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TIME TRANSFER REALIZED BY PPP TECHNIQUE FOR TRIMBLE NETRS AND TTS-4 RECEIVERS

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ABSTRACT. This paper concerns determination of clock readings and position of two geodetic receivers: TRIMBLE NetRS and TTS-4, connected to the same antenna of Dorne Margolin choke ring type (IGS BOR1 point) with the usage of precise point positioning (PPP) technique. The TTS-4 receiver was constructed and provided with its software by the time and frequency team from Borowiec Astrogeodynamical Observatory (AOS). Parameters of the receiver clocks and antenna coordinates were determined for the period from 1 to 30 April 2011. The collected data in RINEX format include code and phase observations from GPS constellation recorded with 30 second interval. The computed positions of the antenna based on RINEX data files from TRIMBLE NetRS and TTS-4 receivers are practically the same. The differences of estimated coordinates are from 0.6 to 1.6 mm. However, the accuracy of the clock parameters computed for TRIMBLE NetRS receiver are by one order lower than for TTS-4. It means that TRIMBLE NetRS receiver synchronized with internal quartz oscillator can not be used for timing applications. Currently the AOS laboratory works on the realization and development of the PPP method are in progress. Ultimately, the method will allow very precise comparison of atomic clocks and atomic time scales over great distances based on GNSS phase measurements. This method will increase the quality of comparisons of the atomic time scales carried out in the world, as well as, significantly strengthen the quality of the Polish Atomic Time Scale - TA (PL).
Keywords: Precise Point Positioning, comparison of time scales, atomic clocks, GNSS, GPS, GLONASS, Galileo.

1. INTRODUCTION

The main purpose of this paper is the determination of the readings of the receivers' clocks connected to the shared GNSS antenna (BOR1 point) and the position of BOR1 point based on RINEX data with the precise point positioning (PPP) method. RINEX data came from two different receivers, the traditional geodetic receiver: TRIMBLE NetRS and the advanced receiver for time transfer: TTS-4 SN 112. Apart from the clock value of a given receiver, the position of BOR1 reference point was determined. Results comparisons for two different receivers were to give answers for questions:

1) what is the accuracy of clock' determinants for each of the receivers based on the PPP method for two different receivers connected to the same antenna?
2) what is the accuracy of position determination based on the same method?

The analyses presented in this paper work are the PPP results obtained by the AOS team realizing

various time transfer and frequency techniques. The PPP method is currently the latest comparison technique of atomic clocks and atomic time scales for long distances based on phase and pseudorange measurements realized by the AOS team. For timing applications several orbital programs are used, e. g. Bernese GPS Software 5.0 developed by Astronomical Institute, University of Bern (Dach et al., 2007), Atomium software developed by Royal Observatory Belgium (Defraigne and Petit, 2003), GIPSY-OASIS software developed by Jet Propulsion Laboratory (Webb and Zumberge, 1997), NICT-C4 software developed by National Institute of Information and Communications Technology (Gotoh et al., 2007) and NRCan software developed by Natural Resource Canada (Kouba and Héroux, 2001).
Computations with the PPP method were carried out with Natural Resource Canada's GPS Precise Point Positioning (GPS - PPP) software based on GPS data recorded with 30-second interval, both for the TRIMBLE receiver and for the TTS-4. About the choice of the NRCan software, a few essential parameters were decided such as processing of very large data sets (very long time series of the data, up to 45 days), flexibility of the software (it is easy to modify the code of the software), easy installation and operation of the software, the final results are recorded in a comfortable form for graphical presentation.

2. THE PPP METHOD AND ITS REALIZATION

Comparison of GNSS receivers' clocks and global time scales with the usage of the PPP method is becoming the main method for precise time transfer for very long distances. The realization of this method became possible when precise satellites' orbits of the GPS system as well as highly precise estimation of satellites clocks become systematically available from International GNSS Service (IGS), European Space Agency (ESA) or Center for Orbit Determination in Europe (CODE) in near real-time. Those data allow reduction of orbital and clock errors of the GPS system. Combining them with dual frequency phase measurements of a single receiver, the PPP method allows for position determination with one centimeter accuracy (Kouba and Héroux, 2001) and offset of the receiver clock with the sub-nanosecond accuracy, that is the difference between the time transmitted by GNSS satellites, and the internal time of the receiver synchronized with the external atomic clock.
The use of the PPP method for GNSS time transfer is applied and developed by several time and frequency laboratories, among others INRIM (L'Istituto Nazionale di Ricerca Metrologica), NRC (Natural Resources Canada), OP (Observatoire de Paris), ROB (Royal Observatory of Belgium) and USNO (United States Naval Observatory). This technique is also drawn up and developed by the AOS group.
Other GNSS time transfer methods: GPS CV (Allan and Weiss, 1980), GLONASS CV (Lewandowski et al., 1996) and TWSTFT (Kirchner et al., 1993) used for comparison of atomic clocks and global time scales, ensure the precision of comparison of atomic clocks readings at the level of 0.7 ns and 0.5 ns and the accuracy at the level 0.5-1.0 ns (RMS). The results of estimation and comparison of receivers' clocks and time scales readings with the usage of the method based on phase and pseudorange measurements of the GPS system satellites show high stability of the new technique and high compliance with the existing methods (Guyennon et al., 2009; Defraigne et al., 2008). The PPP method forms firm basis for the usage of signals from GLONASS system, and in the future also Galileo, for creation of the active net of GNSS receivers working in the real time (Piriz et al., 2009). Currently works on the realization of the PPP method for time transfer based on phase and pseudorange measurements of the GLONASS system satellites are in progress (Defraigne et al., 2010). This method enables rise in the accuracy and stability of the global time scales.
The diagram of the PPP method is presented in Fig.1.

