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综合河外射电源表的编制方法评述

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摘 要

简要介绍了编制综合河外射电源表的几种方法，分析了它们各自的特点。详细讨论了 IERS 编制方法及其系列综合表中存在的一些问题，并对这些问题提出了一些改进意见。

关 键 词 参考系 — 星表 — 方法：数据分析

A Review on the Compilation Methods of Combined Catalogues of Extragalactic Radio Sources

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Abstract

Several compilation methods of combined catalogues of extragalactic radio sources are reviewed and their characteristics are analyzed briefly. Extensive discussions are performed about the IERS compilation method and its resulting catalogues. Some considerations of the authors are given in this paper accordingly.

Key words reference systems—catalogs—method:dataanalysis

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1 Introduction

The idea of using extragalactic objects to define the celestial reference frame is quite old, even before there was proof that such objects existed. Any object sufficiently distant would have no detectable proper motion, thus it would be more desirable to make use of it to define the celestial reference frame than stars.

Since the emergence of the modern radio astrometric technique in 1960's, the observation precision has been improved continuously and now it reaches at the level of 1mas, which laid an indispensable foundation of establishing the high precision extragalactic radio celestial reference frame.

The extragalactic radio celestial reference frame is materialized by catalogues of extragalactic radio sources. These catalogues can be classified into individual (or observation) catalogues and combined catalogues according to the difference in the compilation method. The individual catalogue is constructed directly from VLBI observation data and the combined catalogue is a combination of individual catalogues based on a certain model and algorithm. Several combination methods and their characteristics were introduced and analyzed briefly in this paper. These methods are the Walter's method [1−3], the Yatskiv & Kuryanova's method [4] and the IERS method.[5−10]

2 The Walter's combination method

The Walter's combination method is one of the earliest proposed methods. Its primary equation is as follows:[1]

$$\begin{aligned} b + \Delta {C_i}^b &= b_i, \quad i = 1, ..., n, \\ \sum_{i=1}^{n} \Delta {C_i}^b &= 0, \end{aligned} \tag{1}$$

where b represents the right ascension and the declination of a specified source in the combined catalogue,and b_i represents those in the i-th individual catalogue. $\Delta {C_i}^b$ is the zero-point correction to a specified observation and n is the number of the observations. Each of the two coordinates of a specified source in the combined catalogue and the zero-point corrections to observations can be deduced by solving Eqs.(1).

Afterwards, Eqs.(1) is developed into the following form[2,3]:

$$\begin{aligned} \Delta b + \Delta C_i &= b_i - b_0, \quad i = 1, ..., n, \\ \sum_{i=1}^{n} W_i \Delta C_i &= 0, \end{aligned} \tag{2}$$

where Δb and $\Delta C_i (i = 1, ..., n)$ are the unknowns, Δb representing the correction to the approximate position b_0, and ΔC_i representing the systematic correction of the i-th catalogue in the sky area defined by the object's position. The observation is denoted as

b_i, which stands for right ascension or declination. W_i is the weight of the *i-th* individual catalogue and is evaluated based on the mean coordinate uncertainty of the catalogue.

Evidently, the introduction of b_0 and W_i in Eqs. (2) benefits improving the solution precision, but Eqs. (1) and Eqs. (2) are still basically similar. If we sum up Eqs. (1) and Eqs. (2) through all the individual catalogues, we will get the following relations:

$$b = \frac{1}{n}\sum_{i=1}^{n} b_i, \tag{3}$$

$$\Delta b + b_0 = \frac{1}{n}\sum_{i=1}^{n} b_i - \frac{1}{n}\sum_{i=1}^{n} \Delta C_i. \tag{4}$$

Therefore, the source coordinates in the Walter's combination catalogue are mean values of the coordinates in all the individual catalogues. The solution of Eqs.(1) is a direct mean and the solution of Eqs.(2) contains considerations of the observation precision of individual catalogue but is different from the usual weighting way. The orientation of the combined catalogue is not specified clearly. The difference in orientation and the local relative deformation among individual catalogues are not cleared out. In addition, the combined catalogue can only contain common sources among individual catalogues, which does not make use of all the observations.

