Maintenance of the ICRF using the most stable sources

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Abstract. In preparation for the next realization of the VLBI-based International Celestial Reference Frame (ICRF), we have studied representations of the ICRS by different sets of selected sources. The axes of the ICRS are realized by the coordinates of sources qualified as *defining* object in the ICRF. A different selection of sources has been proposed by Feissel-Vernier based on an analysis of time series of radio source coordinates. We studied the impact of the two sets of sources by using the results of recent analyses representing the state of the art for the next ICRF realization. We shown that the non-rotation condition of the axes with respect to ICRF would not be realized with a better accuracy than 20 μas. We notice an indetermination of 10 to 40 μas in right ascension axes and the presence of an equator tilt with respect to the ICRF of about 22 μas. We conclude that the use of proposed set of stable sources would allow an improvement in the maintenance of the ICRF axes and in the source position precision, to reach 30 μas for the 253 stable sources.

1 Introduction

As was originally proposed by Guinot (1979), the IAU, in its 1991 Recommendations on Reference Systems (Bergeron, 1992), decided to select distant extragalactic objects as the basis of its new celestial reference system and to adopt directions that would remain fixed with respect to a selected set of these objects. Continuity between the old and new system was mandatory so that these directions would be consistent with their previous realizations, i.e., the pole and origin of right ascensions in the new reference system should be close to the FK5 pole and right ascension origin, within the uncertainties of the FK5. A fundamental advantage of selecting extragalactic objects is that they are so distant that their proper motions are currently undetectable, even by the most precise techniques. The choice of extragalactic objects to realize the fiducial directions was made possible by the availability of a mature and highly precise observing technique, Very Long Baseline radio Interferometry (VLBI).

At its 23rd General Assembly in August 1997, the IAU decided (Appenzeller, 1998),

- That, as from 1 January 1998, the IAU celestial reference system shall be the International Celestial Reference System (ICRS) as specified in the 1991 IAU Resolution on Reference Systems and as defined by the International Earth Rotation Service (IERS);
- That the corresponding fundamental reference frame shall be the International Celestial Reference Frame (ICRF) constructed by the IAU Working Group on Reference Frames (WGRF);
- That the Hipparcos Catalogue shall be the primary realization of the ICRS at optical wavelengths;
- That IERS should take appropriate measures, in conjunction with the IAU Working Group on Reference Frames, to maintain the ICRF and its ties to the reference frames at other wavelengths.

The ICRS (Arias et al., 1995) complies with the conditions specified by the 1991 IAU Recommendations. The origin of the ICRS axes is located at the barycentre of the solar system and the directions of its axes are fixed relative to distant extragalactic sources. For the sake of continuity with the FK5 pole, the ICRS pole is in the J2000.0 direction defined by the conventional IAU models for precession (Lieske et al., 1977) and nutation (Seidelmann, 1982). The origin of right ascensions is also defined consistently with that of the FK5 by fixing the right ascension of 3C 273B to the Hazard et al. (1971) FK4 value transformed to the J2000(FK5) System (Kaplan et al., 1982).

The ICRF consists of a catalogue of equatorial coordinates of 608 extragalactic radio sources derived from about 1.6 million observations accumulated by a worldwide network over 1979-1995. It was derived by a sub-group of the WGRF that agreed on an optimal data analysis strategy (Ma et al., 1998). It includes three lists of objects, with

- the most compact and best observed 212 *defining* sources, with a median uncertainty of 0.4 mas on individual positions,
- compact sources (294) named *candidate* whose positions are likely to be improved when more observations are accumulated in the future,
- sources less appropriate for astrometric purposes (102) named *other*, but which are provided for possible ties of reference frames at other wavelengths or for other objectives.

The accuracy of the ICRF realization of the ICRS axes is estimated to be 20 μas (Ma & Feissel, 1997).

The Hipparcos stellar reference frame was astrometrically aligned to ICRF to within ± 0.6 mas for the orientation at 1991.25 and to within ± 0.25mas/a for the spin (Kovalevsky et al., 1997). Consequently the Hipparcos Catalogue provides the master realization of the ICRS in the optical domain with the above uncertainties. As the complete FK5 catalogue was observed by Hipparcos, the directions of the pole and origin of right ascensions of the FK5 relative to Hipparcos were determined, with an accuracy of 2.3 mas at the mean epoch J1991.25. The directions of the FK5 axes in the ICRS were estimated (Fig. 1), taking into account the propagation of the uncertainty of the Hipparcos tie to the ICRS (Mignard & Froeschlé, 1997).

