Evaluation of the Stability of ICRF2 in the Past Five Years Using the Allan Variance

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Abstract This preliminary study is a re-evaluation of the work done in 2010 on the stability of ICRF2, using the most up-to-date source positions catalog from GSFC and comparing to the solution computed in 2009. The example of source 3C418 shows how five more years of data can strengthen statistical studies. The Allan variance shows a threshold of 50 μas for the noise level (flicker noise) for both coordinates in 2010. With five more years of data, the threshold is passed, and for the declination, the white noise reaches a level of 10 μas. Using methods similar to those used in 2010, we also show that the ICRF2 defining sources realize a more stable frame, suggesting the solutions are getting more consistent, and the latest solution shows a better statistical stability.

Keywords ICRF2, stability, Allan variance

1 Introduction

In 2010, we presented a method of analyzing VLBI source time series and evaluating the statistical time stability of VLBI sources, generating a stability index function of time for each source (see Le Bail and Gordon, 2010 [2]). This method is inspired by the paper of Martine Feissel-Vernier "Selecting stable extragalactic compact radio sources from the permanent astrogeodetic VLBI program" [1].

Four years later, we use the same method to study current solutions and compare the evolution of the stability of ICRF2.

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In the first part of this study, we look at a particular source we studied in 2010: 3C418, and we determine by the Allan variance if the previous determination of noise is confirmed by the additional data. The second part of the study looks at the stability of Celestial Reference Frames by using the stability index to quantify each source stability. A look at the ICRF2 defining sources is also given.

2 Studied VLBI Solutions

In this study, we consider three different solution sets: 09GSF005, TS2012a, and TS2014a, all computed at GSFC/NASA with *Calc/Solve*. These time series solution sets were all generated in the same manner.

Five separate *Solve/Globl* solutions were run for each solution set. In the first solution, the positions of all 295 ICRF2 defining sources were estimated as global parameters (a single position for the entire data span) and constrained to their ICRF2 positions using a no-net-rotation constraint. All other source positions were treated as arc parameters; that is, a separate position was estimated for each source in each session. In the second solution, one-fourth (74) of the defining sources were removed from the global parameter list and the no-net-rotation constraint (every fourth source by right ascension). Positions for those 74 sources (along with all the others from the first solution) were estimated as arc parameters. In the third, fourth, and fifth solutions, the next successive 1/4 of the ICRF2 defining sources (74, 74, and 73 sources) were treated as arc parameter sources. The time series for the 295 defining sources were taken from the second, third, fourth, and fifth solutions. All other sources were taken from the first solution.

For these solutions, sessions with small and regional networks were excluded, because they do not yield highly accurate source positions. Also no VCS sessions were used, because most of the VCS sources were observed only once or twice.

The three solution sets differ by the period they cover: 1979 to 2009 for 09GSF005 (29 years and 7.5 months), 1979 to 2012 for TS2012a (32 years and 11 months), and 1979 to 2014 for TS2014a (34 years and 5.5 months). The number of sources in the catalog increases 41% from 1,204 for 09GSF005 to 1,696 for TS2014a (see Table 1).

Table 1 The three solution sets of this study.

	Period	Number of sources
09GSF005	1979-Aug-03 to 2009-Mar-16	1204
TS2012a	1979-Aug-03 to 2012-Jul-02	1517
TS2014a	1979-Aug-03 to 2014-Jan-16	1696

3 The Case of 3C418 with Five More Years of Observations

We use the Allan variance to study source 3C418. This is a statistical tool used to determine the type and level of noise of time series by computing the Allan variance over various sampling times τ. The slope of the Allan variance curve indicates the type of noise as illustrated in Figure 1: -1 indicates white noise, 0 flicker noise, and $+1$ random walk.

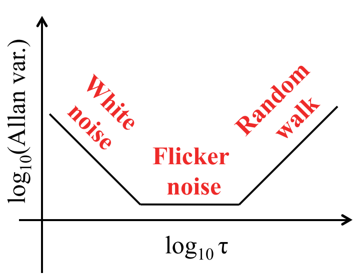

Fig. 1 Using the Allan variance to determine the type of noise.

3C418 is a good example of non-stationarity. From the 09GSF005 solution, the Allan variances computed from 1989–1993 show white noise at the level of 100 μas for both coordinates. The Allan variances computed from 1997 to 2009.5 show a combination of white noise and flicker noise, with a level for the flicker noise as low as 50 μas for both coordinates.