3 The Yatskiv and Kuryanova's method

Drs. Yatskiv & Kuryanova developed a new approach to the construction of a compiled catalogue from observation catalogues of extragalactic radio sources.[4] The positions of the sources common to all individual catalogues are used for combination solution and the individual catalogues are assumed to be independent of each other. The combined catalogue was constructed in the following steps:

(a) calculation of the lengths of arcs between radio sources: S_{ij}^k;

(b) comparison of arcs in different catalogues: (S_{ij}^k, S_{ij}^l);

(c) estimation of mean value of $\overline{S_{ij}}$ and residuals: $\delta {S_{ij}}^k = S_{ij}^k - \overline{S_{ij}}$;

(d) construction of individual reference frames defined by two selected radio sources;

(e) construction of the combined catalogue defined by the two radio sources;

(f) construction of compiled radio frame under the conditions: no net rotation and displacements among radio sources.

The purpose of the steps a,b and c is to construct the net arcs among the radio sources, which is free from the orientation of the radio reference frame, and to estimate the weights of individual catalogues. For the construction of the reference frame by two radio sources the positions of the radio source 0234+285 and 0851+202 were used.

In the Yatskiv & Kuryanova's method, the effect of the orientation difference among individual catalogues on the combined catalogue is excluded and the orientation is defined explicitly. However, this method is expected to be improved in aspects such as:

- The mean value of the arc length contains to some extend the local relative deformations among individual catalogues;
- The selection method of primary sources is too simple to be satisfied;
- This compilation method does not contain information about how to densify the primary radio reference frame, therefore it should be improved.

4 The IERS combination method

The IERS combination method is more comprehensive and systematic than the above two methods. It consists of several aspects such as selecting observation catalogues, selecting primary sources, establishing the fundamental reference frame, densifying the fundamental reference frame, defining or maintaining the fundamental reference frame and so on.[5−10] All these aspects are introduced briefly in this paper.

4.1 The data

All the VLBI data analysis centres around the world submit their individual extragalactic reference frames to IERS every year. These centres include the Goddard Space Flight Centre (GSFC), the Jet Propulsion Laboratory (JPL), the National Geodetic Survey (NGS), the United States Naval Observatory (USNO), the National Astronomical Observatory, Mizusawa Branch (NAOMZ), Shanghai Observatory (SHA) and so on. VLBI observations is mainly acquired from the Crustal Dynamics Project (CDP), the International Radio Interferometric Surveying (IRIS), the Navy VLBI Network (NAVNET), the Deep Space Network (DNS) and other national VLBI networks.

Taking the source number, the sky coverage, the VLBI network, the observation accuracy, the observation history, the reduction algorithm and so on into consideration, IERS classifies individual catalogues into definition (or maintenance), densifying and comparison catalogues. Table 1 lists the individual catalogues used to establish the IERS celestial reference frame from 1988 to 1993. N, S and D represents respectively the number of sources in every individual catalogue, the estimate of the coordinate accuracy and the range of declination. Table 1 shows clearly that the individual catalogues constructed in every VLBI data analysis centre are improved from 1988 to 1993 in the number of sources, the observation accuracy and the sky coverage. The number of sources in the IERS combined catalogue was increased to twice of the original, the coordinate accuracy was improved from 26.95mas to 1.42mas and the sky coverage was also extended to the polar area.

Table1 Individual catalogues used to establish the IERS celestial reference frames