Using a state of the art precession-nutation model (Mathews et al., 2002), the analysis of long VLBI series of the observed motion of the celestial pole in the ICRS allows us to derive the coordinates of the mean pole at J2000.0 in the ICRS (IERS, 2001). Combining VLBI and LLR Earth orientation and terrestrial reference frames and using the JPL planetary ephemeris DE200, Folkner et al. (1994) derived the offset of the mean equinox at J2000.0 relative to the ICRS origin of right ascensions. Resulting values are summarized in Fig. 1.

Practical consequences of the adoption of the ICRS/ICRF are given in Feissel & Mignard, 1998.

The main objectives of the maintenance and extension of the ICRF were:

- to provide positions of extragalactic sources observed since July 1995,
- to refine the positions of candidate sources from additional observations,
- to monitor sources to ascertain whether they continue to be suitable for their use in the ICRF,
- to improve the data analysis.

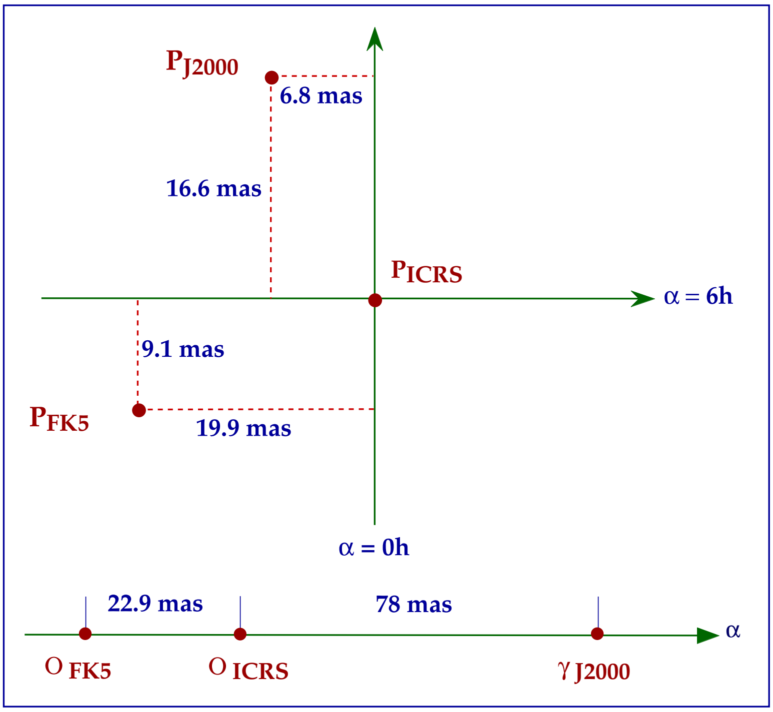

Fig. 1. Location of the poles and the origin of right ascensions of the FK5 and that of the celestial pole and equinox at J2000.0 with respect to the ICRS.

Since 1998, two extensions of the ICRF have been elaborated, ICRF-Ext.1 (IERS, 1999) and ICRF-Ext.2 (Fey et al., 2004), they were both oriented towards the densification of the frame.
The consistency of each maintenance/extension catalogue with the ICRF and the ICRS is of fundamental importance. Improvements in the VLBI analysis can be made but without introducing systematic effects or changing the positions generally beyond the ICRF error threshold. Consequently the main features of the ICRF analysis (Ma et al., 1998) were retained for the extension solutions and only limited changes were made to ensure better modelling.

The data added to the ICRF in ICRF-Ext.1 spanned from December 1994 through April 1999 and were obtained from both geodetic and astrometric observing programs. In the 600,000 observations from 461 sessions added, 59 *new* sources were observed. The ICRF-Ext.1 catalogue contains the positions and uncertainties of 667 extragalactic radio sources (IERS, 1999). As in the original ICRF, the formal errors were inflated applying an additive variance of 0.25 mas and a scaling factor of 1.5 to provide more realistic errors. The positions and errors of the *defining* sources are those of the ICRF one. For *candidate* and *other* sources the refined positions and errors reflect the changes in the data set and the analysis (Gontier et al., 2002). The time series of source positions have been updated. Based on the work of Fey & Charlot (2000), 392 source structure indices were made available, they qualifies the level of position disturbance expected from the source structure (Fey & Charlot, 1997).

