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First Steps to Investigate Long-Term Stability of Radio Sources in VLBI Analysis

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Abstract

Presently, the observation period of several radio sources observed by geodetic VLBI covers more than 20 years. So, the estimation of global source parameters with the modelling of only one source position for the complete length of VLBI data should only be applied to stable compact radio sources. One important tool to handle this aspect consists of analyzing time series for radio source coordinates. The main features regarding the estimation of time series of radio source positions in global VLBI solutions are explained. On the basis of these time series a weighted mean was estimated for each radio source component. The residuals to the weighted mean were tested for normal distribution for the purpose of uncovering systematic errors. First results are discussed.

1. General Information

Presently global complete geodetic VLBI solutions with more than 20 years of data are possible. Stable compact radio sources can be modelled with only one source position for the whole length of time. Unstable radio source, with, e.g., a known high-level source structure, are not suitable for this. This would cause a modelling error. So the question arises; which radio sources are stable? Currently support is given by the list of the ICRF defining sources (ref. [3]), the list of stable compact radio sources determined by MARTINE FEISSEL-VERNIER (ref. [2]), and the list of structure indices of radio sources set up by PATRICK CHARLOT (ref. [1]). But, also, the estimation and analsis of time series for radio source positions constitute a possibility to answer this question.

2. Time Series for Radio Source Positions

The basis to derive time series for radio source positions is a global complete VLBI solution with 24 hours VLBI sessions from January 1984 to February 2005. The main parameter types are globally estimated station coordinates and their velocities and 199 stable radio source positions detected by MARTINE FEISSEL-VERNIER (ref. [2]). Minimal constraints for the datum definition are applied to get zero net rotation and zero net translation for 26 selected station positions and velocities with respect to VTRF2003 (ref. [4]) and to get zero net rotation for 199 stable sources (ref. [2]) with respect to ICRF (ref. [3]). All other source positions are estimated in a local mode in each session for generating the time series. This solution is called basis solution 1. But there is a problem. This solution does not produce time series for the 199 stable radio sources. One possibility to solve this is to reduce the set of stable radio sources for the datum definition by one source. A separate solution with no other changes with regard to the basis solution 1 gets the estimations of local source positions for this selected stable radio source in the respective sessions.

The advantage of this procedure is that there is nearly no change in datum definition for generating time series for all radio source positions. But the disadvantage is the separate calculation for each stable radio source. After these additional computations time series for all radio sources are available.

3. Weighted Mean for Each Radio Source

The following step is based on the assumption that all radio sources are considered stable. So it is possible to use the time series with locally determined source positions L and their standard deviations s to estimate a weighted mean x for each radio source component. If the weights p are given by

$$p_i = (s_i)^{-2} \qquad \text{and}$$

$i = 1, 2, \ldots, n$ (n number of values in the time series of the source component) then the weighted mean x can be estimated by

$$x = \frac{[pL]}{[p]} \qquad \text{and the residuals are}$$

$$v_i = x - L_i.$$

This procedure results in a weighted mean and the corresponding residuals for all radio sources in both components (declination and right ascension).

4. Outlier Detection

The purpose of outlier detection is to increase the reliability of the used data. The basis applied here is the outlier test by GRUBBS (e.g. ref. [7]) with the test of the maximum amount of the residual v_{max}. The test statistic g is computed by

$$g = \frac{|v|_{max}}{\sqrt{\frac{[vv]}{n}}}.$$

The confidence level g_s is listed in a table with the number of data points and the significance level of 1 percent. The decision rule says, if $g \leq g_s$ than no outlier is detected and no action is necessary. But if $g > g_s$ than an outlier is detected and the corresponding data point is not used for the new estimation of the weighted mean.

5. Test for Normal Distribution

Based on time series of radio source position residuals to the weighted mean of a radio source component can be tested for normal distribution. At least 25 sessions should be available for a radio source. Time series with less than 25 sessions are not considered for the test. The purpose of the test is the uncovering of systematic phenomena in the time series of radio source positions. The basis is a smooth test between the empirically determined distribution and the theoretical normal distribution (e.g. ref. [5]). The parameters of the normal distribution are the mean value and the variance computed from the sample (residuals). The mean value is given by $v_{mean} = [v]/n$

and the variance can be estimated by $s^2 = [(v - v_{mean})^2]/n - 1$. The test statistic χ^2 is computed by

$$\chi^2 = \sum_{m=1}^{r} \frac{(h_m - np_m)^2}{np_m} \qquad \text{and}$$

r number of classes ($r = 10$), class width $= s/2$
m current number of classes
h_m empirical absolute frequency of class m
p_m theoretical probability of class m.

