SELECTING DEFINING SOURCES FOR THE NEXT ICRF BASED ON SOURCE STRUCTURE

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ABSTRACT. The intrinsic radio structure of the extragalactic sources is one of the limiting errors in the definition of the International Celestial Reference Frame (ICRF). This paper reports about the ongoing work to monitor the structural evolution of the ICRF sources by using the Very Long Baseline Array and other VLBI telescopes around the world. Based on more than 5000 VLBI images produced from such observations, we have assessed the astrometric suitability of 80% of the ICRF sources. The number of VLBI images for a given source varies from 1 for the least-observed sources to more than 20 for the intensively-observed sources. From this analysis, we identify a subset of 194 sources that are highly compact at any of the available epochs. Such sources are prime candidates to define the next ICRF with the highest accuracy.

1. INTRODUCTION

The International Celestial Reference Frame (ICRF), which has been the official IAU celestial reference frame in use since 1 January 1998, is currently based on the VLBI positions of 717 extragalactic radio sources. Of these, 608 sources are from the original ICRF built in 1995, with a categorization that comprised 212 well-observed *defining* sources (which served to orient the axes of the frame), 294 less-observed *candidate* sources, and 102 *other* sources showing coordinate instabilities (Ma et al. 1998). The accuracy in the individual ICRF source positions has a floor of 250 μas, while the axes of the frame are stable to about 20 μas in orientation. Since then the positions have been improved for the non-defining sources and the frame has been extended by 109 *new* sources in ICRF-Ext.1 and ICRF-Ext.2 using additional data acquired in the period 1995–2002 (Fey et al. 2004).

At the IAU XXVI$^{\text{th}}$ General Assembly in Prague (August 2006), the community decided to engage in the realization of the successor of the ICRF, to be presented at the next IAU General Assembly in 2009. The motivation for generating this new celestial frame is to benefit from recent improvements in VLBI modeling (e.g. for the troposphere) and to take advantage of the wealth of VLBI data that have been acquired since 1995 when the ICRF was built. A major issue to be addressed in this new realization is the revision of the source categorization, in particular the choice of the defining sources. Such a revision is necessary because some of the original ICRF defining sources were found to have extended structures (Fey and Charlot 2000) or position instabilities (e.g. MacMillan 2006), and are therefore improper for defining the celestial frame with the highest accuracy.

The selection criteria that are considered by the working group in charge of the realization of the next ICRF for the identification of proper defining sources are based either on source structure information (VLBI images), to evaluate the compactness and astrometric suitability of the sources, or on time series of source coordinates, to assess the source position stability. In this paper, we discuss only the former. There are now more than 5000 VLBI images available to evaluate source quality, while there were less than a hundred at the time the ICRF was built, thereby permitting considerable progress. In Sect. 2, we present the observational data and analysis method used in this work. Our results are discussed in Sect. 3 with emphasis on statistics of source quality for each ICRF source category and for the entire ICRF. We

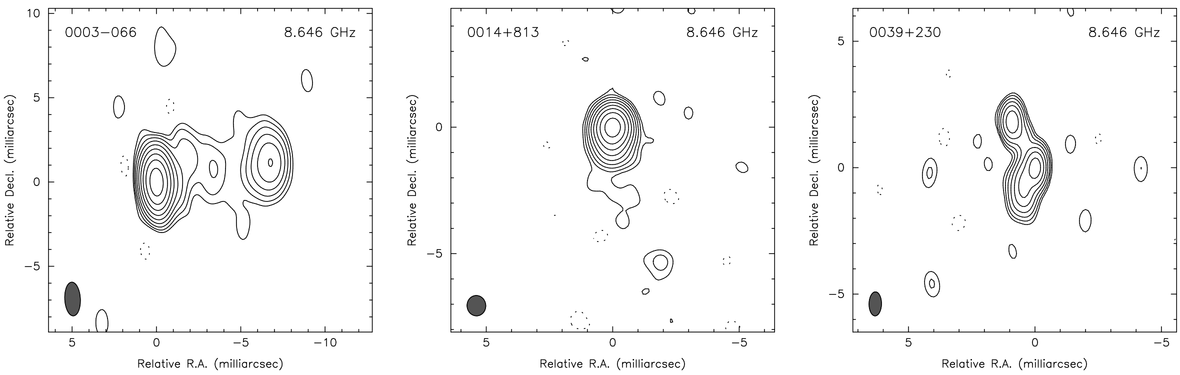

Figure 1: VLBI images at X band (8 GHz) for three ICRF sources (0003−066, 0014+813, 0039+230) as derived from the data of a RDV session conducted on 2003 December 17. The three sources were selected randomly according to increasing right ascension starting at RA=00h.