Combined catalogue			Definition catalogue			Densifying catalogue			Comparison catalogue		
N	S (mas)	D (°)	N	S (mas)	D (°)	N	S (mas)	D (°)	N	S (mas)	D (°)
RSC(IERS) 88 C 01			RSC(GSFC) 88 R 01			RSC(GSFC) 88 R 02					
228	26.95	-30,+80	56	1.17	-30,+80	166	15.68	-30,+85			
			RSC(JPL) 88 R 02								
			142	3.61	-45,+79						
			RSC(NGS) 88 R 01								
			37	0.63	-30,+79						
RSC(IERS) 89 C 01			RSC(GSFC) 89 R 01			RSC(JPL) 89 R 03			RSC(NAOMZ) 89 R 01		
209	14.83	-45,+85	64	0.50	-30,+81	195	4.03	-45,+85	20	/	- 4,+79
			RSC(JPL) 89 R 02						RSC(SHA) 89 R 01		
			189	2.68	-45,+85				14	/	0,+79
			RSC(NGS) 89 R 01								
			50	0.50	-30,+79						
RSC(IERS) 90 C 01			RSC(GSFC) 90 R 01						RSC(GSFC) 90 R 02		
228	3.25	-80,+85	72	0.53	-30,+82				72	/	-30,+82
			RSC(JPL) 90 R 02						RSC(NAOMZ) 89 R 01		
			197	1.89	-45,+85				20	/	-04,+79
			RSC(NGS) 90 R 01						RSC(SHA) 88 R 01		
			70	0.75	-80,+80				19	/	-04,+79
			RSC(USNO) 90 R 02								
			77	1.05	-41,+79						
RSC(IERS) 91 C 01			RSC(GSFC) 91 R 04						RSC(GSFC) 91 R 01		
396	1.99	-84,+85	334	1.63	-84,+85				117	/	-81,+81
			RSC(JPL) 91 R 01						RSC(GSFC) 91 R 02		
			241	1.44	-45,+85				120	/	-81,+81
									RSC(GSFC) 91 R 03		
									234	/	-81,+85
									RSC(NAOMZ)91 R 01		
									54	/	-30,+79
									RSC(NGS) 91 R 01		
									77	/	-81,+79
									RSC(USNO) 91 R 02		
									80	/	-41,+79
RSC(IERS) 92 C 01			RSC(GSFC) 92 R 01						RSC(NAOMZ)92 R 01		
422	1.74	-82,+85	357	1.30	-82,+85				125	/	-81,+81
			RSC(JPL) 92 R 01						RSC(NOAA) 92 R 01		
			282	0.99	-45,+85				84	/	-81,+82
									RSC(USNO) 92 R 03		
									113	/	-81,+79
RSC(IERS) 93 C 01			RSC(GIUB) 93 R 01						RSC(GSFC) 93 R 01		
504	1.42	-82,+86	44	0.44	-81,+79				154	/	-81,+82
			RSC(GSFC) 93 R 05						RSC(GSFC) 93 R 04		
			449	1.92	-82,+86				187	/	-81,+82
			RSC(JPL) 92 R 02						RSC(JPL) 93 R 01		
			333	1.29	-82,+85				284	/	-45.+85
			RSC(NOAA) 93 R 02						RSC(JPL) 93 R 02		
			107	0.86	-82,+82				286	/	-45,+85
			RSC(USNO) 93 R 09								
			123	1.01	-81,+82						

4.2 The source selection method

All the sources in the IERS combined catalogue are classified into primary, secondary and complementary sources. Primary sources are used to define the IERS celestial reference frame. Secondary and complementary sources are used to densify the IERS celestial reference frame. The selection criteria of secondary and complementary sources are fixed, i.e., the radio sources common to at least two individual catalogues which are not in the primary list are defined as the secondary sources of the combined catalogue, while those belonging to only one individual catalogue are the complementary sources. The selection criteria of primary sources have been changing since 1988. The criteria from 1988 to 1993 are summarized as follows:

• 1988: Primary sources are selected based on geometrical and physical considerations such as source structure, sky distribution, time stability and number of observations.

• 1989: The list of primary sources to be included in the 1989's IERS celestial reference frame was elaborated starting from the 1988 list of primary sources. For this purpose a preliminary version of the RSC (IERS) 89 C 01 celestial reference frame has been performed, following the steps of the previous realization, and it has been compared to the RSC(IERS) 88 C 01 reference frame. Only primary sources from the previous list which had changed their coordinates less than twice their uncertainty in the least squares solution are kept, and new sources with coordinate differences smaller than 1σ are added.

