Assessment of ionospheric and tropospheric corrections for PPP-RTK

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INTRODUCTION

PPP-RTK allows to determine accurate positions in real-time, although it still has significant limitations to become a state of art GNSS technique. To perform PPP-RTK and overcome such problems it is necessary to accomplish the SSR (State Space Representation) of the spatially correlated errors impacting GNSS measurements, such as tropospheric and ionospheric delays. This work presents the results of tropospheric and ionospheric modeling employed to obtain the respective SSR corrections. The French Orphéon GNSS active network is used in this study. This network is property of the Geodata Diffusion company, subsidiary of Hexagon Geosystems.

METHODOLOGY

Reference network processing

The Orphéon reference network is presented on Figure 1. Data are used to perform GNSS processing in kinematic mode with constrained positions to estimate ionospheric and tropospheric delays. Table 1 presents details of GNSS data processing at the server side. Figure 2 presents the positioning errors over the first 2 hours after initialization for one of the reference stations. Ambiguity resolution is started after 1 hour from the cold start (when the curve becomes green). Figure 3 presents the 68% quantiles of convergence errors for all the sites. 154 reference stations were computed on day 290/2014 but 28 stations which presented positioning outliers or high errors values have been removed from the SSR computation. Since processing was realized in kinematic mode, quite significant positions variations were observed. For future works positions will be kept fixed.

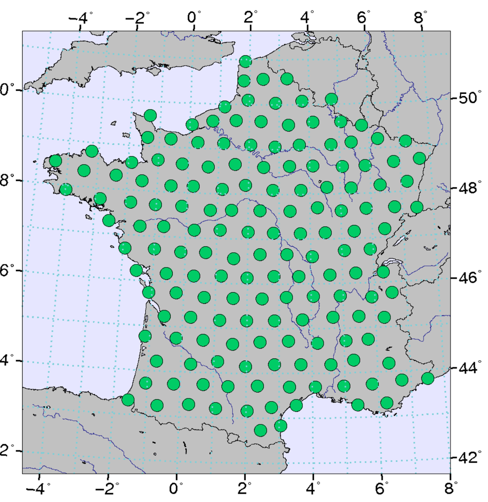

Figure 1 – The Orphéon network used in this study.

Table 1 –GNSS processing strategy for the reference network

Parameter	GNSS Network Processing
Software	**PPP-Wizard** (Laurichesse and Privat, 2015)
Satellites	GPS-Only
Mode	Pseudo-kinematic (Positions Constrained to 5cm)
Orbits, Clocks, and sat. Biases	CNES Products (Laurichesse, 2012)
Ionospheric Delays	Estimated
Zenith Tropospheric Delays	• ZHD: modeled (Saastamoinen, 1972) • ZWD: estimated • Mapping Functions: CNES mapping.
Coordinates	Constrained
Elevation mask	10°
Sampling data	1s
Other parameters	IERS Conventions (2010)

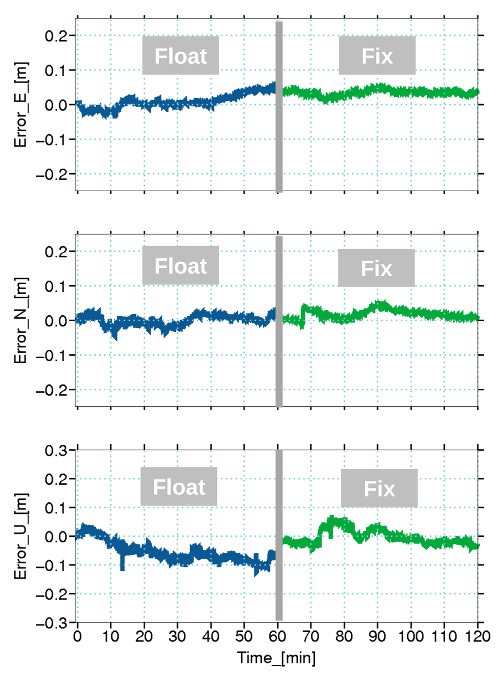

Figure 2 – Positioning errors for an Orphéon reference station (6h-8h/290-2014).

