Evaluation of the stability of ICRF2 in the past five years using the Allan variance

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Session 5

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. This method is inspired by the paper of Martine Feissel-Vernier "Selecting stable extragalactic compact radio sources from the permanent astrogeodetic VLBI program" **[1]**.

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

In the first part of this poster, 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 poster 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.

Studied VLBI solutions

In this study, we consider three different solutions: 09GSF005, 2012a and 2014a, all computed at GSFC/NASA with *Calc/Solve.* These time series solutions were all generated in the same manner: Five separate *Solve/Globl* solutions were run for each time series. In the first solution, the positions of all 295 ICRF2 defining sources were solved for 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, (a separate position was estimated for them 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 R.A.). Positions for those 74 sources (along with all the others from the first solution) were solved for 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, since they do not yield highly accurate source positions. Also no VCS sessions were used, since most of the VCS sources were observed only once or twice.

	09GSF005	2012a	2014a
Period	1979-Aug-03 – 2009-Mar-16	1979-Aug-03 – 2009-Aug-06	1979-Aug-03 – 2014-Jan-16
Number of sources	1204	1517	1696

The case of 3C418 with five more years of observation

In 2010, we studied the case of source 3C418 for solution 09GSF005. It was a good example of non-stationarity: the Allan variances computed from 1989-1993 show white noise at the level of 100µas 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 50µas for both coordinates. We extend this study to 2014 using the solution 2014a. The Allan variances computed from 1989-1993 show white noise at the level of 200 to 400µas, and computed from 1997-2014, a combination of white noise and flicker noise. However, for the declination, the Allan variances 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 50µas reached by the right ascension. The five more years of observation strengthens the previous statistical study.

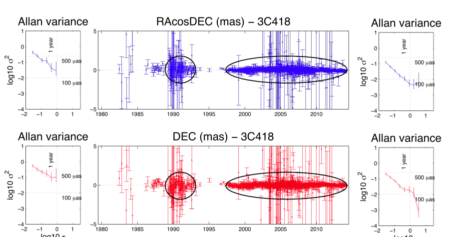
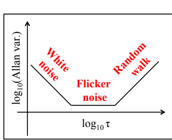


Figure 1. *Position time series of 3C418 (middle plots), Allan variances computed from 1989-1993 time series (left plots) and Allan variances computed from 1997 to 2014.1 time series (right plots).*

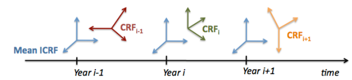


Reminder: The Allan variance is a statistical tool used to determine the type and level of noise of stationary time series by computing the Allan variance over various sampling time τ. The slope of the Allan variance curve indicates the type of noise as illustrated in Figure 2.

Figure 2. *The Allan variance to determine the type of noise.*

Stability study

We use **(*A1,A2,A3,dz*)** as an indicator of the Celestial Reference Frame stability. 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 being computed over the full period. To do so, we process three rotations (*A1,A2,A3*) and a fictitious declination bias *dz*. This is illustrated in Figure 3.



$$\begin{cases}(\alpha_m-\alpha_i)\cos\delta_m = A_1(i)\tan\delta_i\cos\alpha_i + A_2(i)\tan\delta_i\sin\alpha_i - A_3(i)\\ \delta_m-\delta_i = -A_1(i)\sin\alpha_i + A_2(i)\cos\alpha_i + dz(i)\end{cases}$$

Figure 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 solutions are studied over the same period 1989.5-2009.5. The left plot of Figure 4 shows the (*A1,A2,A3*) obtained. The study is done for a longer period for TS2014a (1989.5-2014.1) and the results are shown in the right plot of Figure 4. The standard deviation and the mean are reported in Table 1.

For the latest solutions, the ICRF2 defining sources realize a more stable frame, suggesting the solutions are getting more consistent.

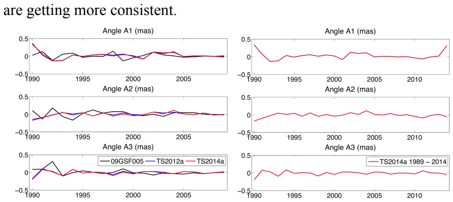


Figure 4. *Stability of the frame realized by the ICRF2 defining sources in each solution.*

Statistics		09GSF005 (1989.5 – 2009.5)	2012a (1989.5 – 2009.5)	2014a (1989.5 – 2009.5)	2014a (1989.5 – 2014.1)
Std	A1	0.0756	0.0703	0.0692	**0.0646**
	A2	0.0839	**0.0415**	0.0494	0.0488
	A3	0.0901	0.0473	0.0482	**0.0440**
Mean	A1	0.0127	0.0131	0.0148	**0.0099**
	A2	0.0108	0.0089	0.0061	**0.0007**
	A3	0.0090	0.0016	**-0.0006**	0.0019

Table 1. *Standard deviation and mean of (A1,A2,A3) in Figure 4.*

In the second part of this study, we look at the stability of each source and build sets of stable sources for each solution. The method is described in **[2]** and summarized hereafter. Using statistical metrics as the Allan variance at one-year sampling time and the normalized values of the drifts for both coordinates (right ascension and declination), we calculate a stability index for each analyzed source. The sources are then sorted from the most stable to the less stable. Reference Frames are built using sets of i^{th} most stable sources. For each of these References 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 5 shows the standard deviation and the mean in function of the number of sources used.

In Figure 5, the solutions 09GSF005, TS2012a and TS2014a are studied over a common period 1989.5-2009.5. Results are shown for TS2014a over a longer period: 1989.5-2014.1 (TS2014aL).

The solution 2014a shows better stability than 09GSF005 and 2012a. A set of 280 sources gives an optimal stability. However, when looking at TS2014aL, the optimal set of stable sources reaches 400 sources.

NB: The improvement in stability of 2014a compared to 2012a may be due in part to a reprocessing of *difx* correlated data from 2011.0 – 2012.5 to fix a *difx2mark4* error.

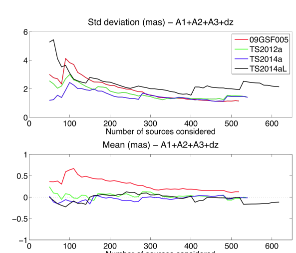


Figure 5. *Stability of subsets of stable sources selected in each solution (09GSF005, 2012a, 2014a over the period 1989.5-2009.5 and 2014a over the period 1989.5-2014.1 -2014aL-).*

References

[1] Feissel-Vernier, M., *Selecting stable extragalactic compact radio sources from the permanent astrogeodetic VLBI program*, ***A&A***, 2003.

[2] Le Bail, K., and D. Gordon, *Time-dependent Selection of an Optimal Set of Sources to Define a Stable Celestial Reference*, in ***Proceedings of the IVS 2010 General Meeting***, Hobart, Australia, Feb 7-13, 2010, Eds D. Behrend and K. D. Baver, p.280–284.

Discussion

In five years, VLBI accumulated more data for more sources. The current solution is getting more consistent and the frame realized by the defining sources seems more stable. Thanks to efforts like the IVS monitoring program (see poster in this same session 5), the IVS observation is becoming more consistent and uses more resources. We have a better understanding of the weakness in the Reference Frame and study new opportunities to strengthen it, like observing more of the southern sources or including Gaia transfer sources to link the future Gaia catalog with the ICRF.

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