The Construction of ICRF2 and Its Impact on the Terrestrial Reference Frame

D. Gordon, K. Le Bail, C. Ma, D. MacMillan, S. Bolotin, and J. Gipson

Abstract

The construction of the second realization of the International Celestial Reference Frame by VLBI (ICRF2) was undertaken to take advantage of the many improvements in geodetic and astrometric VLBI and the vast increase in data since the first ICRF. The impact the switch to ICRF2 has had on the terrestrial reference frame and EOP solutions generated by VLBI is very small, at about the mm level, and should be transparent to most users of VLBI products.

Keywords

ICRF2 • VLBI • Terrestrial reference frame • Earth orientation parameters • Celestial reference frame • Quasars

1 Introduction

The first realization of the International Celestial Reference Frame (hereafter called ICRF1) by Very Long Baseline Interferometry (VLBI) was generated in 1997 and was officially adopted by the IAU on 1 January 1998 (Ma et al. 1997, 1998). It was constructed from geodetic and astrometric VLBI sessions taken between 1979 and 1995. ICRF1 contained coordinates for 608 compact extragalactic radio sources (quasars), with an estimated noise floor of 250 μas. Its axes were defined by the coordinates of 212 "defining" sources and it had an estimated stability of 20 μas in each axes. This precision and stability represented an approximately tenfold improvement over the previous stellar reference frame, the FK5 (Fricke et al. 1988). Two extensions were made to ICRF1, bringing the total number of sources to 717 (IERS 1999; Fey et al. 2004).

One weakness of ICRF1 was that the 212 defining sources were distributed very unevenly, being concentrated in the northern half of the sky, as shown in Fig. 1. Other weaknesses were that some of the defining source positions turned out to be unstable over time, and some had asymmetric structures which can result in different positions being found on different networks.

Many improvements were made in the VLBI technique in the years following ICRF1's adoption. These included broader observing bandwidths, wider spanned bandwidths, use of newer and more sensitive antennas (such as the 10 station VLBA), improvements in troposphere and gradient modelling, and use of pressure loading and thermal deformation corrections. Also, larger networks (such as the weekly R1 and R4 sessions) and specialized sessions (such as the VLBA RDV sessions (Petrov et al. 2009), the VLBA Calibrator Surveys (Beasley et al. 2002; Fomalont et al. 2003; Petrov et al. 2005, 2006; Kovalev et al. 2007; Petrov et al. 2008) and the southern hemisphere CRF sessions) greatly increased the amount of geodetic and astrometric VLBI data and the number of sources observed. And in addition to the Calc/Solve analysis package that was used for ICRF1, several additional VLBI analysis packages had been developed,

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C. Rizos and P. Willis (eds.), *Earth on the Edge: Science for a Sustainable Planet*, International Association of Geodesy Symposia 139, DOI 10.1007/978-3-642-37222-3_23,

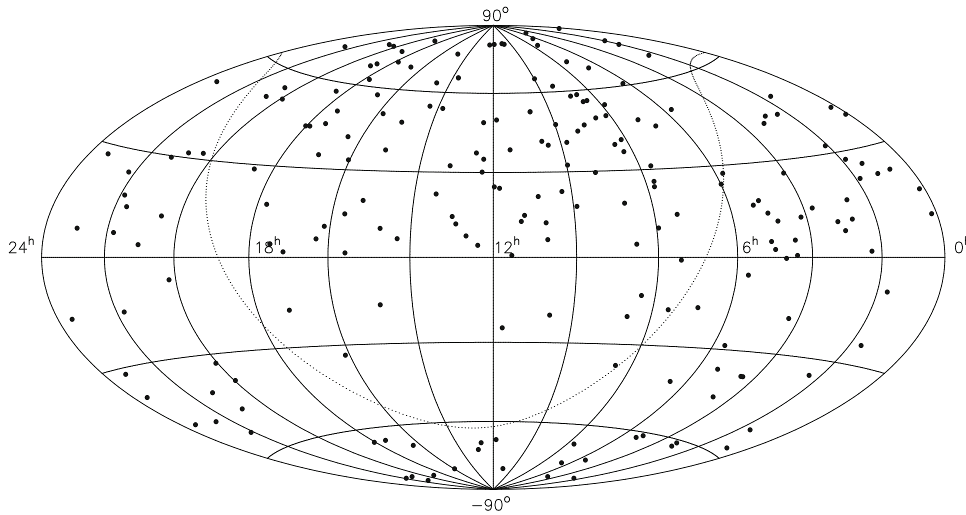

Fig. 1 Sky distribution of the ICRF1 defining sources

such as OCCAM, Steelbreeze, and QUASAR (IERS 2009). For all these reasons, an IVS (International VLBI Service for Geodesy and Astrometry) Working Group composed of members from several different VLBI analysis centers was formed in 2006 to undertake the generation of the second realization of the ICRF.