The confidence level χ_s^2 is listed in a table of the chi-square distribution with the significance level of 1 percent. The decision rule says here, if $\chi^2 < \chi_s^2$ than the distribution of the sample (residuals) is in no contradiction with the assumption that it comes from a normal population. So systematic phenomena could not be proven. But if $\chi^2 > \chi_s^2$ than the distribution of the sample (residuals) is in contradiction with the assumption that it comes from a normal population. So systematic phenomena could be proven, e.g. instabilities of radio source components exist.

6. First Results and Comparisons

Altogether 938 radio sources with position time series are available. 223 radio sources with at least 25 sessions could be investigated. The normal distribution was not rejected ($\chi^2 < \chi_s^2$) for 121 radio sources in both components, declination and right ascension, and for 62 radio sources in only one component, declination or right ascension. If the ICRF stability criterion is applied for the 121 radio sources than the following equation can be set up:

$$121 = 37d + 49c + 29o + 6n,$$

where d defining source, c candidate source, o other source, n new source.
Figure 1 is an example for the time series of radio source 0215+015 in declination and right ascension. For this defining source the test for normal distribution was not rejected in both components.

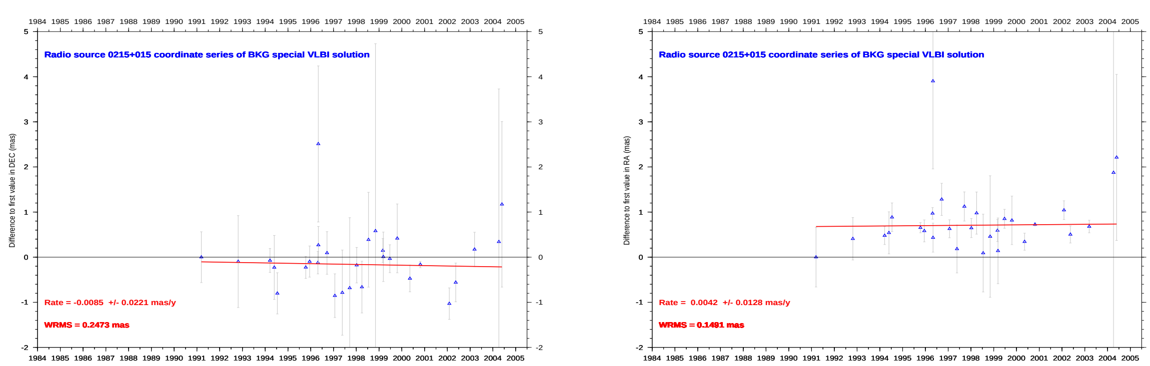

Figure 1. Time series of radio source 0215+015 (DEC on the left, RA on the right)

Figure 2 shows the corresponding histogram with the normal curve for both components.

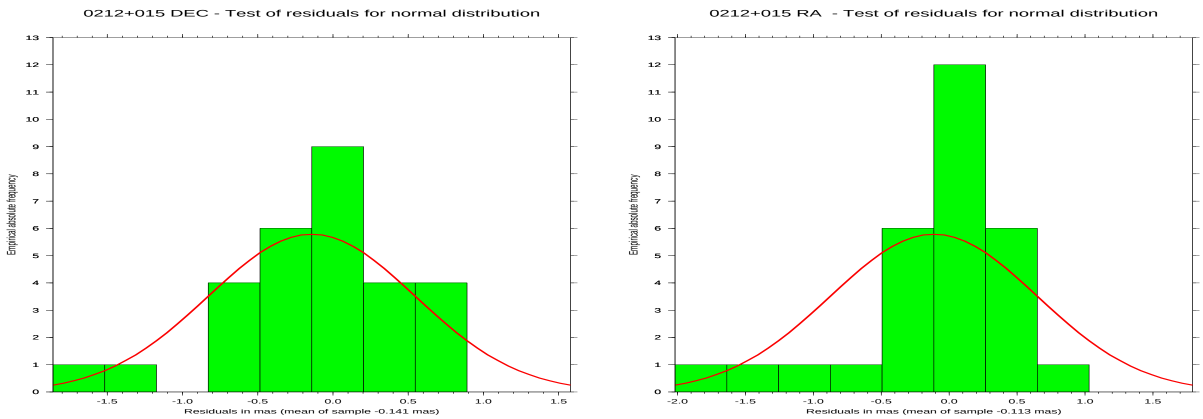

Figure 2. Histogram and normal curve of radio source 0215+015 (DEC on the left, RA on the right)

