Martine Feissel-Vernier: Stability of the VLBI-Derived Celestial Reference Frame, IVS 2004 General Meeting Proceedings, p.346–350
http://ivscc.gsfc.nasa.gov/publications/gm2004/vernier

Stability of the VLBI-Derived Celestial Reference Frame

Martine Feissel-Vernier

Observatoire de Paris/SYRTE and Institut Géographique National/LAREG
e-mail: feissel@ensg.ign.fr

Abstract

We present background information of a paper [5] that investigated several stable source selection processes and proposed a list of 199 stable sources that could be used for a future improvement of the ICRF. Their expected performance in maintening the direction of the ICRF axes (± 6 μas) is better by a factor of four or five than that of the current 212 ICRF defining sources.

1. The Observations

The data analysis in this study is based on the time series of coordinates of 707 radio source derived by Alan Fey (USNO) using 3.6 millions of observations accumulated in various international programs up to May 2002. The observations consist of time series derived from a set of three analyses of the existing VLBI observing sessions. Each analysis results in time series of coordinates per session for one third of the sources ("arc" sources), the coordinates of the other sources being treated as "global", i.e. they are assumed to stay fixed in time and are estimated globally. Each analysis includes a no-net-rotation (NNR) condition with respect to the ICRF based on a part of the ICRF *defining sources* [7] . To avoid inconsistencies that are due to the NNR condition realization in the three analyses, and that can reach the level of 50 microarcseconds (μas), we consider here for each source the time series of its coordinates differences with their global weighted mean.

2. Apparent Motion of Sources

When observed at the current level of precision (a fraction of milliarcsecond, mas), no object is really pointlike. Most of the known activity of quasars takes the form of jets, i.e., aligned emissive structures that cause an apparent motion of the observed phase center. As a result, most objects exhibit time variations of their position in some preferred direction.

We illustrate in figure 1 the 1984-2002 time evolution of the positions of four sources in local equatorial frames. See [6] for more detail on the apparent motion of these sources.

3. The Stable Sources Selection Scheme

Stable sources were selected from the 1989.5-2002.4 data in a two-step process, as follows.

1. A first selection is made on the basis of continuity criteria for one-year weighted average coordinates. The preselection conditions are the following ones.

   (a) Length of observation period longer than five years.

   (b) Not less than two observations of the source in a given session.

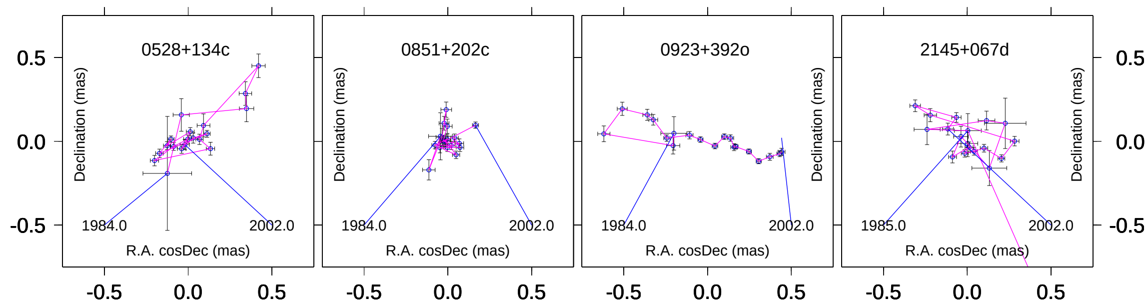

Figure 1. Observed motion of four radio sources over 1984-2002 (yearly averages). Similar plots for 362 well observed sources are available at http://hpiers.obspm.fr/icrs-pc/icrf/time-series.html.

(c) One-year average coordinates based on at least three observations.

(d) Not more than three successive years with no results, conditions (b) and (c) being met.

(e) At least half of the one-year averages available over the source observation time span.

This first screening kept 362 sources for the years centered at 1990.0 through 2002.0. These include 67% of the defining sources, 44% of the candidates and 85% of the others.

2. The time series of yearly values of $\alpha \cos \delta$ and δ of the preselected sources are then analysed in order to derive

   (a) the linear drift (least squares estimation) and the normalized drift. The latter is the absolute value of the linear drift divided by its formal uncertainty;

   (b) the Allan standard deviation [1] for a one-year sampling time. The Allan variance of a time series x_i with N items and sampling time τ is defined as:

$$\sigma_A^2(\tau) = \frac{1}{2N} \sum_i (x_{i+1} - x_i)^2$$

For each local coordinate ($\alpha \cos \delta$ and δ), two partial indices are defined (see Table 1). The partial stability indices range from 1 (most stable) through 3 (least stable), with a rejection value (10) associated to very large drifts or standard deviations.

