Precise Point Positioning (PPP) Services in Kyrgyzstan

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Abstract

Precise Point Positioning (PPP) is becoming one of the most efficient and reliable methods in GNSS data processing. PPP performs precise position determination using a single receiver and precise satellite orbits and clock corrections from the International GNSS Service (IGS) and several other organizations. Three global online and free PPP services, provided by CSRS, APPS and GMV, are tested using observation data collected at the four permanent GNSS stations selected in different regions of Kyrgyzstan. A statistical analysis of the PPP results shows a maximum of 2.5 cm and 4.5 cm deviations in the planar surface for 24 hours and 4 hours GNSS observations respectively and about 10 cm geodetic height deviations under optimal GNSS satellite observation conditions. The use of PPP services can supplement engineering and land surveying depending the positioning purpose and accuracy, feasible observation periods and specific site conditions.

1. Introduction

GNSS point positioning, also known as standalone or single point positioning, involves only one GNSS receiver tracking four or more GNSS satellites to determine its own coordinates. The receiver gets the navigation satellite coordinates through its navigation message, while the ranges are obtained from either the C/A or the P(Y) codes, depending on the receiver type (single or dual frequency). The determination of position coordinates is realized by using different calculation algorithms and techniques, as well as least-squares estimation, troposphere modeling and Kalman filtering. Normally each of the global navigation systems uses own coordinate systems, however the most of GNSS receivers provide precise transformation parameters between international (WGS84, ITRF, etc.) and some of local datums. Two types of point positioning services can be provided by satellite navigation systems for geodetic measurements: the single point positioning (SPP) and the newly emerging precise point positioning (PPP) modes. SPP is the static or fast-static GNSS measurement of point coordinates by using single or double frequency pseudorange observations and satellite broadcast ephemeris data. The computation of SPP is realized with the Least Square and Kalman filter algorithms. The results indicate that the combined single point positioning with GPS/GLONASS code or phase-smoothed code measurements can achieve accuracies better than 2.5 m in the horizontal components and 4.5 m in the vertical component for single-epoch solutions.

In addition, accuracies better than 1 m in all three coordinate components can be obtained during a 24-hour observation period. The accuracy of the GPS, GLONASS and COMPASS/Beidou satellite broadcast ephemeris have better than 1 m orbital accuracy (Santerre et al., 2014). Tropospheric errors in SPP are largely removed by either applying a model which attempts to mathematically simulate the signal delay (as in most commercial software), or by estimating the signal tropospheric delay along with the receiver coordinates (as in most research software). Ionospheric errors are removed by observing both GPS frequencies (L1 and L2) and combining the two observations to derive an ionosphere-free observation (King et al., 2002). Application of the single point positioning mode has decreased in the last years with a sharp increase of other relative satellite positioning techniques as RTK methods supplemented by a GNSS base station or by the network of Continuously Operating Reference Stations (CORSs). However, the emerging new GNSS Precise Point Positioning (PPP) method is creating new perspectives for geodetic measurements with a single GNSS receiver. The evolution of PPP dates back to 1976, however extensive research has been conducted over the last two decades due to rapid development of data processing and communication technologies. Today this method is becoming more and more popular and efficient by taking into account the high cost of the additional geodetic-class GNSS receivers, lack of network RTK services in many countries as well as its increasing potential and convenience (Rizos et al., 2012).