• 1990: The sources retained as primary are those which show position differences smaller than $0''.0015$ in all possible comparisons between the four individual catalogues included in the combination, after the relative rotations being taken out.

• 1991: Comparisons of all the possible pairs of the eight individual frames were performed to determine their relative orientations and to detect regional deformations. After evaluating the rotation angles between frames with a weighted least squares adjustment, a χ^2-test was performed on the post-fit residuals. In order to select in each possible comparison between individual VLBI frames the set of radio sources giving a normal distribution of post-fit residuals, outliers were eliminated in successive steps until a unit χ^2 was achieved. Thus, for each pair of catalogues, a set of candidate primary sources are obtained. From the intersection of all the sets, provided that each source was at least in three individual frames, a final list of 57 primary sources were elaborated.

• 1992: The selection of primary sources is based on the same algorithm of 1991 but comparisons are only performed on pairs of independent individual catalogues.

• 1993: Comparisons of all possible pairs of individual maintenance frames were performed to determine their relative orientations and to detect regional deformations. Statistical tests are performed on the post-fit residuals to eliminate outliers. Thus, for each pair of catalogues, a set of candidate primary sources are obtained. From the intersection of all the sets, a final list of 153 primary sources are obtained. Source structure information was taken into account when available.

4.3 Establishment of the fundamental reference frame

The fundamental celestial reference frame is a free oriented frame, which is defined by the coordinates of primary sources.[11] Thus, the establishment of the fundamental celestial reference frame is equivalent to determine the (initial) coordinates of primary sources.

Take $A_1(i), A_2(i), A_3(i)$ as the rotation angles around the x-, y-, z-axis from the i-th definition catalogue to the combined one. The coordinates of the j-th primary source in the i-th definition catalogue and the combined one are $(\alpha_{ij}, \delta_{ij})$ and $(\alpha_{cj}, \delta_{cj})$, then there are the following relations:

$$\begin{aligned} A_1(i)\cos\alpha_{ij}\tan\delta_{ij} + A_2(i)\sin\alpha_{ij}\tan\delta_{ij} - A_3(i) + \alpha_{cj} &= \alpha_{ij}, \\ -A_1(i)\sin\alpha_{ij} + A_2(i)\cos\alpha_{ij} + \delta_{cj} &= \delta_{ij}. \end{aligned} \tag{5}$$

Three auxiliary parameters attached to the i-th individual frame are introduced when the 1993's IERS combined catalogue was constructed. These parameters are intended to absorb some regional deformations, mainly in declination. Thus Eqs.(5) is developed into the following form:

$$\begin{aligned} A_1(i)\cos\alpha_{ij}\tan\delta_{ij} + A_2(i)\sin\alpha_{ij}\tan\delta_{ij} - A_3(i) & \\ -B_1(i)\sin\alpha_{ij}/\cos\delta_{ij} + B_2(i)\cos\alpha_{ij}/\cos\delta_{ij} + \alpha_{cj} &= \alpha_{ij}, \\ -A_1(i)\sin\alpha_{ij} + A_2(i)\cos\alpha_{ij} & \\ -B_1(i)\cos\alpha_{ij}\sin\delta_{ij} - B_2(i)\sin\alpha_{ij}\sin\delta_{ij} + B_3(i)\cos\delta_{ij} + \delta_{cj} &= \delta_{ij}. \end{aligned} \tag{6}$$

The relative rotation parameters from the definition catalogues to the combined one and the coordinates of primary sources in the combined catalogue (as well as the 1993's auxiliary parameters) are evaluated with a weighted least squares adjustment of Eqs.(5) or (6) . Equations are weighted according to the standard deviations of source coordinates in each definition catalogue.

4.4 Densifying the fundamental celestial reference frame

To densify the celestial reference frame is to determine the coordinates of the secondary and complementary sources. After the orientations of the definition and densifying catalogues are adjusted to that of the combined catalogue, the coordinates of non-primary sources are determined. Rotation angles from definition catalogues to the combined one have been determined together with the coordinates of primary sources in the combined catalogue from Eqs.(5) or (6). Rotation angles from the densifying catalogues to the combined one are evaluated from Eqs.(5) or (6) based on the coordinates of primary sources in the combined and densifying catalogue. At this point, A_1, A_2 and A_3 (as well as B_1, B_2 and B_3) are unknowns, while the rest quantities in Eqs.(5) (or (6)) are the knowns.