also draw prospects for further improvements in assessing the source quality before the next ICRF is generated.

2. OBSERVATIONAL DATA AND ANALYSIS METHOD

The VLBI maps used in our analysis were produced from a total of 38 VLBI sessions conducted between 1994 and 2007, which were imaged either at USNO or at Bordeaux Observatory. These comprise:

- 8 dedicated dual-frequency (8 GHz/2 GHz) imaging sessions conducted with the Very Long Baseline Array (VLBA) between July 1994 and January 1997 (Fey et al. 1996, Fey and Charlot 1997, Fey and Charlot 2000);
- 23 dual-frequency (8 GHz/2 GHz) Research & Development VLBA (RDV) sessions conducted between January 1997 and June 2007; these sessions include the 10 VLBA stations and up to 10 additional geodetic telescopes;
- 5 dedicated southern-hemisphere 8 GHz imaging sessions conducted between July 2002 and April 2004 with the Australian Long Baseline Array, augmented by radio telescopes in South-Africa, Hawaii, and Japan (Ojha et al. 2004, Ojha et al. 2005);
- 2 VLBA sessions at 2 GHz/8 GHz/24 GHz and 8 GHz/24 GHz conducted in February 2004 and August 2005 as part of a project to extend the ICRF to higher frequencies (Lanyi et al. 2007).

Altogether, this represents a total of 2697 maps at X band (8 GHz) from 577 ICRF sources and 2388 maps at S band (2 GHz) from 492 ICRF sources. Less sources have been imaged at S band because the southern-hemisphere sessions only observed at X band. There are up to 28 VLBI epochs available for the most intensively-observed source, whereas only one epoch is available for the least-observed sources. A sample of X-band VLBI images for three ICRF sources, as derived from the data of a RDV session conducted in December 2003, is shown in Fig. 1. From these images, one sees that only one of the three sources (0014+813) is relatively compact, while the two others (0003−066 and 0039+230) show extended structures. This fraction of compact sources is consistent with that found for the entire ICRF, as discussed in Sect. 3 below.

Based on these VLBI images, we derived the expected effects of intrinsic source structure on the VLBI delay astrometric quantities, following the algorithm of Charlot (1990). We then used the "structure index" indicator to define the astrometric source quality, as devised by Fey and Charlot (1997). Structure index values of 1 and 2 point to excellent and good astrometric suitability, respectively, while values of 3 and 4 point to poor suitability. A given source may have differing structure indices at X band and S band, depending on properties of the brightness distribution at each band. The structure index may also vary with time because of possible temporal evolution of the brightness distribution.

For each source, we obtained a series of structure index at each band according to the number of VLBI images available (see Charlot et al. 2006 for examples of such structure index series). Adopting a

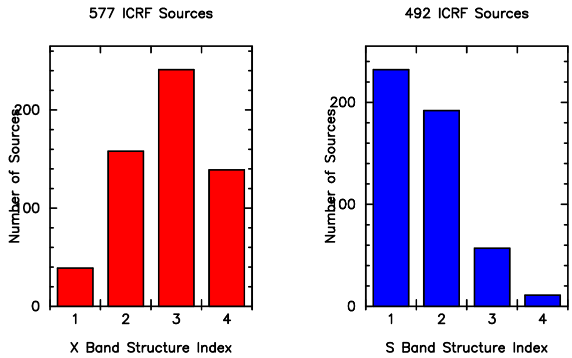

Figure 2: The structure index distribution at X band (8 GHz) and S band (2 GHz) for all ICRF sources that have a structure index available at these frequencies.

conservative approach, we chose the maximum value of the structure index as the source quality indicator when multi-epoch structure indices are available. In other words, if a source shows a structure index value of 3 or 4 at one or more epochs, it should be regarded as unsuitable for highly-accurate astrometry even though it has structure index values of 1 or 2 at some other epochs. This multi-epoch structure index value is the criterion used below for drawing statistics on source quality.