2. Precise Point Positioning (PPP)

PPP is a method that performs precise position determination using a single GNSS receiver and it becomes possible with the availability of precise satellite orbits and clock corrections from the International GNSS Service (IGS) and several other organizations. The word "precise" also is used to distinguish it from the conventional point positioning techniques that use only code or phase-smoothed code as the principal observable for position determination. PPP uses differenced code and phase measurements from a single GNSS receiver and freely available precise GNSS orbit and clock data products for positioning with centimeter and sub-centimeter accuracy in the static mode and at the decimeter error level in the kinematic mode. Precise ephemerides substantially reduce the errors in GNSS satellite orbits and clocks, two of the most significant error sources in point positioning with a single GNSS receiver (Cao et al., 2010). The availability, reliability and positional accuracy of PPP are strongly dependent on the number of visible satellites and of accuracy of satellite orbits that have been computed made available with frequent updates by IGS data products. There are available "real time" (RT) and "post-processed" (PP) products, processed by the PPP service providers using precise GNSS satellite orbits and clock corrections, Earth rotation and atmospheric parameters in the broadcast, ultra-rapid, rapid and final IGS data products. Currently the post-processed PPP products are mainly used in geodetic measurements because of the complicated and resource demanding real time precise positioning. The multi-frequency GNSS receivers in use for geodetic PPP because of the large errors in single-frequency PPP, mainly due to ionospheric effects that cannot be mitigated effectively using single-frequency measurements. The GNSS receiver in use is conditionally accepted as a "rover" station and then it has the advantages of using many active receivers distributed worldwide, for example, in the IGS network. These advantages enable the PPP data processing server to quantify the influence of the distribution of satellites in view, the performance with respect to the distance from the single GNSS receiver to the nearest "network" receiver with tropospheric and ionospheric conditions as well as other potential effects. A number of sophisticated software and online services, both for commercial and free use, has been developed recently using a PPP processing strategy by international and government organizations, companies and universities. Some of the free PPP services available globally:

- CSRS-Precise Point Positioning (CSRS-PPP) operated by Canada Geodetic Survey Division of Natural Resource Canada (NRCan) - http://webapp.geod.nrcan.gc.ca/geod/tools-outils/ppp.php?locale=en;
- Automatic Precise Positioning Service (APPS) by NASA Jet Propulsion Laboratory (JPL) in USA - http://apps.gdgps.net/apps_file_upload.php;
- The private company GMV, Spain, is providing real-time post-processed PPP products. Free PP PPP service is available via email communication - http://magicgnss.gmv.com;
- Online Positioning User Service (OPUS) operated by United States National Geodetic Survey (NGS) - http://www.ngs.noaa.gov/OPUS;
- Australian Online GPS Processing Service (AUSPOS) operated by National Mapping Division of GeoScience Australia - http://www.ga.gov.au/bin/gps.pl.

These and other internet-based GNSS processing services use different static and kinematic PPP processing software. For instance, CRCS-PPP uses NRCan-PPP software, APPS uses GIPSY software and GMV uses MagicGNSS/PPP software. These online services have data submission and receiving procedures with internet access and email communication as well as the centimeter and sub-centimeter positioning accuracy depending on GNSS observation period and data quality. Sophisticated processing and network servers ensure uninterrupted distribution of GNSS satellite orbit and clock corrections, receive and distribute observation files and processing results to users via internet. Most of these PPP services have their own regional or global networks of Continuously Operating Reference Stations (CORS) extended by the IGS network. The user interfaces of the online PPP services allow to submit RINEX and other format observation data from single or dual-frequency GNSS receivers, operated in static or kinematic mode, over the internet using Hypertext Transfer Protocol (HTTP) or File Transfer Protocol (FTP) for further processing. Some of PPP service providers have developed desktop applications, such as PPP direct v1.4 by CSRS for submitting GNSS data files (RINEX, Hatanaka) for CSRS-PPP processing without use of a web browser. The current investigation and analysis of PPP methods will be based on post-processing of the static GNSS observation data, which is illustrated in Figure 1.

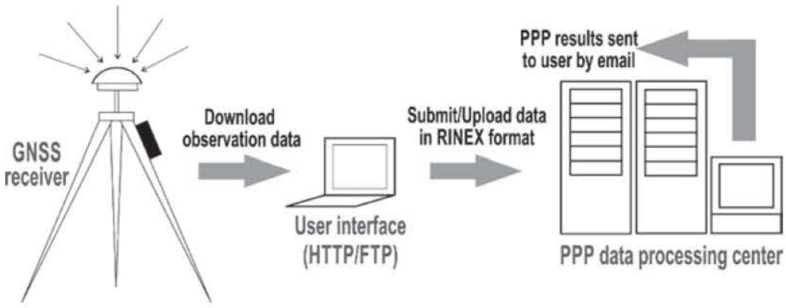


Figure 1: Simplified workflow of the online PPP service

Determined precise coordinates of the point and the processing report including standard deviations of data, sky plots and other information for analysis can be downloaded via hyperlink normally received from the PPP data processing center by email.

