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Radio Source Stability and the Observation of Precession-Nutation

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Abstract

Some of the radio sources used by VLBI to materialize the celestial reference frame are known to have apparent motions at the sub-milliarcsecond level, particularly those observed in the early years. On the other hand, state of the art precession-nutation models match the observations at this same level. We investigate to what extent the source instability may contaminate the VLBI determination of precession and nutation corrections in several frequency domains.

1. Introduction

Precise determination of precession and nutations is based on VLBI data analysis. The classical way to analyse the data is to consider that the celestial objects used to materialize the reference frame are fixed in space and to use this fixed reference frame to observe the fluctuations of the Earth orientation in space. Those VLBI-derived values are then compared with the output of theoretical precession/nutation models and the differences are analysed. In this paper, the reference nutation model is MHB2000 [1], which was adopted as the international conventional model by the International Astronomical Union in 2000. Two possible causes for the observed discrepancies may be considered ([2]): (1) the variations in the atmospheric forcing (and potentially the oceanic forcing) of the nutations derived from actual observations, and (2) the contamination of VLBI-derived nutation amplitudes by apparent motions of the extragalactic radio sources. This paper concentrates on the second effect.

2. Radio Sources Stability

While the classical precession-nutation VLBI analysis process is based on the assumption that the apparent direction of the observed radio sources is fixed in space, the emitting structure of radio sources is known to have variability. Figure 1 shows examples of time variability for four well observed sources (derived from [4]) and Figure 2 (reproduced from [3]) shows the envelopes of source variability for several hundred of the ICRF [5] sources. As the result of this variability, the effective celestial reference used in the VLBI analysis may be slightly changing with time, raising the question of contamination of the derived nutation amplitudes.

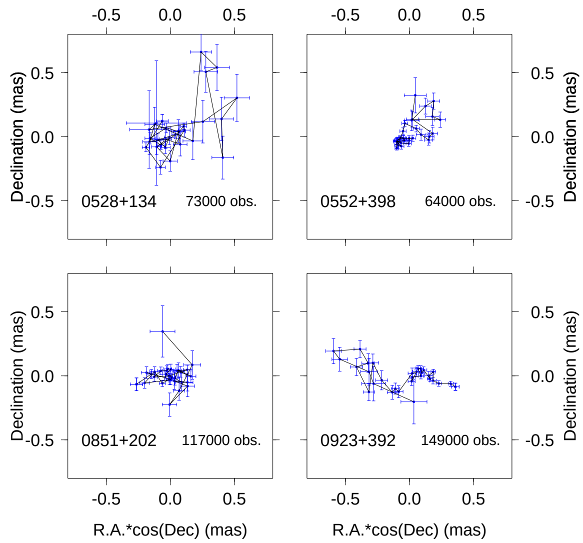


Figure 1. Source position time series at 0.5-year intervals, 1984-1999

3. VLBI Analysis of Precession and Nutation

In order to evaluate the stability of VLBI nutation observations, results obtained with two different approaches are considered. They are described hereafter.

1. The first set of VLBI results used here are time series of ($d\psi$, $d\epsilon$) derived from the analysis of the complete observations data set (over 1980.0 - 2001.4) in two parallel ways, (1) with all source coordinates held fixed, and (2) by restricting the analysis to the most stable sources. We label "ΔVLBI" the difference of nutation results derived from the second series with those derived from the first one. The two series of celestial pole offsets are analysed, looking for differences in the low frequency terms (precession, obliquity rate and 18.6-year term) as well as variable medium-frequency terms (annual and semi-annual forced nutation, 430d Free Core Nutation).

2. The second set of VLBI results that we consider are time series of source coordinates, estimated for each session in which the source was observed [4]. The time variations of the right ascensions and declinations of 639 sources over 1980.0-1999.3 (150,000 individual coordinates) are analysed by the least-square method to detect a possible contamination of the apparent celestial pole direction, either linear or with the main nutation periods. Would such signatures be found, additive corrections "ΔCRF" to the VLBI estimates of ($d\psi, d\epsilon$) for the corresponding components would have to be considered.