The ICRF-Ext.2 solution differed from that of the ICRF and ICRF-Ext.1 solutions primarily in the use of the NMF mapping function (Niell,

1996) for troposphere modeling. The data added in ICRF-Ext.2 spanned from 1999 May through 2002 May and were obtained from both geodetic and astrometric observing programs. Approximately 1.2 million new observations from 400 sessions were added. There were 50 additional new sources. The positions and errors for the *defining* sources were unchanged from the ICRF. Revised positions and errors for the *candidate* and *other* sources were estimated and reflect the changes in the data set and the analysis (Fey at al., 2004). ICRF-Ext.2 marks a milestone in that it utilizes the available VLBA (Very Long Baseline Array) data. A total of over 652,000 delay observations (almost 20% of all observations) from 30 VLBA geodesy/astrometry sessions were included in the solution.

Meanwhile, the general improvements in VLBI technology, the development of the observing network and the extension of the set of observed objects that took place in operational VLBI, brought the astrometric results to its current precision towards the end of the first decade of operation. Starting about 1990, individual time series of source coordinates stabilize (Gontier et al., 2001). In a study of individual source motions, Feissel-Vernier (2003) devised a stability selection scheme based on a statistical assessment of source stability. A set of 199 well observed and stable sources was identified and 163 well observed but highly unstable or drifting sources were pinpointed. Another set of 358 sources were observed too sparsely in this time frame for a statistical evaluation of their stability. The use of the stable sources in the definition of the axes of a celestial reference frame was shown to lower the medium-term instability of the celestial reference frame from 28 to 6 μas when compared to the ICRF (Gontier & Feissel, 2003). Background information on this selection process is given by Feissel-Vernier (2005).

The Feissel-Vernier (2003) scheme was applied to time series of source coordinates that were derived taking subsets of the ICRF *defining* sources as the background reference, but it was shown that a sizable part of these are unstable. One could not rule out the possibility that the intrinsic instability of the set of reference sources create spurious instabilities in the sources under study. Using as a reference a VLBI solution in which the set of stable sources are used to define the orientation of the frame (no-net-rotation condition) and all the sources are global parameters except the unstable ones treated as arc parameters, time series of the unstables or sparsely observed sources were derived. The standard Feissel-Vernier (2003) scheme was applied to this time series and, as expected, a number of sources (54) were detected as stable (Feissel-Vernier, 2005).

The total number of stable sources selected by the Feissel-Vernier process is 253 (199 original + 54 additional) and will be referred as F-V stable sources in the present study.

Analysis by Arias & Bouquillon (2004), on a set of two VLBI independent solutions obtained in 2002, demonstrated that the orientation of the axes of the ICRS is better realized by using the 199 F-V stable sources. This indicates that in the selection of the more stable sources for the realization of the celestial reference system, statistical tests on the time-varying behaviour of source coordinates should be included. The present study extends the Arias & Bouquillon analysis to a larger number of individual celestial frames with different characteristics, and to the total set of 253 F-V stable sources, to assess the previous results and to contribute to a future redetermination of the ICRF.

In section 2 of this report we describe the five VLBI celestial reference frames elaborated in 2003-2004 with the purpose of contributing to the

ICRF maintenance. In section 3 we compare the individual frames with the ICRF-Ext.2 by using two different sets of common sources, the ICRF defining sources and the F-V stable sources.
In section 4 we discuss the impact of the F-V stable sources selection on the definition of axes and on the source coordinates precision. Finally we summarize in section 5 the arguments in favour of a new ICRF realization.

2 Data analyzed

Five VLBI solutions are used for this study and are briefly described in this section. All have referred their respective celestial frames to ICRS by applying a no-net-rotation constraint based on a subset of the ICRF defining sources.

RSC(AUS) 04 R 01 was derived by Geoscience Australia from VLBI observations acquired in the period April 1980- May 2004. OCCAM 6.1 software has been used for the solution. The orientation of the celestial frame has been defined through a no-net-rotation constraint applied to the positions of 207 ICRF defining sources. IERS 1996 and MHB2000 (Mathews et al., 2002) have been adopted as the a priori precession and nutation model respectively.

