EARTH'S INTERIOR WITH VLBI... AND THE CELESTIAL REFERENCE FRAME?

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ABSTRACT. This paper proposes some insights into the sensitivity of nutation estimates and subsequent geophysical parameter determinations to the strategy adopted to handle the radio source coordinates during the astrogeodetic VLBI analysis. The calculations and results presented at the Journées 2007 have since then been reported in the paper Lambert et al. (2007). We invite the reader to consult this paper for further details and references and we chose to present here a summary of the most important ideas.

1. OBSERVATIONAL AND ANALYSIS STRATEGIES IN ASTROGEODETIC VLBI

Astrogeodetic VLBI aims to measure the relative orientation of the terrestrial and the celestial reference frames. It achieves this by observing radio sources from ground-based radio telescopes. In one observing session 6 to 12 antennas observe $\sim$80 sources. Repeating this every few days allows one to get orientation parameters (the well-known Earth orientation parameters, or EOP) and other relevant astrogeodetic quantities on a regular basis since 1984. Nevertheless, the VLBI instrument is changing at every session: the network array is different as well as the set of observed sources, making the realization of the terrestrial and celestial reference frames difficult and clearly introducing a source of error in the EOP themselves. Fig. 1 shows the observational history of some subsets of the 816 sources as observed in 2995 sessions analyzed at the Paris Observatory IVS Analysis Center. One clearly sees that the density of observing sources is significantly varying with time. The nutation offsets, basically the corrections to the IAU 2000A, that traduce a motion of the Earth's figure axis in space, show a pretty high noise level, although some patterns do show up (for instance the nearly diurnal free wobble associated with the free core nutation, and smaller annual and seasonal terms that can bring crucial information about the Earth's deformability). A consequence of the observing strategy is that a substantial part of the nutation offsets could be nothing but a propagated error due to a misleading analysis scheme and reflecting the radio source positional instabilities.

To evaluate this error, we propose to compare several analysis schemes that differ only in the way the radio source positions are handled (i.e., estimated as local or global parameters, and constrained). The International Celestial Reference Frame (ICRF, Ma et al. 1998), yields a catalogue of sources built on the basis of VLBI observations until 1995. It has been updated by Fey et al. (2004) and designated by ICRF-Ext.2. The simplest analysis scheme is to fix the radio source coordinates to their ICRF-Ext.2 values. However, doing so is implicitly considering that source positions have not changed since the release of the ICRF-Ext.2, which is wrong to some extent. A safer way is to estimate (either globally or locally) the radio source coordinates during the analysis, applying nevertheless a no-net rotation (NNR) constraint on some of them. The NNR is the mathematical translation of the fact that the source are globally and at any time non rotating with respect to the far universe. The ICRF yields 212 defining sources that are traditionally used for the NNR. However, Feissel-Vernier et al. (2006) (referred to as MFV in the following) yielded a set of 247 sources selected for their positional time stability. The same work selected 163 highly unstable sources, some of them being part of the 212 ICRF defining sources, that could obviously prevent the NNR from being verified along the complete observational time span. Table 1 reports on our analysis scheme that mix the ICRF and MFV subsets for the NNR and that put the unstable either as global or local parameters.

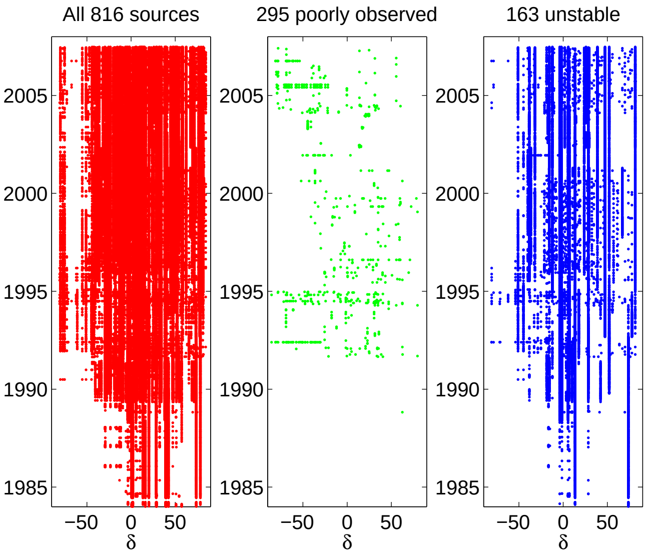

Figure 1: Observational history of (left) all the 816 sources, (middle) only the 295 sources having less than 20 observations in less than 2 sessions, and (right) the 163 unstable sources of Feissel-Vernier et al. (2006).