3. GNSS Data Collection and Submission for PPP Processing

The duration of the static GNSS data collection depends on required precision, number of visible satellites, satellite geometry (DOP) and whether the receivers are single frequency or multi-frequency. GNSS observation, however, should be long enough for the post processing software to resolve the integer ambiguity, a higher accuracy of positioning can be achieved by collecting data over the long period, up to many hours. Precise Point Positioning (PPP) can reduce the observation period by significantly increasing the efficiency of the positioning with a single GNSS receiver. The PPP service is not widely used in Kyrgyzstan yet and it needs detailed investigations and analysis for implementing this new satellite positioning technique in the regional and local conditions. PPP would be one of the most efficient and accessible positioning methods in the country by taking into account the extremely high cost of multi-frequency geodetic-class GNSS receivers for local surveying companies and lack of professionally trained staff able to process GNSS data. The network-based Real-Time Kinematic (RTK) service is available on less than half of the territory because of the scarcely located CORSs of the Active GNSS Network in Kyrgyzstan. Three free online PPP services, provided by CSRS, APPS and GMV, are tested using static observation data collected at the four permanent GNSS stations selected in different regions of Kyrgyzstan. Locations of the nearest GNSS stations of the IGS network and test stations are given in Figure 2. Three of the test stations (BATK, BEL_ and JALA) are operational within the Active GNSS Network of Kyrgyzstan and one test station (KRGT) is included in the network of permanent GNSS stations of the Central Asian Institute of Applied Geosciences (CAIAG) in Bishkek (Chymyrov and Karypov, 2014). Two test stations (BATK in Batken city and JALA in the Djalal-Abad city) are supporting network RTK services by the GNSS Reference Network Control Center “KyrPOS” for cadastral and engineering survey in the southern part of the country. The other GNSS reference station (BEL_ in the Belovodsk city) included in KyrPOS network in the northern part of Kyrgyzstan. The most eastern permanent GNSS receiver (KRGT in the Kerege-Tash town) has been used for the geophysical and other research studies since 2008 and operated by CAIAG. The GNSS observation data are collected at the test stations and IGS stations on three days with different length of sessions. 30 min and 1 hour long observation data collected on March 19, 2014 (Day of year – 78 in GPS Week/Day 1784/4, Modified Julian Day-56736), 4 hours long data on March 15, 2014 and 24 hours long session data collected on March 21, 2014 with 30 sec intervals. The 24 hours long GNSS recordings were used to calculate the network of test stations with control station POL2 (IGS) using desktop Trimble Business Center 3.40 software for the preliminary spatial analysis. The processing results show the high precision GNSS positioning results with sub-centimeter level accuracy on the planar surface and centimeter level accuracy on ellipsoid heights (Figure 3). Further submission of the GNSS observation data is realized by using web browsers (CSRS and APPS), desktop application (CSRS) and by email (GMV) in different RINEX and Hatanaka file formats. Post-processed final PPP results are downloaded using hyperlinks received by email (CSRS and GMV) or instantly from the web page of PPP service provider (APPS).

4. Analysis of PPP Products by Different Service Providers

GNSS receivers and antennas at the three KyrPOS stations and their ITRF2008 reference coordinates at the epoch of observation 2014-09-05 (Leinen, 2014), are given in Table 1.