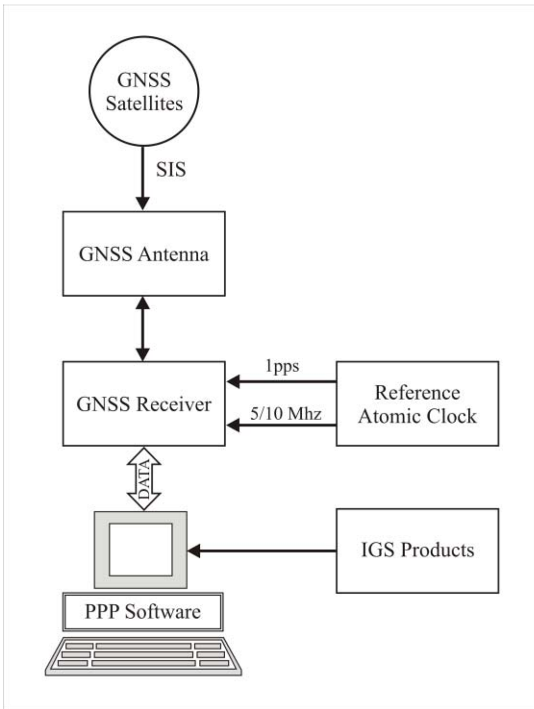

Fig.1. The PPP method diagram.

Signals from the GPS satellites are received by a standard GNSS antenna. Next, the received signal is processed by the receiver. Synchronization of the receiver clock within 1 pps (1 pulse per second) and frequency signals (5/10 MHz) from the reference standard is essential for the success of the method. The last step is carried by a computer with appropriate software.

For the purpose of this paper, the Dorne Margolin temperature stabilized antenna of choke ring type and two working continuously receivers: a standard geodetic TRIMBLE NetRS receiver operating at the IGS station BOR1 and the advanced receiver for time transfer: TTS-4 were used. It is the latest version of the receivers from the TTS series developed by the AOS team.

The TTS-4 receiver works under control of PLD Linux operating system and stores the received signals in both CGGTTS and RINEX formats. It is a 116 channel GNSS receiver picking up the following signals: GPS (L1C / L1P - 16, L2P / L2C - 16, L5 - 16), GLONASS (L1C / L1P - 16, L2P / L2C - 16, L5 - 16), GALILEO (E1 - 16, E5A - 16) and 4 additional channels (SBAS). Observations are carried out continuously and the RINEX files are updated every 30 seconds. The receiver produces 24 hour data files.

An active hydrogen maser CH1-75A, delivered by KVARZ, a Russian company, serves as a reference clock. The TTS-4 receivers are synchronized by an external frequency signal using a TIMETECH frequency distribution amplifier. The adjustment of frequency, and what follows, of the functioning of the maser, is achieved by a SYMMETRICOM phase microstepper connected to the maser. The CH1-75A maser characterizes relatively low frequency drift, of an order of +1.39E-16 per day. The maser provides a standard frequency (5/10 MHz) and 1 pps signal of the second. The same clock is being used for the realization of UTC time scale at Borowiec Astrogeodynamical Observatory.

3. RESULTS

All computations were conducted with the usage of the Canadian program NRC GPS-PPP (Lahaye et al., 2006). The options and parameters of the software presents Table 1.

Table 1. Parameters and options of the NRCan software.

User dynamics	STATIC
Data span	1 month
Observation processed	CODE & PHASE
Frequency observed	L3
Satellite orbits and clocks	IGS (final products)
Satellite product input	5 min.
Ionospheric model	L1 & L2
Ocean tide model	GOT00.2
Tropospheric models: Hydrostatic delay Wet delay Mapping functions	 Davis(GPT) Hopf(GPT) GMF
Surface meteorological data: Temperature (GPT model) Pressure (GPT model) Relative humidity (default)	 5.33 (deg. C) 1005.24 (Mb) 50.00 (%)
Marker coordinates	ESTIMATED
Troposhere zenith delay (TZD)	ESTIMATED+GRADIENTS
Satellite clock interpolation	NO
Parameter smoothing	YES
FLTDNL* *Dual-frequency filter delta narrowlane tolerance for cycle slip detection	20 cm
FLTDWL* *Dual-frequency filter delta widelane tolerance for cycle slip detection	150 cm
FLTDAM* *Dual-frequency filter delta ambiguity tolerance for filter	150 cm
FLTDPL* *Single-frequency delta code-carrier tolerance for cycle slip detection	5000 cm
FLTDTT* *Filter delta time tolerance for gap detection	300 sec.
Use P1-C1 satellite DCBs	YES
Reference frame	ITRF
Coordinates system	ELLIPSOIDAL
Pseudorange sigma	5.00 m
Carrier phase sigma	0.01 m
TZD random walk	5.00 mm/hr
Trop. Grad. random walk	0.10 mm/hr
Cutoff elevation	5.00 deg.

Both parameters of receivers' clocks, as well as the antenna phase center were determined for the period from April 1 till 30, 2011 from 24 hour RINEX data files. Those files include both code and phase data from the GPS constellation recorded with 30 second interval.

The main purpose of this paper is determination of readings of the TRIMBLE NetRS equipped with internal quart oscillator and TTS-4 receiver connected to the external H-maser and comparison of the obtained results with the results obtained for other time laboratories and other methods of time transfer. The last point regards only the TTS-4 receiver, since the clock stability of the TRIMBLE NetRS receiver is more or less by 1 order lower. This means that in such a configuration, the Trimble NetRS receiver is not suitable for the needs of time transfer. This effect explains Fig. 2 representing indications for the TRIMBLE NetRS receiver (BOR1), TTS-4 receiver (AOS) and two ASHTECH Z-XII3T (PTBB and USNO) receivers.