3.1. Precession and the 18.6-year Nutation

Table 1 gives the value of the precession correction that is associated with the MHB2000 nutation model, the difference of the VLBI results with this reference value, and the two estimates of the effect of source instability on the precession and obliquity rates. The VLBI discrepancy with the MHB2000 precession correction is in statistical agreement with the MHB2000 residual.

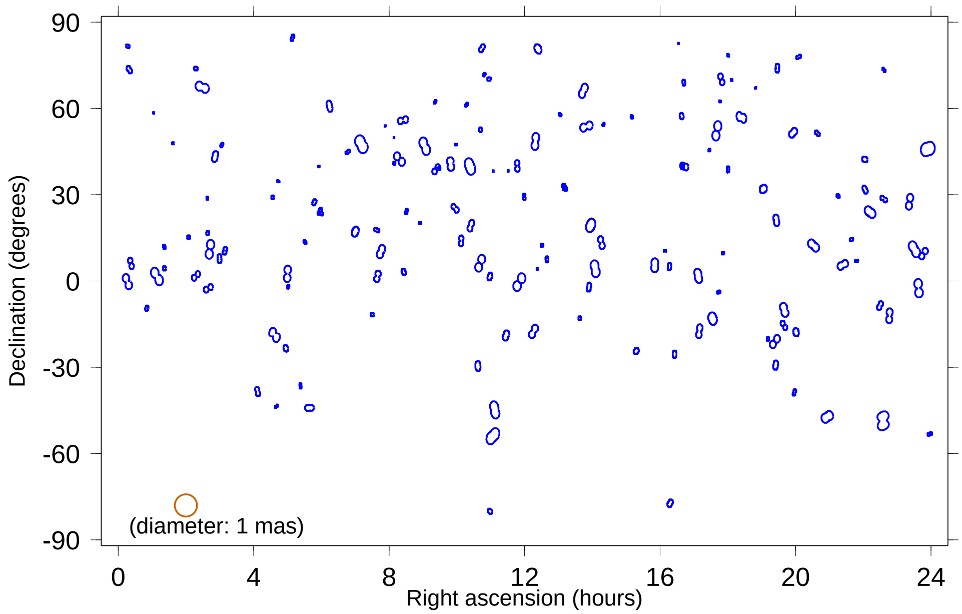


Figure 2. Extragalactic radio sources observed with VLBI, 1985.5-1999.3: envelopes of local variability at 0.5-year intervals.

The two estimates of the source instability effect are in weak agreement, but their similar order of magnitude, as well as their amplitudes relative to the MHB2000 residuals, are an indication of the relevance of considering this aspect.

Table 1. Modeled and estimated values of trends in the celestial pole motion

Data	Precession corr. 0.001"/year		Obliquity rate 0.001"/year	
MHB2000	-2.997			
MHB residual	.036	± .018		
VLBI-MHB	.018	± .005		
Estimated perturbation due to source selection				
Arcs	-.001	± .008	-.031	± .003
CRF	.009	± .002	-.008	± .001

Figure 3 shows the two estimates of the impact of source instability on the determination of the 18.6-year nutation term. The point labelled "VLBI" is the estimate derived from the VLBI series based on all radio sources. The estimate of the atmospheric effect is taken from [2]. The "CRF" correction estimate is smaller than the "Arcs" one. The correction obtained by the two methods are somewhat in disagreement: "CRF" would better reconcile the observations with the model in the case of the prograde component, while "Arcs" works better in the retrograde component. Again, the similar orders of magnitude, both between the two estimates and with the discrepancy with the MHB2000 model, give arguments for the relevance of the question asked.