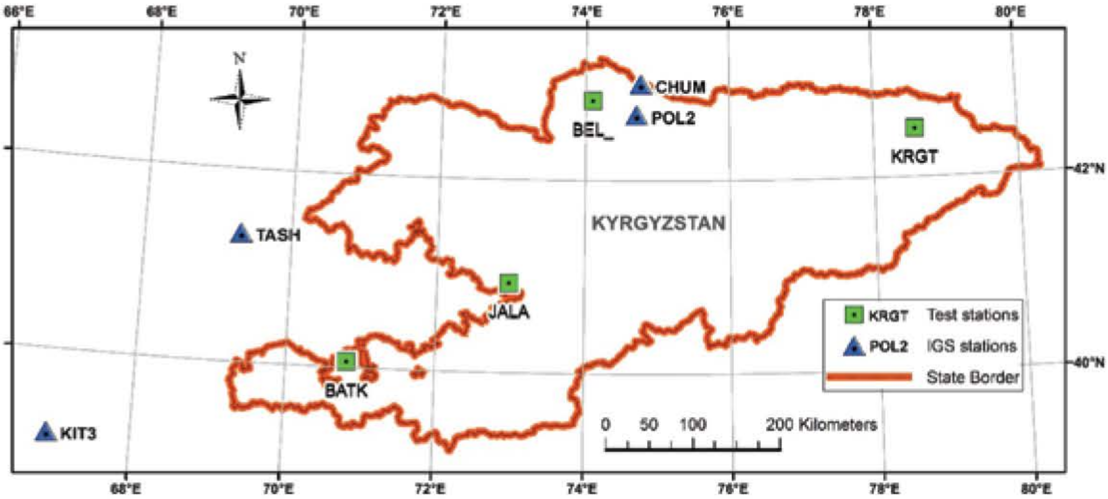


Figure 2: GNSS stations of IGS and selected test sites

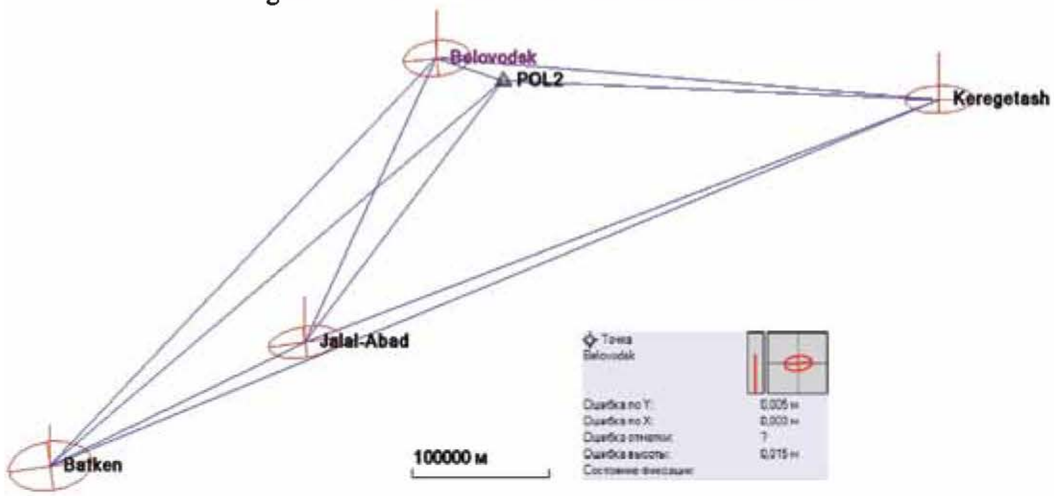


Figure 3: The calculated and adjusted network of GNSS test and IGS stations

Table 1: ITRF2008 coordinates and ellipsoid heights of the test stations

Station ID	GNSS receiver	Antenna	UTM Zone	X, m	Y, m	h, m
BATK	LEICA GRX1200	LEIAR10	42	654784.219	4435343.865	1002.281
BEL_	TRIMBLE NETR9	GPPNULL ANTENNA	43	426117.362	4741896.022	716.764
JALA	LEICA GRX1200	LEIAR10	43	330015.821	4533146.096	732.989
KRGT	TPS GB-1000	TPSPG_A1	44	301182.374	4708067.377	1924.330

These coordinates are based on the evaluation of a period of 14 days of GNSS data (GPS+GLONASS) from the nineteen KyrPOS stations to achieve the most. The simultaneous GNSS observation data on March 21, 2014 (Day of year – 80, GPS Week/Day 1784/5, Modified Julian Day-56737) are received from the operators of test stations (KyrPOS and CAIAG) in the RINEX format as in-kind contribution to the research studies. The PPP processing products are received in different formats and content. Linear differences between the reference and calculated planar coordinates in the longitudinal (ΔX) and latitudinal (ΔY) directions and geodetic heights (Δh) of test stations by each of services are shown in Table 2.