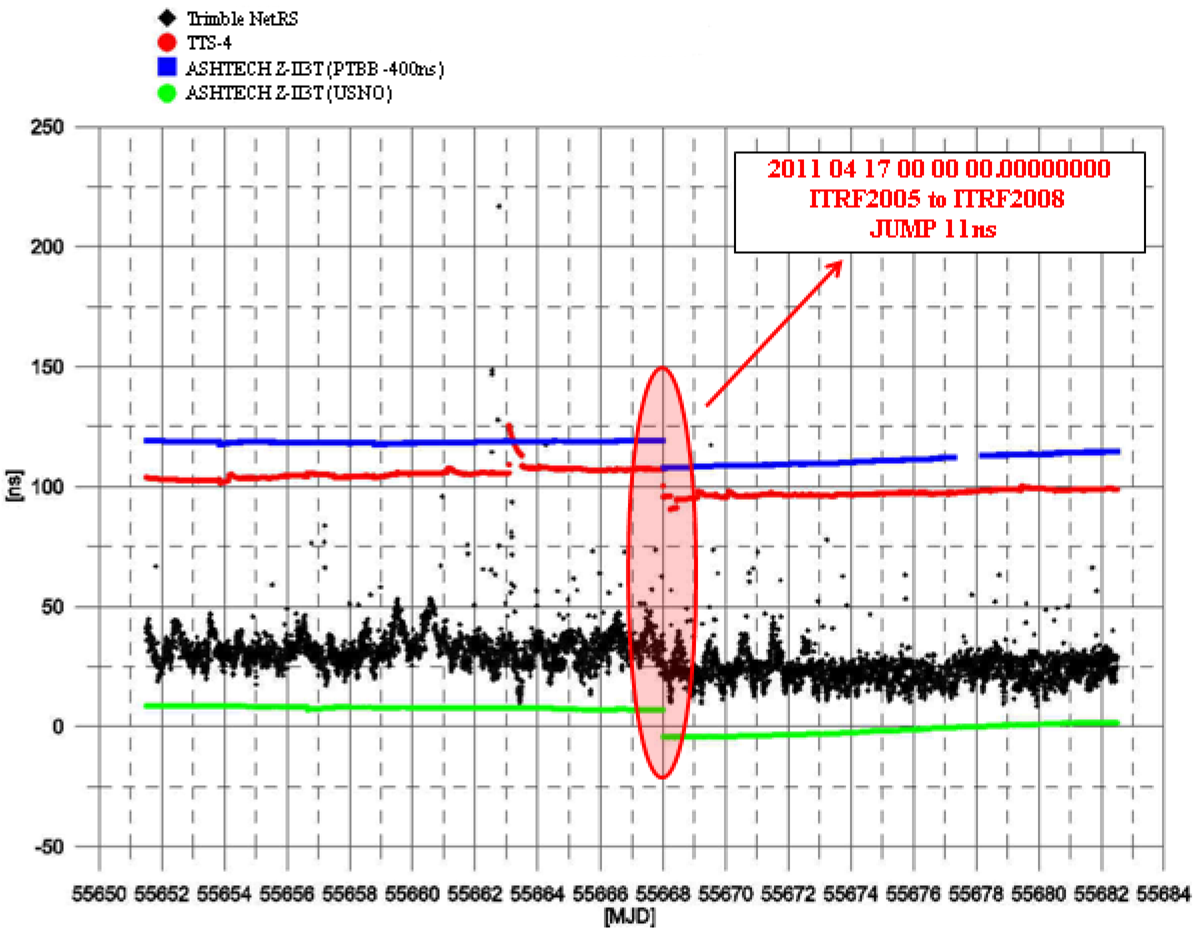

Fig. 2. Clock readings of Trimble NetRS (black), TTS-4 (red), Aschtech Z-XII3T for PTBB (blue) and Aschtech Z-XII3T for USNO (green) receivers against IGS time scale.

For the better clarity of the Fig.2, the results for PTB are shifted by -400 ns. Additionally, a jump of order of 11 ns is marked with red ellipse registered by all receivers on April 17, 2011 at 00:00:00. This jump is related to the change from ITRF2005 to ITRF2008.

The Trimble NetRS receiver is not connected to external reference clock, but is only driven by internal quartz oscillator. The obtained results presented in Fig.2 compared to TTS-4 and ASHTECH Z-XII3T show the difference when external primary atomic reference is used. If jump correction from April 17, 2011 will be included, the average of the clock readings are 33.37 ns for TRIMBLE NetRS and 106.86 ns for TTS-4. The standard deviations are 6.24 ns and 1.94 ns respectively.

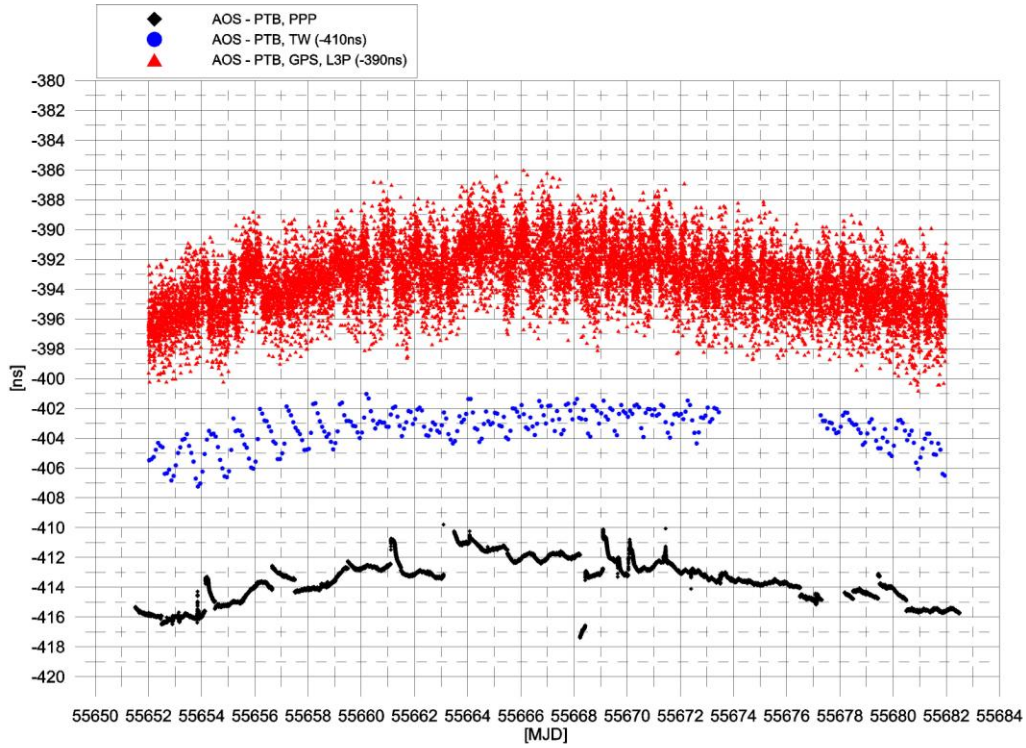

Fig. 3. Time transfer for AOS-PTB time link obtained by PPP (black), TWSTFT (blue) and GPS L3P CV (red) methods.