4. Relationship of the Stable Sources with the ICRF Source Qualifications

The **partial stability indices** for each of the 362 sources investigated (drift, Allan variance and normalized drift) can be compared with two existing ICRF qualifiers:

- the source status: defining, candidate or other, and
- the source structure index [3] in the X band. Structure index values 1 and 2 indicate very good and good astrometric suitability, values 3 and 4 poor and very poor suitability.

The comparisons are plotted in figures 2 and 3. The sources considered as stable are those inside the lower left rectangles. The plots show only partial agreement of the ICRF qualifiers with the stability criteria.

Table 1. Partial stability criteria.

Statistics	Threshold	Partial index
Allan Standard deviation (AlSd)		
	AlSd $\leq$ 100 μas	1
	100 μas $\leq$ AlSd $\leq$ 200 μas	2
	200 μas $\leq$ AlSd $\leq$ 300 μas	3
	AlSd $\geq$ 300 μas	10
|Drift| (Vel)		
	Vel $\leq$ 10 μas/year	1
	Vel $\geq$ 50 μas/year	10
|Normalized drift| (Nvl)		
	Nvl $\leq$ 1	1
	1 $\leq$ Nvl $\leq$ 3	2
	Nvl $\geq$ 3	3

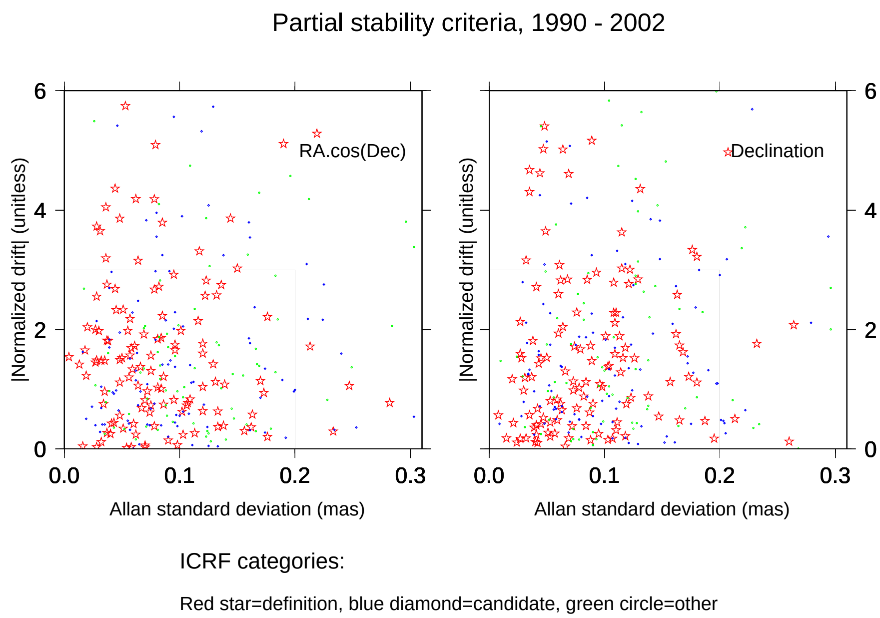

Figure 2. Relationship of the ICRF source status with the partial stability index

Table 2 gives the relationship of the **global stability index** with the ICRF qualifiers. Sources with global stability indices 1 and 2 are considered as stable. Although a number of defining sources get small partial stability indices, some of them are clearly detected as unstable. The candidate sources are globally in the same situation. Conversely, a number of "other" sources, i.e. considered as having questionable stability in the ICRF work, are detected as stable. Compared to the ICRF selection, the proposed scheme rescues a number of sources that are in fact efficient for maintaining the ICRF axes directions [2]. For what concerns the source stability indices, 80% of the stable sources have a good structure index (1 or 2), while the ratio is also large for the unstable sources (64%). Altogether, 61% of the well observed sources with a good structure index