Table 1: Characteristics of the VLBI solutions used in this work. MFV: 247 stable sources of Feissel-Vernier et al. (2006); ICRF: 212 ICRF defining sources of Ma et al. (1998).

	No. sources fixed	global	local	NNR	Postfit rms ps	rms δX μas	rms δY μas
A	816	0	0	-	24.0	165	167
B	0	816	0	ICRF	23.6	166	173
C	0	816	0	MFV	23.6	161	169
D	0	521	295	ICRF	23.6	162	170
E	0	521	295	MFV	23.6	161	169
F	0	653	163	ICRF	23.2	167	168
G	0	653	163	MFV	23.2	166	168

Our interest is to compare the various nutation offset time series obtained from the solutions designated A to G in Table 1. The comparison in terms of rms and noise is detailed in Lambert et al. (2007). Let us here write down some ideas about the comparison in terms of nutation amplitudes and Earth's interior parameters. We therefore propose to look at how the amplitude of the prominent nutation terms varies from one the another solution in A–G. In the nutation offsets taken as a complex time domain quantity $\delta X(t) + i\delta Y(t)$, we fit a number of terms of the form $(A^{\rm Re} + {\rm i}A^{\rm Im}){\rm e}^{{\rm i}\Theta}$ where Θ is a linear combination of the Delaunay's frequencies and phases. We choose to fit the prograde and retrograde 18.6-yr, 9.3-yr, 6.2-yr, annual, semi-annual, tri-annual, monthly and semi-monthly terms, along with a retrograde term of period 430.21 days (accounting for the nearly diurnal free wobble) and a linear trend. These terms are then corrected to remove the contribution of non-linear terms (see Lambert & Mathews 2006). Resulting amplitudes for A–G are reported in Fig. 2. It appears that the largest offsets to MHB are on the prograde annual and on the retrograde 18.6-yr nutations. The thick, red line represents an average of the solutions, the associated red error bars represent the cumulated error due to (i) the least-squares fit (estimated as the square root of the sum of the squared formal errors) and (ii) to the unperfect realization of the celestial frame. This latter contribution is obtained as the difference between the maximum and minimum amplitudes for each frequency. As already mentioned earlier, the influence of the celestial frame for annual and smaller periods is smaller than for longer periods.

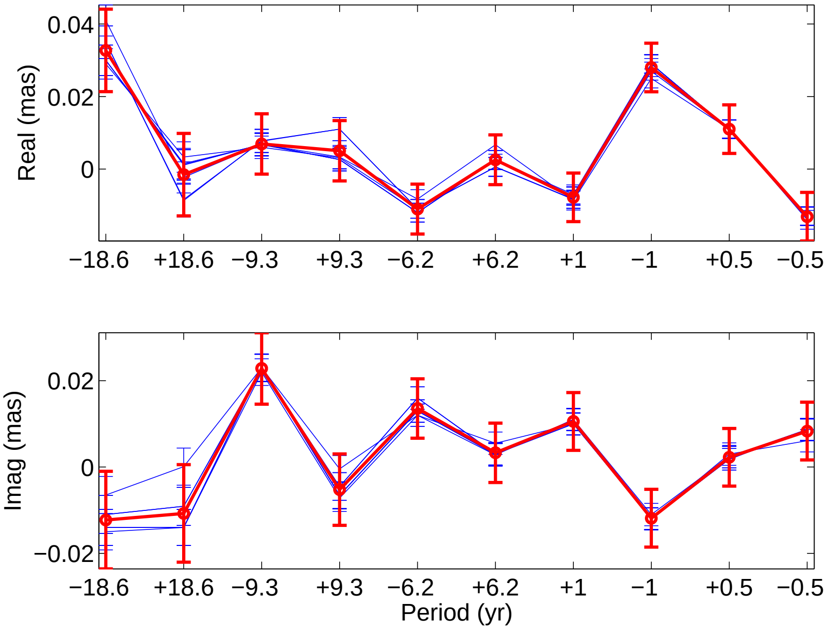

Figure 2: Amplitude of the VLBI residuals for prominent nutation periods against MHB from solutions A to G. The red, thick line is the averaged amplitude.

