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# Comparison of Radio Source Positions from Individual Solutions

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**Abstract.** Various VLBI analysis centers that participate in the IVS/IERS Working Group on ICRF-2 provided their results of source coordinate estimations as well as time series of source position variations. In this presentation results of a comparison of these catalogs are discussed.

## 1. Introduction

The International Celestial Reference Frame (ICRF) is realized by positions of extragalactic radio sources which are obtained from data analysis of geodetic and astrometric VLBI observations. Efforts of many VLBI analysis centers are focused on producing new solutions of source coordinates in the frame of the international project ICRF-2, the second realization of the ICRF (e.g., [3]).

In order to study systematic errors in the construction of celestial reference frames, two types of solutions were obtained by various analysis centers: "catalog" and "time series". A purpose of the first type of solutions is to investigate systematic effects in realizations of celestial reference frame (CRF) by different analysis centers. The second type of solutions is aimed at studies of stability of sources positions and selection of so-called DEFINING radio sources for the ICRF-2 implementation.

In this article the results of catalog comparisons are presented. Also, preliminary results of time series analysis are shown.

## 2. Comparisons of Catalogs

Four VLBI analysis centers submitted solutions for the celestial reference frame. The general characteristics of the obtained catalogs and the reference catalog ICRF-Ext.2 [1] are presented in Tabl. 1. The $\sigma_\alpha$ and $\sigma_\delta$ columns of the table correspond to mean formal uncertainties of the solutions in right ascension and declination. The solutions are based on almost the same set of VLBI observations, collected since 1979 until mid-2007. The exception is the inclusion of the VCS sessions in two of the solutions (aus000a and mao000a) and their omission in the other two solutions.

Table 1. General characteristics of CRF solutions

| Solution ID | Number of Sources | $\sigma_\alpha$, $\mu$as | $\sigma_\delta$, $\mu$as | Software | Analysis Center |
|---|---|---|---|---|---|
| ICRF-Ext.2 | 717 | 1224 | 1243 | | |
| aus000a | 1515 | 1433 | 1752 | OCCAM6.2 | Geoscience Australia |
| gsf000a | 923 | 473 | 521 | CALC/SOLVE | NASA GSFC |
| mao000a | 2541 | 529 | 888 | SteelBreeze | MAO NASU |
| usn000a | 923 | 523 | 521 | CALC/SOLVE | US Naval Observatory |

A comparison of the catalogs was performed in the following way: first, the parameters of a model of transformation between two catalogs were estimated with the least squares method. Then, the model was applied to coordinates of one of the catalogs and weighted root mean square residuals were calculated for the right ascension and declination.

We applied a transformation model similar to the one was used in the IERS Annual Reports (e.g, [2]), with added harmonic terms. The differences in right ascension, $\Delta\alpha$, and declination, $\Delta\delta$, are presented as:

$$\begin{aligned}\Delta\alpha &= A_1 \tan\delta\cos\alpha + A_2 \tan\delta\sin\alpha - A_3 + D_\alpha(\delta-\delta_0) + C_\alpha \sin(\alpha+\varphi_\alpha),\\ \Delta\delta &= -A_1\sin\alpha + A_2\cos\alpha + D_\delta(\delta-\delta_0) + B_\delta + C_\delta\sin(\alpha+\varphi_\delta),\end{aligned}$$

where $A_1$, $A_2$, and $A_3$ are small angles of global rotations about three axes; $D_\alpha$ and $D_\delta$ are slopes in right ascension and declination as functions of declination; $B_\delta$ is a bias in the declination; $C_\alpha$, $\varphi_\alpha$ and $C_\delta$, $\varphi_\delta$ are amplitudes and phases of harmonic oscillations in right ascension and declination.

Table 2. Number of common sources in the catalogs (all, defining)

| ID | aus000a | | gsf000a | | mao000a | | usn000a | |
|---|---|---|---|---|---|---|---|---|
| ICRF-Ext.2 | 572 | 210 | 708 | 212 | 665 | 211 | 717 | 212 |
| aus000a | | | 678 | 210 | 1231 | 210 | 671 | 210 |
| gsf000a | | | | | 800 | 211 | 905 | 212 |
| mao000a | | | | | | | 798 | 211 |

To calculate the parameters of the model, the coordinates of common (between twoh catalogs) DEFINING radio sources were used. Then, after the model was applied, the WRMS were evaluated for the whole set of common radio sources. The numbers of common DEFINING and all sources for each pair of catalogs are presented in the Tabl. 2.

