for low elevation satellites, strengthens the observations geometry and provides a noticeable improvement for the convergence, as we are going to show in the following sections.

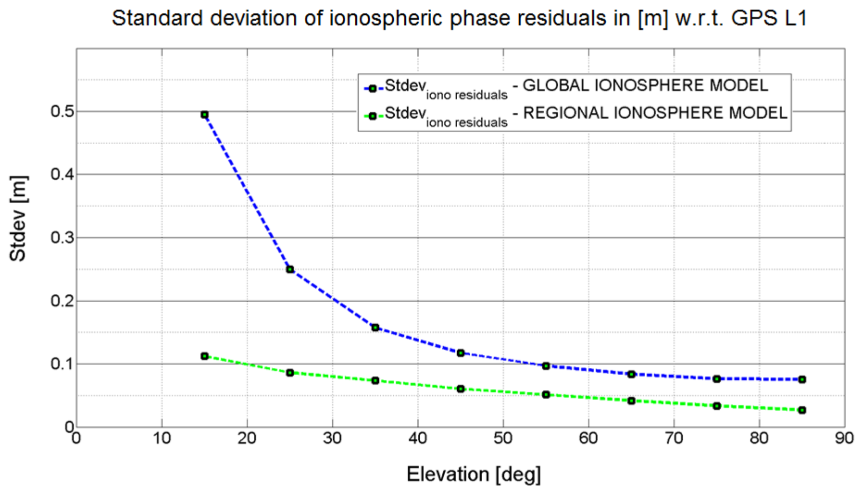

Figure 4. Residual Ionosphere Error of CenterPoint RTX ionosphere models

3 PERFORMANCE OF THE CENTERPOINT RTX IONOSPHERE CORRECTION MODELS

3.1 Dual frequency convergence

In the dual frequency scenario, the performance is assessed by means of a set of 35 geodetic receivers located in the region covered by the European Regional Reference Network. The tests were performed on March 2015 for a 14 day time interval (2nd to 15th of March). The receivers were restarted every 30 minutes. The average update interval for the Regional Ionosphere Model was 22 seconds, while for the Global Ionosphere Model it was 56 seconds. Observations from both GPS and GLONASS system were used (GPS+GLONASS case).

The performance indicators for horizontal positioning performance are defined by the convergence time at 68, 90 and 95 percentile. The results are reported in figure 5 and 6. The improvement is manifest: the global model is able to provide a position solution with a 4 cm horizontal error in 16.4 minutes for the 95% of the time, while the regional model can provide the same results in 0.9 minutes. The overall statistics have been computed using 22992 samples.

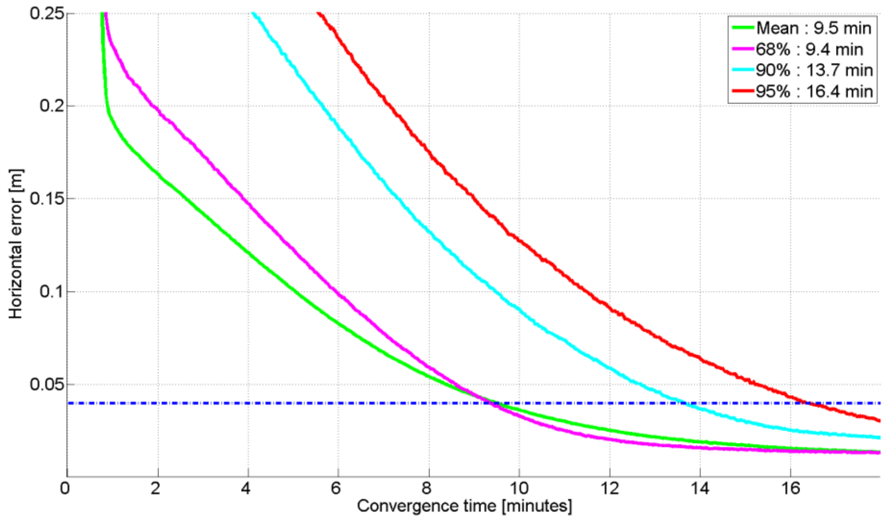

Figure 5. Dual Frequency Horizontal Convergence (4cm threshold, Global Ionosphere Model)

