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The IGS products in GNSS time transfer using TTS-4 receivers

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Remote clocks comparisons

The International Atomic Time (TAI) and the Coordinated Universal Time (UTC) are calculated as the result of remote comparisons of atomic clock data from more than 60 laboratories spread worldwide.

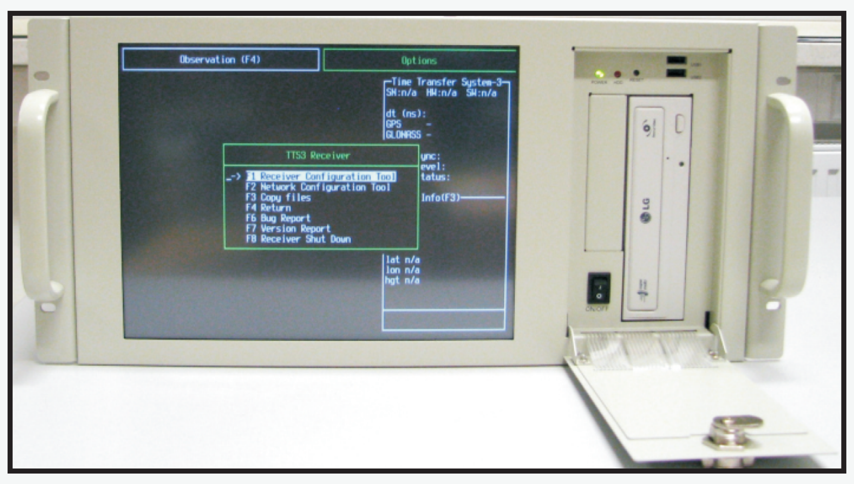
The introduction of GPS C/A code common-view method into the regular comparisons of remote clocks during the 1980s resulted in a major improvement of accuracy, precision and coverage in comparison to the usage of the LORAN-C system.
At this epoch for the first time the remote clocks were compared at their full level of performance.

The introduction of IGS products into TAI and UTC computation has brought second significant change. It allowed the improvement of the common-view method and the introduction of new methods - all-in-view in 2006 and PPP in 2009.

TTS-4 receiver

The Astrogeodynamical Observatory in Borowiec (AOS) of the Space Research Center, following a very successful TTS-2 and TTS-3, has developed a new high-performance Time Transfer System 4 (TTS-4). TTS-4 is a new generation receiver allowing all available GNSS methods of time transfer.

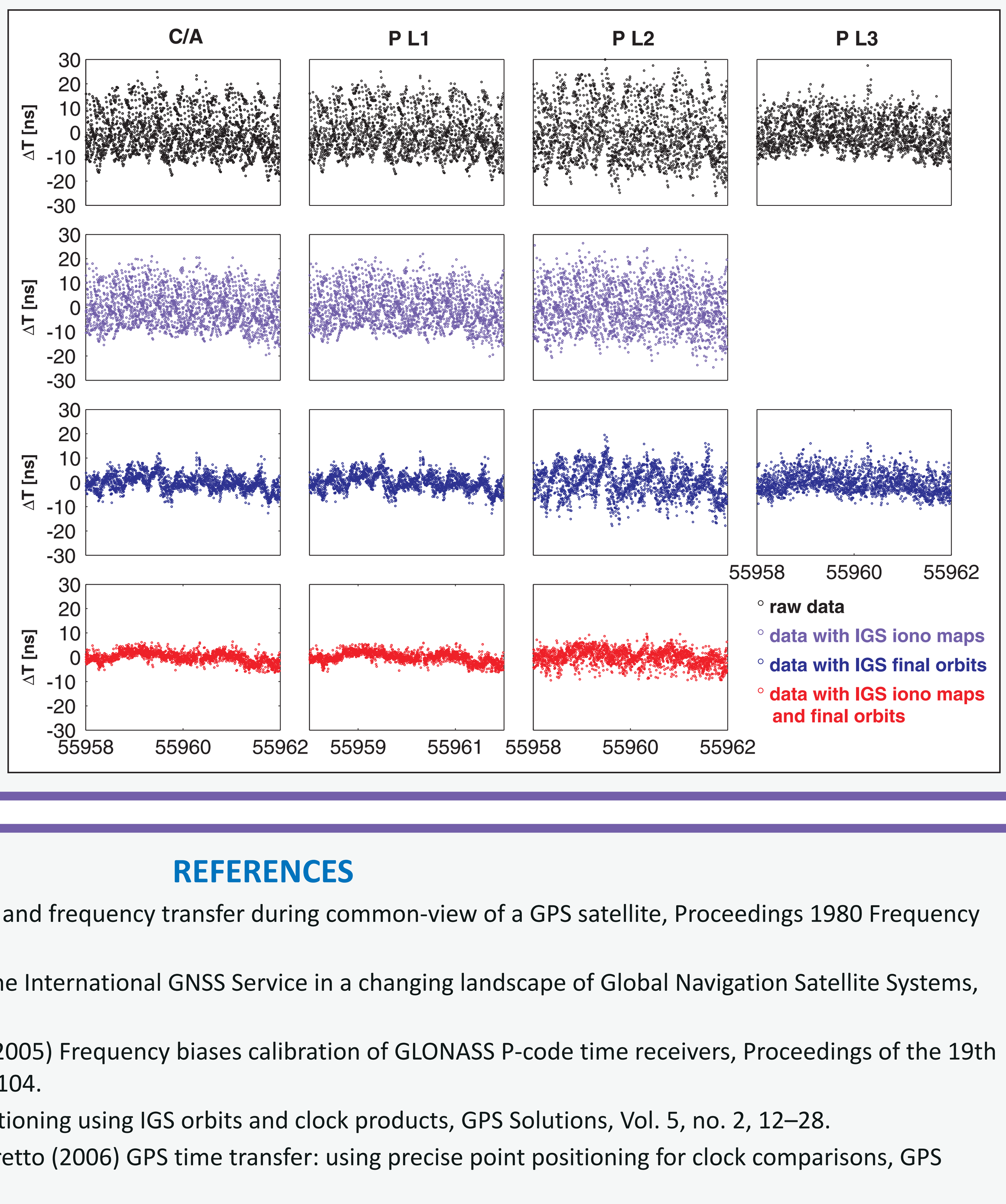
- Integrated multi-constellation GNSS observations: GPS, GLONASS, WAAS, EGNOS and Galileo,
- 116 channels (all-in-view):
  GPS L1-16, GPS L2-16,
  GPS L5-16, SBAS-4,
  GLONASS L1-16,
  GLONASS L2-16,
  Galileo E1-16,
  Galileo E5A-16,