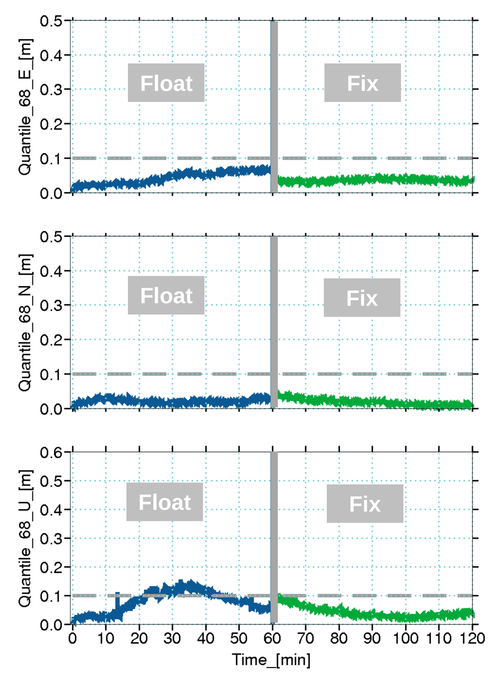

Figure 3 – 68% quantiles using all Orphéon reference stations (6h-8h/290-2014).

Generation and application of SSR atmospheric parameters

SSR ionospheric and tropospheric corrections are obtained using a barycentric interpolation of slant ionospheric delays and zenith wet delays from the three closest reference stations (Zhang et al, 2013). This strategy is consistent with the RTCM standards evolution (stage 3). Stations from IGN are used to simulate rovers positioning. For these stations standard real-time PPP in kinematic mode is compared with solutions using SSR corrections: Tropo-Only, Iono-Only and Iono+Tropo. Processing parameters are described in Table 2.

Table 2 – Rover GNSS processing strategies

Parameter	GNSS Rover Iono-Only	GNSS Rover Tropo-Only	GNSS Rover Iono+Tropo
Software	**PPP-Wizard** (Laurichesse and Privat, 2015)		
GNSS constellations	GPS-Only		
Mode	Kinematic		
Orbits, Clocks, and sat. Biases	CNES Products (Laurichesse, 2012)		
Ionospheric Delays	Constrained (2cm)	Estimated	Constrained (2cm)
Zenith Tropospheric Delays	• ZHD: modeled • ZWD: estimated • Mapping Functions: CNES	• ZHD: modeled • ZWD: constrained (2cm) • Mapping Functions: CNES	• ZHD: modeled • ZWD: constrained (2cm) • Mapping Functions: CNES
Coordinates	Estimated		
Elevation mask	10°		
Sampling data	1s		
Other parameters	IERS Conventions (2010)		

ATMOSPHERIC CORRECTIONS

Using processing parameters presented in Table 1, atmospheric delays are estimated over the Orphéon GNSS network. Some examples for tropospheric and ionospheric delays are presented in Figures 4 and 5, respectively. In these figures it is possible to see the spatial variations of such atmospheric corrections. Ionospheric delays (Figure 5) are presented at the ionospheric piercing points (IPP) location considering an infinitesimal layer of 400km height. IPPs have been colored according to the magnitude of their vertical ionospheric delays. In this example the maximum observed value is 3.62m among 898 ionospheric delays (GPS-Only) available for this epoch (117 reference stations were used). An important aspect to check is the coherence among different IPPs with respect to a same satellite.

