NEAR REAL-TIME MONITORING OF FREQUENCY STANDARDS AND TIMESCALES USING PRECISE POINT POSITIONING (PPP)

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Abstract

The potential of using the Precise Point Positioning (PPP) with the Natural Resources Canada (NRCan) Ultra-Rapid products to serve as a short latency time-transfer tool is assessed. A specific experiment has been set up, where the NRCan Ultra-Rapid products, as well as all currently available International GNSS Service (IGS) products, are used in PPP time transfer between selected IGS stations co-located in timing laboratories. Results and relative merits are compared between products, in light of their respective delivery characteristics and in view of designing an automated near-real-time monitoring system to assist timing laboratories in their operational maintenance of frequency standards and timescale dissemination to external users.

INTRODUCTION

The PPP time-transfer technique **[1]** requires the availability of precise estimates of GNSS satellite orbits and clocks offsets. Several such products are available from the IGS, each having their own characteristics in terms of robustness, update rate, latency, and satellite clock offset time interval. The most frequently updated IGS products are the Ultra-Rapid products, which are generated four times a day with a latency of 3 hours. NRCan contributes its own Ultra-Rapid product to the IGS for combination. However, the underlying processes running at NRCan generate these products much more frequently (24 times a day), with a latency of 90 minutes, offering an opportunity for more timely time-transfer results when used in PPP.

EXPERIMENT SETUP

In order to evaluate the time transfer capabilities of the NRCan PPP and NRCan Ultra-Rapid products as a monitoring tool to assist timing laboratories in their operational maintenance of frequency standards and timescale dissemination to external users, a specific experiment has been set up. As indicated in Table 1, a set of 12 IGS stations, mostly co-located in time and frequency laboratories, have been selected and considered.

Table 1. IGS stations considered for the experiment.

Station	Clock	Receiver
amc2	HM	ASHTECH Z-XII3T
brus	HM	ASHTECH Z-XII3T
ieng	HM	ASHTECH Z-XII3T
nrc1	HM	ASHTECH Z-XII3T
nrl1	HM	ASHTECH Z-XII3T
onsa	HM	JPS E_GGD
ptbb	HM	ASHTECH Z-XII3T
sfer	HM	ASHTECH Z-XII3T
spt0	HM	ASHTECH Z-XII3T
sydn	Cs	JPS E_GGD
usn3	HM	ASHTECH Z-XII3T
wsrt	HM	AOA SNR-12 ACT

Their daily and hourly RINEX 30-second observation files have been automatically retrieved and processed by means of the NRCan PPP algorithm. Together with the stations' RINEX observation files, a set of external products has been taken into account, namely the IGS Ultra-Rapid (IGU), the IGS Rapid (IGR), and the NRCan Ultra-Rapid (EMU) products. The NRCan PPP station clock estimates related to each product are labelled, respectively, as PPP (IGU), PPP (IGR) and PPP (EMU), as indicated in Figure 2. Also, the IGS Rapid station clock solutions are labelled IGRP.

The characteristics of the satellite orbits and clock products considered herein for use in NRCan PPP computation, that are the principal drivers for the computations and their latencies, are:

<u>IGS Ultra-Rapid Products</u>

The IGU products are produced four times a day, with a delay of 3 hours after the last observation, and consist of a SP3 format orbit/clock file at 15-minute intervals for all satellites in the GPS constellation, covering a total of 48 hours, the first 24 hours being estimated from observations and the last 24 hours being an extrapolation of the orbital elements and clocks.