Table 2: PPP deviations (m) by the selected online free services (24 hour sessions, UTM, ITRF2008)

Station ID	CSRS			APPS			GMV		
	ΔX	ΔY	Δh	ΔX	ΔY	Δh	ΔX	ΔY	Δh
BATK	-0.018	-0.007	-0.002	-0.018	-0.003	-0.024	0.006	-0.007	-0.015
BEL_	-0.018	0.000	0.099	-0.025	0.002	0.073	-0.002	-0.001	0.061
JALA	-0.013	-0.006	-0.016	-0.010	0.000	-0.028	0.008	-0.006	-0.030
KRGT	-0.262	0.030	-0.002	-0.269	0.035	-0.007	-0.286	0.030	0.000

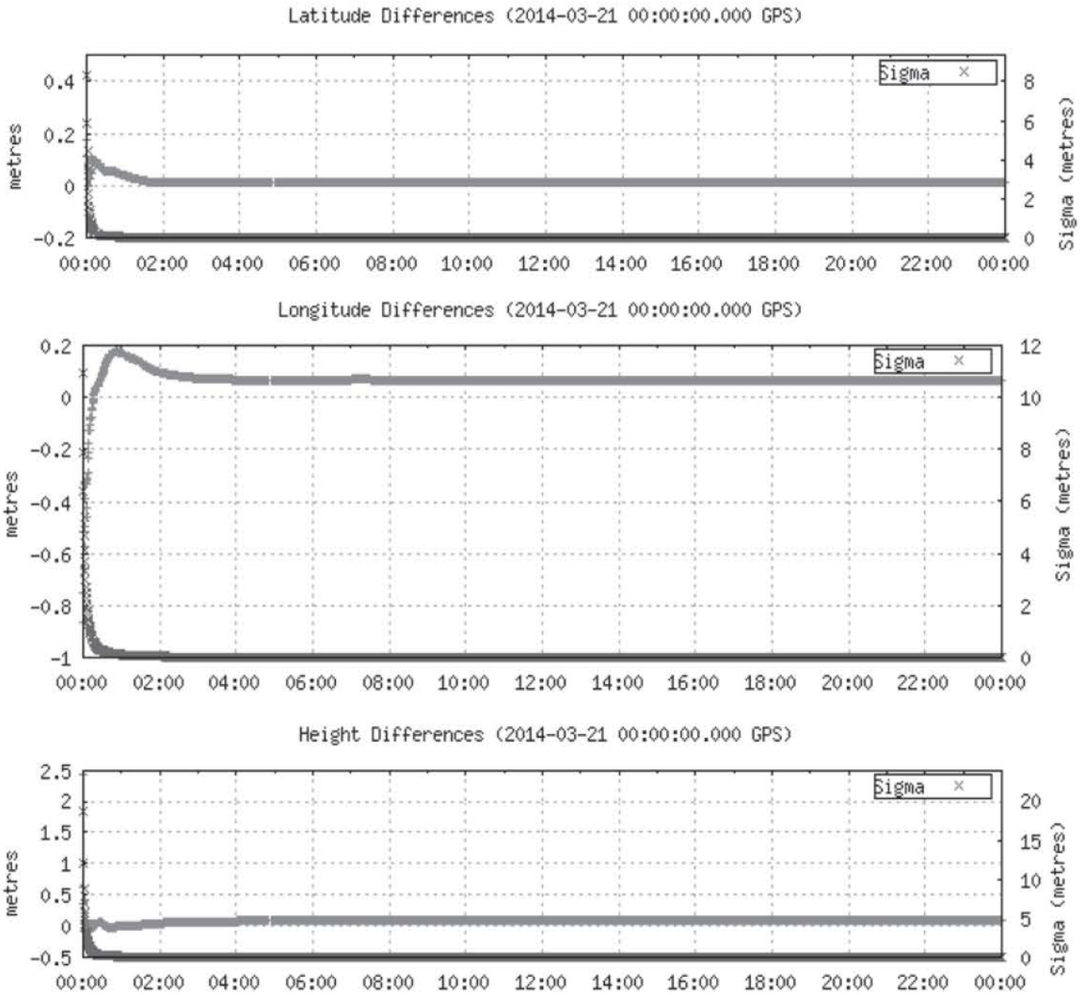
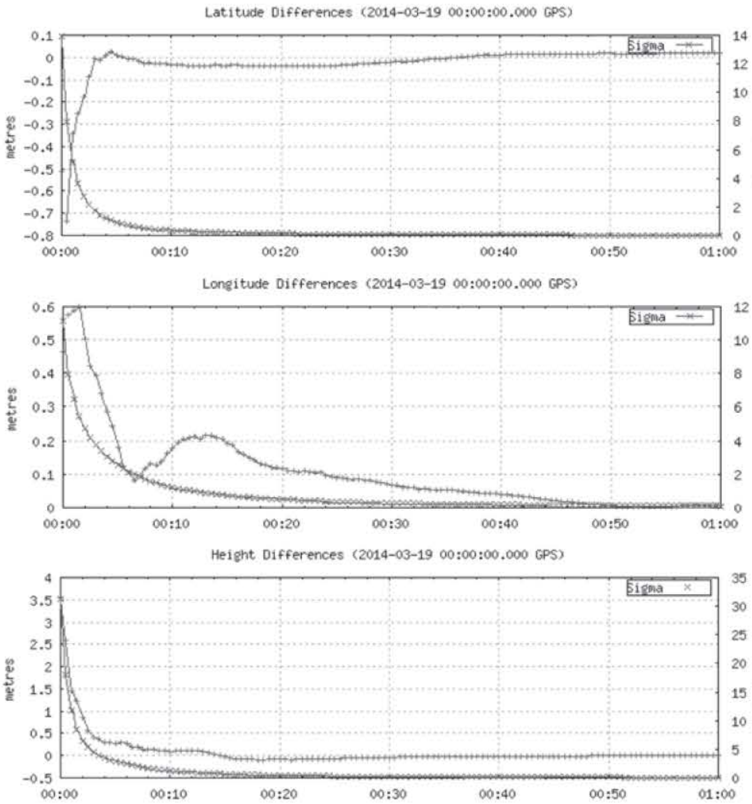