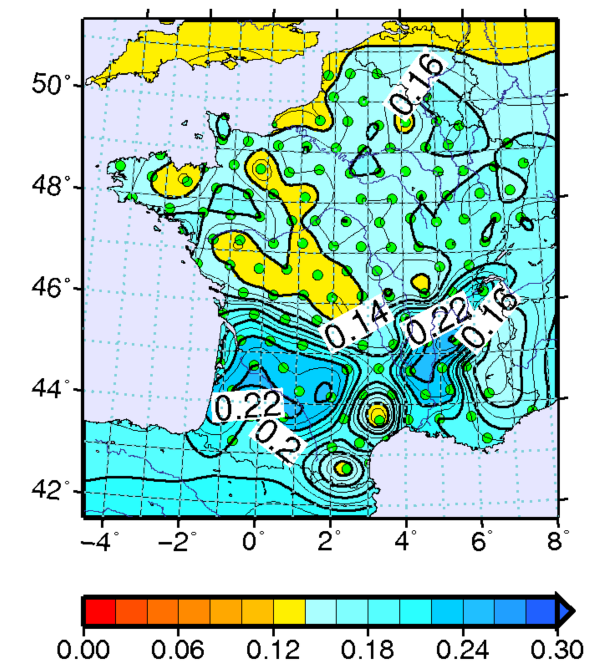

Figure 4 – Zenith Wet Delays (m) (6h30min/290-2014).

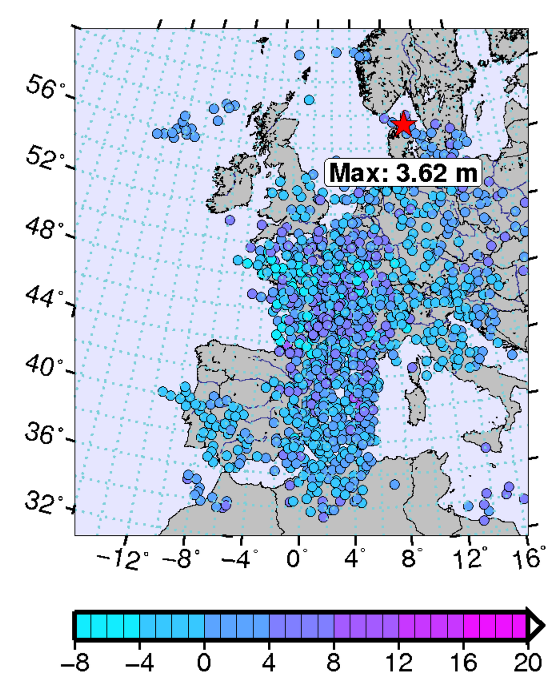

Figure 5 – Vertical Ionospheric Delays (m) at IPPs (6h30min/290-2014).

ASSESSMENT OF PPP-RTK PERFOMANCES

SSR atmospheric corrections are introduced in PPP to constrain their a priori values. It allows 1) to improve ambiguity fixing and 2) to reduce the positioning convergence time. In Figure 6, an example of standard real-time PPP (kinematic mode) is plotted w.r.t. real-time PPP using SSR corrections (Iono+Tropo). **Ambiguities fixing is achieved in ~5min** (using 8 GPS satellites, 7 Wide-Lanes and 6 Narrow-Lanes ambiguities are fixed to integer values) when SSR corrections are used. However, it is important to state that in several cases, outliers in SSR atmospheric delays can impact positioning performances. This means that further improvements in quality control need to be performed to garanty reliability. Tables 3 and 4 bring means and standard deviations values of positioning errors. It can be observed that the ionospheric corrections (Iono-Only) carry more significant biases reduction than the tropospheric corrections (Tropo-Only), although the best results are achieved when both corrections are used together (Iono+Tropo).

Table 3 – Mean of absolute errors after 3min

Positioning strategy	E [m]	N[m]	U[m]
Standard RT-PPP	-0.04	0.05	-0.12
PPP Tropo-Only	-0.03	0.06	-0.23
PPP Iono-Only	0.01	-0.05	-0.08
PPP Iono+Tropo	0.01	0.02	0.04

Table 4 – STD of absolute errors after 3min

Positioning strategy	E [m]	N[m]	U[m]
Standard RT-PPP	0.15	0.10	0.10
PPP Tropo-Only	0.08	0.07	0.21
PPP Iono-Only	0.05	0.05	0.16
PPP Iono+Tropo	0.02	0.04	0.04

