PARAMETRIZATION OF THE SOURCE COORDINATES AND ITS ASTROPHYSICAL INTERPRETATION

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ABSTRACT. In the ICRF3 catalog, the positions of the radio-sources are given as invariant with time. New evidences argued recently on the generalization of systematic variation of the position to all reference sources, albeit at different levels and time scales. By neglecting these systematics in the realization of the celestial reference frame (CRF), its quality may be deteriorated, and it may affect the quality of derived parameters. One solution is to extend the parametrization of the source positions in VLBI data analysis. We use the multivariate adaptive regression splines (MARS) which combines recursive partitioning and spline fitting on position time series. Then, we investigate the source coordinate residual time series after application of the found parameterization. We aim to identify their noise level and content through the computation of the Allan standard deviation functions.

1. MOTIVATION

The International Celestial Reference Frame ICRF3 [Charlot et al., 2020, in press] was released in August 2018 after approval by the International Astronomical Union during its XXX$^{\text{th}}$ general assembly in Vienna. It is the newest realization of the International Celestial Reference System [ICRS, Arias et al., 1995]. In the ICRF3 catalog, the positions of the radio-sources are given as time invariant coordinate pairs. Nevertheless, systematic variation within the astrometric positions are known, which led, in the past, to the alienation of a small number of sources in the ICRF2 catalog [Fey et al., 2015]. Recently new evidences were presented for a generalization of such systematics, showing that a majority of the sources is subjected to positional variations [Karbon et al., 2016, Gattano et al., 2018], albeit at different levels and time scales. Such systematics, if neglected, may affect the quality of the CRF, and consequently impair depending parameters such as the Earth orientation parameters (EOP). A proven approach to overcome these shortcomings is to extend the parameterization of the source positions within the VLBI data analysis [Karbon et al., 2016] : the multivariate adaptive regression splines (MARS) allow a complete automation by combining recursive partitioning and spline fitting in an optimal way.

In this paper, we present our initial investigation based on the combination of the MARS parametrization of source coordinate time series with the Allan standard deviation analysis of the residuals after the application of said parameterization. With this methodology, we aim to identify the effect of the parameterization on the noise content and level within the residual source position time series. We illustrate the principle with three examples on the sources 0048−097, 4C39.25 and 2234+282.

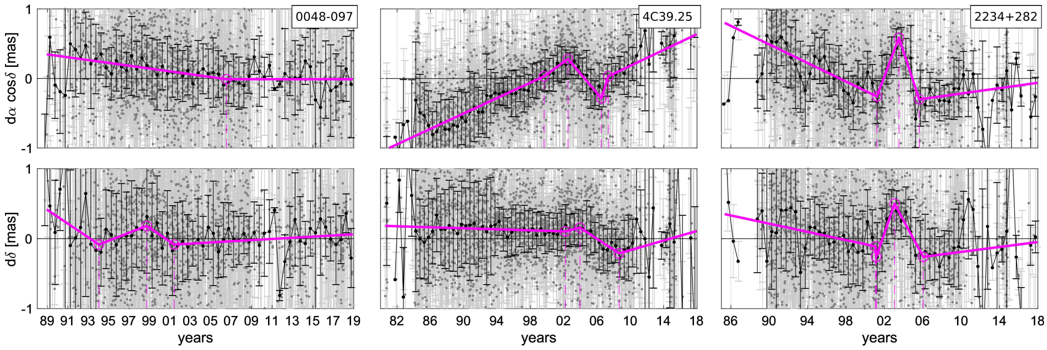

Figure 1: Position time series with respect to the a-priori coordinates given in the ICRF3 catalog of the ICRF3 defining source 0048−097 and the ICRF2 special handling sources 4C39.25 and 2234+282. The individual session-wise results are represented in gray, the half-year mean values in black, both with the corresponding error bars. In magenta, the splines are represented as determined by the MARS algorithm.

2. METHOD

Our study is based on more than 4 500 sessions with global station networks spanning the time frame 1980–2018. The geodetic data analysis is performed using the VLBI software package VieVS [Böhm et al., 2018], and following the conventions of the International Earth Rotation and Reference Systems Service [IERS, Petit et al., 2010]. The modeling settings are chosen with respect to the routine single-session data analysis strategies of the International VLBI Service for Geodesy and Astrometry [IVS, Nothnagel et al., 2015].

2.1 Multivariate adaptive regression splines (MARS)

The resulting source position time-series are processed using the MARS algorithm to determine the splines. The methodology is discussed in Karbon et al [2016]. In Figure 1, we present exemplarily the results of the spline determination for the ICRF3 defining source 0048−097 and the ICRF2 special handling sources 4C39.25 and 2234+282. The resulting splines can then be used to correct the a-priori source positions, i.e. the position in the ICRF3 catalog, which enter the VLBI analysis. Such time-dependent corrections improve the determination of correlated parameters, such as the EOP. By subtracting the splines to the initial source position time series, we get the source coordinate residual time series.