2. DOWN INTO THE EARTH'S INTERIOR

Nutation amplitudes give the response of the non rigid Earth to an excitative external potential. Though, for a rigid Earth, the admittance is simply the Earth's flattening, for a more complex stratified anelastic Earth with liquid core and solid inner core, the admittance is much more complex (see Mathews et al. 2002 for instance and reference therein). This admittance include strong resonances associated with the main ellipsoidal layers (mantle, core and inner core) and known as the Chandler wobble, the retrograde free core nutation (RFCN) and the free inner core nutation (FICN), respectively. The former one acts only in the long-periodic band in the Earth-fixed frame of reference and is therefore irrelevant here. However, the resonant frequencies of the latters, adjusted on VLBI data, are of −430.21 days and 1024.36 days, respectively, following Mathews et al. Let us look at the sensitivity of these parameters to the celestial frame instability already propagated into nutation amplitudes.

The method of retrieving the RFCN and FICN resonant frequencies is detailed in Lambert et al. (2007) and elsewhere in the literature. The obtained values of the resonant RFCN and FICN periods P and quality factors Q are reported in Fig. 4 wherein the uncertainties represent the formal error of the least-squares fit. The influence of the analysis strategy can be seen by comparing P and Q from one to the other solution. One can see that the RFCN period goes from -430.30 to -430.32 days, an interval smaller than the least-squares standard error which amounts to 0.08 day. The quality factor is stable within less than 200. The FICN period stays between 1042 and 1113 days (with a formal error around 120 days). Its quality factor is between 885 and 974 with error bars of 200.

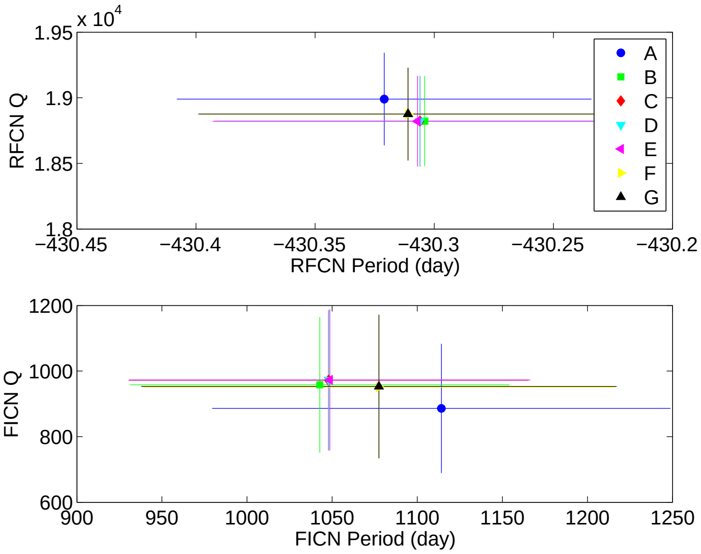

Figure 3: Resonant period and quality factor of the RFCN and of the FICN estimated from various VLBI solutions A to G.

Our work points out the order of magnitude of the error coming from the positional instability of the radio sources and the handling of the celestial frame in VLBI-derived nutation analyses for use in geophysics. This error can produce an additional error in the estimates of nutation spectral components of 15 μas for the 18.6-yr term, and that decreases for shorter periods. In terms of resonant frequencies of the outer and inner cores, this means an uncertainty of a few tenth of day on the RFCN period and of 200 on Q, and an uncertainty of less than 100 days on the FICN period and of 100 on Q. Although not within the scope of this paper, finding the best strategy for taking account of radio source instabilities in geodetic VLBI analysis remains a challenging question for the near future. Solutions A to G were processed with analysis strategies that are currently in use through the VLBI community. It is therefore expected that some operational solutions proposed within the VLBI community will be more reliable for geophysical investigations since they bring Earth orientation parameters with a best internal accuracy.

3. REFERENCES

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