THE GAOUA SERIES OF COMPILED CELESTIAL REFERENCE FRAMES

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The GAOUA series of compiled celestial reference frames is obtained by using the original Kyiv arc length approach for combination of initial RSC solutions which are yearly submitted to the IERS CB by various VLBI Analysis Centers. The presentation is concerned with an analysis of accuracies of these individual and combined solutions and that of the ICRF.

KYIV ARC LENGTH METHOD

The history of the GAOUA (acronym used by the IERS to designate the Main Astronomical Observatory of NASU) series begins since 1989 when Y. Yatskiv and A. Kur'yanova [5] proposed and realized new approach to combine individual VLBI solutions. This approach combines a geometrical arc length method with a statistical evaluation of uncertainties of individual and compiled catalogues. The following items explain essentials of the approach (corresponding mathematical formulas can find in [2]):

- selection of "basic" catalogues of radio source (RS) positions as part of all the collected individual ones;
- search for defining RSs which are common for the selected "basic" catalogues;
- calculation of arc lengths (below simply "arcs") between all common defining RSs in each basic catalogue;
- intercomparison of the arcs for all basic catalogues, evaluation of catalogue weights, and determination of mean values of the arcs and "arc minus mean arc" residuals;
- construction of individual rigid frames based on the arcs and defined by positions of two selected RSs;
- construction of a combined rigid frame using the data of previous steps;
- alignment of this combined rigid frame to a standard celestial reference frame (the ICRF) and construction of a compiled reference frame under the following conditions: absence of a net rotation; minimum displacements among common RSs of the standard and compiled frames;
- extension of the reference frame realized by common defining RSs to the rest of RSs, involved in the process of constructing the compiled frame.

CONSTRUCTION OF THE GAOUA SERIES OVER 1997-2000

By using this method the 12 combined solutions were prepared in Kyiv on base of the individual solutions submitted to the IERS CB during 1989–2000 span (see [1], or of the recent publication [4]). Table 1 gives overview on the combined catalogues since 1997 when the RSC(WGRF)95 R 01 solution, known currently as the ICRF, was prepared by the IAU WGRF [1]. The Kyiv solutions obtained before 1996 were aligned to positions of the 23 primary RSs selected by the IERS and thus they are not included in Table 1. The frames are ordered as follows: basic frames, other ones, and compiled frame obtained. A calculation procedure follows the steps described above. Some distinctions were due to a number of common defining RSs. The more this number, the more is number of celestial zones, selected to adjust the rigid frame with the ICRF. Moreover, the different pairs of selected RSs were used to construct the rigid frames defined by this pair of RS. This circumstance is not critical because, in principle, any RSs' pair can be used in the method.

CONCLUSIONS

Analysis of results obtained gives a possibility to make the next conclusions:

Table 1: **List of VLBI frames used to construct the GAOUA compiled series over 1997–2000**. N is the number of RSs in a frame; N_d is the number of the defining RSs, which are common for the basic frames; σ_α and σ_δ are the averaged uncertainties in mas for right ascension and declination, respectively; W is the weight of the basic frame used for the rigid frame constructing; $\bar{\Delta\alpha_*}$ and $\bar{\Delta\delta}$ are the mean differences in terms of "Frame – ICRF" calculated for 212 defining RSs; $|\Delta\alpha_*|$ and $|\Delta\delta|$ are the m.r.s. of those differences

Frame	N	N_d	σ_α	σ_δ	W	$\bar{\Delta\alpha_*}$	$\bar{\Delta\delta}$	$\|\Delta\alpha_*\|$	$\|\Delta\delta\|$
	a) 1997								
RSC(USNO) 95 R 04	556	27	0.07	0.08	0.57				
RSC(GSFC) 95 R 01	550	27	0.12	0.09	0.33				
RSC(JPL) 95 R 01	287	27	0.14	0.21	0.03				
RSC(NOAA) 95 R 01	249	27	0.18	0.25	0.07				
RSC(GIUB) 95 R 01	89	5	0.17	0.24	–				
RSC(SHA) 95 R 01	45	3	0.06	0.08	–				
RSC(GAOUA)97 C 01	598	212	0.15	0.18	–	.00	.20	.27	.31
	b) 1998								
RSC(USNO)97 R 08	615	82	0.15	0.18	0.36				
RSC(GSFC)97 R 01	600	82	0.14	0.18	0.49				
RSC(JPL)97 R 01	287	82	0.20	0.28	0.15				
RSC(GIUB)97 R 01	266	26	0.78	0.59	–				
RSC(GAOUA)97 R 01	129	17	0.21	0.38	–				
RSC(GAOUA)98 C 01	631	212	0.11	0.13	–	.00	.00	.24	.26
	c) 1999-1								
RSC(USNO) 98 R 01	640	187	0.14	0.16	0.69				
RSC(GIUB) 98 R 01	580	187	0.18	0.21	0.22				
RSC(JPL) 98 R 01	522	187	0.46	0.52	0.09				
RSC(GAOUA)98 R 01	198	54	0.24	0.41	–				
RSC(GAOUA)99 C 01	655	212	0.11	0.12	–	–.01	–.05	.32	.30
	d) 1999-2								
RSC(GSFC) 99 R **	644	187	0.11	0.14	0.41				
RSC(USNO) 98 R 01	640	187	0.14	0.16	0.39				
RSC(GIUB) 98 R 01	580	187	0.18	0.21	0.15				
RSC(JPL) 98 R 01	522	187	0.46	0.52	0.06				
RSC(GAOUA)98 R 01	198	54	0.24	0.41	–				
RSC(GAOUA)99 C 02	673	212	0.08	0.09	–	.00	–.04	.26	.28
	e) 1999-3								
RSC(SHA) 99 R 01	720	205	0.15	0.18	0.09				
RSC(USNO) 99 R 01	652	205	0.12	0.14	0.46				
RSC(GSFC) 99 R **	644	205	0.11	0.14	0.25				
RSC(GIUB) 99 R 01	602	205	0.15	0.17	0.20				
RSC(IAA)99 R 01	506	82	0.46	0.56	–				
RSC(FFI)99 R 01	431	58	0.16	0.12	–				
RSC(GAOUA)99 C 03	726	212	0.06	0.07	–	.00	.00	.23	.27
	f) 2000								
RSC(SHA) 00 R 01	636	204	0.15	0.18	0.30				
RSC(GSFC) 00 R 01	624	204	0.11	0.13	0.42				
RSC(BKGI) 00 R 01	621	204	0.15	0.17	0.28				
RSC(IAA)00 R 03	312	81	0.13	0.20	–				
RSC(GAOUA) 00 R 01	191	47	0.22	0.39	–				
RSC(FFI)00 R 01	104	41	0.13	0.11	–				
RSC(GAOUA)00 C 01	669	212	0.07	0.08	–	.00	.01	.24	.26

