# Comparison of Russian Ru-U and IVS Intensive Series

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**Abstract** This article presents results of a comparison of the Russian national UT1–UTC estimation observing program Ru-U and the international IVS Intensive program. It is shown that the Ru-U sessions performed with good accuracy and that the Ru-U results can be included in the international VLBI data processing scheme. A comparison of different distributions shows that the problem of the lack of correlation between single delay formal errors and UT1 estimates are present both in the Ru-U and the IVS Intensive series.

**Keywords** VLBI, Intensive, Ru-U, UT1–UTC, “Quasar”

## 1 Introduction

The Russian national VLBI network “Quasar” started to operate in 2006. In 2009, it was adopted that the “Quasar” network would provide the fundamental time-positioning service of the GLONASS [1, 2]. The Quasar network performs regular 24-h VLBI sessions in standard IVS VLBI S/X wideband for EOP estimations every week and hourly sessions for UT1–UTC estimation every day. Hourly sessions are observed on the baseline Zelenchukskaya–Badary. The observations are delivered to the IAA Correlation Center (hardware correlator ARC) by e-VLBI data transfer [3]. UT1–UTC sessions have been observed daily since 01.07.2012. The time delay between the session start and the UT1–UTC results is between two and six hours. Observations are available for analysis in NGS card format at the IAA Web site.

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What is the Ru-U observation program?

- Russian national UT1–UTC estimation
- One-baseline S/X VLBI sessions
- Zelenchukskaya–Badary or Svetloe–Badary baseline
- e-VLBI data transfer
- IAA hardware correlator
- Daily sessions since 01.07.2012
- Two to six hours between observation start and dUT1 results
- Duration: one hour
- Available for analysis in NGS card format at the IAA website:
  ftp://quasar.ipa.nw.ru/pub/EOS/IAA/ngs/
  http://www.ipa.nw.ru/vlbi/

We use the “QUASAR” software [4] for VLBI data processing and obtaining the UT1–UTC results. All calculations meet the IERS Conventions [5].

## 2 Mean Formal Uncertainty of Single Delay

The mean formal errors of single delay from the Ru-U sessions are presented in Figure 1. As one can see, the accuracy of the observations differs up to 4–5 times from one session to another. (It is not a secondary processing result. It is the mean correlator formal error.) The differences can be explained by the fact that some sessions were observed with cold receivers and others with warm receivers. The minimum points in Figure 1 correspond to the moments of 24-h EOP-oriented Ru-E sessions performed with cold receivers.

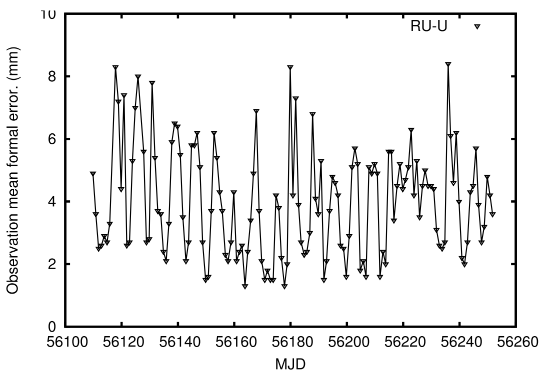


**Fig. 1** Mean formal uncertainty of single delay in Ru-U sessions.

It should be noted that the RMS after the solution has no correlation with the formal errors of single delay as seen in Figure 2. The problem looks similar both for the Ru-U and the IVS Intensive sessions. The RMS after the solution is a crucial parameter and directly affects the accuracy of the UT1–UTC estimation (Figure 4).