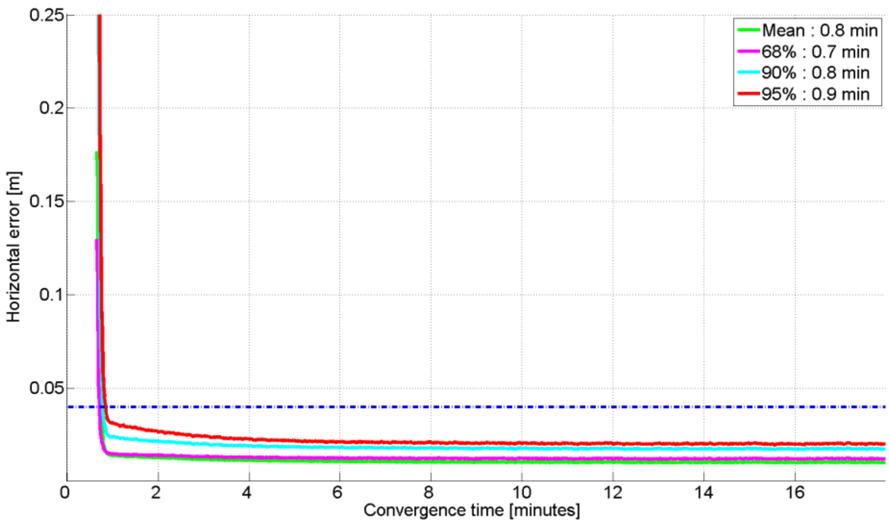

Figure 6. Dual Frequency Horizontal Convergence (4cm threshold, Regional Ionosphere Model)

3.2 Single frequency convergence

Single frequency performance is assessed through a set of 27 receivers located on the region covered by the Regional Reference Network. The tests were performed on March 2015 for a 14 day time interval (2nd to 15th of March), but using a different subset of receivers w.r.t. the dual frequency investigation. The receivers were restarted every 60 minutes. Again, GPS+GLONASS were used and the horizontal positioning performance is expressed as 68-90-95 percentile. The average update rates of the ionosphere models were the same as for the dual frequency scenario.
In figure 7 we see that the Global Ionosphere Model is not able to provide a single frequency positioning solution better than 25 cm (horizontal) in 50 minutes, at the 95-percentile. The Regional Ionosphere Model, instead, provides much better performance: the 25 cm horizontal threshold is achieved in 4 minutes, at 95-percentile (figure 8). The overall statistics have been computed using 8016 samples.

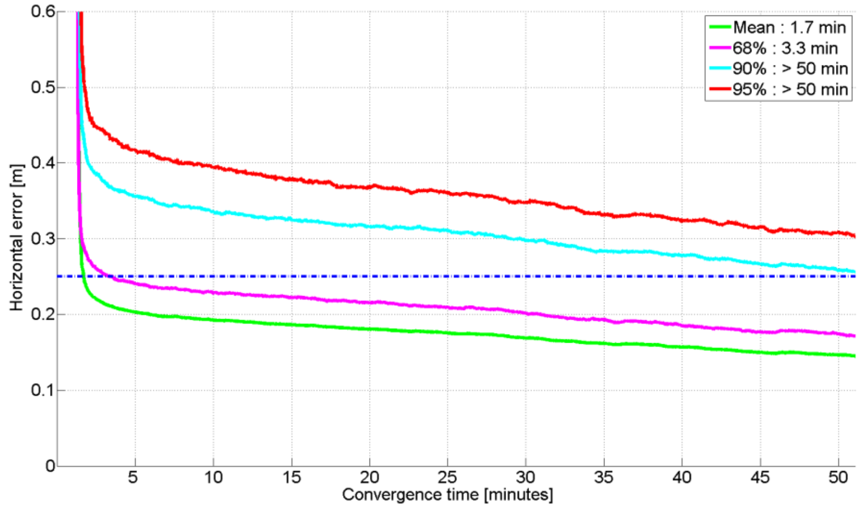

Figure 7. Single Frequency Horizontal Convergence (25cm threshold, Global Ionosphere Model)