We extend this study to 2014 using the solution TS2014a (see Figure 2). The Allan variances computed from 1989–1993 show white noise at the level of 200 to 400 μas. This is the same four-year period as in the previous study. The results can be explained by the short period on which the Allan variances are computed, as well as the improvement of the technique after 1993. The Allan variance computed from 1997–2014 shows a combination of white noise and flicker noise. However, for the declination, the Allan variance curve is characteristic of white noise with a periodic signal with a period close to one year: the declination time series do not reach the same threshold of 50 μas reached by the right ascension. The five more years of observations strengthen the previous statistical study and brings more details on the noise in the time series.

4 Stability Study

To judge the stability of a subset of chosen sources, we compare two Celestial Reference Frames realized by this subset: one is the yearly mean realization $(CRF)_i$ while the other is the mean computed over the full period. To do so, we process $(A1, A2, A3)$, three rotation angles around the X, Y, and Z axes, respectively, and a fictitious declination bias dz. This is illustrated in Figure 3.

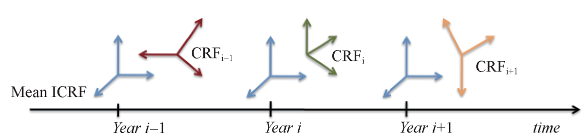

Fig. 3 Method used to compute the parameters $(A1(i), A2(i), A3(i), z(i))$ to access the stability of Celestial Reference Frame.

First, we apply this to study the 295 ICRF2 defining sources. The three solution sets are studied over the same period 1989.5–2009.5. Figure 4 shows the $(A1, A2, A3)$ obtained. We repeat this study for a longer period for TS2014a (1989.5–2013.5), and the results

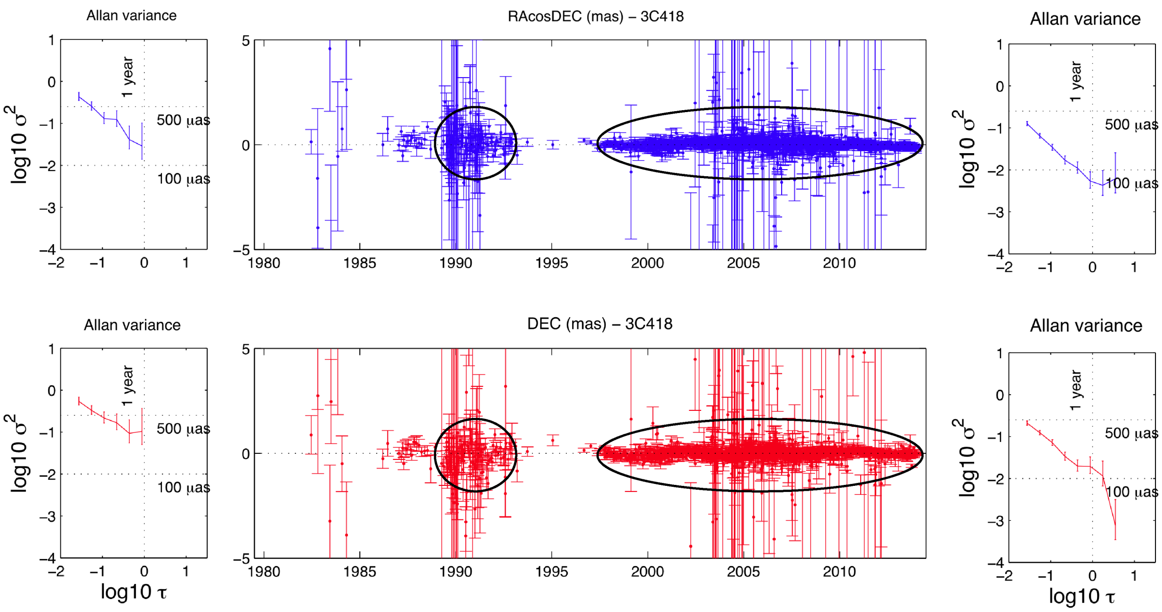

Fig. 2 Position time series of 3C418 (middle plots), Allan variances computed from 1989 to 1993 time series (left plots) and Allan variances computed from 1997 to 2014.1 times series (right plots).

are shown in Figure 5. The standard deviation and the mean are reported in Table 2.

