Pulkovo Observatory IVS Analysis Center (PUL) Report 2015–2016

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Abstract This report briefly presents the PUL IVS Analysis Center activities during 2015–2016 and plans for the coming year. The main topics of the scientific investigations of the PUL staff in that period were ICRF related studies, EOP series analysis, celestial pole offset (CPO), and free core nutation (FCN) modeling. Regular activities include UT1 Intensive data processing, OCARS catalog support, and support of the PUL archives of data and products.

1 General Information

The PUL IVS Analysis Center was organized in September 2006. It is located at and sponsored by the Pulkovo Observatory of the Russian Academy of Sciences. It is a part of the Pulkovo EOP and Reference Systems Analysis Center (PERSAC) [1]. The main topics of our IVS related activities are:

- Improvement of the International Celestial Reference Frame (ICRF).
- Computation and analysis of the Earth orientation parameters (EOP) from Intensives and 24-hour IVS sessions.
- Analysis of EOP and source position time series.
- Modeling of the celestial pole offset (CPO) and free core nutation (FCN).
- Comparison of VLBI products, primarily EOP, with results of other space geodesy techniques.
- Computation and analysis of observation statistics.

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The PUL Analysis Center Web page [2] is supported. Its contents was described in previous reports.

2 Staff

The following persons contributed to the PUL activities in 2015–2016:

1. Zinovy Malkin (70%) — team coordinator, EOP and CRF analyst;
2. Yulia Lopez (née Sokolova) (50%) — CRF analyst.

3 Activities and Results

The main activities and results of the PUL IVS Analysis Center during 2015–2016 included the following topics.

- *ICRF related research.*
  - We compared results of determination of the orientation angles between celestial reference frames realized by radio source position catalogs using three methods of accounting for correlation information: using the position errors only, using additionally the correlations between the right ascension and declination (RA/DE correlations) reported in radio source position catalogs published in the IERS format, and using the full covariance matrix [10]. The computations were performed with nine catalogs computed at eight Analysis Centers. Our analysis has shown that using the RA/DE

correlations only slightly influences the computed rotational angles, whereas using the full correlation matrices lead to substantial change in the orientation parameters between the compared catalogs.

– The current state of the link problem between radio and optical celestial reference frames was analyzed [11]. The main objectives of the investigations in this direction during the next few years are the preparation of a comparison and the mutual orientation and rotation between the optical *Gaia* Celestial Reference Frame (GCRF) and the 3rd generation radio International Celestial Reference Frame (ICRF3), obtained from VLBI observations. Both systems, ideally, should be a realization of the ICRS (International Celestial Reference System) at micro-arcsecond level accuracy. Therefore, the link accuracy between the ICRF and GCRF should be obtained with similar error level, which is not a trivial task due to relatively large systematic and random errors in source positions at different frequency bands. In this paper, a brief overview of recent work on the GCRF–ICRF link is presented. Additional possibilities to improve the GCRF–ICRF link accuracy are discussed. The suggestion is made to use astrometric radio sources with optical magnitude to 20^m rather than to 18^m as currently planned for the GCRF–ICRF link.
– Using radio stars for linking the optical *Gaia* Celestial Reference Frame (GCRF) to the VLBI-based ICRF was considered [9]. In this work, an obtainable accuracy of the orientation angles between GCRF and ICRF frames was estimated by Monte Carlo simulation. If the uncertainties in the radio star positions obtained by VLBI are in the range of 0.1–4 mas and those obtained by *Gaia* are in the range of 0.005–0.4 mas, the orientation angle uncertainties are 0.018–0.72 mas if 46 radio stars are used, 0.013–0.51 mas if 92 radio stars are used, and 0.010–0.41 mas if 138 radio stars are used. The general conclusion from this study is that a properly organized VLBI program for radio star observation with a reasonable load on the VLBI network can allow for the realization of GCRF–ICRF link with an error of about 0.1 mas.
– In collaboration with Geoscience Australia (Oleg Titov) a new approach was developed to facilitate the structure delay for extended radio sources using post-fit residuals calculated after processing of geodetic VLBI observations in the standard way. No imaging of a radio source is required for the new approach. In this method, the simplest model of a radio source including two point-like components can be represented by four parameters, namely angular separation, orientation, flux ratio, and difference of spectral indices [5] for each baseline of the multi-baseline VLBI network separately. To demonstrate the effectiveness of this approach, we have analyzed post-fit residuals of the radio source 0014+813 intensively observed during the two-week CONT14 campaign under the auspice of the IVS in May 2014. Large systematic differences in post-fit residuals for northern hemisphere baselines of 5,000 km and longer were detected. We have estimated all four parameters for each baseline and determined average characteristics of the 0014+813 radio structure at the frequency 8.4 GHz. The radio source is found to consist of two components separated by 0.5 mas and in north-south direction. Implementation of this structure model to analysis of the CONT14 data results in 0014+813 declination displacement of 0.070 mas in the north direction with respect to the reference position [14].
– The OCARS catalog (Optical Characteristics of Astrometric Radio Sources) [3] is supported. The catalog provides morphological type, redshift info, visual and NIR magnitudes, and cross-identification with other catalogs [12]. The latest OCARS version includes photometric data in 14 bands *uUBgVrRiIzJHKG*. Cross-identification table is yet only provided for IVS and LQAC catalogs.

