Modeling Special Handling Source Positions in the GFZ VLBI Solution

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Abstract Based on the GFZ VLBI solution obtained using the Vienna VLBI Software (VieVS), we estimate time series of the ICRF2 special handling sources. We investigate their time-variable positions based on our VLBI solution, which compared to ICRF2 includes the more recent VLBI observations. In a next step, the parameterization of the special handling sources is appropriately extended by allowing a linear variation in time. We present our first results, and we propose further studies with the aim of improving our research.

Keywords VLBI, radio sources, AGNs, apparent proper motions, special handling sources

1 Introduction

Very Long Baseline Interferometry (VLBI) is the space geodetic and astrometric technique for determining the International Celestial Reference Frame (ICRF) (Ma et al., 1998). The current catalog (ICRF2) is made up of 3,414 radio sources which are classified into three categories: i) defining sources: the sources are included in the axes definition, being a part of the global NNR condition; ii) special handling sources: the sources are not estimated as a global parameter, and iii) other sources: the sources are estimated as a global parameter but not considered in the axes definition.

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The special handling sources (hereafter, SHS) are a subset of 39 sources which exhibit non-constant positions in time due to source structure changes (MacMillan & Ma, 2007). These radio sources exhibit time-variable extended structure and hence are not good candidates for very precise geodesy and astrometry (Charlot, 1990). Furthermore, the SHS show strong instability either in right ascension or declination (Figure 1) up to the level of 1 mas (Titov, 2007). Variations can be observed over days, weeks, or longer time scales (Fey et al., 2009).

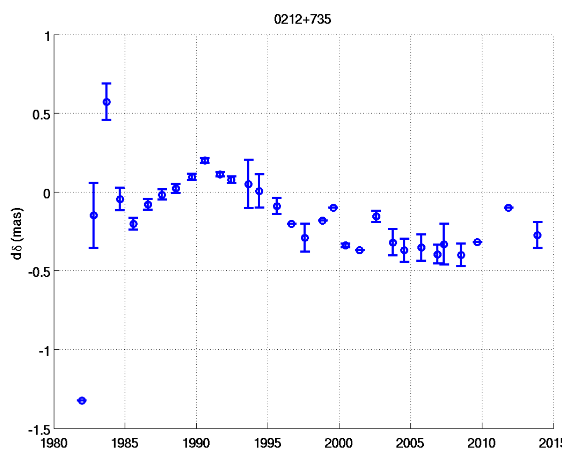

Fig. 1 Time series of declination of the special handling source 0212+735.

Based on the GFZ VLBI solution (Heinkelmann et al., 2014), we study the variability of the SHS positions to provide better a priori coordinates by applying extended parameter models to the celestial coordinates. As a first trial, we test linear apparent proper motions.

The ICRF2 is the actual realization of the International Celestial Reference System (ICRS), which contains precise coordinates of extragalactic radio sources observed by VLBI. In it, the SHS are not treated as global parameters in order to avoid distortions of the frame (Altamimi et al., 2013). When studying session-wise estimates of radio source coordinates, the SHS show significant non-constant systematics. These are not considered by the radio source coordinate model of the ICRF. The source positions are treated as constant, and all variations are believed to be measurement errors and are expressed by an error bar which is reported along with the position. This error bar can be made much smaller, if more sophisticated coordinate models are introduced.

This preliminary study is the first implementation of an extended radio source coordinate model. Later, having realized optimized models, we expect to be able to include special handling and other radio sources into the datum by likewise extension of the datum constraints. Then, we will obtain a more reliable celestial reference frame and correspondingly more reliable Earth orientation parameters.

2 Data Analysis

The GFZ VLBI solution contains 5,793 sessions solved by using the Vienna VLBI software VieVS. The analysis options follow the IERS 2010 Conventions and the ITRF2013 specifications. For the estimation of the SHS coordinates, the ICRF2 defining sources were fixed to their a priori coordinates in order to have consistency between celestial and terrestrial reference frames, while SHS and other sources were adjusted (Heinkelmann et al., 2014).

Based on the almost complete VLBI solution, we plot time series of declination and right ascension times cosine declination of the special handling radio sources, which were not included in the datum and were, therefore, independently adjusted (see Figure 2 and Figure 3). By visual inspection, we detected that estimates of a few sessions showed larger scatter than those of the majority of sessions. For the determination of the linear trend, we decided to ignore those outlying sessions in order to not distort the trend determination.