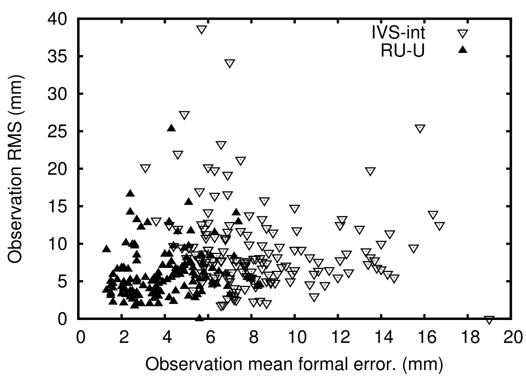


**Fig. 2** Mean formal errors of single delay vs. RMS after solution for Ru-U and IVS Intensive sessions.

## 3 Ru-U UT1–UTC Statistics and Scheduling

Observations were carried out with cold receivers weekly using the single schedule pattern with scans of 60-second length. In July 2012, observations became daily, but use of the same scheduling pattern continued. Sessions from Thursday to Saturday always had cooled receivers, and sessions from Sunday to Wednesday had warm or cool receivers, depending on the time schedule for a particular station. The next major change in observing strategy occured in April 2013. It was separate scheduling depending on the state of the stations' receivers: the warm (hot) and the cool (cold) state were scheduled with different patterns. The last important change in observing strategy was scans with arbitrary durations from 22 to 127 seconds. The comparison of the UT1 series from IAA observations and IERS finals is presented in Table 1. All values are in $\mu$s. The table has RMS in the 3rd column, calculated bias in the 4th column, and weighted RMS without bias in the 5th column. The table shows that the last scheduling change significantly improves our results.

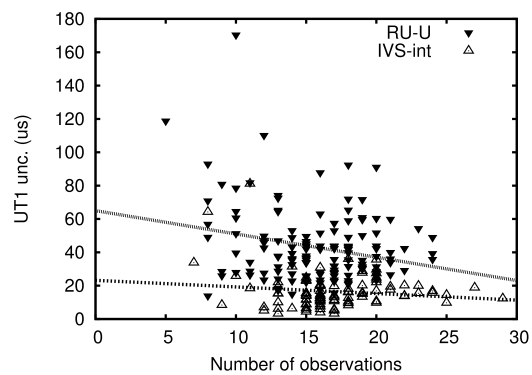


**Fig. 3** Number of observations vs. UT1–UTC uncertainty.

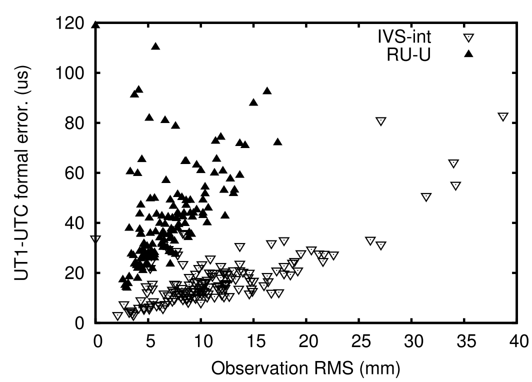


**Fig. 4** RMS after solution vs. UT1–UTC formal errors for the IVS Intensive and Ru-U sessions.

The following important changes in schedule pattern were made since the Ru-U sessions became daily (schedules are in the SKED software format):