- Observation data in CGGTTS format for GPS and GLONASS:
  - L1 data - C/A and P code (GPS reconstructed) [L1C, L1P],
  - L2 data - C/A and P code (GPS reconstructed) [L2C, L2P],
  - L3 ionosphere free combination - C/A and P code (GPS reconstructed) [L3C, L3P],
  - L5 data (GPS reconstructed) [L5P],
- Observation data in RINEX format (code and phase data) - supported observation types: L1, L2, L5, C1, C2, P1, P2, P5, D1, D2.

Common-view

The common-view method, which was the most widely used tool for remote clock comparisons for two decades, consists of the simultaneous observations of the same satellite made at two time laboratories. The main sources of errors in this method are the satellite orbits and the ionosphere.
Since the early 1990s the GPS precise orbits and since the late 1990s the GLONASS precise orbits have been provided by the IGS and used for time transfer links. Since 2000 the CODE ionosphere maps are used for ionospheric corrections of single-frequency time links.
The use of IGS products resulted in the uncertainty reduction to the level of 1 ns for the GPS links up to 1000 km and less than 3 ns for the very long distances.
The results presented below concern GLONASS time link of about 2600 km IPQ (Caparica, Portugal, TTS-4 sn 103) - AOS (Borowiec, Poland, TTS-4 sn 126).
The remaining errors are due mostly to the non-calibrated GLONASS frequencies.