RSC(BKG) 04 R 01 was derived by the Federal Agency for Cartography and Geodesy and the geodetic Institute of the University of Bonn, in Germany. The software used for the solution is CALC 9.13, SOLVE release 2004.03.18. The celestial reference frame has been oriented by a no-net-rotation constraint applied to the positions of the 212 defining ICRF sources. The time span of the observations used in the solution is January 1984- March 2004. The a priori precession and nutation models are both IERS 1996.

RSC(CGS) 04 R 01 was derived by the Space Geodesy Centre in Matera (Italy) from observations in the period April 1980- October 2003. The software used is CALC 9.12 SOLVE release 2002.10.04 and SOLVE revision 2002.10.11. The celestial frame has been oriented by a no-net-rotation imposed to the positions of 141 ICRF defining sources. The a priori precession and nutation models are both IERS 1996.

RSC(GAOUA) 03 R 01 was derived by the Main Astronomical Observatory of the National Academy of Sciences of Ukraine, from observations acquired in the period August 1979- September 2003. The software used is SteelBreeze-2.0.2. The orientation of the celestial frame has been made by a no-net-rotation constraint applied to the positions of 23 ICRF defining sources. The IAU-2000A precession-nutation models have been chosen as a priori models.

RSC(GSFC) 03 R 03 was derived by the Goddard Space Flight Centre from observations made during the period 1980.0-2002.7. A not-net-rotation constraint has been applied on the defining sources to orient the celestial frame. All observed sources except the unstables are global parameters in this solution. Unstable sources pinpointed by Feissel-Vernier scheme (2003) are treated as arc parameters and therefore have not been included in the catalogue.

For each individual frame, table 1 gives the total number of sources, the number of ICRF defining sources, the number of F-V stable sources present in the catalogue, the number of sources used for the no-net-rotation condition and the declination range.

Table 1. Individual celestial reference frames analyzed.

Frame	Total	IERS def.	F-V stable	NNR const.	Dec. range (°)
RSC(AUS) 04 R 01	571	202	188	207 def.	-81 ; +84
RSC(BKG) 04 R 01	668	207	253	207 def.	-81 ; +84
RSC(CGS) 04 R 01	554	183	252	141 def.	-80 ; +84
RSC(GAOUA) 03 R 01	1571	211	253	23 def.	-81 ; +86
RSC(GSFC) 03 R 03	562	152	208	152 def.	-85 ; +84

3 Catalogue comparison

In order to study the influence of the set of selected sources on the orientation of the celestial frame, we compared the five VLBI catalogues listed in table 1 with the ICRF.

The relative orientation of two celestial reference frames is modeled by three rotation angles A_1, A_2, A_3 around the axes of the equatorial coordinate system and systematic effects by three deformation parameters (D_α, D_δ and dz). These parameters are estimated using equations (1) and (2), where α, δ are the source coordinates and $\Delta\alpha$, $\Delta\delta$ are the differences of coordinates in the two frames. The D_α and D_δ parameters represents a slope in right ascension as a function of the declination and a slope in declination as a function of the declination respectively. The dz parameter is a fictitious equator tilt in declination that reflects systematic differences in declination that may be caused by inaccuracy of the tropospheric propagation correction for sources observed at low elevations.

$$\Delta\alpha = A_1 \tan\delta \cos\alpha + A_2 \tan\delta \sin\alpha - A_3 + D_\alpha(\delta - \delta_0) \tag{1}$$

$$\Delta\delta = -A_1 \sin\alpha + A_2 \cos\alpha + D_\delta(\delta - \delta_0) + dz \tag{2}$$

The transformation parameters are evaluated by a weighted least squares fit; the equations are weighted by using the inverse of the variance of the coordinate differences $(\Delta\alpha, \Delta\delta)$. For the assignment of weights, formal coordinate uncertainties smaller than 10 μas in the individual frames are set to this value in order to have more realistic weights. Radio sources with residuals higher than 2.5 the rms residual of the fit are considered as outliers, and consequently deweighted. One could note that we usually have either none, one or four outlier sources in the following comparisons.