3. RESULTS

As noted above, we have now obtained structure indices for 577 sources at X band and 492 sources at S band (representing 80% and 69% of the current 717 sources of the ICRF, respectively). The X-band structure index distribution (Fig. 2) shows that 197 sources (or equivalently a portion of 34% of the sources) are astrometrically-suitable at this frequency according to our criterion (structure index value of either 1 or 2). At S band, 86% of the sources have a structure index value of either 1 or 2 (Fig. 2). This indicates that the contribution of the S-band structure to the dual-frequency (S/X) calibrated delay is usually smaller compared to the X-band structure contribution, as already noted in Fey and Charlot (1997). Comparing the X- and S-band structure indices individually for each source shows that, with three exceptions, all sources that have a S-band structure index of either 3 or 4 have also a X-band structure index of 3 or 4. Based on the S-band structure index indicator, we thus exclude an additional 3 sources, thereby leaving a total of 194 ICRF sources astrometrically-suitable at both frequencies.

In Fig. 3, the X-band structure index distribution is compared for each ICRF source category. As expected, the distribution is somewhat better for the defining sources than for the candidate and “other” sources. However, only about 40% of the ICRF defining sources have a structure index value of either 1 or 2. The fraction of suitable sources drops down to 32% for the candidate sources and 22% for the “other” sources, while it is 48% for the “new” sources. Overall, these results confirm that revision of source categories is mandatory for the next ICRF.

4. CONCLUSION

We have evaluated the astrometric suitability of 80% of the sources in the ICRF based on multi-epoch VLBI maps of their structures. From this analysis, a sample of 194 astrometrically-suitable ICRF sources that have compact or very compact structures according to our “structure index” indicator has been identified. It is anticipated that the remaining 20% of ICRF sources for which the astrometric suitability has not been assessed (mostly in the southern sky) will be imaged in the near future through further VLBI observing programs in the southern hemisphere. The astrometric suitability of the sources already imaged, which has been discussed in this paper, will also be refined as new VLBI sessions are processed and maps become available. This information will be essential for selecting the proper defining sources and generating the next ICRF by 2009.

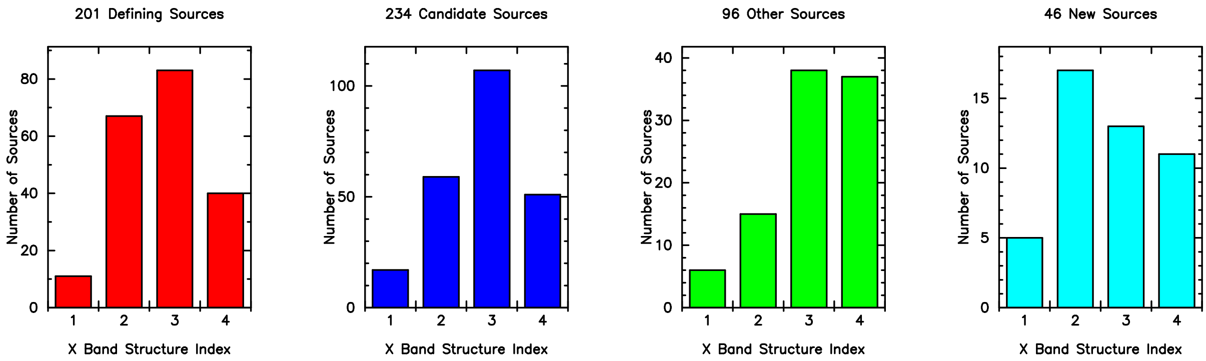

Figure 3: Distribution of the X-band (8 GHz) structure indices in each ICRF source category (defining, candidate, "other", "new"). The 577 ICRF sources with currently available structure indices are included in this figure.

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