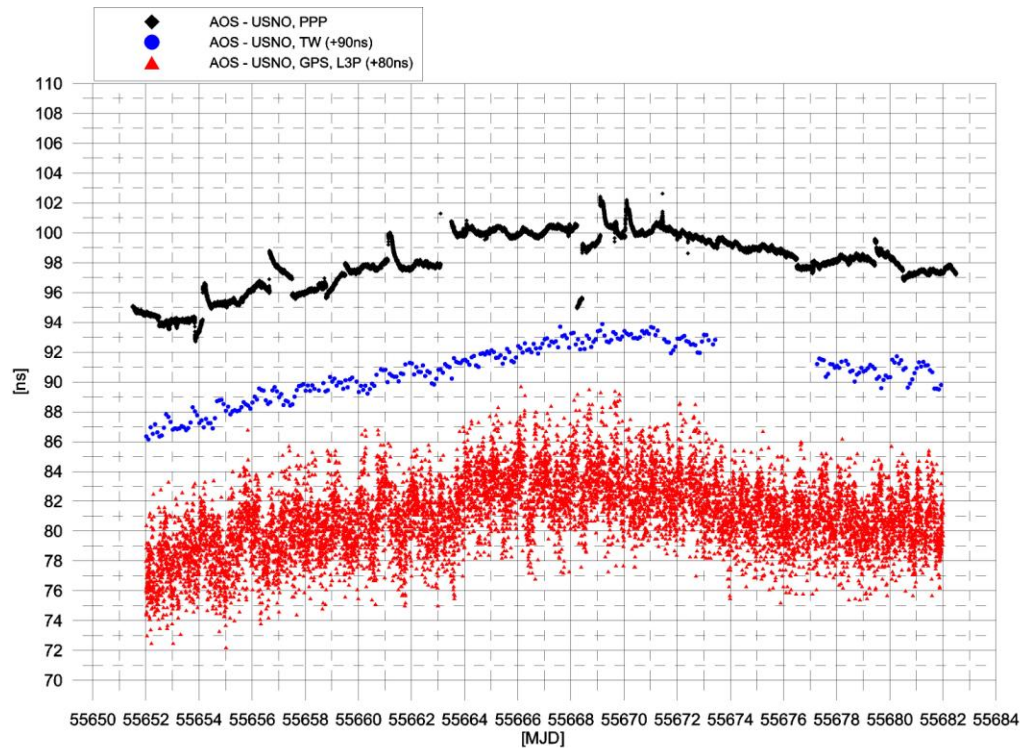

Fig. 4. Time transfer for AOS-USNO time link obtained by PPP (black), TWSTFT (blue) and GPS L3P CV (red) methods.

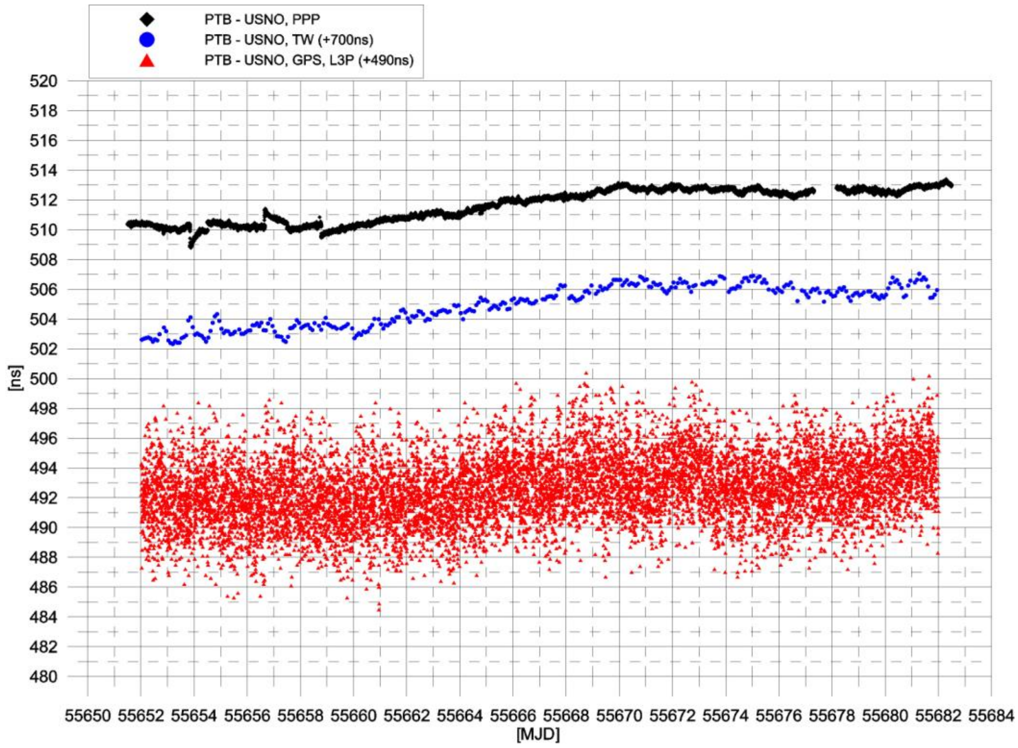

Fig. 5. Time transfer for PTB-USNO time link obtained by PPP (black), TWSTFT (blue) and GPS L3P CV (red) methods.

In Figures 3-5, comparisons of three measuring methods: PPP, TWSTFT (Two-Way Satellite Time and Frequency Transfer) and L3P (linear combination L1+L2 of the phase data) GPS between AOS and PTB laboratories, AOS and USNO, as well as PTB and USNO for the period 1-30 of April 2011 are presented. The L3P technique bases on the dual-frequency GPS and GLONASS code measurements (Petit and Arias, 2009; Petit and Jiang, 2004). The TWSTFT technique uses the signals transmitted simultaneously between two time laboratories by means of geostationary telecommunication satellite. These techniques ensure an precision at the level of 0.7 ns and 0.5 ns for L3P and TWSTFT respectively. The comparison presents the differences in clocks' readings obtained by the PPP method, TWSTFT method and differences obtained by the GPS Common View L3P method. For the purpose of chart clarity the results were shifted for the TWSTFT and L3P GPS techniques.