4.5 The determination of the frame orientation

The catalogue compiled in Section 4.4 was freely oriented and all the coordinates are not the final coordinates, therefore the orientation of the catalogue must be fixed. The orientation of the 1988's IERS celestial reference frame is the initial orientation of the IERS celestial reference frame. It is defined by the following equation:

$$\sum_{i=1}^{3} A_{ic}(l) = 0, \tag{7}$$

where $i = 1, 2$ and 3 corresponds respectively to RSC (GSFC) 88 R 01, RSC (JPL) 88 R 02 and RSC (NGS) 88 R 01. $A_{ic}(l)$ with $l = 1, 2, 3$ represents respectively the rotation angle around x-, y-, z-axis from the 1988's IERS combined catalogue to the *i-th* individual one.

The orientations of the IERS catalogues from 1989 to 1993 are determined based only on the primary sources of a specified year. A specified catalogue is aligned on its preceding one based only on its primary sources by a weighted adjustment of Eqs.(5) or (6), and that is the maintenance process of the IERS celestial reference frame. It can be deduced that in the process of the 1988's IERS combined catalogue being constructed, Eqs.(5) and (7) are solved together, which means that the coordinates of primary sources is determined together with the orientation of the 1988's IERS combined catalogue. While, in the process of the source coordinates being determined in 1989 to 1993, the initial source coordinates are firstly determined by solving Eqs.(5) or (6) and a freely oriented combined catalogue is constructed, then this catalogue is aligned on its preceding one and the specified IERS combined catalogue is finally obtained.

5 A discussion about the IERS combination method and the IERS combined catalogues

The IERS combination method is a tremendous influential one. A combined catalogue is constructed every year as a materialization of the IERS celestial reference frame. The history of the IERS combined catalogue is only a few years and the combination method has been developing and improving. Several considerations of the authors of this paper are proposed as follows concerning the IERS combination method and its corresponding compiled catalogues.

5.1 The selection of data

The fact that the VLBI observations available in NGS have been a part of the data available in GSFC[12–16] leads to the dependence between the individual catalogues submitted to IERS by the two centres. If individual catalogues of the two centres are taken as definition frames at the same time, it is equivalent to increase the weight of the

NGS VLBI network (Polaris/IRIS), and therefore the objectivity of the IERS combined catalogue may not be true. Though the individual catalogues of NGS were not definition catalogues any more since 1991, the dependence between other definition catalogues (such as RSC(GSFC) 93 R 05 with RSC(JPL) 92 R 02) still deserves discussion. Every independent analysis centre always expects that more data available is better, and that may lead to the situation that a same set of data be analyzed by several centres. If only from the point of view to compile the combined catalogue, IERS as a known internationally analysis and service centre should be responsible for the coordination of the data distribution in order to select flexibly the individual catalogues which are independent of observation network, analysis software etc. to guarantee the objectivity and practical value of the combined catalogue.

5.2 The source selection criteria

The source selection criteria were developed in a way from emphasizing on the source structure, time stability, number of observations, sky distribution and other objective aspects of sources to emphasizing on statistical analysis (the post-fit residuals). Test shows that selection criteria with different emphases will lead to different sets of selected radio sources. The observation background (such as the observation frequency, history, change in environment etc.) of sources and the individual characteristics (such as the structure, spectral power flux density, sky location and so on) of sources are different from each other, and hence the reference frames defined by two different sets of radio sources will be certainly different. Therefore, the selection criteria should be improved continuously and comprehensive criteria should be utilized. If important change is performed to the criteria, the correlation between the old and the new should be studied to conform the stability of orientation of the reference frame.