1. 2012/07/01 — Ru-U sessions became daily. $OP section: estimated parameters DUT, AOFF, ARAT, COFF, and CRT1 for SvZcBd; optimized for ZcBd baseline only, used reference station Bd;
2. 2012/09/01 — Slew time additive constants C1 and C2 (in $STATIONS: A-line) were changed for Sv, Zc, and Bd from 60 to 40 seconds;
3. 2012/12/01 — Source NRAO190 was removed from the $SOURCES section. 158 sources remained in the pattern;
4. 2013/01/21 — Source 0723-008 was removed from the $SOURCES section (based on Ru-U190, 192, 201, 203, 418, and 419). 157 sources remained in the pattern;
5. 2013/02/10 — Separate session patterns for HOT and COLD receivers state at stations. In the HOT pattern, $MAJOR MIN_BETWEEN was changed from 25 to 20 and BEST% from 85 to 100;
6. 2013/04/24 — In the HOT Ru-U pattern, the $SOURCES list was replaced with a new list of 38 selected sources;
7. 2013/04/25 — ARAT was removed from the optimization and estimation parameters in the $OP section;
8. 2013/06/14 — Sources 4C67.05 and 1038+52B were removed from the COLD session pattern. The first was too weak in S-band, and the second was too weak in X-band (based on Ru-U558, 559, and 560). Probably, RFI at Zc in the North direction affected the 4C67.05 scans;
9. 2013/12/01 — The scan durations became arbitrary. The HOT and COLD Ru-U patterns' basic parameters were changed: CORSYNCH was changed from 3 to 0, MINSCAN from 60 to 30, SNR X from 20 to 40, and SNR S from 15 to 40. Both SNR MARGINS were set to 0. Several weights changed in $MINOR. In $MAJOR, MIN_BETWEEN was changed from 25 to 40 and BEST% from 85 to 100. This was a trial period to look for optimal parameters;
10. 2013/12/15 — In the HOT Ru-U pattern, the $SOURCES list was replaced with a new list of 151 COLD sources, except for the following sources: CTA26, 0400+258, 0657+172, and 0945+408. Basic parameters were changed: CORSYNCH from 0 to 3, MINSCAN from 30 to 22, MAXSCAN from 300 to 200, SNR X from 40 to 38, and SNR S from 40 to 37. In $STATIONS, SEFD X changed from 400 to 1200 and SEFD S from 600 to 1200;
11. 2013/12/24 — Changes were made to the COLD Ru-U pattern's basic parameters: CORSYNCH changed from 0 to 7, MINSCAN from 30 to 22, MAXSCAN from 300 to 127, SNR X from 40 to 38, and SNR S from 40 to 37. This restricted the maximum scan duration to 120 seconds at the correlator. Source 2021+614 was removed from the HOT Ru-U pattern due to low S flux. Changes were made to the HOT Ru-U pattern's basic parameters: CORSYNCH changed from 3 to 7, MAXSCAN from 200 to 127, and SNR S from 37 to 38;
12. 2013/12/29 — Changes were made to the HOT Ru-U pattern's basic parameters: ELEVATION changed from 18.0 to 10.0, and in $MAJOR, MIN_BETWEEN changed from 40 to 30.

**Table 1** Comparison of the Ru-U UT1 estimates with the IERS series.

| Period covered | Scheduling strategy changes | Ru-U–IERS, $\mu$s | | |
|---|---|---|---|---|
| | | RMS | BIAS | WRMS |
| 2012/07/20 –2013/04/23 | Ru-U became daily | 61 | 18±3 | 50 |
| 2013/04/24 –2013/11/30 | Different cold and hot sessions | 62 | 8±4 | 54 |
| 2013/12/01 –now | Arbitrary scan length | 44 | 25±4 | 35 |

## 4 IVS Intensive UT1–UTC Statistics

IVS Intensive sessions can be divided into two parts: the XK sessions with baseline Wettzell–Tsukuba and XU sessions with baseline Wettzell–Kokee. We processed sessions for year 2013 (78 XK and 266 XU sessions) and calculated statistics for the complete set and for XU and XK separately. The obtained RMS and unbiased WRMS vs. the IERS finals series for the XK and XU series are presented in Table 2. It can be assumed that the XK series shows worse results due to the unstable Tsukuba position. The two series have different biases, and the XK series has better unbiased WRMS values than the total Intensive series. The relation between the Ru-U and the IVS Intensive estimations are in good agreement with the baseline length relation. Our results for the IVS Intensive sessions are also consistent with the results of other VLBI data analysis centers.

**Table 2** Differences of IVS Intensive vs. IERS finals (from 01.01.2013 to 01.01.2014).

| | XU+XK | XU | XK |
|---|---|---|---|
| RMS, $\mu$s | 43 | 27 | 46 |
| WRMS, $\mu$s | 29 | 15 | 26 |

## 5 Conclusion

The main result of this article is that the IAA Ru-U UT1–UTC estimations have comparable accuracy to the IVS Intensive results and can be used by IERS and IVS as contributions to the IERS UT1–UTC series. Raw observation data and the results of UT1–UTC estimations can be obtained at the IAA ftp sites:

ftp://quasar.ipa.nw.ru/pub/EOS/IAA/ngs/
ftp://quasar.ipa.nw.ru/pub/EOS/IAA/veopi-ru.dat

Moreover it should be noted that:

- Ru-U sessions have better single delay formal errors (see Figure 2).
- Ru-U sessions show a faster decrease in error with an increase in the number of observations (see Figure 3).
- There is a lack of correlation between the delay formal error and the RMS both for the Ru-U and IVS Intensive series (see Figure 2).
- The scheduling significantly affects the accuracy of UT1–UTC estimation. A complex investigation of the scheduling algorithms is needed.

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