From Fig.3-5 follows that the best results are obtained for the PPP method, for observations between AOS and PTB as well as for AOS and USNO. For PTB-USNO time link, the results obtained by PPP and TWSTFT methods are comparable.

The average of differences obtained by the PPP method for AOS-PTB time link amounts to 413.6 ns, for AOS-USNO 98.0 ns, and for PTB-USNO 511.6 ns (the method calls for special calibration). In Table 2 the RMS of PPP method for three time links AOS-PTB (≈ 450 km), AOS-USNO (≈ 7000 km), PTB-USNO (≈ 6550 km) obtained for 24-hour solutions are presented (one value for middle of the MJD day). The RMS varies from 0.01 to 0.20 ns. The best RMS were obtained for PTB-USNO time link.

Table 2. RMS of PPP method obtained for AOS-PTB, AOS-USNO and PTB-USNO.

MJD	AOS-PTB RMS [ns]	AOS-USNO RMS [ns]	PTB-USNO RMS [ns]
55651.50000	0.03	0.06	0.03
55652.50000	0.02	0.04	0.04
55653.50000	0.08	0.03	0.07
55654.50000	0.12	0.04	0.12
55655.50000	0.09	0.15	0.04
55656.50000	0.08	0.05	0.15
55657.50000	0.07	0.08	0.04
55658.50000	0.06	0.04	0.04
55659.50000	0.16	0.07	0.04
55660.50000	0.08	0.12	0.05
55661.50000	0.17	0.04	0.04
55662.50000	0.03	0.04	0.04
55663.50000	0.02	0.07	0.05
55664.50000	0.15	0.11	0.05
55665.50000	0.20	0.14	0.06
55666.50000	0.15	0.09	0.04
55667.50000	0.04	0.04	0.06
55668.50000	0.05	0.13	0.06
55669.50000	0.08	0.18	0.08
55670.50000	0.03	0.05	0.07
55671.50000	0.11	0.04	0.09
55672.50000	0.05	0.06	0.10
55673.50000	0.06	0.15	0.08
55674.50000	0.02	0.11	0.12
55675.50000	0.05	0.07	0.06
55676.50000	0.08	0.07	0.08
55677.50000	0.01	0.05	0.05
55678.50000	0.11	0.09	0.04
55679.50000	0.16	0.08	0.06
55680.50000	0.05	0.05	0.06
55681.50000	0.03	0.07	0.04
55682.50000	0.07	0.12	0.07
Average	0.08	0.08	0.06

In Figures 6-7 the results of modified Allan deviation are shown for Trimble NetRS, TTS-4 and two ASHTECH Z-XII3T (PTB and USNO labs) receivers for analyzed period. Much better frequency stability (of order 100 times better) are obtained for TTS-4 and ASHTECH Z-XII3T receivers. This is because the TTS-4 and ASHTECH Z-XII3T receivers are synchronized to H-masers and Trimble NetRS receiver is synchronized to its internal oscillator.

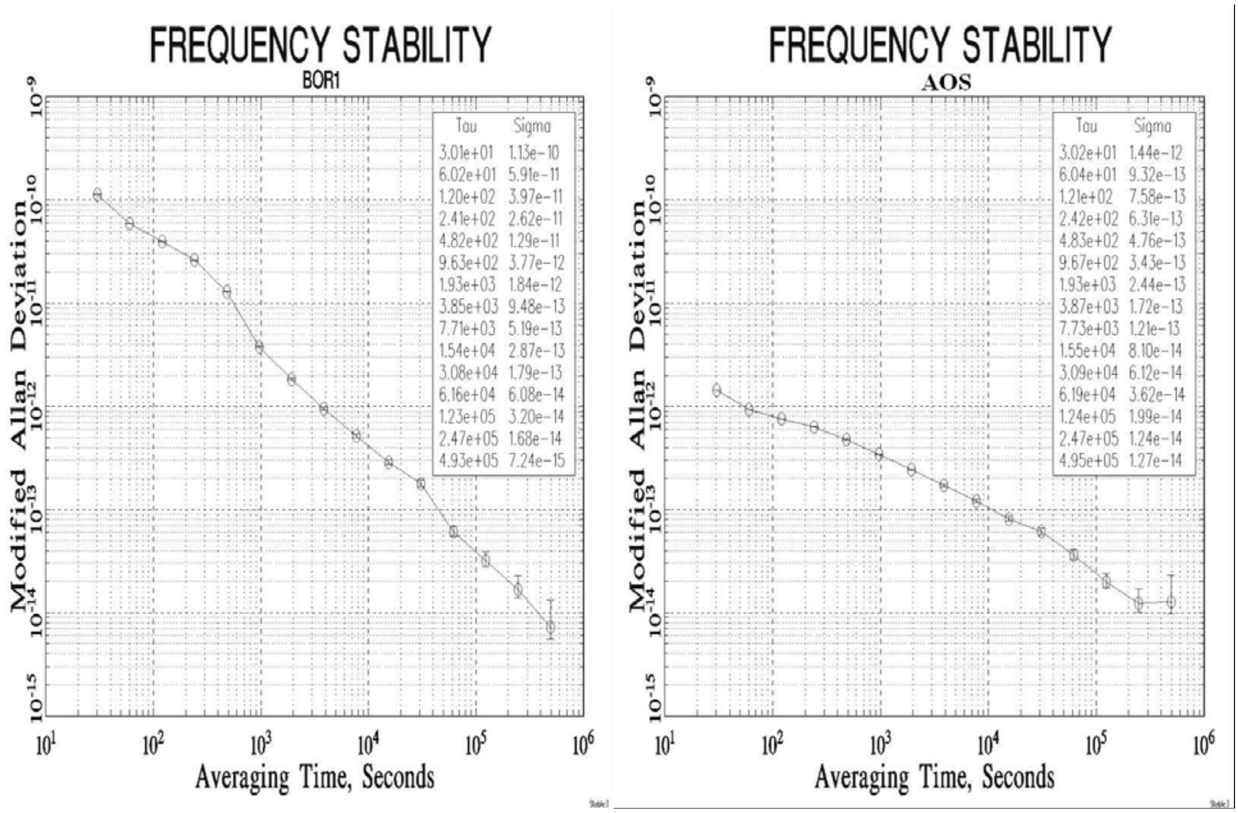

Fig. 6. Modified Allan deviation for Trimble NetRS (left) and TTS-4 (right) receivers.