Some radio sources for geodesy have been used more than ten years since 1980. The observation precision has reached a considerable high level and the knowledge of the sources is quite complete. While, every individual catalogue contains some radio sources which are observed extensively or observed routinely. These radio sources are qualified representatives of the individual catalogue. They represent the reference frame materialized by the individual catalogue as well as the highest precision of it. These sources are highly qualified candidates for primary sources of the combined catalogues. Though the IERS combination method emphasizes the consistency of the individual catalogues, it pays insufficient attention to the representative character of the sources in individual catalogues, which deserves further study and discussion.

The small rotation angle model of a comparison between radio source catalogues is a model of a mathematical mean of all coordinate differences. The rotation parameters will affected by the local relative deformations accordingly. If different sets of sources are compared, there may be different rotation parameters and then different sets of residuals.

Therefore, the post-fit residuals are relative and dependent on each other, which are not suitable to evaluate the precision or to judge the consistency of the source coordinates.

If there are relative rotations between individual catalogues, the coordinates of the common sources are different accordingly. If the consistency among coordinates of some sources is relatively high (i.e. regional deformations are very small), the lengths of common arcs connecting the sources should be equal to each other approximately in spite of the existence of relative rotations between frames. If relative deformations exist among coordinates of some sources, these deformations should be reflected to some extent on the length differences of common arcs. Therefore, by comparing the lengths of the common arcs, we can detect local relative deformations between catalogues without the effect of the relative orientations of catalogues, and can select the sources with relatively high consistency of coordinates to define the reference frame. We name this method for selection of primary sources as the arc-length-difference selection method. Tests show that this method is feasible and effective.[17]

5.3 The orientation maintenance method

The orientation of the IERS celestial reference frame is maintained based on all the primary sources of a specified combined catalogue and it is easy to understand that the primary sources in every IERS catalogue have the highest coordinate precision. A set of primary sources could be modified. Some perfectly qualified sources may not be fully observed and so are still used as non-primary sources. While some primary sources may be rejected when they are deeply recognized. Also, different selection criteria can lead to different sets of primary sources.[17]

If the orientation of a specified combined catalogue is to be aligned to its preceding one on basis of all the primary sources, among which some are non-primary ones of the preceding year with relatively low coordinate precision (even with systematic deviation), such alignment should decrease the precision of orientation. If this alignment is performed based only on common primary sources, the effect of non-primary sources on the alignment precision can be minimized. Therefore, the common parts of the two frames will be surely free from relative rotation (i.e, the frame is defined only by primary sources). It is more reasonable theoretically than the IERS maintenance method. Tests show that this orientation maintenance method is feasible.[20]

5.4 Auxiliary parameters

If two radio source catalogues R_1 and R_2 have small orientation difference and the rotation parameters from R_1 to R_2 are A_1, A_2 and A_3 (corresponding to x-,y- and z-axis respectively). Then the declination difference of a common source can be expressed as the following formula:[21]

$$\delta_1 - \delta_2 = B_i \sin(\alpha_2 + \phi_i) + \nu, \tag{8}$$

where

$$\begin{aligned} B_i &= (A_1^2 + A_2^2)^{1/2}, \\ \phi_i &= -\arctan(A_2/A_1), \end{aligned} \tag{9}$$

α_2 is the right ascension of a specified source in R_2; ν is the residuals corresponding to A_1, A_2 and A_3. If the sources are numerous enough, the series of ν will be white noise.

Eqs.(8) and (9) show that the trend of the distribution of differences in declination versus the right ascension is a sinuous curve with white noise. The amplitude and phase of the curve are determined only by the rotation parameters between the two frames. On the contrary, we can judge whether the orientations of the two frames are consistent or not according to the distribution trend (amplitude and phase) of the declination difference of sources versus right ascension. We can also judge this consistency by the curve of the right ascension differences versus right ascension though it is relatively complex to do so.

The distribution of the declination differences of the common sources in RSC (IERS) 92 C 01 and RSC (IERS) 93 C 01 versus right ascension is shown in Fig.1, where P, A and nP represents respectively the primary, all and non-primary sources. "A:P" means the sources which are common to all the 1992's radio sources and all the 1993's primary sources, and other denotations can be deduced in the same way as "A:P". Fig.1 shows that the curve with nonzero amplitude and phase. The amplitude is bigger than 0.1mas and the phase is about 50°, and that indicates a noticeable orientation difference between the two combined catalogues.