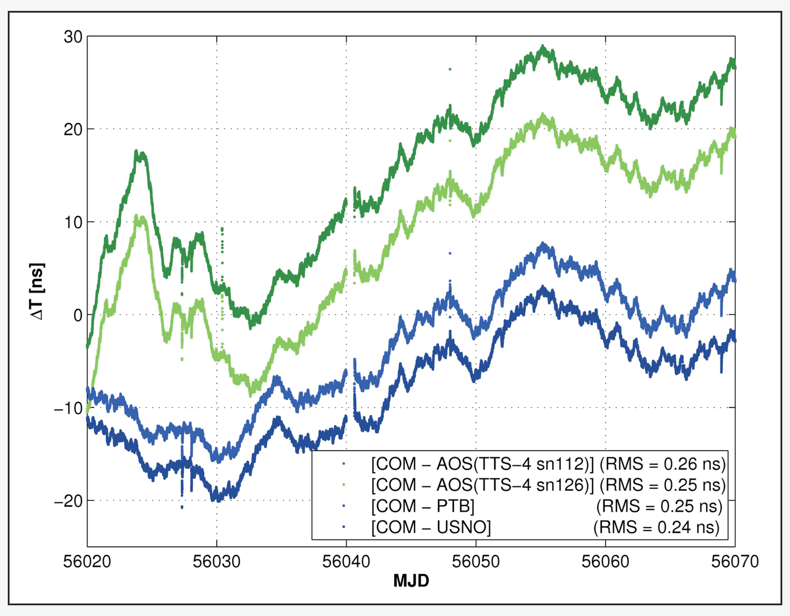


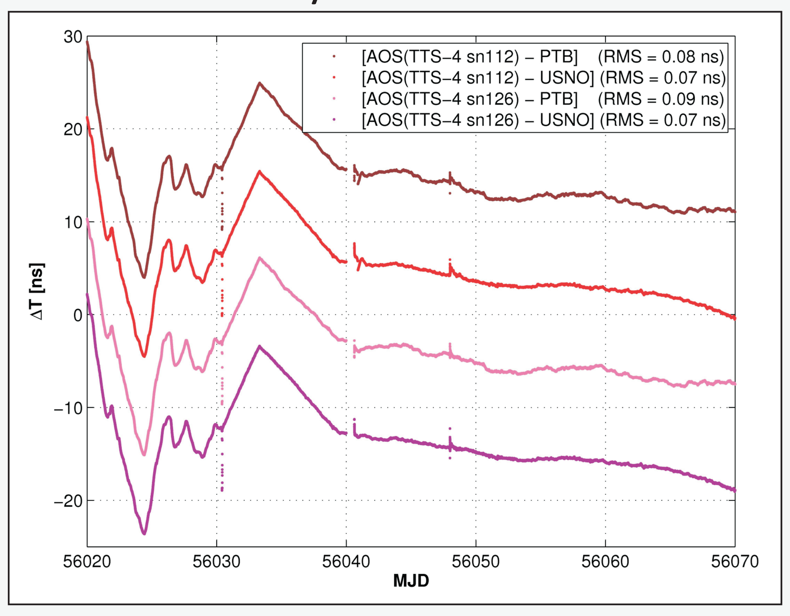
Precise Point Positioning

In Precise Point Positioning (PPP) the use of precise satellite position and precise satellite clock is necessary. The ionospheric delay is eliminated in the ionosphere-free linear combination (L3). The presented results concern 30-seconds GPS RINEX data collected by 5 timing receivers in 4 laboratories.

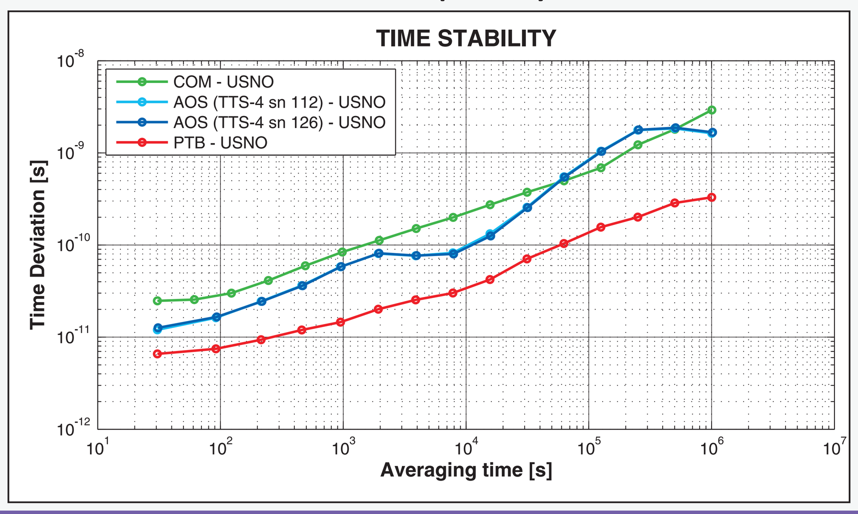
receiver	laboratory	clock
TTS-4 sn 112	AOS - Astrogeodynamical Observatory SRC PAS, Borowiec, Poland	H-maser CH1-75A
TTS-4 sn 126	AOS - Astrogeodynamical Observatory SRC PAS, Borowiec, Poland	H-maser CH1-75A
TTS-4 sn 108	COM - Central Office of Measures, Warsaw, Poland	HP5071 (cesium)
ASHTECH Z-XII3T	PTB - Physikalisch-Technische Bundesanstalt, Brunswick, Germany	cesium fountain
ASHTECH Z-XII3T	USNO - United States Naval Observatory, Washington, USA	~100 hydrogen masers and cesium clocks