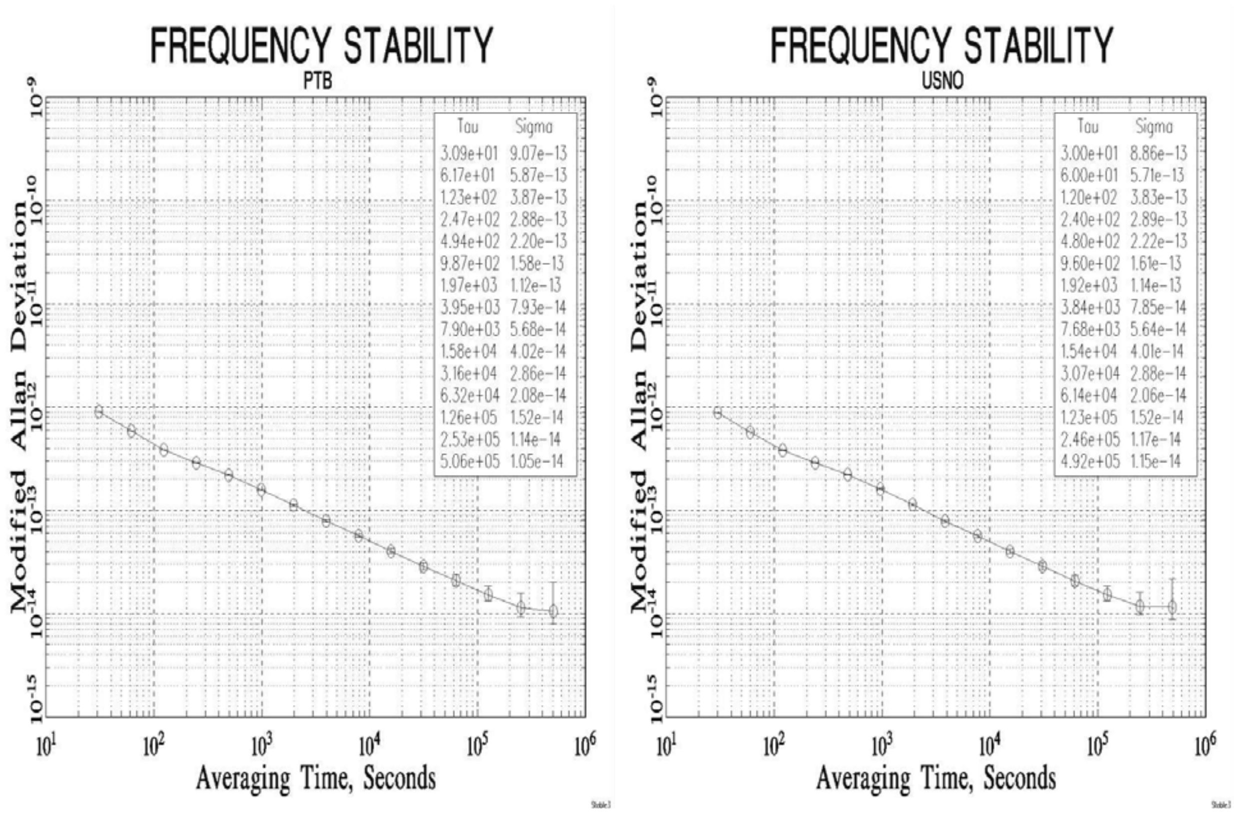

Fig. 7. Modified Allan deviation for ASHTECH Z-XII3T receivers (PTB-left and USNO-right).

In Figures 8-9 the results of time deviation are shown for Trimble NetRS, TTS-4 and two ASHTECH Z-XII3T receivers for analyzed period. Also in this case much better time stability (of order 100 times better) are obtained for TTS-4 and ASHTECH Z-XII3T receivers. This effect is also caused by synchronization of the TTS-4 and ASHTECH Z-XII3T receivers to H-masers and

Trimble NetRS receiver to its internal quartz oscillator, such setup excludes Trimble NetRS receivers from timing applications.