Rotations between the two catalogues obtained by a weighted adjustment of Eqs.(5) are listed in Table 2, which shows that the corresponding angles among different combinations of sources are consistent with each other. Table 2 and Fig.1 reflect identical phenomena which can be examined by Eqs.(8) and (9) . Therefore, there exists orientation difference between the two frames.

Reference [10] lists the corresponding rotations which are obtained by adjustment of Eqs.(6). The angles are as follows:

$$\begin{aligned} A_1 &= 0.000 \pm 0.027\text{mas}, \\ A_2 &= 0.001 \pm 0.025\text{mas}, \\ A_3 &= 0.000 \pm 0.020\text{mas}. \end{aligned} \tag{10}$$

The corresponding auxiliary parameters are as follows:

$$\begin{aligned} B_1 &= -0.152 \pm 0.024\text{mas}, \\ B_2 &= 0.154 \pm 0.025\text{mas}, \\ B_3 &= -0.227 \pm 0.023\text{mas}. \end{aligned} \tag{11}$$

Table 2 Relative rotations from the 1992's IERS catalogue to the 1993's one

Unit: 1mas

Source Type	A_1	A_2	A_3
P:A	0.05±0.04	0.15±0.04	−0.08±0.04
A:A	0.07±0.02	0.10±0.02	−0.02±0.02
P:P	0.04±0.05	0.15±0.05	−0.07±0.04
A:P	0.07±0.03	0.12±0.03	−0.01±0.03
P:nP	0.08±0.09	0.13±0.09	−0.08±0.08
nP:P	0.11±0.04	0.10±0.04	0.04±0.04