The catalogues have been compared to the ICRF-Ext.2 by using common sources of two different sets:

- the ICRF defining sources
- the F-V stable sources

VLBI observations from 1979-1995 were used in the construction of the ICRF and in the classification of its radio sources (Ma et al., 1998). The ICRF has three types of sources, in decreasing order of astrometric quality: *defining, candidate* and *other*. The classification of sources in the ICRF has been done over the 608 sources for the first realization of the frame; 212 fulfilled the criteria for the *defining* sources, 294 were classified as *candidate* sources and 102, showing excessive position variation, had been included in the category *other*. The two extensions of ICRF densify the frame by adding coordinates of *new* sources; the coordinates and uncertainties of the *defining* sources remain the same as in ICRF; for *candidate* and *other* sources the positions and uncertainties reflect the changes in the data set and the analysis.

The alignment of the axis of the various realizations of the system is assessed by the *defining* sources.

The F-V analysis is based on time series of source coordinates produced by an independent analysis centre (USNO). It consists of a two step process on about 700 radio sources observed in the period 1989.5-2002.4. A first selection, made on the basis of continuity criteria for one-year weighted average coordinates, retained 362 sources. The second step of the procedure consists of selecting a set of stable sources by applying various criteria like the computation of standard deviation, the Allan standard deviation and the normalized linear drift and looking at their intersection. A subset of 253 sources has been retained as *stable* after these tests. The originality with respect to previous classification is that in F-V selection, studies are conducted on the stability of radio source positions by statistical analyses of the time series of the yearly averaged coordinates.

Whilst in the ICRF work sources have been classified by applying criteria based on the quality of the data, the observational history of the radio sources, the consistency of coordinates derived from different data subsets and the radio source structure, F-V classification is mainly supported by the observational history of sources and the analysis of time series of radio source coordinates.

One could note that from the set of 253 F-V stable sources 101 are previously classifed as *defining*; 87 as *candidate* and 61 as *other* sources. This means that 74% of the F-V selected sources are either *defining* in the ICRF or *candidate* which are potentially *defining* sources in the future. A consequence of using ICRF-Ext.2 as reference catalogue is that some of the F-V stable sources could have revised coordinates with respect to ICRF.

3.1 Catalogue comparison using ICRF defining sources

The five individual frames of table 1 were compared with ICRF-Ext.2 using the usual catalogue comparison model of the ICRS-product centre of IERS. The number of defining sources used in the comparisons is shown in the "IERS defining" column of table 1. The global relative orientation and the deformation parameters between ICRF and the individual frames given in table 2 and 3 were estimated by a weighted least squares fit.

Following the usual practice in VLBI work, constraints described in the data analyzed section, have been applied to align the axes of the individual solutions to those of ICRS; the angles of table 2 show that they are aligned better than 50 μas. The deformation parameters D_α, D_δ of table 3 indicate that no systematic effects are present under the form of slopes varying with the declination. No significant bias of the principal plane of the frames are observed except for RSC(CGS) 04 R 01 where a dz of 35 μas is seen.

3.2 Catalogue comparison using F-V stable sources

The number of common stable sources used in the comparisons is shown in the column "F-V stable" of table 1. Results of comparison of individual frames with ICRF-Ext.2 are shown in tables 4 and 5.

Table 2. Comparison of individual VLBI frames with ICRF-Ext.2 by using common ICRF defining sources. A_1, A_2, A_3 are the rotation angles which transform coordinates from the individual frames into ICRF; unit is μas.

Frame	A_1	A_2	A_3
RSC(AUS) 04 R 01	-24 ± 19	$+50 \pm 19$	-04 ± 25
RSC(BKG) 04 R 01	-04 ± 18	-19 ± 18	-32 ± 23
RSC(CGS) 04 R 01	$+16 \pm 22$	$+39 \pm 22$	$+07 \pm 31$
RSC(GAOUA) 03 R 01	$+14 \pm 19$	$+39 \pm 19$	-22 ± 24
RSC(GSFC) 03 R 03	$+19 \pm 19$	$+24 \pm 20$	-22 ± 28

Table 3. Comparison of individual VLBI frames with ICRF-Ext.2 by using common ICRF defining sources. D_α, D_δ are the slopes in right ascension and declination respectively, dz is the bias in declination; units are μas/deg for the slopes and μas for the bias.