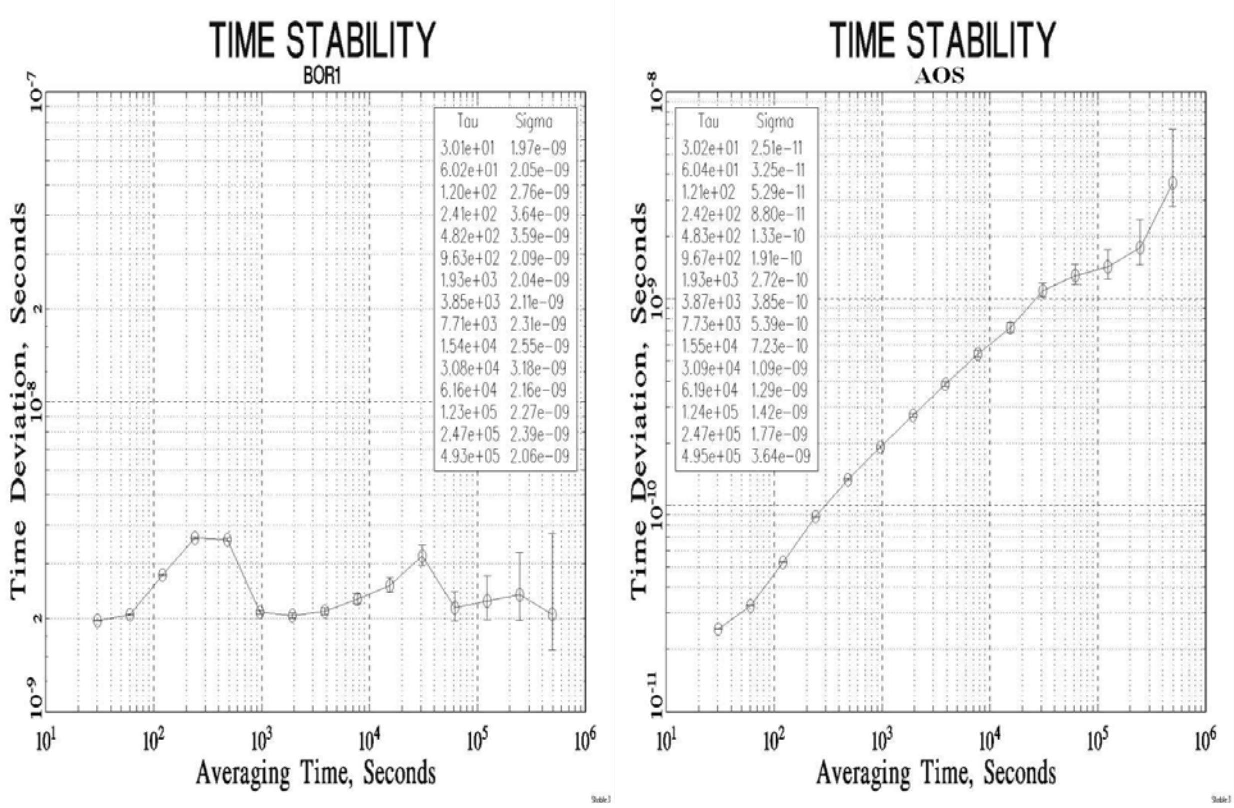

Fig. 8. Time deviation for Trimble NetRS (left) and TTS-4 (right) receivers.

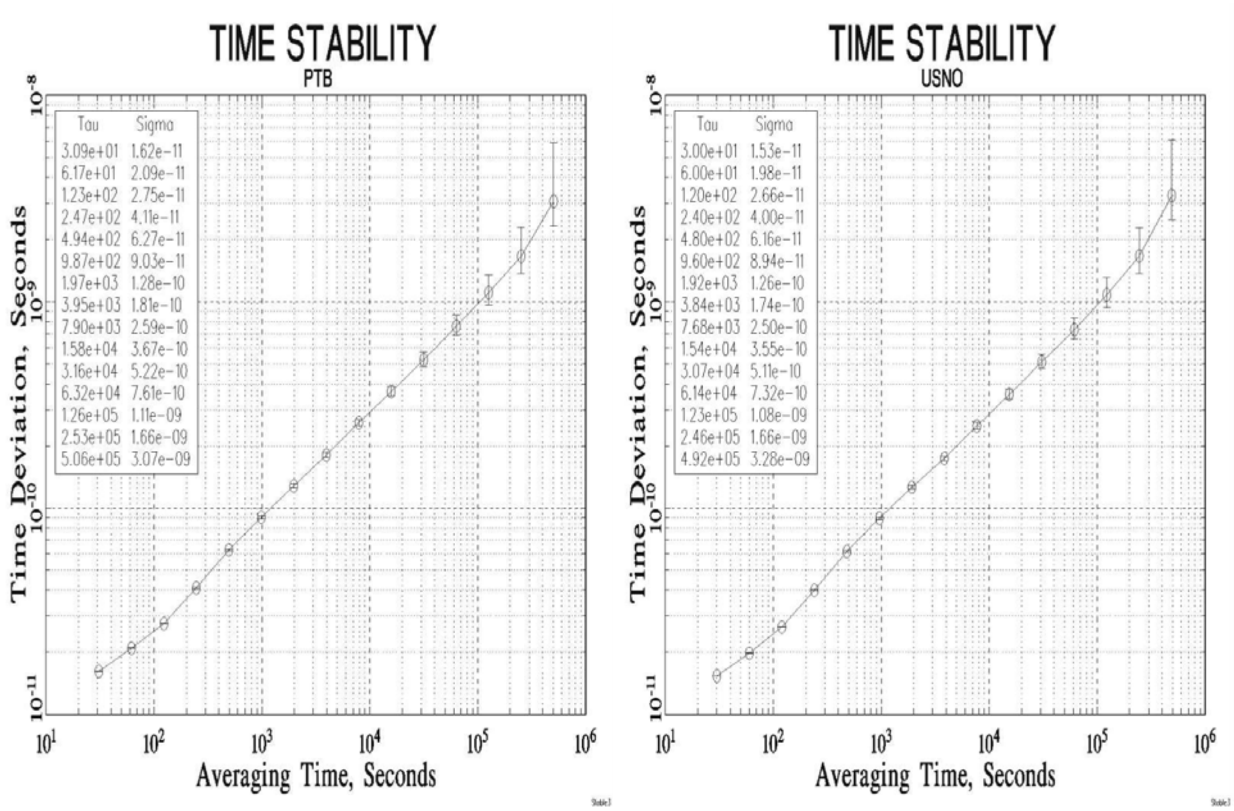

Fig. 9. Time deviation for ASHTECH Z-XII3T receivers (PTB-left and USNO-right).

An indirect goal of this paper was determination of BOR1 point coordinates based on data coming from two different receivers: TRIMBLE NetRS and TTS-4. Calculations of the position were conducted for the static model in relation to ITRF2008 frame based on precise ephemeral and clock data of GPS satellites acquired from the IGS data base.
Computed geodetic coordinates of the receivers antenna are presented in Table 3. The results were calculated for one month of RINEX data.

Table 3. Cartesian and ellipsoidal coordinates determined for TRIMBLE NetRS and TTS-4 receivers.