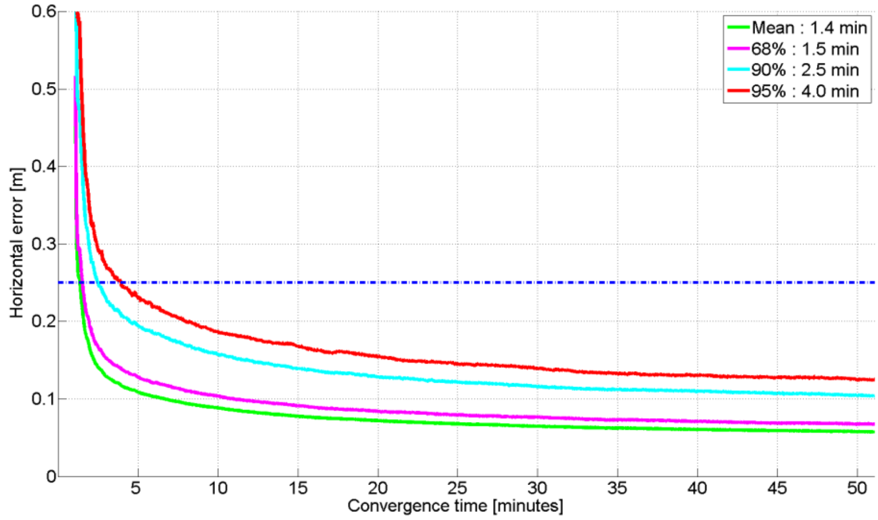

Figure 8. Single Frequency Horizontal Convergence (25cm threshold, Regional Ionosphere Model)

3.3 Single frequency horizontal error

In figure 8 the horizontal error during the position convergence phase is shown. It is worth noting that, this error is finally much smaller than 25 cm. That result led us to investigate in more detail the level of horizontal accuracy that can be achieved by using the global and the regional model.

The single frequency horizontal error is assessed through a set of 24 receivers located on the region covered by the Regional Reference Network. The tests were performed on March 2015 for a 14 day time interval (2^{nd} to 15^{th} of March) and again the GPS+GLONASS case was investigated.

The horizontal error after convergence is expressed as 90-95-99 percentile. As we see in figure 9, the horizontal positioning error associated with the Global Ionosphere Model is 21 cm, at the 95-percentile, while the Regional Ionosphere Model's counterpart is 14 cm.

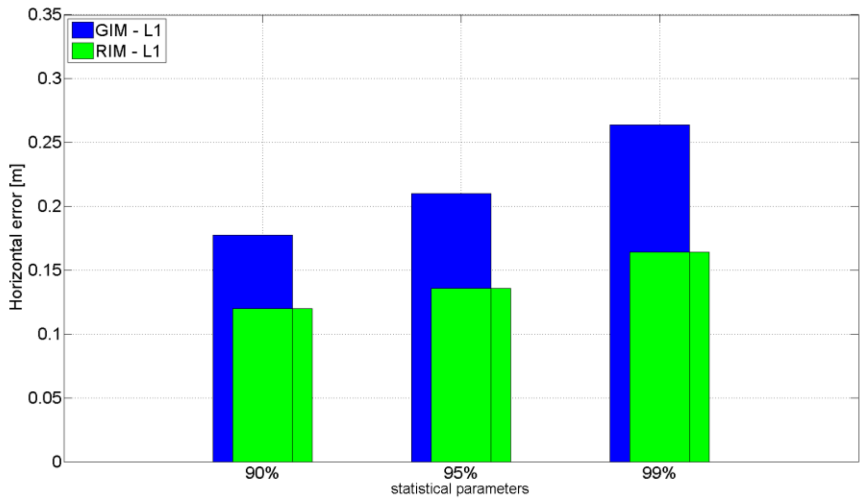

Figure 9. Single Frequency Horizontal Error, comparison between GIM and RIM converged solution

3.4 Single frequency horizontal error, comparison with EGNOS positioning

The results of the previous sections, especially for the single frequency, led us to investigate how they compare to the positioning solution obtained by using EGNOS service. Therefore we set up the following experiment: three geodetic receivers have been connected to the same antenna, each receiver providing a converged positioning solution based on a different mode, namely, EGNOS-based (GPS only), single frequency L1 RTX (based on RIM) and dual frequency L1/L2 RTX (ionosphere free). The used station is located in Munich and the test lasted 24 hours on 17th March 2015. GPS+GLONASS observations were used in RTX single and dual frequency solutions.