Frame	D_α	D_δ	dz
RSC(AUS) 04 R 01	-1.8 ± 0.8	$+0.1 \pm 0.4$	$+15 \pm 21$
RSC(BKG) 04 R 01	-0.9 ± 0.7	-0.8 ± 0.4	$+20 \pm 19$
RSC(CGS) 04 R 01	-0.7 ± 1.0	-0.8 ± 0.6	$+35 \pm 27$
RSC(GAOUA) 03 R 01	-0.8 ± 0.8	-0.4 ± 0.4	-08 ± 19
RSC(GSFC) 03 R 03	-1.6 ± 0.8	$+0.4 \pm 0.4$	$+04 \pm 21$

Table 4. Comparison of individual VLBI frames with ICRF-Ext.2 by using common F-V stable sources. A_1, A_2, A_3 are the rotation angles which transform coordinates from the individual frames into ICRF; unit is μas.

Frame	A_1	A_2	A_3
RSC(AUS) 04 R 01	-05 ± 13	$+39 \pm 12$	$+06 \pm 13$
RSC(BKG) 04 R 01	-02 ± 10	-11 ± 09	$+09 \pm 10$
RSC(CGS) 04 R 01	$+26 \pm 12$	$+38 \pm 11$	$+46 \pm 13$
RSC(GAOUA) 03 R 01	$+18 \pm 10$	$+47 \pm 09$	$+12 \pm 10$
RSC(GSFC) 03 R 03	$+18 \pm 09$	$+11 \pm 09$	$+18 \pm 10$

Table 5. Comparison of individual VLBI frames with ICRF-Ext.2 by using common F-V stable sources. D_α, D_δ are the slopes in right ascension and declination respectively, dz is the bias in declination; units are μas/deg for the slopes and μas for the bias.

Frame	D_α	D_δ	dz
RSC(AUS) 04 R 01	-1.4 ± 0.5	$+0.1 \pm 0.3$	$+14 \pm 13$
RSC(BKG) 04 R 01	-0.2 ± 0.3	-0.9 ± 0.2	$+36 \pm 10$
RSC(CGS) 04 R 01	-0.3 ± 0.4	$+0.0 \pm 0.3$	$+12 \pm 13$
RSC(GAOUA) 03 R 01	-0.3 ± 0.4	-0.0 ± 0.3	-19 ± 11
RSC(GSFC) 03 R 03	-0.7 ± 0.3	$+0.1 \pm 0.2$	$+22 \pm 10$

4 Discussion

Results in tables 2 and 4 show that the set of F-V stable sources defines the axes of the ICRS better than the defining sources. Except for RSC(CGS) 04 R 01 and RSC(GAOUA) 03 R 01 which have the smallest number of defining sources used initially for the alignment, the directions of the axes are closer to those of ICRS when they are represented by the F-V stable sources. In all cases, the uncertainties of the evaluated angles are smaller when the F-V stable sources are used in the comparison. For A_1 and A_2 angles, the differences between the values estimated using F-V stable or defining sources of an individual frame are not significant. From the differences observed on A_3 angle we could note a global rotation weakly significant of 10 to 40 μas. Except for A_3 the scattering of the rotation parameters obtained in the different comparisons indicate that the axes are stable within 20 μas which is the accuracy claimed for the ICRF.

The results in tables 3 and 5 show that in general the deformations represented by slopes in the coordinates are not significant for both comparisons. The values of the slopes Dα and Dδ indicate for both sets of sources that the radio source coordinates in the five catalogues do not present any systematic effect varying with the declination. As for the rotation angles the uncertainties of the evaluated parameters are smaller when the F-V stable sources are used in the comparison.

One could note that the equator of the individual frame are biased with respect to the ICRF for both sets of sources. The RSC (GAOUA) 03 R 01 dz bias is of opposite sign with respect to all other values which might be explained by the small number of defining sources used for the alignment. The mean quadratic dz term is 20 ± 22 μas when using defining sources and 22 ± 11 μas for the F-V stable sources. In the pre-ICRF celestial frames, significant values of dz were found when comparing solutions obtained by different analysts. However, McMillan and Ma (1997) showed that adding the so-called gradient parameter in the modeling of the tropospheric delay minimizes this defect. The gradient parametrization is now commonly used in VLBI analysis. Although the dz parameter is expected to be negligible, it is still significant when the F-V stable sources are used for the comparison. This could be due to the better sky coverage of the F-V stable sources with respect to the defining ones (Fig. 2) in the declination range [$+30^o$; -30^o] where the effect of the tropospheric mismodelling is larger. This effect should be discussed in the framework of the next ICRF realization.