- *CPO and FCN related research.*

  – Two CPO and two FCN series are being updated daily and are available at the PERSAC Web page [1].
  – A previous study (Malkin, 2013) revealed that the epochs of the observed extremes in the FCN amplitude and phase variations are close to the GMJ epochs. Recently, new evidence of this

connection was found [7]. The large FCN amplitude and phase disturbance occurred at the epoch close to the newly revealed GMJ 2011. This event occurred to be the second largest change in the FCN amplitude and phase after the 1999 disturbance that is also associated with the GMJ 1999. Moreover, the long-time FCN phase drift had changed suddenly in 1998–1999, immediately before the GMJ 1999, and seemed to change again at the epoch immediately preceding the GMJ 2011. The FCN amplitude showed a general long-time decrease before GMJ 1999, and it subsequently grew until GMJ 2011, and then seemed to decrease again. A smaller FCN change can be observed at the epoch around 2013, which is also suspected as the GMJ epoch. The latter confirms the suggestion that a rapid change in the FCN amplitude and/or phase can be used as evidence of the GMJ that is not clearly detected from the geomagnetic observations.

– Three combined celestial pole offset (CPO) series computed at the Paris Observatory (C04), the United States Naval Observatory (USNO), and the International VLBI Service for Geodesy and Astrometry (IVS), as well as six free core nutation (FCN) models, were compared from different perspectives, such as stochastic and systematic differences and FCN amplitude and phase variations [13]. The differences between the C04 and IVS CPO series were mostly stochastic, whereas a low-frequency bias at the level of several tens of μas was found between the C04 and USNO CPO series. The stochastic differences between the C04 and USNO series became considerably smaller when computed at the IVS epochs, which can indicate possible problems with the interpolation of the IVS data at the midnight epochs during the computation of the C04 and USNO series. The comparison of the FCN series showed that the series computed with similar window widths of 1.1 yr to 1.2 yr were close to one another at a level of 10 μas to 20 μas, whereas the differences between these series and the series computed with a larger window width of 4 yr and 7 yr reached 100 μas. The dependence of the FCN model on the underlying CPO series was investigated. The RMS differences between the FCN models derived from the C04, USNO, and IVS CPO series were at a level of approximately 15 μas, which was considerably smaller than the differences among the CPO series. The analysis of the differences between the IVS, C04, and USNO CPO series suggested that the IVS series would be preferable for both precession-nutation and FCN-related studies.