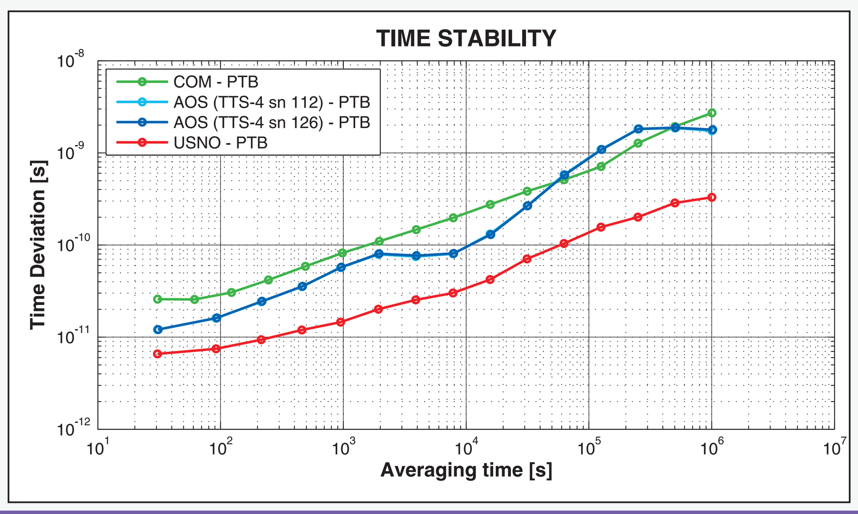
All computations were performed using the Natural Resource of Canada GPS Precise Point Positioning (GPS-PPP) software, release 052011. The results of PPP one-month solutions of AOS-COM (~270 km), AOS-PTB (~450 km), COM-PTB (~720 km), PTB-USNO (6550 km), AOS-USNO (~7000 km) and COM-USNO (~7270 km) time links are presented in figures below (for better clarity the results are shifted). Big peaks in April for AOS time links concern a breakdown of H-maser and its return to full efficiency.





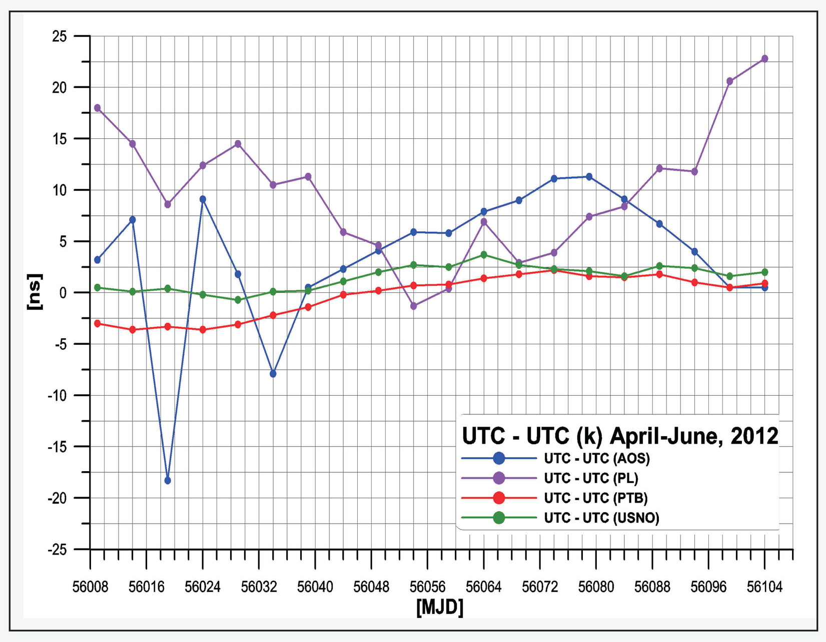
The RMS of PPP method obtained for 24-hour solutions varies from 0.07 to 0.25 ns.
The best RMS were obtained for AOSsn112-USNO time link. The COM time links show the worse COM clock quality.





UTC realization

The stability of the UTC clocks is on the level of 10e-15 ns. The differences between UTC and UTC(lab) are 1-2 ns for UTC(AOS), UTC(PTB), UTC(USNO) and 20 ns for UTC(PL) realized by COM. Jumps in UTC(AOS) in April are related to the failure of the H-maser in AOS. However on June UTC(AOS) was back to high quality and stability comparable with UTC(PTB) and UTC(USNO), which are the best UTC time scales in the world.



Summary and Conclusions

The use of the IGS products resulted in significant improvement of GNSS time transfer. IGS final products are available with at least 14 days latency, but for the time transfer the quality of the rapid products (available within ~24 hours) is sufficient.
The TTS-4 receivers allow all GNSS methods of time transfer. The results obtained for continental and intercontinental links show good quality of the data.
Currently PPP and common- view are the main time transfer methods used at AOS.

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