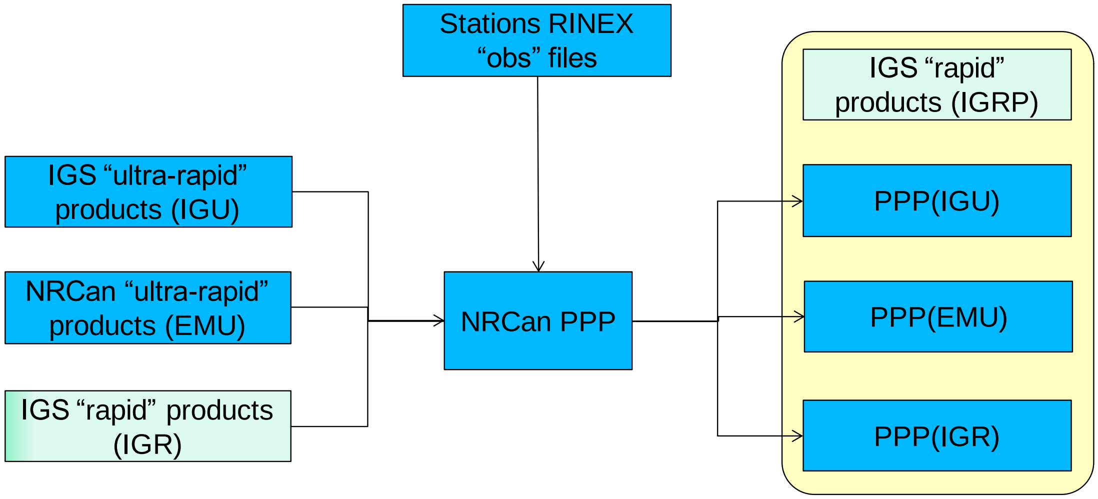

Figure 2. Functional scheme of the experiment setup.

<u>IGS Rapid Products</u>

The IGR products are produced daily with a delay of 17-18 hours after the last observation and consist of a SP3 ephemeris format file at 15-minute intervals for all satellites in the GPS constellation and a RINEX clock format file at 300-second intervals for all satellites in the GPS constellation.

<u>NRCan Ultra-Rapid Products</u>

The EMU products are produced hourly with a delay of 60-90 minutes after the last observation. They consist of a SP3 format orbit/clock file at 15-minute intervals for all satellites in the GPS constellation, covering a total of 48 hours, the first 24 hours being estimated from observations and the last 24 hours being an extrapolation of the orbital elements and clocks (Figure 3 shows the median orbit RMS with respect to IGS Rapid products). Also included are a RINEX clock format file at 30-second intervals for all satellites in the GPS constellation for the estimated portion only. The EMU products generation process was described in **[2]**.

In order to have an automatic operational process, procedures able to periodically retrieve PPP-required inputs, namely the RINEX station observation files and the products described above, have been set on an NRCan-operated computer. Three automated processes are regularly scheduled:

- a process gathering the hourly/daily RINEX observation files for the selected 12 stations, running three times per hour, namely 10, 30 and 50 minutes after the hour;

- a process gathering the orbit (and clock) products (IGU, IGR, and EMU), running every 10 minutes, namely 0, 10, 20, 30, 40, and 50 minutes after the hour;

- a process checking the presence of each product within its availability window, running every 10 minutes, namely 5, 15, 25, 35, 45, and 55 minutes after the hour.

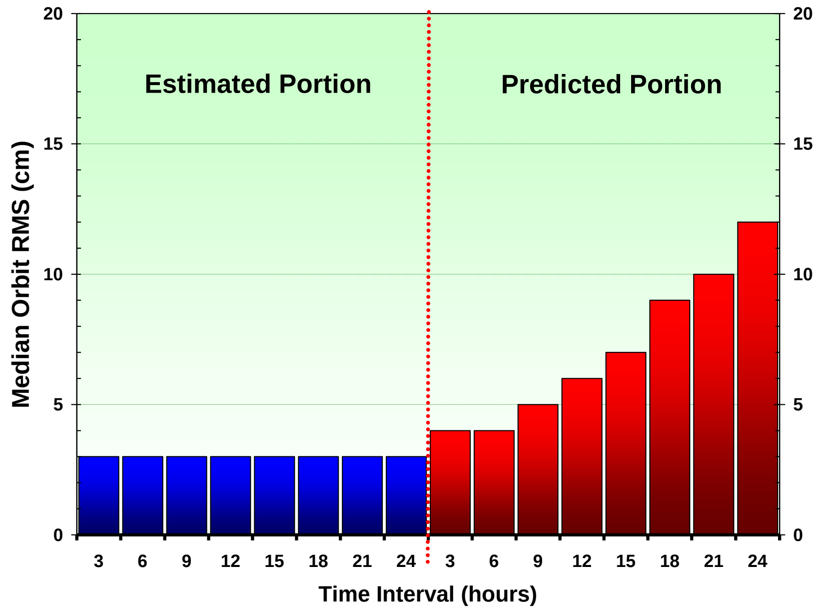

Figure 3. Quality of the NRCan EMU orbit products, in terms of median orbit RMS with respect to IGS Rapid.

As soon as a specific product is available, the PPP processing for the 12 selected stations is scheduled using the available data and specified products, as shown in Figure 4.