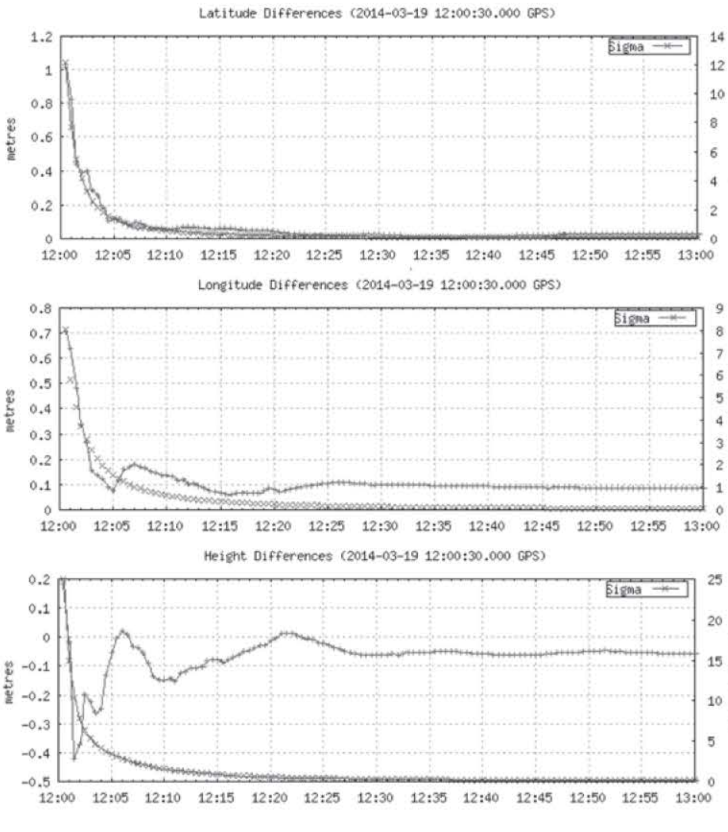
Figure 4: PPP Diagrams by CSRS service for BEL_ station (24 hour session)

Table 3: Four hours long PPP deviations (m) by selected online free services

Station ID	CSRS			APPS			GMV		
	ΔX	ΔY	Δh	ΔX	ΔY	Δh	ΔX	ΔY	Δh
BATK	-0.021	-0.010	0.000	-0.017	0.001	-0.023	-0.036	0.011	-0.009
BEL_	-0.045	0.000	0.100	-0.016	0.001	0.083	-0.020	0.015	0.064
JALA	-0.010	-0.006	-0.021	-0.009	-0.002	-0.032	0.008	-0.006	-0.036
KRGT	-0.259	0.027	0.017	-0.269	0.031	-0.004	-0.234	0.052	0.026



a)



b)