Table 3. Comparison of catalogs: ICRF.Ext-2 vs individual solutions

| $A_1$, μas | $A_2$, μas | $A_3$, μas | $D_\alpha$, μas/rad | $D_\delta$, μas/rad | $B_\delta$, μas | $S_\alpha$, μas | $\varphi_\alpha$, deg | $S_\delta$, μas | $\varphi_\delta$, deg |
|---|---|---|---|---|---|---|---|---|---|
| ICRF-Ext.2 – aus000a | | | | | | | | | |
| −16.7 | 6.4 | −51.4 | −79.1 | −193.3 | 173.9 | 65.0 | 62.0 | 91.7 | 148.5 |
| 118.1 | 106.4 | 76.7 | 139.6 | 70.2 | 60.1 | 98.5 | 87.0 | 137.2 | 80.7 |
| ICRF-Ext.2 – gsf000a | | | | | | | | | |
| 58.7 | −7.7 | −19.7 | −25.0 | 0.8 | −3.1 | 33.2 | 55.8 | 78.6 | 349.3 |
| 36.5 | 32.3 | 23.5 | 42.8 | 21.5 | 18.4 | 30.1 | 52.6 | 42.5 | 28.5 |
| ICRF-Ext.2 – mao000a | | | | | | | | | |
| 61.7 | 76.0 | −37.2 | −27.7 | −28.1 | 6.7 | 50.8 | 75.0 | 58.4 | 350.2 |
| 40.0 | 35.7 | 25.9 | 47.1 | 23.8 | 20.4 | 33.6 | 37.2 | 46.7 | 42.4 |
| ICRF-Ext.2 – usn000a | | | | | | | | | |
| 90.2 | −48.4 | −35.7 | −43.7 | 0.4 | −10.4 | 48.5 | 141.2 | 100.5 | 17.3 |
| 39.4 | 35.0 | 25.6 | 46.4 | 23.1 | 19.9 | 33.3 | 38.5 | 45.2 | 24.7 |

The results of the least squares estimation of model parameters are given in Tabl. 3 and 4. Tabl. 3 shows the comparison of the reference catalog, ICRF-Ext.2, with the individual solutions. Mutual comparisons between the individual solutions are presented in Tabl. 4. In the tables the first lines for each pair

Table 4. Comparison of catalogs: mutual comparison of individual solutions

| $A_1$, μas | $A_2$, μas | $A_3$, μas | $D_\alpha$, μas/rad | $D_\delta$, μas/rad | $B_\delta$, μas | $S_\alpha$, μas | $\varphi_\alpha$, deg | $S_\delta$, μas | $\varphi_\delta$, deg |
|---|---|---|---|---|---|---|---|---|---|
| aus000a – gsf000a | | | | | | | | | |
| 19.8 | −69.4 | 31.4 | 32.8 | 17.7 | −21.0 | 32.7 | 70.3 | 26.6 | 36.6 |
| 26.7 | 25.8 | 19.3 | 33.3 | 19.4 | 16.8 | 23.1 | 40.4 | 28.3 | 69.0 |
| aus000a – mao000a | | | | | | | | | |
| 27.8 | 1.0 | 18.2 | 45.6 | 7.6 | −37.0 | 50.9 | 77.5 | 24.3 | 79.4 |
| 25.0 | 25.6 | 19.9 | 33.0 | 19.7 | 17.6 | 22.3 | 27.0 | 28.9 | 69.8 |
| aus000a – usn000a | | | | | | | | | |
| 51.8 | −112.6 | 22.0 | 33.0 | 36.2 | −47.8 | 51.4 | 132.3 | 64.1 | 49.8 |
| 42.2 | 40.6 | 29.8 | 52.4 | 31.2 | 27.1 | 34.1 | 42.0 | 45.0 | 45.4 |
| gsf000a – mao000a | | | | | | | | | |
| 15.8 | 78.6 | −13.0 | 13.8 | −6.2 | −19.0 | 15.1 | 100.7 | 6.4 | 162.1 |
| 6.5 | 6.6 | 5.1 | 8.6 | 5.4 | 5.0 | 5.4 | 23.9 | 7.8 | 66.7 |
| gsf000a – usn000a | | | | | | | | | |
| 30.8 | −51.9 | −11.6 | −3.2 | −2.5 | −7.8 | 39.4 | 169.2 | 39.6 | 72.1 |
| 5.2 | 5.1 | 3.8 | 6.7 | 4.2 | 3.8 | 4.6 | 6.4 | 5.9 | 9.0 |
| mao000a – usn000a | | | | | | | | | |
| 16.3 | −131.1 | 0.6 | −16.8 | 4.2 | 9.0 | 34.6 | 192.1 | 40.0 | 60.1 |
| 7.6 | 7.7 | 5.9 | 10.1 | 6.4 | 5.9 | 7.3 | 10.4 | 8.7 | 13.3 |

of catalogs give the estimated values, on the second lines standard deviations are shown. Here, the parameters $A_1$, $A_3$, $A_3$, $B_\delta$, $S_\alpha$, and $S_\delta$ are measured in $\mu$as; units for $D_\alpha$ and $D_\delta$ are $\mu$as/rad, and the phases $\varphi_\alpha$ and $\varphi_\delta$ are in degrees.