The station RINEX data files are concatenated to span the previous *n* days, to which the first *x* hours of current day are added. This process provides 24 RINEX data file for each station per day, each file 1 hour longer than the previous and the last file covering the full *n+1* days.

Each of *n* to *n+1* days RINEX files are processed in the NRCan PPP with:

- the IGU products for each of the initial *n* days, plus the latest IGU product covering the hours of the additional day (6, 12, 18, and 24 hours);

- the EMU products for each of the initial *n* days, plus the latest EMU product, covering the hours of the additional day (1, 2, 3, … , 24 hours).

- only those data files containing the full *n+1* days are processed with the corresponding IGR products.

These three processes were operated continuously over 6 weeks, namely for the MJD 55399-55441 period (2010 July 22 – 2010 September 2 ; GPS Week 1593 (day 4) – 1599(day 4)).

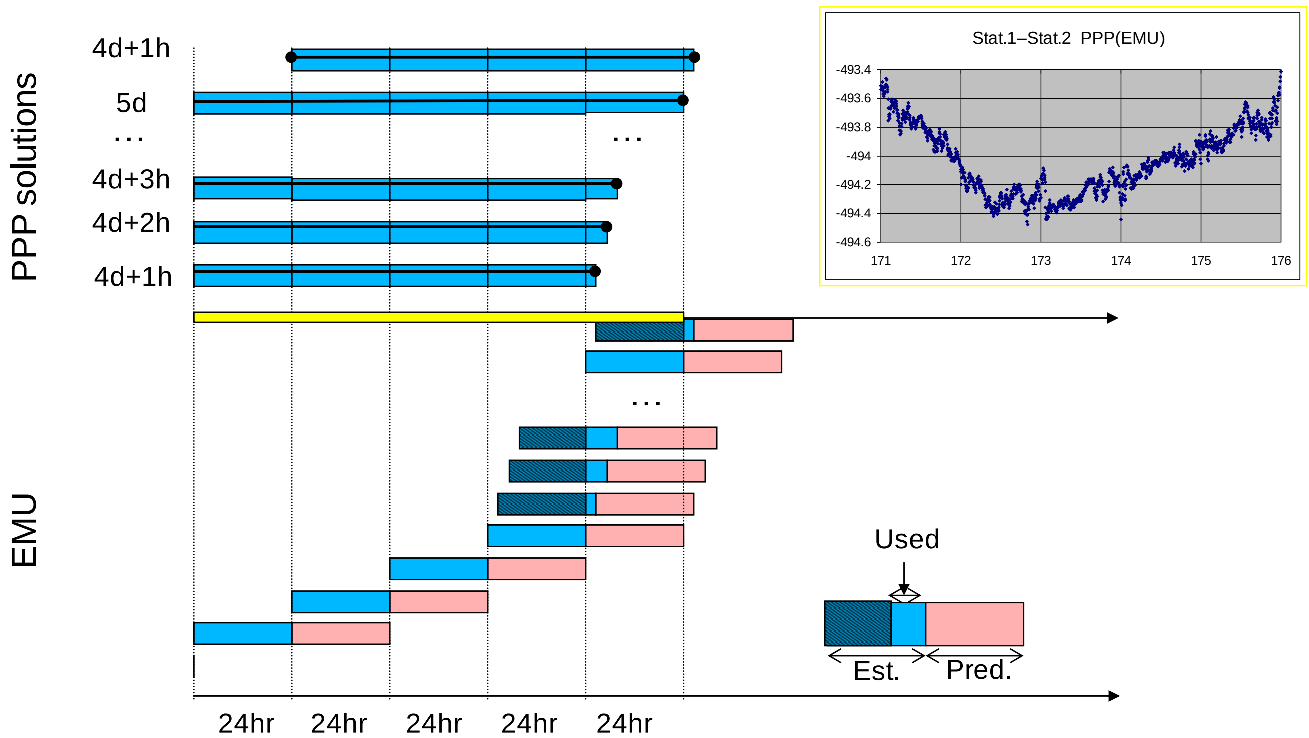

Figure 4. Details of the automated NRCan PPP process using NRCan EMU products with *n*=4.

The NRCan PPP version considered for this experiment is the Version 1.5, Release 06010, characterized by the following new features:

- 2003 IERS tide model;
- Global Pressure & Temperature (GPT) model **[3]** for hydrostatic troposphere delay;
- Kouba's simplified yaw/attitude model **[4]**;
- Adaptive wide-lane & narrow-lane thresholds for cycle clip detection;
- Kinematic antenna orientation tracking;
- Station clock constraints;
- GLONASS-only and GPS+GLONASS processing.