2 Construction of ICRF2

In preparation for ICRF2 (IERS 2009), VLBI source position time series solutions were generated by the different analysis centers using the various software packages and were studied in detail. A few sources were found to be so unstable that there was concern that holding them to fixed positions in the solution might distort the overall solution. A total of 39 such sources were identified and it was decided to solve for their positions in each session rather than as single positions over the entire data span. Seven of these unstable sources were also ICRF1 defining sources, and thus their instability may have caused some artificial drifts in the TRFs and EOP series in earlier VLBI solutions.

Separate CRF solutions were generated by seven analysis centers. Most were fairly complete and in good agreement. A combined solution was also made and studied. However, it was decided to use a single solution, the GSFC Calc/Solve gsf008a solution, because of its completeness and because of the complications involved with a combined solution. The ICRF2 solution used data from August 1979 though March 2009 and contained the positions of 3414 compact extragalactic radio sources, a nearly sixfold increase over ICRF1.

In fixing the axes of ICRF2, a concerted attempt was made to find a set of defining sources that were not only positionally stable but also evenly distributed over the entire sky. In this way, two of the largest weaknesses of ICRF1 were addressed. The sky was divided into several declination bands, and the most stable sources in each band were selected, which resulted in 423 potential defining sources. For all sources with X-band images available, a source structure index defined by Fey and Charlot (1997), modified to yield a continuous index starting at 0.0, was computed. Source structure indices are computed from the estimated structure delay corrections for each source. Sources with large structure indices can give VLBI positions which may vary with baseline orientation, and are an indicator of possible future instability. As recommended by Fey and Charlot (1997), only sources with structure indices less than 3.0 (10 ps maximum structure delay correction at X-band) were retained as defining sources. However, a modest number of sources with no structure indices (mostly southern sources) were also retained, based on good positional stability only. In all, 295 of the potential defining sources were retained and became the ICRF2 defining sources. Their much more even sky distribution is shown in Fig. 2. The final ICRF2 catalog has an estimated noise floor of 40 µas, roughly six times better than ICRF1 and an estimated axis stability of 10 µas per axis, a twofold improvement over ICRF1.

In comparing the ICRF2 defining sources with the ICRF1 defining sources, only 97 sources were common to both sets, and 73 of those were in the northern half of the sky. This did not make for a proper alignment between ICRF1 and ICRF2, so an additional 41 ICRF2 defining sources that were also in the ICRF-Ext2 catalog (Fey et al. 2004) were selected for this alignment, and 35 of these were in the southern half of the sky. The small rotation required to align these 138 ICRF2 defining sources with their ICRF1/ICRF-Ext-2 positions was computed and then applied to all the positions in the gsf008a solution to obtain the final ICRF2 positions.

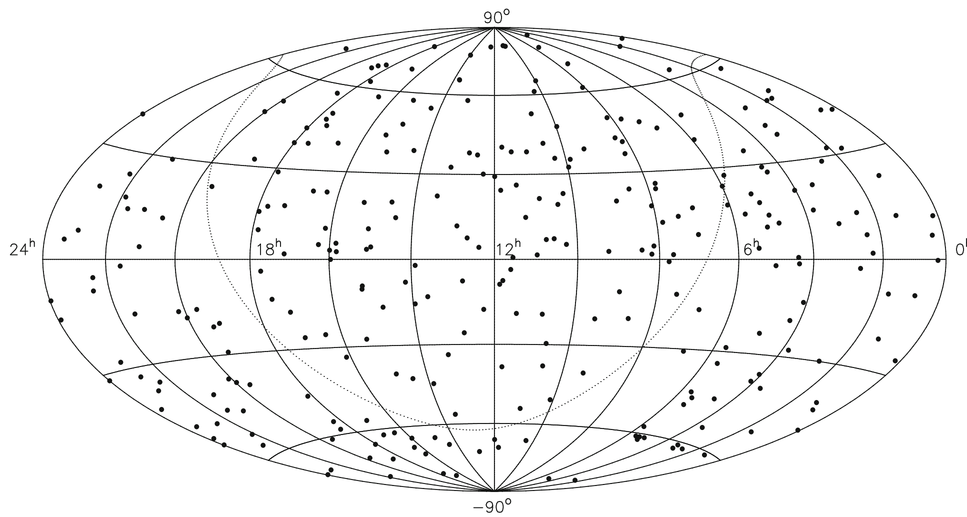

Fig. 2 Sky distribution of the ICRF2 defining sources

2.1 Impact on the Terrestrial Reference Frame and Earth Orientation Parameters

In an earlier study, Gordon et al. (2013) found only a small impact on the TRF between ICRF1-based and ICRF2-based solutions. A rotation of the TRF on the order of ∼.5 mm and a shift in pole position of ∼.35 mm were the largest effects seen. These effects are roughly an order of magnitude less than the differences seen among the many TRF solutions done at GSFC from 2000 to 2009.