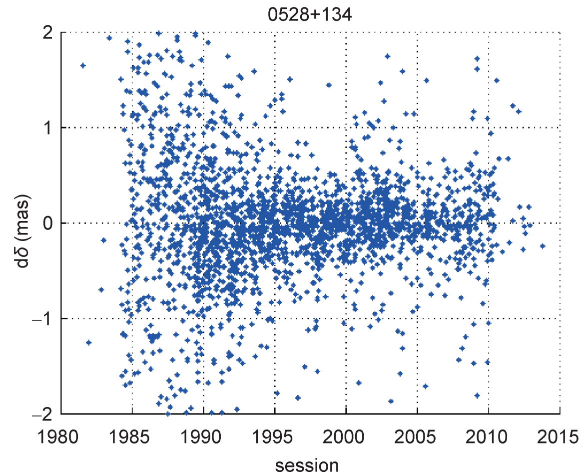

Fig. 2 Declination of 0528+134 from the GFZ VLBI solution. The same analysis was applied to all SHS.

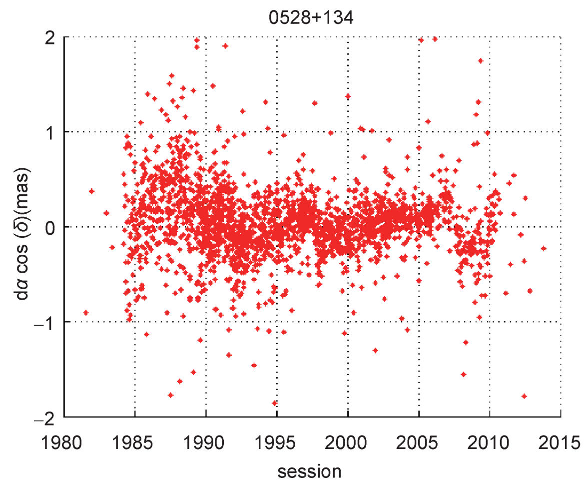

Fig. 3 Right ascension of 0528+134 from the GFZ VLBI solution. The same analysis was applied to all SHS.

3 Time Series of Source Positions

We determine yearly weighted means of source coordinates from the time series as follows:

$$\bar{X} = \frac{\sum_{i=1}^{n} w_i x_i}{\sum_i w_i} \tag{1}$$

where $w_i = 1/\sigma_i^2$ and σ_i is the formal error of the radio source coordinate estimate.

Time series of all of the 39 ICRF2 SHS were analyzed in that way. We estimate linear trends in the time series

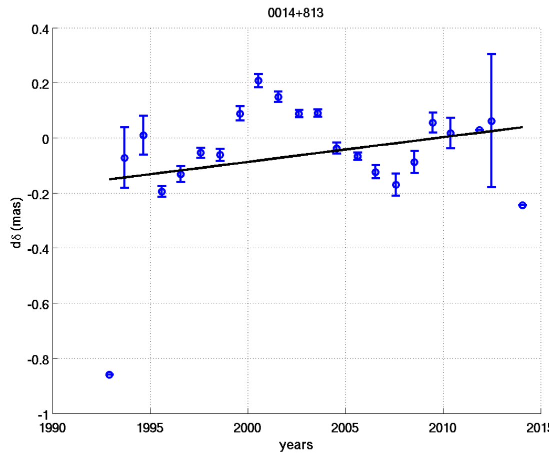

Fig. 4 Weighted mean with yearly resolution of declination for 0014+813. The error bars were determined as the yearly root-mean-square error.

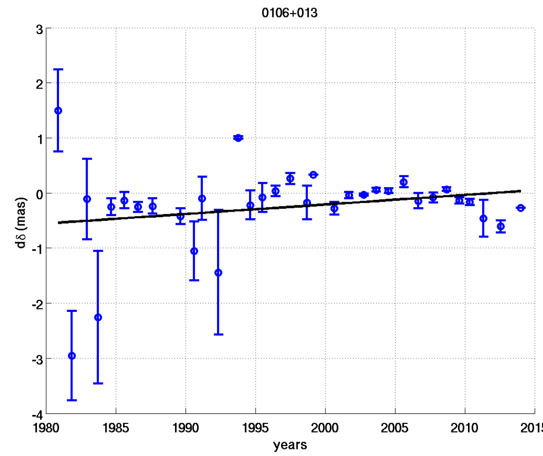

Fig. 6 Linear trend of declination of 0106+013.