The multi-day station data were processed using dual-frequency pseudorange and carrier-phase with a 10° elevation mask and exercising the adaptive wide-lane and narrow-lane cycle slip detection. One static position was estimated for the whole multi-day period with earth tides and ocean loading applied. Hydrostatic tropospheric delays were modeled with Hopfield using pressure and temperature from the GPT model and 50% relative humidity. The wet troposphere delay component was estimated with 0.05m/√hr process noise, as well as North and East hydrostatic delay gradients. Finally, the station clocks were estimated at the interval of the satellite clock products without constraints. No GLONASS observations or products were used.

Being based on different external products characterized by different latencies, the final NRCan PPP outputs latencies are:

- "hourly" EMU-based station clocks are available between 1h40 and 2h00 after last observation;

- "6-hourly" IGU-based station clocks are available between 3h20 and 3h40 after last observation;

- "daily" IGR-based station clocks are available between 17h and 18h after last observation.

In general, the tracking data latency does not appear to be a factor in the overall latency of the NRCan PPP solutions, at least for most stations. The main limiting factors are the latency of products and machine speed. For the machine used for this experiment (HP-UX 9000/800), 10 minutes are required to prepare the multi-day RINEX files and 20 minutes to process the data, meaning 30 minutes for the whole 12 station data set. Of course, a faster machine or reducing the number of stations would reduce the latency.

RESULTS

All the station clock estimates obtained by means of the NRCan PPP algorithm strictly depend on the associated product, especially for the latency, but also for the reference timescale. The PPP (IGU) and PPP (EMU) clock estimates are roughly aligned to GPS time in a piece-wise fashion, whereas the PPP (IGR) clock estimates are referenced to the IGRT timescale. That the PPP (EMU) and PPP (IGU) clock products, unlike those of PPP (IGR), are not referenced to a continuous timescale is clearly seen in Figure 5, showing the results of a 5-day solution for stations AMC2 and NRL1 using the IGR, IGU, and EMU products for the 2010 DOY 171-175 period.

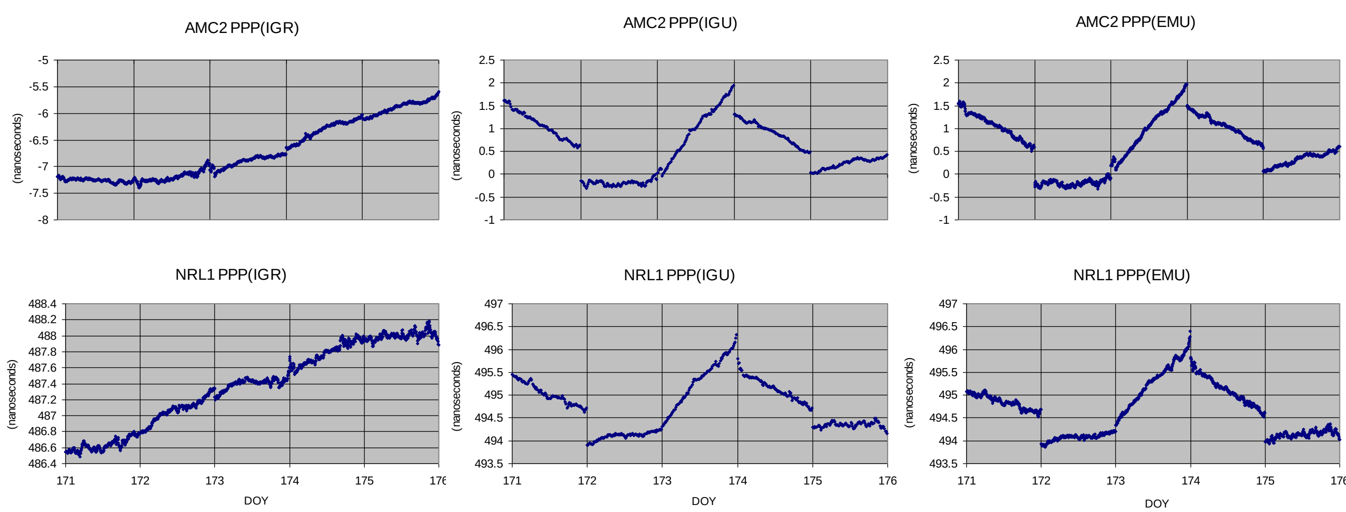

Figure 5. NRCan PPP 5 day solutions using IGR, IGU, and EMU products.