Trimble NetRS						
	Latitude (dms)	**Longitude (dms)**	**Height (m)**	**X (m)**	**Y (m)**	**Z (m)**
Apriori	52 16 37.0414	17 04 24.4343	124.4035	3738358.5958	1148173.5785	5021815.7483
Estimated	52 16 37.0473	17 04 24.4495	124.3627	3738358.3502	1148173.8054	5021815.8269
RMS	0.1811	0.2890	0.0407	0.2456	0.2269	0.0786
TTS-4						
	Latitude (dms)	**Longitude (dms)**	**Height (m)**	**X (m)**	**Y (m)**	**Z (m)**
Apriori	52 16 37.0452	17 04 24.4453	124.3666	3738358.4232	1148173.7442	5021815.7917
Estimated	52 16 37.0473	17 04 24.4496	124.3615	3738358.3486	1148173.8062	5021815.8263
RMS	0.0632	0.0811	0.0051	0.0746	0.0620	0.0346

The RMSs of the computed coordinates shown also in Table 3 were calculated with 95% confidence level. As is presented in Table 3, the a priori coordinates of the receivers are different. This difference is caused because the coordinates for the TRIMBLE receiver were determined at the epoch 2004. The coordinates for TTS-4 receiver recorded in the header of the RINEX file are more actual. However, the estimated coordinates of the receivers are practically the same. The difference of estimated coordinates are 0.0016 m for X component, -0.0008 m for Y component and 0.0006 m for Z component.

4. CONCLUSIONS

The time transfer method based on Precise Point Positioning was discussed in the paper. The main goal of the paper was answering the question: what is the accuracy of clock determinants of the TRIMBLE NetRS and TTS-4 receivers based on the PPP method ? The obtained results for one month of data set show that for TTS-4 receiver the RMS of clock determinants is on the level of 2 ns and about 6 ns for TRIMBLE NetRS receiver. The scattering of the clock readings are higher for the TRIMBLE receiver which is synchronized to the internal quartz oscillator. It means that the results are rather related to the frequency standard, not to the receiver type. In comparison to other time links (AOS-PTB, AOS-USNO, PTB-USNO) the PPP method give RMS on the level of 0.06-0.08 ns.
In case of antenna position determination both TRIMBLE NetRS as well as TTS-4 receivers give very similar results. The estimated coordinates are in principle the same within the range of tenth part of millimeter. However the RMS of each component is by one order of magnitude higher for TRIMBLE NetRS receiver.
In terms of precision, the PPP technique is at least comparable to the TWSTFT method (precision on the level of 100 ps or better). In future this method will be verified and compared with the obtained results of the following methods of time transfer: Time Transfer by Laser Link (T2L2) or Galileo. In case of the AOS team, the PPP technique will provide the significant step forward increasing the quality of the realization of UTC(AOS) and TA (PL). The GNSS time transfer using phase measurements of GPS/GLONASS signals is in early development phase, and the first results presented in the quoted literature are very promising. For the effective realization of the PPP method, the choice of the appropriate software is an open case. For the purpose of this paper the Canadian program: NRC GPS-PPP was used. However, still a lot is to be corrected e.g.: the improvement of mathematical methods used by the software, usage of the IGS or ESA products,

development of the receiver calibration, application of the other GNSS systems' data: GLONASS, Galileo and COMPASS in the future.

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REFERENCES

Allan, D., and Weiss, M., *Accurate time and frequency transfer during Common-View of a GPS satellite*, Proc. Frequency Control Symposium, pp. 334-336, 1980.

Dach, R., U. Hugentobler, P. Fridez, M. Meindl (Eds), *Bernese GPS Software Version 5.0***.**, Astronomical Institute, Universtiy of Bern, 2007.

Defraigne, P., Petit, G., *Time transfer to TAI using geodetic receivers*, Metrologia, 40:184–188, 2003.

Defraigne, P., Guyennon, N., Bruyninx, C., *GPS time and frequency transfer: PPP and phase-only analysis*, Intern. Journ. of Navigation and Observation*,* Vol. 2008, Article ID 175468, 2008.

Defraigne, P., Baire, Q., *Combining GPS and GLONASS for time and frequency transfer*, Advanced in Space Research, Advances in Space Research, Vol. 47, Issue 2, p.265-275, 2011.

Gotoh, T., Fujieda, M., Amagai, J., *Comparison study of GPS carrier phase and Two-Way Satellite Time and Frequency Transfer*. In Frequency Control Symposium, Joint with the 21st European Frequency and Time Forum. IEEE International, pages 1188–1193, Geneva, Switzerland, May 29-June 1, 2007.

Guyennon, N., Cerretto, G., Tavella, P., Lahaye, F., *Further characterization of the time transfer capabilities of Precise Point Positioning (PPP): the Sliding Batch Procedure*, IEEE Trans Ultrasonics Ferroelectrics and Frequency Control, 56(8):1634-41, 2009.

Kirchner, D., Ressler, H., Grudler, P., Baumont, F., Veillet, Ch., Lewandowski, W., Hanson, W., Klepczynski, W., Uhrich, P. *Comparison of GPS Common-view and Two-Way Satellite Time Transfer over a baseline of 800 km*, Metrologia, 30, pp. 183-192, 1993.

Kouba J., Héroux P., *Precise point positioning using IGS orbits and clock products*, GPS Solutions, vol. 5, no. 2, pp. 12–28, 2001.

Lahaye, F., Orgiazzi, D., Tavella, P., Cerretto, G., *GPS time transfer: using precise point positioning for clock comparisons*, GPS World, Vol. 17, no. 11, pp. 44-49, 2006.

Lewandowski, W., Azoubib, J., Gevorkyan, A. G., Bogdanov, P. P., Danaher, J., de Jong, G., Hahn, J., *First results from GLONASS Common-View time comparisons realized according to the BIPM international schedule*, Proc. 28th Annual Precise Time and Time Interval (PTTI) Meeting, pp. 357-366, 1996.

Petit, G., Jiang, Z., *Stability of geodetic GPS time links and their comparison to two-way time transfer*, 36th Annual Precise Time and Time Interval (PTTI) Meeting, 7-9 December 2004, Washington, USA, 2004.

Petit, G., Arias, E. F., *Use of IGS products in TAI applications*, Journal of Geodesy, Vol. 83, Numbers 3-4, 327-334, 2009.

Píriz, R., Cerretto, G., Perucca, A., Tavella, P., *Evaluation of the time and frequency transfer capabilities of a network of GNSS receivers located in timing laboratories*, Proc. 41st Annual Precise Time and Time Interval (PTTI) Meeting, Santa Ana Pueblo, New Mexico, pp. 559-573, November, 2009.

Webb, F., Zumberge, J., *An introduction to GIPSY/OASIS-II, precision software for the analysis of data from the Global Positioning System*, Jet Propulsion Laboratory, Pasadena, CA, JPL D-11088, July 1997.

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