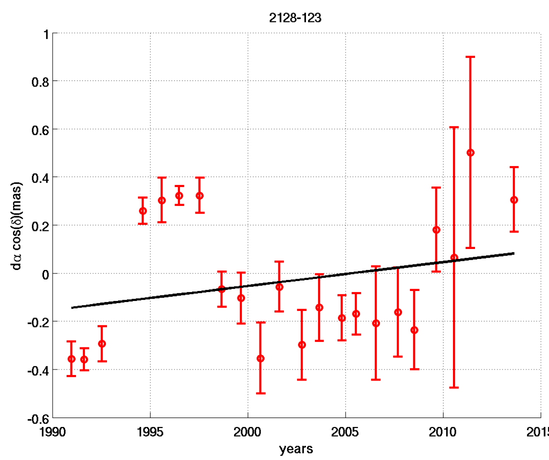

Fig. 5 Weighted mean with yearly resolution of right ascension for 2128-123. The error bars were determined in the same way as described in Figure 4.

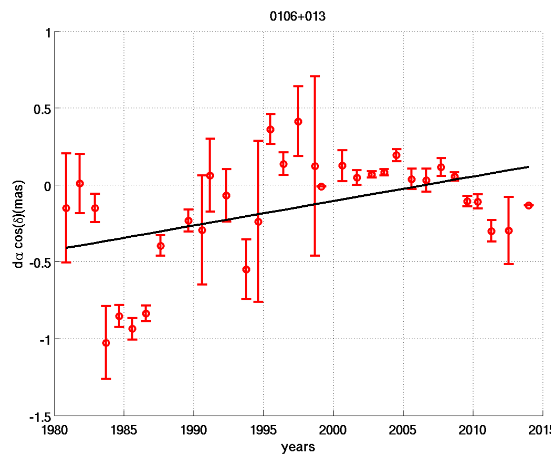

Fig. 7 Linear trend of right ascension of 0106+013.

of the source positions based on the annual weighted mean values for all SHS (see Figures 4 through 7). Most of the SHS exhibit significant non-constant positions (Figures 6 and 7). However, to our surprise, in some cases we found no evidence for significant positional variations in at least one component (Figure 4 and Figure 5). Using a linear interpolation, we compute apparent proper motion displacements (Table 1), which allows us to see what are the yearly rates of changes in source coordinates. To properly understand what the main causes are of such long-term variations in the coordinates of the SHS, more studies should be done, especially with respect to the underlying astrophysics. On the other hand, we bring up an example already given in the literature which is useful for the purpose of discussing and comparing our results. Radio source 4C39.25 has been showing interesting astrophysical behavior since the first time that it was observed in 1979. This source showed significant proper motion during 1986–1997 due to superluminal motion (Fey et al., 1997) that caused a fast change in right ascension (Titov, 2007). We notice this fact in our plots (Figure 8). According to our measurements, the right ascension of the source varies approximately 0.05 mas per year.

Table 1 Linear apparent proper motion displacements. There are very few data for the radio source 2134+004. Therefore we do not take it into account in the present study.