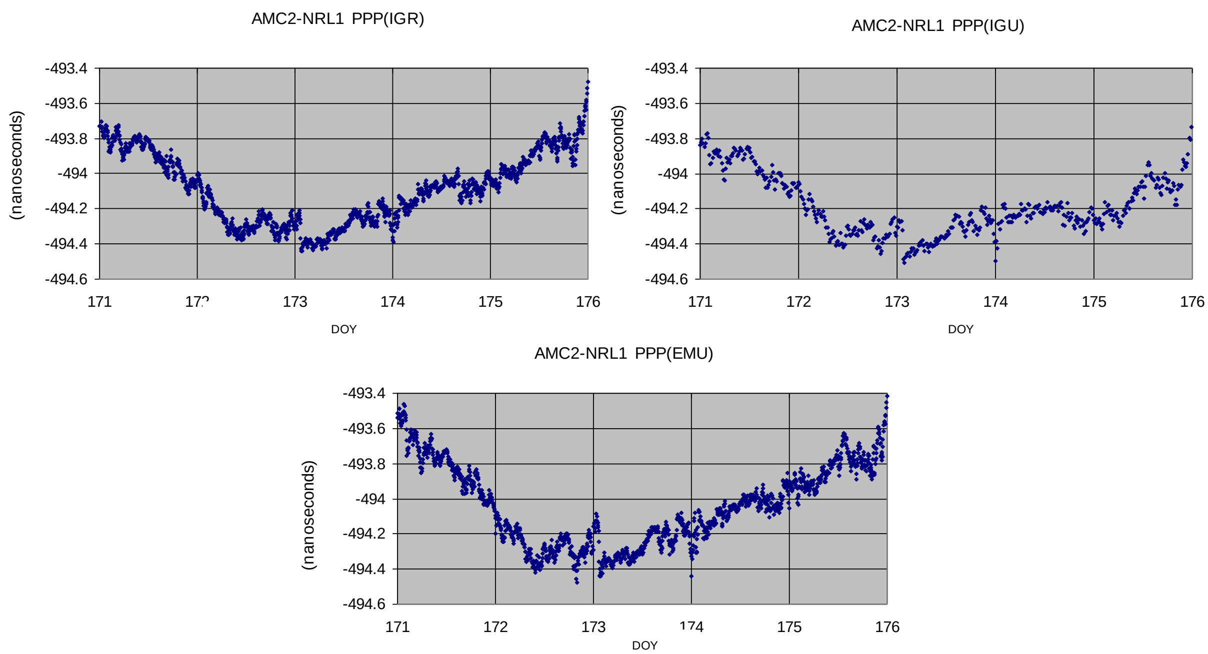

Figure 6. NRCan PPP 5-day solutions using EMU, IGU, and IGR products differenced between stations.

For this reason, in order to provide useful clock monitoring, it is advisable to difference out the discontinuous reference from both Ultra-Rapid PPP clock solutions, as displayed in Figure 6 showing the NRCan PPP results differenced between stations and where it is clear that the EMU-based results are quite comparable to those based on IGS products.

For the AMC2-NRL1 baseline, the phase and frequency offset estimates, together with the frequency stability expressed in terms of Allan deviation, were computed and are reported in Figures 7, 8, and 9, showing a good agreement among all the considered PPP computations. This result, as well as others not reported here for sake of brevity, shows that using the NRCan EMU products it is possible to reduce the latency of the NRCan PPP computations without negatively impacting the estimated frequency stability. The possibility of using this near-real-time process and posting its results on a dedicated Web page would form an important tool to support the operators in Time and Frequency Laboratories in their day-by-day maintenance of frequency standards and timescale generation. In Figure 10, a screenshot of an INRIM Web page reporting NRCan PPP estimates is shown.