Figure 5: PPP difference diagrams by CSRS service for JALA station: a) one hour session after 00:00:00, b) one hour session after 12:00:30, March 19, 2014

Comparative analysis of the planar coordinate and height differences shows that all of the tested free online services provide precise point positioning at centimeter and sub-centimeter level acceptable as geodetic measurements. The almost identical PPP deviations of UTM coordinates of the KRGT marker in longitudinal direction (26-29 cm), more likely, may result from the combined effects of the reference and observation epoch difference, plate movement, and antenna or coordinate transformations. The most accurate PPP coordinates are received from the GMV service, but the most significant data processing results are available from the online CSRS service. Such a good correlation of the positioning results may assume the same regional GNSS reference station network parameters and data processing algorithms used by the global level PPP service providers. Another conclusion emphasizes that straight line distances between the test stations and IGS stations do not have significant effect on the horizontal and vertical positioning accuracies. The preliminary estimation of the spatial quality of PPP products shows that the significant improvement in the measurement accuracy occur in the first hours of GNSS observation (Figure 4). The statistical analysis of the final PPP results from CSRS service shows sample standard deviations with 95% confidence, determined at the BEL_ test station, are 0.002 m, 0.005 m and 0.010 m in the latitudinal, longitudinal and vertical directions, respectively. Such high accuracy and precision of online and free PPP services underscores the increasing potential of single GNSS receivers for precise geodetic positioning. However, the long observation sessions are not efficient and further studies are continued to investigate the minimum acceptable observation periods depending on survey purposes. The following test datasets have been collected in four hours long GNSS sessions for further detailed analysis of the capacity of selected online and free PPP services on March 22, 2014 (Day of year – 81 in GPS Week/Day 1784/6). The standard deviations (m) of four hours GNSS measurements by the selected online free services are given in Table 3. The maximum deviations of PPP products by different service providers are 4.5 cm in the planar surface (UTM) and 10.0 cm in geodetic height (ITRF2008). The PPP diagrams by CSRS service for the test stations normally have sharp changes from the apriori position of station markers at the observation start and are smoothly converging after 3 hours of measurements. Preliminary analysis shows the most fluctuating positioning within the first hours of observation. The next study was focused on investigation of precise point positioning for the one hour static GNSS observation. The one hour observation datasets have been collected at the JALA station at midnight (00:00:00-01:00:00) and after noon (12:00:30-13:00:00) on March 19, 2014 in order to analyze the influence of tropospheric and ionospheric effects of the atmosphere (Figure 5). The PPP results by CSRS service show that standard deviations with 95% confidence are 0.030 m, 0.106 m, 0.086 m (midnight) and 0.044 m, 0.056 m, 0.109 m (noon) in the latitudinal, longitudinal and vertical directions respectively with decimeter level differences without significant dependence from the day periods.

5. Conclusion

The Precise Point Positioning (PPP) method is one of the most significant steps in geodetic applications of GNSS positioning. Kyrgyzstan and other Central Asian countries, experiencing the lack or insufficient quality of network RTK services by the emerging Active GNSS Networks, will benefit from wider implementation and promotion of free online PPP services. The study shows that 1 hour long GNSS observations in the Central Asian region can yield decimeter level positioning accuracy and 4 hours long observations under optimal conditions will be sufficient for 4-5 centimeter precise positioning by the most of free online PPP service providers. The investigation has identified that PPP can be useful in computing the base station's coordinates before starting the Real Time Kinematic (RTK) or Total Station survey. Surveyors set up the base station ahead of survey time and collect raw GNSS data from 1 hour to 4-6 hours depending on the accuracy required. Then raw data is submitted for online PPP processing, and surveying can be started with precise coordinates of the GNSS base station within approximately 10-30 minutes after the static data collection. PPP data processing time varies for each different service provider, multiple raw observation data submission and processing is recommended. It is obvious that PPP services continue to evolve and become more and more sophisticated matching the growing complexity of customer applications. These services will provide more convenient and higher precision geodetic satellite applications which would have seemed impossible just a few years ago with only local RTK base-stations and without Active GNSS Networks available.

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