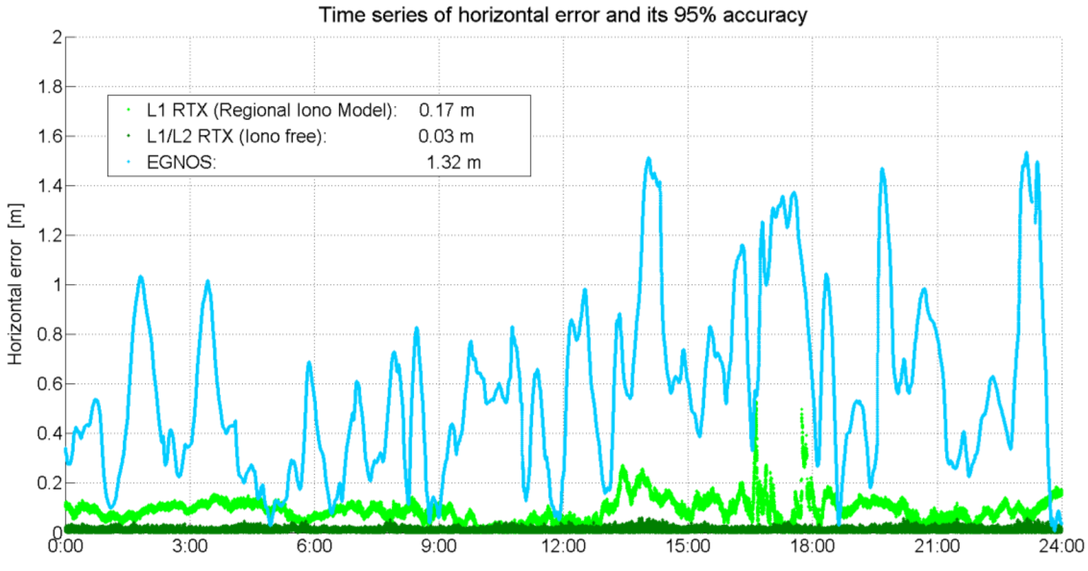

Figure 10. **Comparison between EGNOS, L1 RTX and L1/L2 RTX converged solutions**

As we can see in figure 10, the horizontal positioning error provided by the converged L1 RTX solution is 17 cm at 95-percentile, which agrees well with the results shown in figure 9, if we consider that the ionosphere was impacted by a strong geomagnetic storm after 12 pm [8]. The error associated to the EGNOS solution is 1.32 m. The L1/L2 RTX solution horizontal error is 3 cm and in agreement with the values reported in previous publications.

4 SUMMARY

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 sophisticated bias, orbits and clock corrections for the currently supported GNSS (GPS, GLONASS, QZSS and BeiDou). A Global ionosphere model was introduced in 2013 to further reduce the convergence time [5].

The current release of a European Regional Ionosphere Model represents a further step towards a very fast and precise positioning service. This new approach allowed us to reduce the ionosphere model error by e.g. 89% w.r.t. the Global Ionosphere Model for low elevation satellites (below 20 deg), thus reducing convergence time for dual and single frequency positioning and improving positioning error in the single frequency case.

Extensive tests of the new regional model – the overall statistics are based on more than 20 receivers running for 14 days – demonstrated that, for dual frequency operations, the solution converges to 4 cm horizontal error in 0.9 minutes (at 95%), compared to the 16.4 minutes required when using the Global Ionosphere Model. The single frequency solution converges to 25 cm in 4.0 minutes (at 95%). The horizontal error assessed through converged positioning solutions is 21 cm when the Global Ionosphere Model is used and 14 cm when the Regional Ionosphere Model is used (at 95%).

This horizontal error of 14 cm derived from the extensive tests over 14 days agrees well with the values obtained by the one day experiment used to compare the L1 RTX (converged, based on RIM) and the EGNOS solution. In this case, our test indicates that the L1 RTX solution using the Regional Ionosphere Model outperforms the EGNOS solution by 87%.

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