2.2 Allan standard deviation

To asses the noise content of the source position time series, we used the Allan standard deviation function [Allan, 1966] that enables to identify in a data time series the different colors of the noise dominating at different time scales by the slope of the function represented in a log-log scale. The principle is illustrated by the scheme in Figure 2. The details of the method in practical and in the context of VLBI source position time series are presented and discussed in Gattano et al. [2018]. On the astrometric point of view, a perfect source as fiducial mark on the sky would have its two coordinate offset time series with respect to the a priori position, given in the ICRF3 catalog, that return a dominating white noise at all time scales. On the opposite, a source affected by any position perturbation would present a dominating colored noise at some time scales from one or both coordinates.

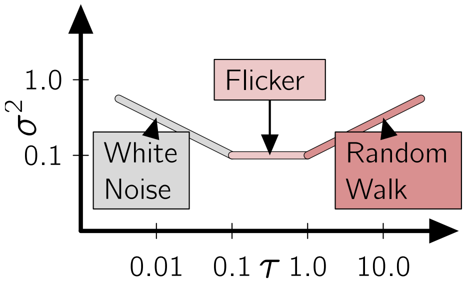

Figure 2: Scheme of the noise identification by the slope of the Allan standard deviation function represented in a log-log scale : a −0.5-slope is white noise, a 0-slope is flicker noise, and a +0.5-slope is random walk.

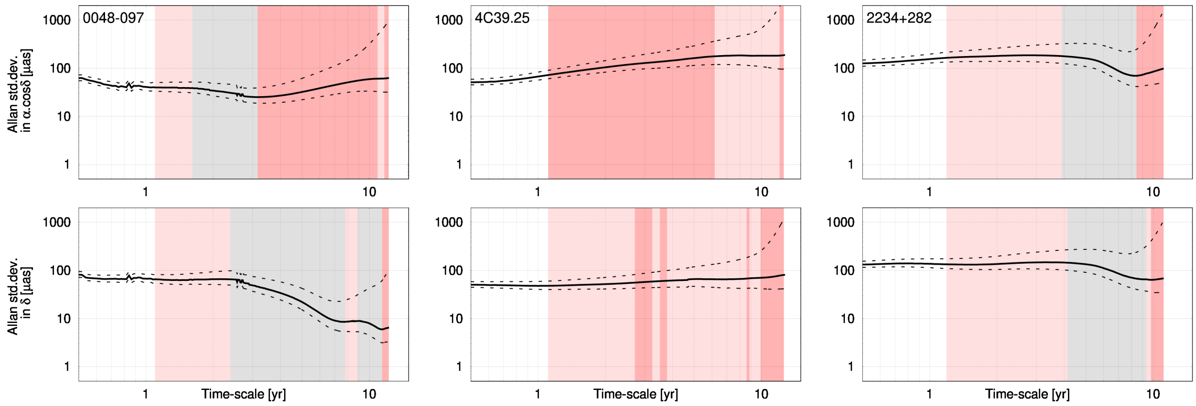

Figure 3: Allan standard deviation functions of the original position offset time series with respect to the ICRF3 a-priori coordinates of 0048−097, 4C39.25 and 2234+282. The background colors indicate the noise color identified at the corresponding time scale following the color scheme of Figure 2.

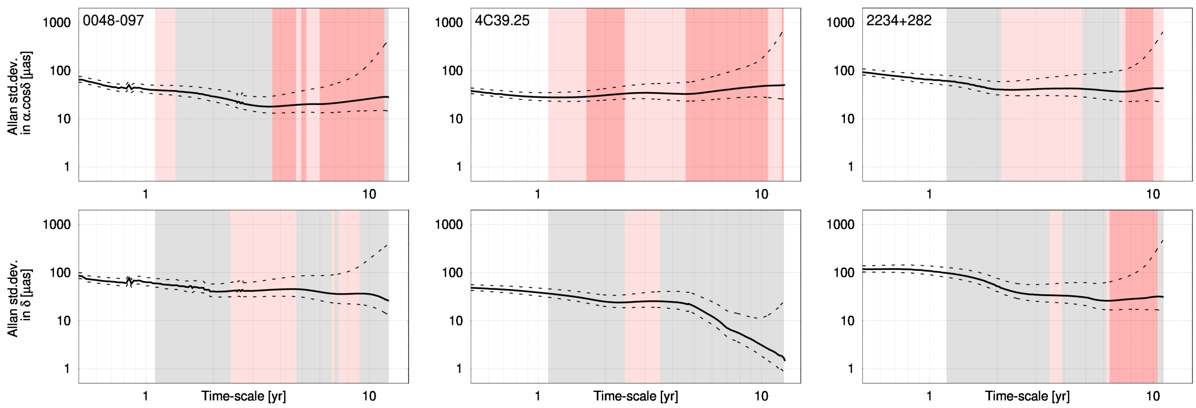

Figure 4: Allan standard deviation functions of the position residual time series after applying the correction using the MARS splines for 0048−097, 4C39.25 and 2234+282. The respective splines are represented in magenta in Figure 1. The background colors indicates the noise color identified at the corresponding time scale following the color scheme of Figure 2.