Source	$\alpha\cos\delta$ (mas year^{-1})	δ (mas year^{-1})
0014+813	-0.0283 ± 0.0401	0.0090 ± 0.0128
0106+013	0.0159 ± 0.0282	0.0173 ± 0.0307
0202+149	-0.0102 ± 0.0156	0.0218 ± 0.0334
0208-512	0.0008 ± 0.0001	0.0017 ± 0.0025
0212+735	0.1148 ± 0.1937	-0.0081 ± 0.0136
0235+164	-0.0029 ± 0.0050	-0.0257 ± 0.0445
NGC1052	-0.0709 ± 0.1223	-0.0853 ± 0.1468
3C84	-0.0014 ± 0.0037	0.1079 ± 0.2464
3C120	-0.0029 ± 0.0054	-0.0627 ± 0.1162
0438-436	-0.0426 ± 0.1831	0.0271 ± 0.1162
0451-282	0.0342 ± 0.0507	0.0892 ± 0.1317
0528+134	-0.0033 ± 0.0058	-0.0061 ± 0.0110
0607-157	0.0314 ± 0.0497	0.1034 ± 0.1638
0637-752	0.0061 ± 0.0093	0.0011 ± 0.0018
0711+356	-0.0259 ± 0.0616	-0.0560 ± 0.1299
0738+313	0.0012 ± 0.0027	0.0986 ± 0.2128
0919-260	-0.0460 ± 0.0680	-0.0104 ± 0.0154
4C39.25	0.0475 ± 0.0862	-0.0105 ± 0.0190
OK290	0.0211 ± 0.0377	0.0475 ± 0.0853
1021-006	0.2564 ± 0.7216	0.2033 ± 0.5723
1044+719	0.0137 ± 0.0188	0.0151 ± 0.0208
3C273B	0.0080 ± 0.0142	0.0147 ± 0.0269
3C279	0.0273 ± 0.0530	-0.0519 ± 0.0996
1308+326	-0.0134 ± 0.0234	-0.0160 ± 0.0277
OQ208	-0.0097 ± 0.0167	0.0044 ± 0.0077
1448+762	-0.2001 ± 0.2865	-0.0030 ± 0.0044
3C309.1	0.0420 ± 0.0695	-0.0699 ± 0.1156
1611+343	-0.0243 ± 0.0410	0.0087 ± 0.0146
1610-771	0.1636 ± 0.2521	-0.0369 ± 0.0566
3C345	0.0694 ± 0.1384	-0.0131 ± 0.0264
1739+522	0.0036 ± 0.0055	-0.0029 ± 0.0044
2121+053	-0.0026 ± 0.0043	-0.0153 ± 0.0248
2128-123	0.0220 ± 0.0341	0.0152 ± 0.0237
2145+067	-0.0102 ± 0.0176	0.0027 ± 0.0046
2201+315	0.0223 ± 0.0321	-0.0364 ± 0.0522
2234+282	-0.0174 ± 0.0282	-0.0126 ± 0.0204
2243-123	-0.0643 ± 0.1061	-0.0081 ± 0.0131
3C454.3	0.0275 ± 0.0524	-0.0029 ± 0.0054

4 Conclusions

We successfully obtained time series of source coordinates based on the new GFZ VLBI solution. We first looked into the ICRF2 list of the SHS to check the variability of those sources by studying their linear trends. Long-term trends are seen in the time series of the source coordinates (Table 1). Checking our preliminary results, for some sources there are no significant changes in coordinates, bringing us to several questions: (1) What were the criteria in which the ICRF2 defined the selection of SHS? (2) If some sources exhibit no significant proper motion, why not consider them as "defining sources"? (3) Hence, what should be the exact definition of SHS?

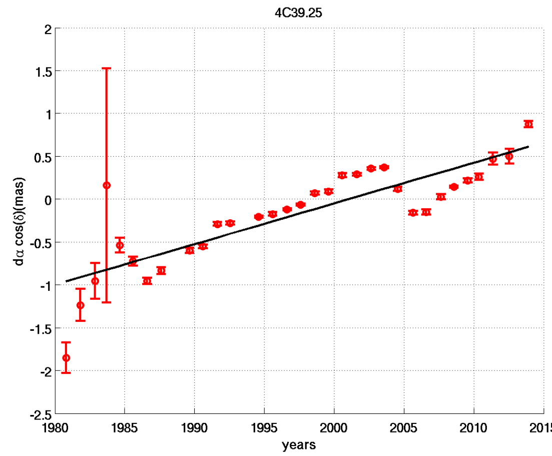

Fig. 8 Linear trend of right ascension of 4C39.25.

The information about the variability in source positions of the SHS could be used as improved a priori source coordinates. Thus, more precise a priori coordinates could be used, which would allow us to improve the theoretical delays and in the end the VLBI estimates.

We need to study in more detail global solutions with different settings, i.e., parameterization, datum definitions, and so on. An implementation of a suitable time-variable coordinate model is needed in order to assess the impact on the global parameters such as EOP and station coordinates. Finally, we have to investigate different mathematical models for the extension of the radio source coordinate model, for example using Chebyschev polynomials, linear spline functions, and so on and including those in a time dependent NNR (No-Net-Rotation) condition.

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