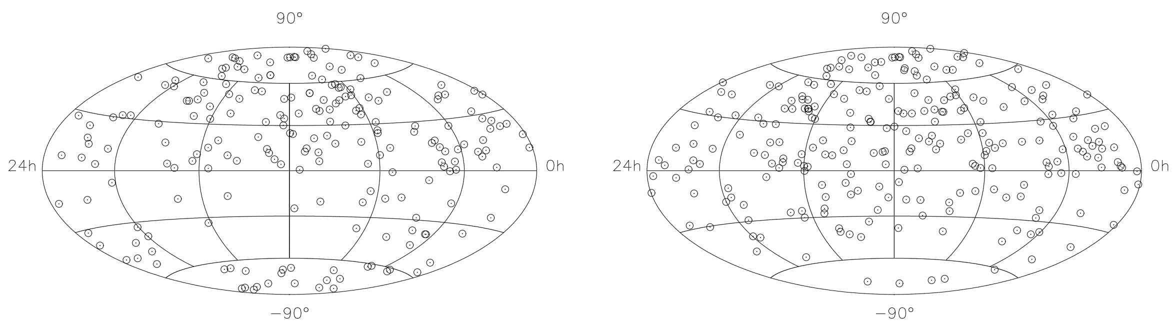

Fig. 2. Sky distribution of the ICRF defining sources (left) and the F-V stable sources (right).

Table 6. Rms residual after fitting the global rotations and the deformation parameters between individual frames and ICRF- Ext.2 by using the common ICRF defining sources (Def.), and by using the common F-V stable sources (Stab.); unit is μas.

Frame	rms $\alpha\ cos\delta$		rms δ	
	Def.	Stab.	Def.	Stab.
RSC(AUS) 04 R 01	202	136	268	157
RSC(BKG) 04 R 01	189	110	246	145
RSC(CGS) 04 R 01	212	142	303	181
RSC(GAOUA) 03 R 01	182	108	267	153
RSC(GSFC) 03 R 03	182	97	240	126

The post-fit rms residuals in $\alpha\ cos\delta$ and in δ for both comparisons are given in table 6, where "Def." indicates that the comparison has been made on the basis of common defining sources, and "Stab." on common F-V stable ones. This residuals illustrate the fit to the model.

By inspecting the table, we can conclude that the rms residuals in $\alpha\ cos\delta$ and in δ are better for the F-V stable set of sources by at least a factor 1.5, which means that the comparison model represents better the inconsistencies in the orientation of the catalogues with respect to ICRS when the frames are compared on the basis of F-V stable sources.

Figure 3 plots for the frame RSC(GSFC) 03 R 03 the normalized residuals (ratio of the postfit residuals to the uncertainty of the coordinate difference between frames) in two dimensional local plane for the fit based on the common defining sources (left) and for the fit based on the common F-V stable sources (right). A circle of radius one has been plotted. A large number of ICRF defining sources show residuals dispersed out of the circle of unit radius, with values that be up to 2, whereas most of F-V stable sources are limited to the unit radius circle. The same behaviour is observed for the other frames analyzed.

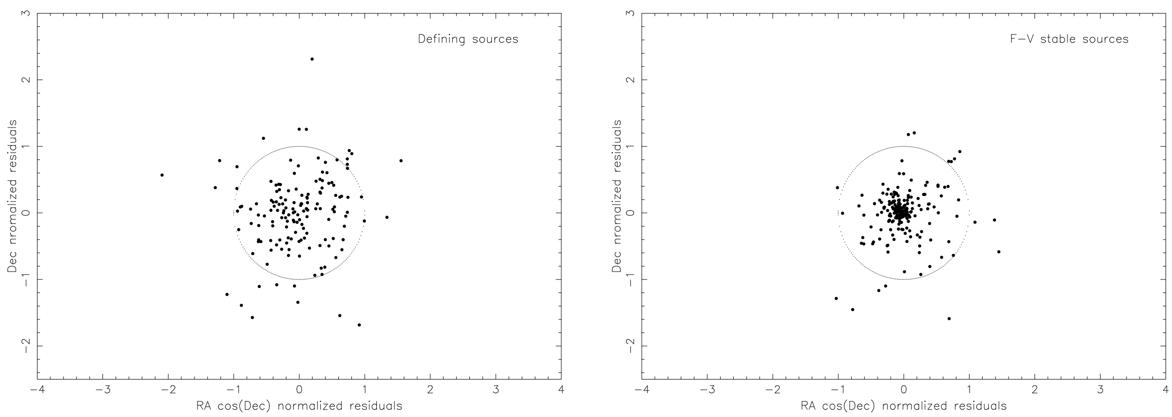

Fig. 3. Normalized residuals in two dimensional local plane for the fit based on defining sources (left) and the F-V stable sources (right).