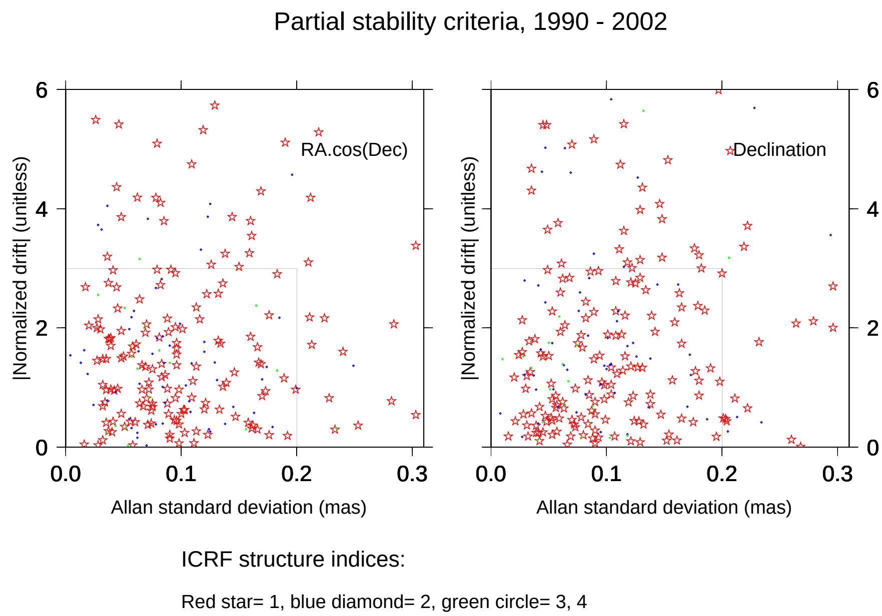

Figure 3. Relationship of the source structure index with the partial stability index

are detected as stable, and 39% are detected as unstable. This finding is of interest in the context of studying the dynamics of the quasars' activity.

Table 2. Stability index and ICRF source qualifiers.

Stab. index	Source status			Structure index			Stab. index	Source status			Structure index		
	Def.	Can.	Oth.	1	2	3-4		Def.	Can.	Oth.	1	2	3-4
Stable							Unstable						
1	33	26	15	46	11	7	3	2	1	4	6	2	0
2	48	42	34	76	26	6	4	58	61	34	70	26	13

5. Testing Source Selections

Out of the 362 preselected sources the stability scheme described in section 3 produces 199 stable sources, a number to be compared to the 212 defining sources in the ICRF. To test their efficiency for maintaining the direction of the axes of the celestial reference frame, we consider the 13 yearly differential reference frames (1990.0 - 2002.0) that are formed by the set of stable sources observed in each year and we compute the series of yearly differential rotation angles A_1, A_2, A_3 around the axes of the equatorial coordinate system for the 13 years. Table 3 lists efficiency estimates for the stable sources and for the ICRF defining sources. These estimates are

- the average standard deviation of the series of A_1, A_2, A_3, that characterizes the scattering of the series of yearly rotation angles, and
- their Allan standard deviations for one-year and four-year sampling times, that characterize

their stability in time. Note that if the time series of the rotation angles have white noise, the four-year Allan standard deviation will be equal to half (square root of one fourth in sampling time) the one-year one. In the case of flicker noise, both values will be equal.

The estimated efficiency of the ICRF defining sources is lower than that of the proposed selection by nearly a factor of three for the one-year estimates and a factor of five in the longer term. In addition, the axis stability spectrum is nearly white noise in the case of the stable sources, while it is degraded to flicker noise in the case of the defining sources.

Table 3. Stability of rotation angles of yearly reference frames relative to the 1990-2002 mean frame.

Source selection scheme	Nb of sources kept	Std dev. μas	Allan Std dev. 1 year μas	Allan Std dev. 4 years μas
Stable	199	10.8	9.4	5.9
ICRF Defining	212	25.6	26.0	27.6

6. Discussion

When compared to the current ICRF defining sources, the selection scheme developed in [5] achieves improved time stability of yearly reference frames (6 μas vs 28 μas) , which implies improved internal consistency.

This has consequences in astrometric applications, but it may also have bearings in the geophysical interpretation of the Earth's orientation in inertial space. As an example, Dehant et al. [4] have shown that source instabilities perturb precession and long term nutation determinations at the level of tens of μas, a level comparable to that of the discrepancy of VLBI results with the precession constant or the 18.6-year nutation component in the IAU2000 Nutation model.

Finally, we recommend that the set of selected stable sources be considered in the scheduling of repeated VLBI sessions for Earth rotation, geodesy and astrometry, as well as in any future improvement of the International Celestial Reference Frame.

References

[1] D.W. Allan, 1966, Proc. IEEE 54, 221

[2] E.F. Arias, S. Bouquillon, 2003, A&A, In press

[3] P. Charlot, 2004, This volume

[4] V. Dehant, M. Feissel-Vernier, O. de Viron, C. Ma, M. Yseboot, C. Bizouard, 2002, JGRB, 108, 2275

[5] M. Feissel-Vernier, 2003, A&A, 403, 105

[6] M. Feissel-Vernier, 2004, in IERS Technical Note in preparation (J. Souchay ed.)

[7] C. Ma, E.F. Arias, T.M. Eubanks, A.L. Fey, A.-M. Gontier, C.S. Jacobs, O.J. Sovers, B.A. Archinal, P. Charlot, 1998, AJ 116, 516