- Non-linear VLBI station motions and their impact on the celestial reference frame and Earth orientation parameters were investigated [6]. The increasing accuracy and growing time span of Very Long Baseline Interferometry (VLBI) observations allow the determination of seasonal signals in station positions which still remain unmodeled in conventional analysis approaches. In this study we focused on the impact of the neglected seasonal signals in the station displacement on the celestial reference frame and Earth orientation parameters. We estimated empirical harmonic models for selected stations within a global solution of all suitable VLBI sessions and created mean annual models by stacking yearly time series of station positions which were then entered a priori in the analysis of VLBI observations. Our results revealed that there is no systematic propagation of the seasonal signal into the orientation of celestial reference frame but position changes occurred for radio sources observed non-evenly over the year. On the other hand, the omitted seasonal harmonic signal in horizontal station coordinates propagates directly into the Earth rotation parameters causing differences of several tens of microarcseconds
- Operational data processing of IVS Intensive sessions in operational automated mode and submission of results to IVS was continued. The latest UT1 time series includes $\sim$5,700 UT1 estimates for 1999–2016 and is available at the IVS Data Centers and at the PERSAC Web page [1].
- The PUL archive of VLBI data and products obtained in the framework of IVS activity is supported. At present, all available X-band NGS cards for $\sim$15.5 thousand sessions observed in 1979-2016 are stored. The PUL NGS archive contains $\sim$14 million ($\sim$12 good) observations and looks to be the most complete among other IVS NGS card archives.

- Development of algorithms and software for data processing and analysis continued. In particular, a review was prepared of the experience of using AVAR and its modifications in processing astronomical and geodetic time series [8].
- PUL staff members participated in activities of several IAG, IAU, IERS, and IVS projects, committees, and working groups.

4 Future Plans

Plans for the coming year include:

- Continuing ICRF related studies.
- Continuing CPO/FCN related studies.
- Continuing UT1 Intensive data processing.
- Continuing OCARS catalog support.
- Continuing development of algorithms and software for data processing.
- Continuing support of the PUL archives of data and products.

References

1. http://www.gao.spb.ru/english/as/persac/index.htm
2. http://www.gao.spb.ru/english/as/ac_vlbi/
3. http://www.gao.spb.ru/english/as/ac_vlbi/ocars.txt
4. http://www.gao.spb.ru/english/as/ac_vlbi/occultations_approaches.pdf
5. Charlot P. (1990) Radio-source structure in astrometric and geodetic very long baseline interferometry. AJ, 99:1309.
6. Krasna H., Malkin Z., Boehm J. Non-linear VLBI station motions and their impact on the celestial reference frame and Earth orientation parameters. J. of Geodesy, 2015, v. 89, No. 10, 1019-1033. DOI: 10.1007/s00190-015-0830-4
7. Malkin Z. Free core nutation: new large disturbance and connection evidence with geomagnetic jerks. Acta Geodyn. Geomater., 2016, v. 13, No. 1 (181), 41-45. DOI: 10.13168/AGG.2015.0042
8. Malkin Z. Application of the Allan Variance to Time Series Analysis in Astrometry and Geodesy: A Review. IEEE Transactions UFFC, 2016, v. 63, No. 4, 582-589. DOI: 10.1109/TUFFC.2015.2496337
9. Malkin Z. Using radio stars to link the Gaia and VLBI reference frames. MNRAS, 2016, 461(2), 1937-1942. DOI: 10.1093/mnras/stw1488
10. Sokolova Y., Malkin Z. On the Impact of Correlation Information on the Orientation Parameters Between Celestial Reference Frame Realizations. In: IAG 150 Years, C. Rizos, P. Willis (eds.), IAG Symposia, 2016, v. 143, 41-44. DOI: 10.1007/1345_2015_179
11. Malkin Z. Connecting VLBI and Gaia celestial reference frames. Front. Astron. Space Sci., 2016, v. 3, 28. DOI: 10.3389/fspas.2016.00028
12. Malkin Z. The Second Version of the OCARS Catalog of Optical Characteristics of Astrometric Radio Sources. Astronomy Reports, 2016, v. 60, No. 11, 996-1005. DOI: 10.1134/S1063772916110032
13. Malkin Z. Joint analysis of celestial pole offset and free core nutation. J. of Geodesy, accepted, DOI: 10.1007/s00190-016-0966-x
14. Titov O., Lopez Y. (2016) Calculation of the structure delay for extended radio sources using geodetic VLBI observations, under preparation.