In Tabl. 5 weighted post-fit residuals are shown. The residuals were evaluated for each pair of the catalogs after the estimated models of transformation were removed.

Table 5. Weighted post-fit residuals ($\Delta\alpha \cos\delta$, $\Delta\delta$), $\mu$as

| ID | aus000a | | gsf000a | | mao000a | | usn000a | |
|---|---|---|---|---|---|---|---|---|
| ICRF-Ext.2 | 206 | 659 | 263 | 228 | 279 | 257 | 280 | 254 |
| aus000a | | | 128 | 178 | 106 | 180 | 133 | 319 |
| gsf000a | | | | | 34 | 44 | 31 | 34 |
| mao000a | | | | | | | 42 | 52 |

The comparisons between the individual solutions and the current realization of the ICRF, ICRF-Ext.2, reveals shortcomings of the latter. The fact that the standard deviations of the parameters of the transformation model between recent solutions are about five–six times smaller than those obtained from comparisons with ICRF-Ext.2 indicates that the coordinates of most of the DEFINING radio sources should be improved.

Also, the results show that the solution aus000a differs significantly from the other three solutions. The solutions gsf000a, mao000a, and usn000a are close; however, there are systematic effects between them. It is interesting to note that the solutions gsf000a and usn000a are obtained with the same software and for the same set of data; nonetheless, there are systematic differences between them.

To study the systematic effects in catalogs of radio sources more solutions are necessary, especially those obtained with OCCAM and QUASAR software.

## 3. Comparisons of Time Series

Time series of source positions usually are estimated simultaneously with the Earth orientation parameters for each session. Therefore they are presented in its own CRF, unique for each session. Before starting an investigation of source variability, one has to transform the CRF solutions of each session onto some reference celestial frame. On the other hand, the length of arc connecting two radio sources is invariant to the chosen CRF. Therefore, studying the variability of the arc lengths, it is possible to infer the stability of the radio sources.

Time series of three arcs, which form a closed triangle with radio sources 0955+476, 2145+067 and 2234+282, are shown in Fig. 1. These arc lengths are evaluated using gsf001a. From the plots it is obvious to conclude that the radio sources 0955+476 and 2145+067 are stable, while the position of the source 2234+282 is varying with time.

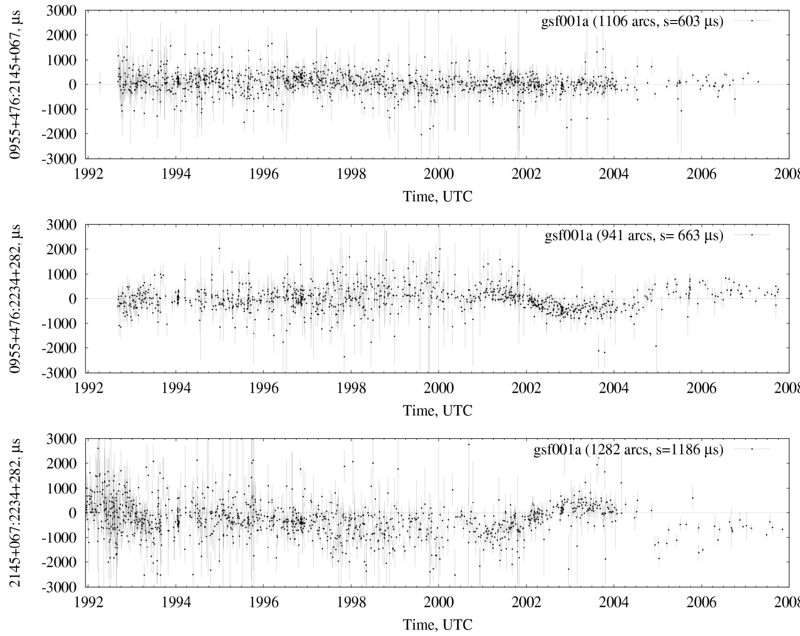


Figure 1. Time variability of the arc lengths between three radio sources

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## References

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