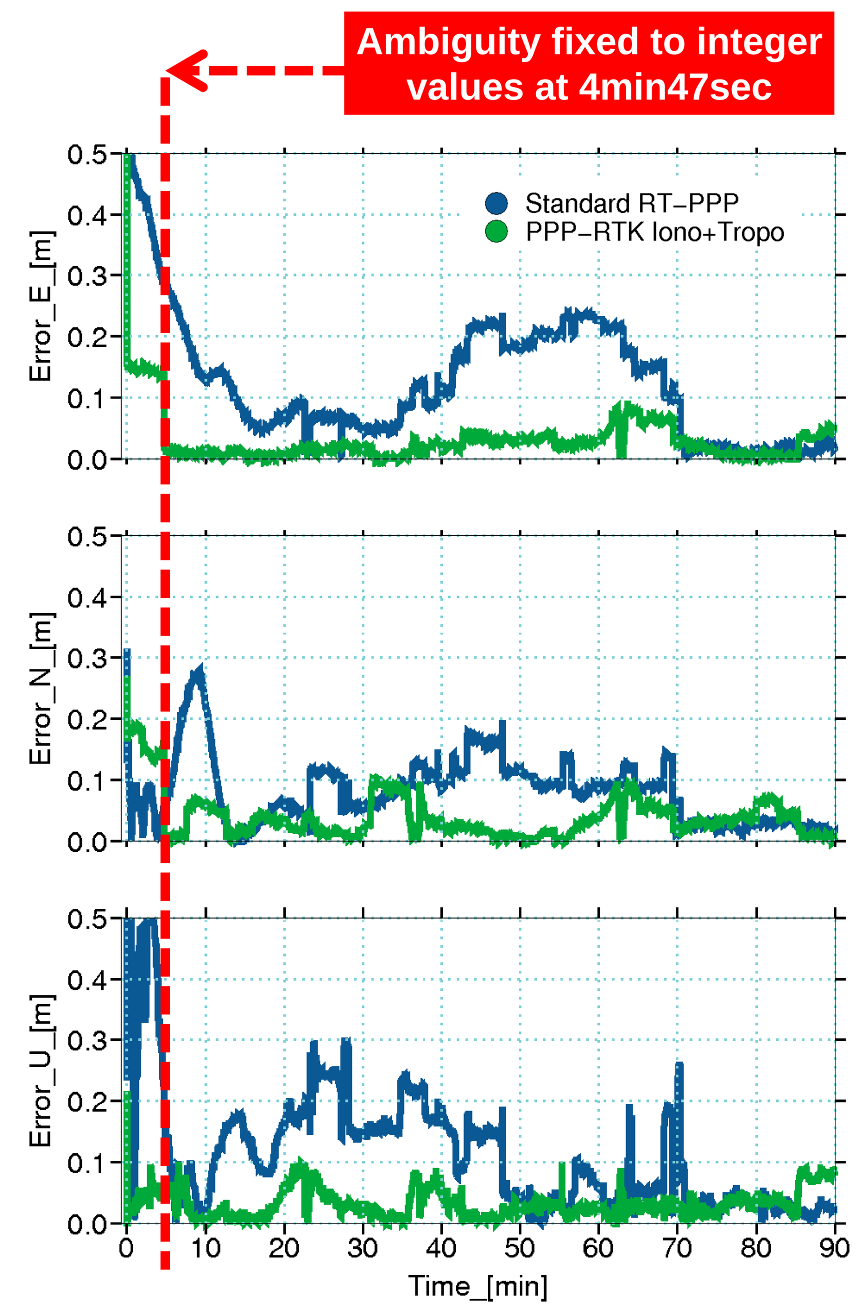

Figure 6 - Positioning errors for IGN station VFCH (1h-3h/290-2014).

CONCLUSIONS AND PROSPECTS

Considering the preliminary outcomes of SSR atmospheric corrections, it is possible to conclude that the implemented approach can improve PPP performances, even if significant efforts are still required to perform a successful quality control to achieve reliability. Fast and accurate PPP-RTK becomes achievable. This will be accomplished and further tests will be realized to investigate these improvements over longer periods. Further, assessments with a sparser reference network will be carried out as well as the use of other interpolation/modeling approaches.

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