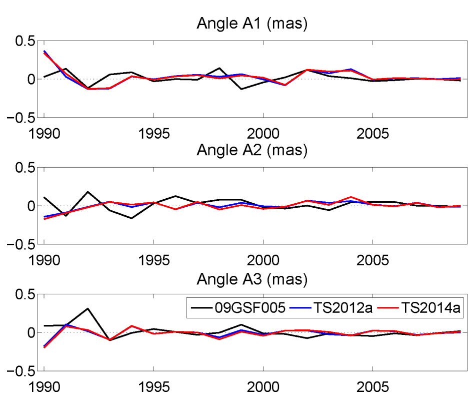

Fig. 4 Stability of the frame realized by the ICRF2 defining sources in each solution 09FSF005, TS2012a, and TS2014a studied, over the same period 1989.5–2009.5.

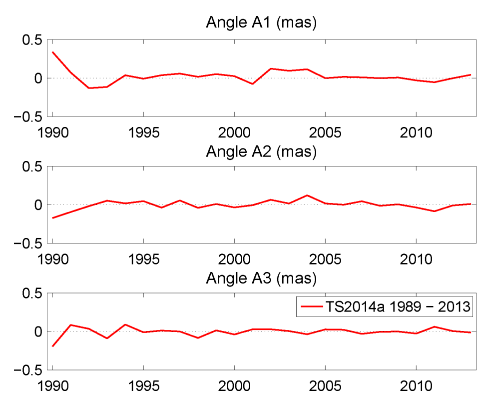

Fig. 5 Stability of the frame realized by the ICRF2 defining sources in the solution TS2014a over the period 1989.5–2014.1.

For the latest solution sets (TS2012a and TS2014a), the means and standard deviations are smaller than for solution set 09GSF005. The stability of A3 is improved by a factor of two. The curves in Figures 4 and 5 are significantly more stable, especially after 1995. The ICRF2 defining sources realize a more stable frame, suggesting the solutions are getting more consistent.

In the second part of this study, we look at the stability of each source and build sets of stable sources for each solution set. The method is described in Le Bail and Gordon, 2010 [2] and summarized hereafter. Using statistical metrics such as the Allan variance at a one-year sampling time and the normalized values of the drifts for both coordinates (right ascension and

Table 2 Standard deviations and means of (A1,A2,A3) in Figures 4 and 5.

Statistics		09GSF005 (1989.5 - 2009.5)	TS2012a (1989.5 - 2009.5)	TS2014a (1989.5 - 2009.5)	TS2014aL (1989.5 - 2013.5)
Std	A1	0.0756	0.0703	0.0692	0.0644
	A2	0.0839	0.0415	0.0494	0.0488
	A3	0.0901	0.0473	0.0482	0.0443
Mean	A1	0.0127	0.0131	0.0148	0.0103
	A2	0.0108	0.0089	0.0061	0.0026
	A3	0.0090	0.0016	-0.0006	0.0021

declination), we calculate a stability index for each analyzed source. The sources are then sorted from the most stable to the least stable. Reference Frames are built using sets of the i^{th} most stable sources. For each of these Reference Frames, we compute a set of $[A1(i), A2(i), A3(i), dz(i)]$ for each year i, and then calculate the standard deviation and the mean for the quantity $A1+A2+A3+dz$.

Figure 6 shows the standard deviation and the mean as a function of the number of sources used, for the solutions 09GSF005, TS2012a, and TS2014a studied over a common period 1989.5–2009.5.

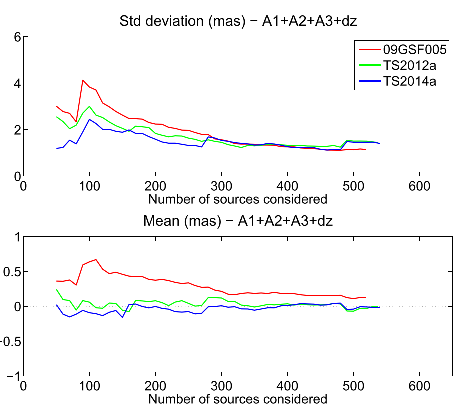

Fig. 6 Stability of subsets of stable sources selected in each solution set: 09GSF005, TS2012a, and TS2014a over the period 1989.5–2009.5.

The solution set TS2014a shows better stability than 09GSF005 and TS2012a. A set of 280 sources gives an optimal stability.

Let us note that the improvement in stability of TS2014a compared to TS2012a may be due in part to a reprocessing of *DiFX* correlated data from 2011.0 to 2012.5 to fix a *difx2mark4* error.

5 Discussion

We compare solution sets done with data through the beginning of 2009 (09GSF005), through the middle of 2012 (TS2012a), and through the beginning of 2014 (TS2014a). The latest solution set has five more years of data.

The current solution set is more consistent, and the frame realized by the defining sources seems more stable. Thanks to efforts such as the IVS monitoring program, IVS observing is becoming more consistent and uses more resources.

References

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