3. RESULTS

Despite its ICRF3 defining status, we observed systematics for the source 0048−097, revealed by the MARS algorithm (Figure 1) and the Allan standard deviation functions of its two coordinates (Figure 3). The right ascension is dominated by a random walk at time scales longer than 3 years. The declination is affected by a flicker noise at time scales shorter than 3 years and by a white noise at longer time scales. The effect of the correction from the splines mitigates the noise level on the right ascension but does not change the noise content (Figure 4). The flicker noise on declination is removed at shorter time scales. The source 4C39.25 is known to present exceptionally large systematics in its astrometric position as seen in Figure 1. Its right ascension systematic is recognized as random walk, whereas its declination systematic is recognized as flicker noise like (Figure 3). The effect of the spline corrections change the dominating noise content at most of the time scales. The right ascension becomes mostly dominated by flicker noise whereas the right ascension is in majority dominated by white noise. The two coordinates of the source 2234+282 are both dominated by flicker noise at time scales shorter than 4 years and by white noise in majority at longer time scales. The linear spline corrections evince in majority the flicker noise and the noise level is diminished at all time scales even if the final residuals are not purely dominated by white noise.

4. INTERPRETATION

Taking into account the linear splines to correct the source coordinates from systematics mitigate the noise level of the residual position time series, and sometimes changes the noise content. Colored noises (e.g. flicker noise, random walk) may be associated with source-dependent perturbation that affect the position estimates from VLBI. The most probable perturbation is a change of the source structure. For example, starting from a compact structure, the appearance of an extension may drift the position estimates in a peculiar direction on the plane of the sky. Such a noisy drift would appear as a random walk domination. Then, if the extent disappears, the position will drift in the opposite way. A succession of jumps in the position estimates is characterized by a flicker noise. Therefore, only the white noise process is an evidence of source stability in term of behavior.

5. CONCLUSIONS AND OUTLOOK

We present a new approach to model the astrometric position variations of radio sources selected to define the CRF from VLBI data analysis. We assess the quality of the models in terms of noise content in the residuals after subtraction of the models. The method benefits from two statistical tools: the MARS algorithm enables to extract an empirical model of the source position variation in time, and the Allan standard deviation analysis enables to characterize the noise content of data time series. Their combination allows the tuning of the parametrization in order to retrieve purely white noise source position residuals. This method will be applied to the most observed sources within VLBI sessions. The primer aim is to find a parameterization for the position of each source so that their remaining noise is white. For the determination of the MARS splines, we will investigate different methods, allowing more nodes between the splines, or using cubic splines. Also, the effect of irregular data coverage from VLBI observation will be evaluated. Last but not least, further work will be done to interpret the physical nature of the splines models. The final goal is to pin down the astrophysical processes driving the source.

6. REFERENCES

Charlot, P., Jacobs, C. S., Gordon, D., et al., 2020, "The third realization of the International Celestial Reference Frame by very long baseline interferometry", A&A , doi: 10.1051/0004-6361/202038368.

Arias, E. F., Charlot, P., Feissel, M., et al., 1995, "The extragalactic reference system of the International Earth Rotation Service, ICRS", A&A 303, pp. 604–608.

Fey, A. L., Gordon, D., Jacobs, C. S., et al., 2015, "The Second Realization of the International Celestial Reference Frame by Very Long Baseline Interferometry", AJ 150, p. 58.

Karbon, M., Heinkelmann, R., Mora-Diaz, J., et al., 2016, "The extension of the parametrization of the radio source coordinates in geodetic VLBI and its impact on the time series analysis", Journal of Geodesy.

Gattano, C., Lambert, S. B., Le Bail, K., 2018, "Extragalactic radio source stability and VLBI celestial reference frame: insights from the Allan standard deviation", A&A 618, A80.

Böhm, J., Böhm, S., Boisits, J., et al., 2018, "Vienna VLBI and satellite software (VieVS) for geodesy and astrometry", Publications of the Astronomical Society of the Pacific, 130(986), p. 044503.

Petit, G., Luzum, B., et al., 2010, "IERS Conventions", IERS Technical Note 36.

Nothnagel, A., Alef, W., Amagai, J., et al., 2015, "The IVS data input to ITRF2014", GFZ Data Services, Helmoltz Centre, Potsdam, Germany.

Allan, D. W., 1966, "Statistics of atomic frequency standards", IEEE Proceedings 54, pp. 221–230.