To evaluate the impact of F-V selection of sources on the precision of the source positions, we compare pairs of independant celestial frames. In each comparison, the two frames are rotated to common axes in a least square adjustment of the equations (1) and (2) applied to the 199

F-V stable sources common to the frames. In the set of F-V stable sources, only the 199 initial set was used because the three-cornered-hat method requires that the tested population be homogeneous. The variances of the post fit residuals $\Delta\alpha cos\delta$ and $\Delta\delta$ are computed. In this process, the estimated parameters A_1, A_2, A_3 and dz absorb systematic differences that can be expected from the construction schemes of the compared reference frames. The variance of the residuals is a measure of the residual differences. The three-cornered-hat method is then applied to these variances. This method allows to estimate the variance of the noises of three or more sets of measurements of the same quantities, here the source right ascensions and declinations, under the assumption that the errors are independent in the three data sets. Considering the variances of the differences between two data sets i and j, one can write

$$var(\alpha_i \cos\delta - \alpha_j \cos\delta) = var(\alpha_i \cos\delta) + var(\alpha_j \cos\delta) \tag{3}$$

$$var(\delta_i - \delta_j) = var(\delta_i) + var(\delta_j) \tag{4}$$

If three reference frames are considered, one gets three sets of the above equations, that can be solved to obtain the individual residual variances $var(\alpha_k \cos\alpha)$ and $var(\delta_k)$ for $k = 1, 3$. If more than three data sets with independent errors are available, the individual residual variances can be estimated by means of a least squares algorithm.

Table 7 gives the individual standard deviations thus derived for the reference frames of table 1. The RSC(AUS) 04 R 01 catalogue was excluded from the comparison because only 155 out of the 199 F-V stable sources are present in the frame. The robustness of the estimations was tested by associating the data in various ways. The results remain stable within 5 μas. We conclude from the values of table 7 that the precision of sources coordinates for the set of stable sources is better than 30 μas.

Table 7. Standard deviations of source positions for the set of 199 F-V stable sources; unit is μas.

Frame	Standard deviations	
	$\Delta\alpha\ \cos\delta$	$\Delta\delta$
RSC(BKG) 04 R 01	21	26
RSC(CGS) 04 R 01	27	29
RSC(GAOUA) 03 R 01	22	29
RSC(GSFC) 03 R 03	23	18

5 Conclusion

The ICRF was defined on the basis of the pre-1995 astrogeodetic VLBI observations. Since, the core of the *defining* sources was kept fixed in the composition and coordinates, and the two subsequent updates were limited to extending the list of sources with coordinates referred to the original ICRF. Analyses recently published show that a set of 253 stable sources can be selected by applying statistical test on the time-varying behaviour of source coordinates (Feissel-Vernier et al., 2005).

We have compared five individual reference frames obtained from independent VLBI analysis using the *defining* sources on one side, and the *F-V stable* sources on the other side. The analysis performed confirm the Arias & Bouquillon (2004) result that the orientation of the ICRS

axes is better determined when the set of F-V stable sources is used for the comparison. We have noted that also the gradient parametrization is used in VLBI analysis, we still have an equator tilt in declination which is significant at the level of accuracy better than 20 μas.
The intrinsic stability of the sources would allow to reach 5 μas in the maintenance of the ICRF axes, provided that the coherence defaults are solved, else the accuracy will be kept between 10 to 20 μas.
The use of selected stable sources for the definition of the axes and the realization of the pimary frame (source coordinates treated as global parameter in the data analysis) would allow an improvement by a factor of eight in the source position precision, to reach 30 μas with respect to the 250 μas claimed for the ICRF.

Therefore we support the elaboration of the next ICRF on the basis of a set of stable sources by applying criteria based on data quality, observationnal history, source structure as well as statistical tests on the time-varying behaviour of source coordinates.

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