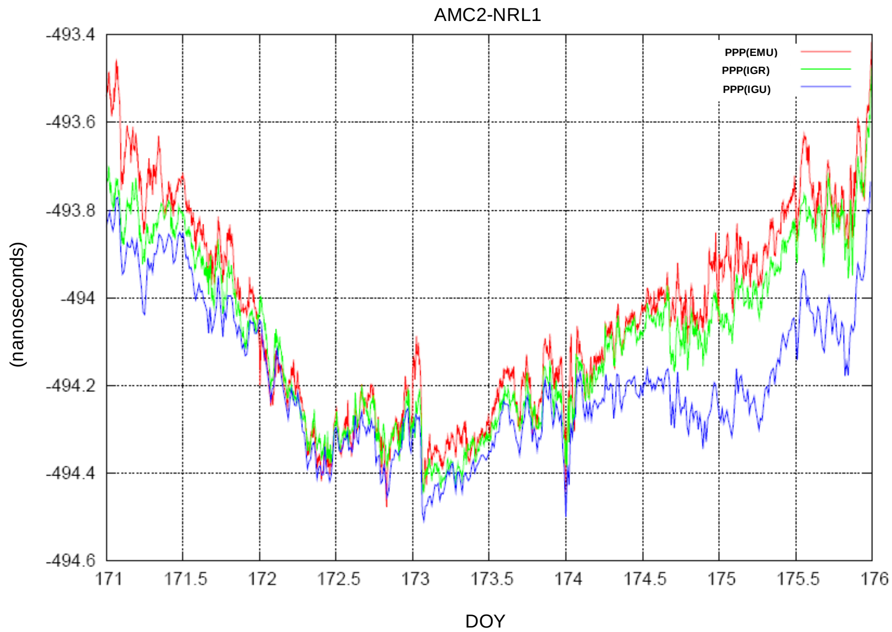

Figure 7. Phase offset for the AMC2-NRL1 baseline, for the 2010 DOY 171-175 period.

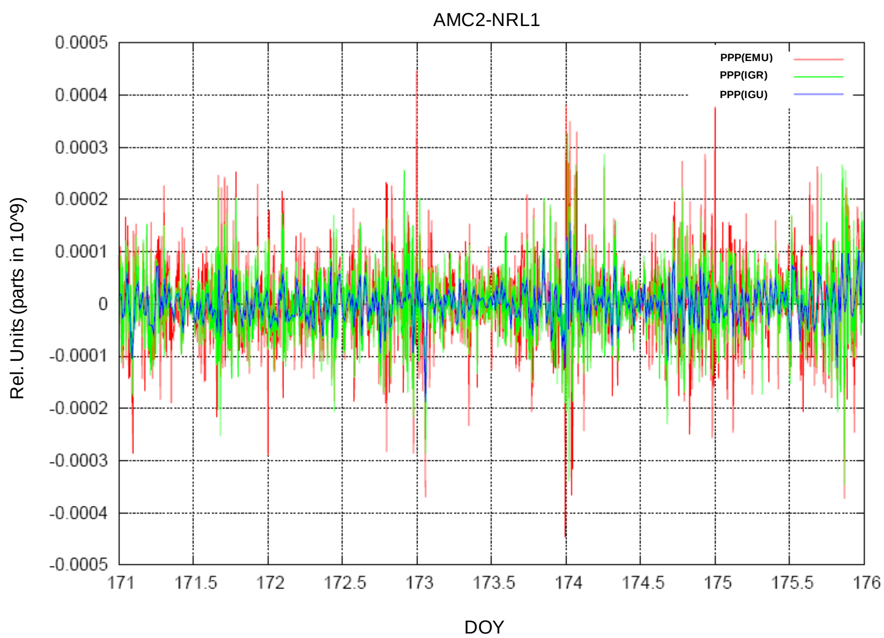

Figure 8. Frequency offset for the AMC2-NRL1 baseline, for the 2010 DOY 171-175 period.