$\Delta\alpha_* = \Delta\alpha \cdot \cos\delta$; ** – this frame is obtained directly from the GSFC

Table 2: **Rotational angles** $A1$, $A2$, and $A3$ of VLBI initial frames' axes to align its to those of the RSC(GAOUA)00 C 01 solution. The angles are calculated for common RSs of Table 1. σ is the averaged m.r.s. error of angles; all values in *mas*

Frame	$A1$	$A2$	$A3$	σ
RSC(SHA) 00 R 01	0.023	0.000	−0.014	0.008
RSC(GSFC) 00 R 01	0.008	0.023	0.003	0.008
RSC(BKGI) 00 R 01	0.021	0.009	−0.033	0.008
RSC(IAA)00 R 03	0.028	−0.004	0.154	0.043
RSC(GAOUA) 00 R 01	4.150	0.250	−0.045	0.120
RSC(FFI)00 R 01	0.023	−0.120	−0.760	0.120

- Uncertainties in right ascension are systematically better than those in declination for all Analysis Centers except for the FFI.
- Precision of the GAOUA series improves more than twice when uncertainties of initial frames improve only in 20 per cents. Likely, this peculiarity is connected with accumulation of observations.
- Two of the basic individual catalogues, the USNO and GSFC, have the same accuracy and during this span they have maximal weights. The weights of the basic solutions of other institutions are less more than twice except the last year. The GIUB solutions systematically differed a valuable rigid rotation with order of 0.5 mas around the ICRF. The BKGI solution has not this peculiarity (see Table 2 and tables in former papers).
- Axes of all GAOUA solutions align to those of the ICRF with accuracy 0.021 mas based on all 212 common defining radio sources.
- Comparisons between GAOUA solutions and the ICRF give zero mean differences in right ascension. Behavior of declination differences is more complex. While for the RSC(GAOUA)97 C 01 the big difference is explained by the effect of tropospheric gradient, not taken into account in some initial frames at 1995, one can see that the difference grows in the two first solutions of 1999. This effect can be introduced by the different subsamples of the ICRF sources used in the arc method. Thus, in Table 3 the defining RSs are listed with the differences more than 0.6 mas in any coordinate between last Kyiv solution RSC(GAOUA)00 C 01 and RSC(WGRF)99 R 01 (the ICRF–Ext–1). Almost all these RSs except 1604-333 have been registered already as those with big differences "RSC(GAOUA)99 C 03 – RSC(WGRF)99 R 01". Additional calculation were carried out to clear up the question on influence of errors of initial catalogues on the combined solution. The result is that only deviations of three southern RSs (0629-418, 1604-333, and 1718-649) can be explained by this manner.

Table 3: **List of large positional differences of the defining RSs** in terms of "RSC(GAOUA)00 C 01 – RSC(WGRF)99 R 01". σ_α and σ_δ are the GAOUA uncertainties; all values in *mas*

RS Designation	$\Delta\alpha$	σ_α	RS Designation	$\Delta\delta$	σ_δ
1604-333	+0.94	0.64	1604-333	−0.78	0.22
2312-319	−0.60	0.20	2312-319	−1.13	0.24
0138-097	+1.64	0.10	0440-003	−1.08	0.09
1143-245	−0.87	0.09	0458+138	−0.84	0.29
1448+762	+0.88	0.24	0812+367	+0.71	0.07
			1616+063	−0.61	0.13
			2059+034	−0.66	0.09

Acknowledgements. Authors are grateful to the staff of the Central Bureau of the IERS as well as to Dr. Chopo Ma (GSFC) for providing us the initial VLBI reference frames used in this work.

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