A comparison with the stability criterion derived by MARTINE FEISSEL-VERNIER (ref. [2]) shows the values 1 and 2 (stable) for 61 radio sources, 3 and 4 (unstable) for 51 sources. 9 sources were not determined. Another comparison with the source structure index for X band, the level of position disturbance (1 least disturbed, 4 most disturbed), derived by PATRICK CHARLOT (ref. [1]) amounts to the values 1 and 2 for 56 radio sources, value 3 for 29 sources, 4 for 8 sources. 28 sources were not determined. A complete list of 183 radio sources with their stability criteria, each one positively tested in one or both components, islisted in 1 (ref [6]); Table 1 shows an excerpt.

Table 1. Stability criteria for 183 radio sources, I = stability criterion ICRF, II = source structure index for X band / S band by P. Charlot, level of position disturbance expected as a result of the source structure, 1=least disturbed, 4=most disturbed, III = stability criterion by M. Feissel-Vernier, 1 and 2=stable sources, 3=unstable, 4=highly unstable, IV = result of statistical test for normal distribution of residuals to the weighted mean on the basis of time series of radio source positions, N2=normally distributed in both radio source components, N1_DEC=normally distributed in declination, N1_RA=normally distributed in right ascension, Number of data points A=all data, M1=one-month average coordinates (smoothed data set)

No.	Source name IVS/IERS or IVS	I	II	III	VI	Number of data points	A/M1	Length of time
1	0003-066	c	3/1	2	N2	114	M1	1988.04 2005.11
2	0013-005	c	2/1	4	N2	37	A	1990.83 1999.86
3	0016+731	o	2/1	2	N1_RA	74	M1	1988.01 2004.23
4	0104-408	o	-	1	N2	147	M1	1988.96 2005.12
5	0111+021	c	3/1	1	N1_RA	83	M1	1987.62 2004.70
6	0119+041	c	2/1	2	N1_RA	186	M1	1987.50 2005.08
7	0119+115	c	2/1	2	N2	116	M1	1990.11 2005.11
8	0146+056	c	3/1	4	N2	40	A	1989.07 2000.32
9	0202+149	c	2/2	2	N1_DEC	183	M1	1987.49 2005.11
10	0212+735	o	2/2	3	N1_RA	189	M1	1984.05 2004.90
11	0215+015	d	1/1	1	N2	29	A	1991.19 2004.40

No.	Source name IVS/IERS or IVS	I	II	III	VI	Number of data points	A/M1	Length of time
12	0229+131	c	2/1	2	N1_DEC	245	M1	1984.07 2005.11
13	0234+285	c	3/2	2	N1_DEC	173	M1	1984.05 2005.12
14	0238-084 NGC1052	o	4/2	4	N1_DEC	107	M1	1988.04 2004.17
15	0239+108	d	2/2	4	N2	47	A	1988.96 2004.82
16	0256+075	d	2/1	1	N2	43	A	1987.59 2004.65
17	0300+470	o	2/1	2	N2	98	M1	1984.07 2004.86
18	0306+102	d	3/1	2	N2	35	A	1993.73 2005.11
19	0308-611	d	-	2	N2	57	A	1991.89 2003.84
20	0316+413 3C84	o	-	-	N2	53	A	1985.35 2004.65
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
182	2355-106	c	1/1	2	N2	68	M1	1989.26 2005.03
183	2356+385	c	-	4	N2	90	M1	1994.46 2005.11

7. Conclusions and Outlook

Generating and statistically analyzing time series for radio source positions are useful to get more information about long-term stability of radio sources. After the successful test for normal distribution of residuals to the weighted mean of both radio source components also an inspection of WRMS, rate estimation, and distribution of the data points (sessions) in the time scale are necessary to answer the question for stable sources. Another helpful way for answering this question is also the planned development of a procedure for checking the stability of the axes of the CRF materialized by a set of selected radio sources.

The investigations about stable radio sources are not finished yet. So be careful with the use of the "N2" stable sources from Table 1.

References

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