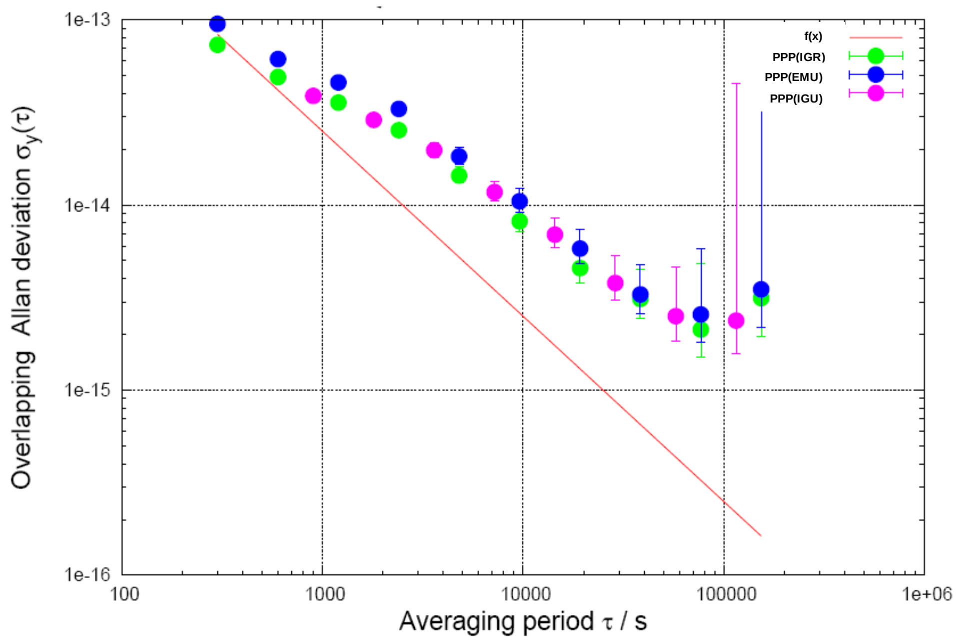

Figure 9. Frequency stability in terms of Allan deviation for the AMC2-NRL1 baseline, for the 2010 DOY 171-175 period.

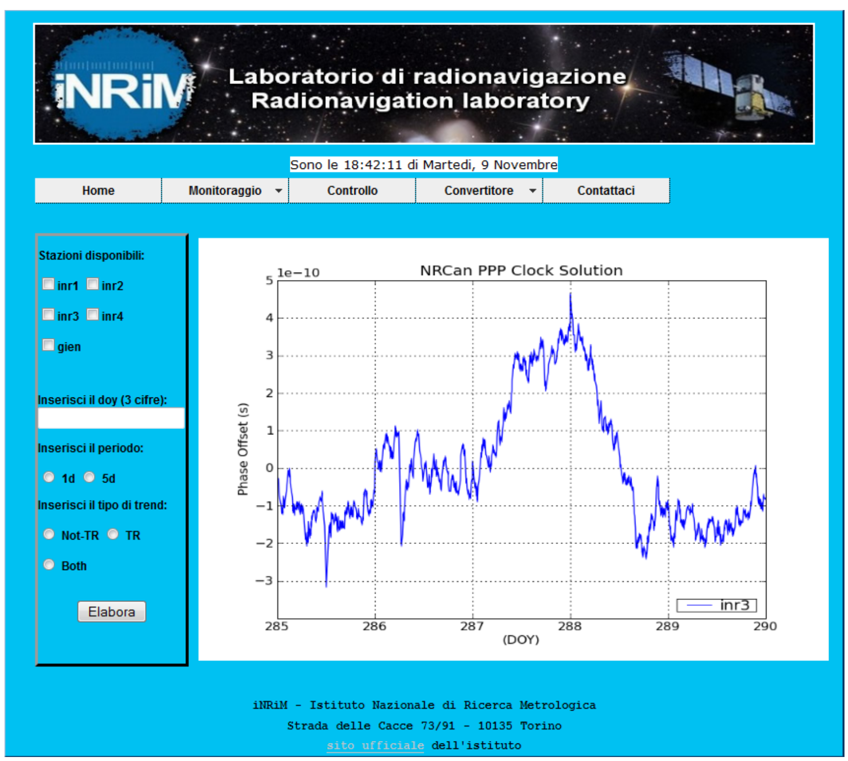

Figure 10. Example of a Web page posting the NRCan PPP results, hosted on the INRIM Intranet.

CONCLUSIONS

NRCan PPP estimates generated using NRCan EMU products show a good agreement with respect to those obtained using IGS products, in terms of frequency stability. The level of performance is very promising, especially taking into account the reduced latency of the final station clock product of about 2 hours. This goes in the direction of considering the PPP as a monitoring tool for the timely support of time and frequency laboratories' activities in the generation of timescales and frequency-standard maintenance. Although the processing is demanding in terms of computation time and robustness, it was possible to effectively automate the whole process, from data collection to plotting of the station clock differences. These station clock differences obtained using EMU products, as well as IGU and IGR products, could be posted in an dedicated Web page to provide the timing community with timely information, helping to maintain a preset level of "quality of service" for time and frequency laboratories.

REFERENCES

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