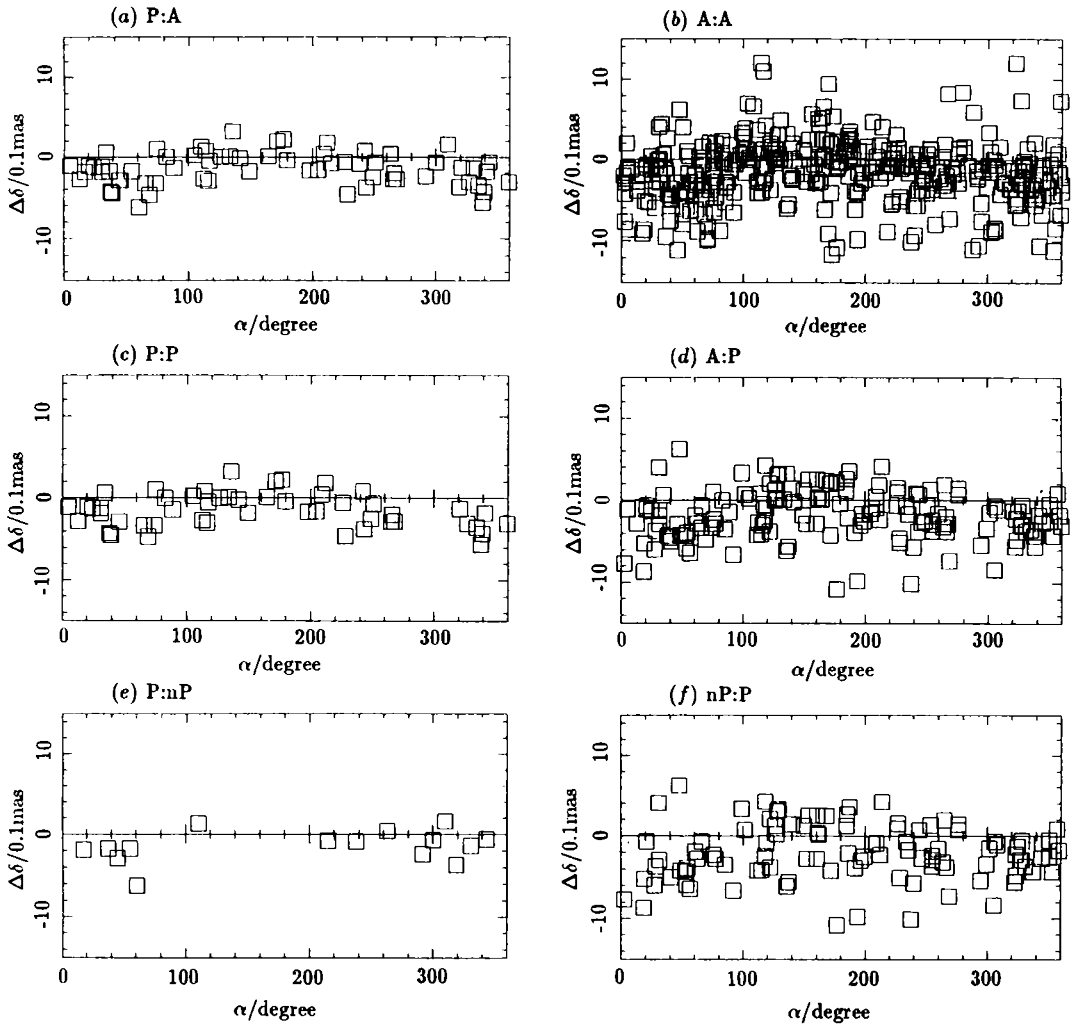

Fig.1 The distribution of the declination difference of common sources in the 1992's and 1993's IERS combined catalogues versus the right ascension

So the orientations are consistent and the relative local deformations exist (mainly in the declination). But this conclusion can not be derived from Fig.1, which shows the orientation difference exists. Fig.1 is plotted directly according to the coordinates listed in catalogues without any mathematical amelioration and so it is objective. Therefore, it is an objective conclusion that the orientation difference exists between the 1992's and 1993's IERS combined catalogues. This difference is about 0.15 ± 0.05mas.

In the recommendations of the IAU Reference Frame Working Group, the orientation maintenance of frame was especially emphasized. It is pointed out that when adjustment (such as deletion, substitution or increase) is performed to a set of radio sources, materializing a reference frame, the orientation of the frame should be assured with no change.[25] The introduction of the three auxiliary parameters resulted in the variation of the IERS reference frame orientation (about 0.15mas) and the coordinate difference (about 0.1mas) in declination of sources (as false proper motion). This variation or difference should be corrected in order to avoid the unnecessary problems in the construction of the terrestrial reference frame and in the determination of the Earth orientation parameters.

5.5 The IERS combined catalogues

There are problems of inconsistency of the coordinate reference system in the IERS combined catalogues from 1988 to 1991 because of calculation errors. The coordinate system of some non-primary sources is deviated by about 4mas from that of the primary sources.[22,23] The real orientation of the 1988's IERS combined catalogue differed from the theoretically expected directions about 0.2mas.[17] Because of the inconsistency of the coordinate system problem, the orientation of the IERS catalogues from 1989 to 1992 changed year by year. The largest shift among the corresponding axes accounts to more than 0.5mas.[24] Theoretically speaking, these problems cannot be ignored, and they should be at least recognized and amended by essential measures.

At the end of this review, though there are problems about the IERS combination method and its corresponding catalogues, there are still some problems which even deserve further discussion. But these problems are really blemishes in an otherwise perfect thing. The IERS combination method has perfect conceptions. The sources are selected to define the IERS celestial reference frame according to the criteria, such as sources with simple structure, enough observations, and a capability of representing (under certain criteria) the definition catalogus. The sources observed which are non-primary sources are used to densify the IERS frame. The source coordinates are improved on the basis of newly available observations under certain criteria and the orientation of frame is maintained with quite high precision. This is the creation of IERS, which reflects exactly the spirits of the related recommendations of the IAU Reference Frame Working Group.[25] The IERS combined radio source catalogues have high precision. There is no optical counterpart of the IERS catalogues. The IERS catalogues are the solely series of radio source catalogues which are internationally accepted and widely applied to practice as well as scientific research.

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