For the current study, we have re-evaluated the effect of switching to ICRF2 on the VLBI solutions. We took the latest GSFC solution, gsf2011b,[1] as our ICRF2-based solution, and generated an equivalent ICRF1-based version. It should be stressed that this is not a comparison between the original ICRF1 and ICRF2, but rather a comparison of their different definitions of the reference frames. The two solutions differ only in the set of defining sources that are held to a no-net-rotation constraint and in the handling of the 39 ICRF2 special handling sources. The input data and models used are otherwise identical, and thus the precisions of the resulting TRFs, EOPs, and CRFs are also nearly identical.

These two solutions show only a very small difference in their terrestrial reference frames (TRFs). The translation and rotation differences are shown in Table 1. There is an approximately 1 mm average shift in site positions, and less than a mm of rotation (1 mm ≃ 32 µas). The scale difference is only 0.032 ± 0.036 ppb, which is essentially insignificant. The EOP differences are given in Table 2. The pole position changes by only ∼.5 mm and UT1 by ∼.3 µs (∼.13 mm), on average. These differences are no greater than the noise seen in the weekly R1 and R4 sessions, and are similar to the differences seen among quarterly VLBI solutions over the past 11 years (Gordon et al. 2013).

[1] http://lupus.gsfc.nasa.gov/dataresults_main.htm

Table 1 TRF differences 2011b_ICRF2 and 2011b_ICRF1

Parameter	X	Y	Z
Translation (mm)	$0.6 \pm .3$	$1.0 \pm .3$	$-0.6 \pm .3$
Rotation (µas)	$-25. \pm 12.$	$-10. \pm 11.$	$-11. \pm 8.$

2.2 Impact on the Celestial Reference Frame

We also solved for a relative rotation between the CRFs found from the ICRF2-based solution and the ICRF1-based solution. Comparing the coordinates of 1,434 sources, we get the rotation given in Table 3. The largest effect is a 38 µas rotation about the Y-axes (at 6 h RA, 0° declination). This rotation is similar to that seen in an earlier comparison (Gordon et al. 2013) and to the rotation that was applied to the gsf008a solution to obtain ICRF2 (IERS 2009). It results from the alignment of ICRF2 with the set of ICRF1/ICRF-Ext-2 sources described earlier. It could be due to a combination of factors, such as the use of subsets of the two sets of defining sources, of a possible small misalignment between ICRF1 and ICRF-Ext-2, and possible drifts in the ICRF1 axes due to positional instability of some of the defining sources.

Another way to assess the impact of the switch to ICRF2 is to compare two large VLBI astronomical source catalogs, one based on ICRF2 and one based on ICRF1. We computed the rotation between the latest GSFC astro

Table 2 EOP differences 2011b_ICRF2 and 2011b_ICRF1

	Offset	Rate (per year)	WRMS of diff.	R1/R4 uncertainties
Xp (µas)	15.3 ± .8	−1.0 ± .14	48.2	40–150
Yp (µas)	−8.0 ± .8	3.1 ± .12	39.0	40–150
UT1 (µs)	−0.29 ± .05	0.02 ± 0.01	2.7	1.5–4
dX (µas)	35.5 ± .8	−0.1 ± .1	44.5	30–100
dY (µas)	17.3 ± .7	0.1 ± .1	43.0	30–100

Table 3 CRF rotation differences 2011b_ICRF2 and 2011b_ICRF1

X (µas)	Y (µas)	Z (µas)
−14.6 ± .5	38.3 ± .5	2.4 ± .4

Table 4 CRF rotation differences gsf2011b_astro and rfc_2012a_cat

X (µas)	Y (µas)	Z (µas)
−34 ± 46	28 ± 45	22 ± 38

catalog, gsf2011b_astro[2] (ICRF2-based) and the latest "radio fundamental catalog", rfc2012a_cat[3] (ICRF1-based) using 3,580 common sources. The relative rotation between these two large catalogs is given in Table 4. This rotation is similar to that between the two gsf2011b solutions, but is not statistically significant because of the much larger uncertainties in each axis. This greater noise is indicative of the different analysis methods and models used on what is mostly the same observational data.

3 Conclusion

The comparisons made here show that the switch from an ICRF1-based CRF to an ICRF2-based CRF has only a very small effect on the terrestrial reference frame and has had no adverse effects on the VLBI solutions. As such, the transition to ICRF2 should be essentially transparent to most users of VLBI products. ICRF1-based VLBI solutions may have suffered from small drifts due to positional instabilities of some of its defining sources. In this respect, ICRF2-based VLBI solutions should be more stable.

Acknowledgements We would like to thank the International VLBI Service for Geodesy and Astrometry (IVS) and all its components, which have made the ICRF2 and this study possible. This study was funded at the Goddard Space Flight Center under NASA contract NNG07HW11C. We also thank the National Radio Astronomy Observatory (NRAO) for VLBA observing time and support which greatly improved the quantity and quality of the data used in the ICRF2 and in this study. NRAO is an NSF facility operated under cooperative agreement by Associated Universities, Inc.

[2]http://gemini.gsfc.nasa.gov/solutions/2011b_astro/2011b_astro.html
[3]http://astrogeo.org/vlbi/solutions/rfc_2012a/

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