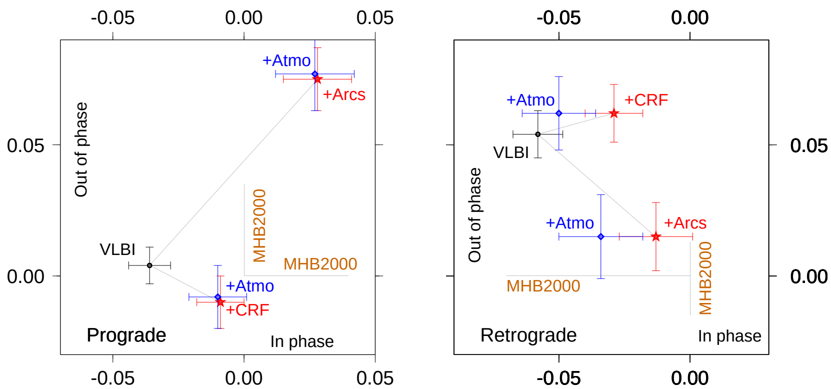


Figure 3. Corrections to the MHB2000 18.6-year nutation term, obtained from analysis of the VLBI series (VLBI) based on all sources, corrected for the effect of arc sources ΔVLBI (+Arcs) or of celestial pole motion effect ΔCRF (+CRF), and then for the atmospheric excitation (+Atmo). Unit: 0.001".

3.2. The forced Annual and Free Core Nutations

Figure 4 shows the Earth's transfer function for a core resonance period of 430 days, retrograde. Excitations near this frequency are expected to be enhanced.

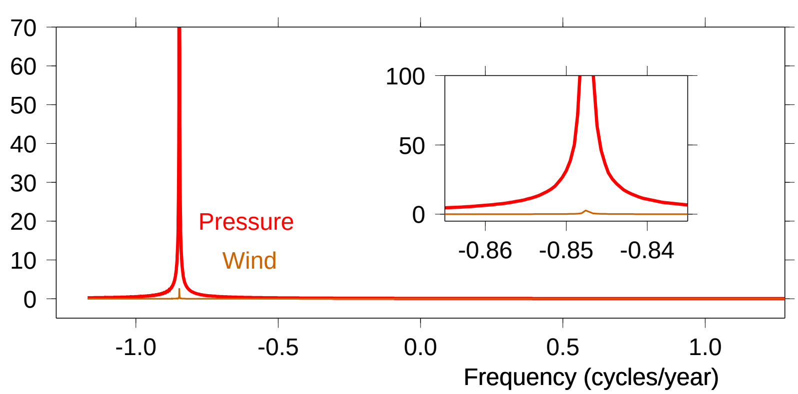
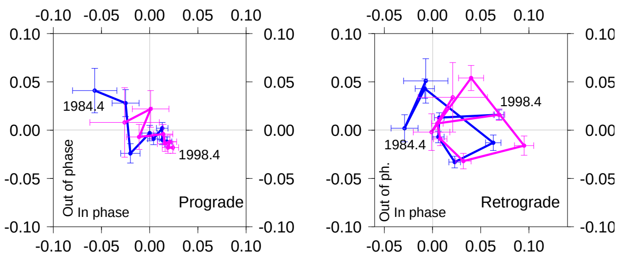


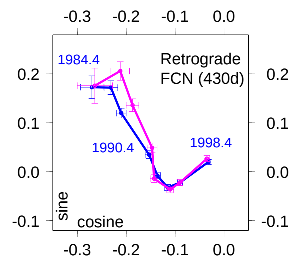
Figure 4. Transfer function for a non-rigid Earth, with a 430-day retrograde FCN. The relative influences of the pressure and wind terms (resp. red and brown/lighter) of atmospheric excitation are shown (arbitrary units).

The left part of figure 5 illustrates the influence the treatment of the source coordinates in the determination of the time-varying annual nutation. The atmospheric excitation in the seasonal frequency band is active mainly in the retrograde component and it varies with time [2]. One indeed hopes to observe these variations in the VLBI results. The observed prograde component shows negligible variations after about 1986, especially when only the stable sources are used. The retrograde component results show significant time variations, as expected. Note that the solution based on the more stable sources is shifted toward positive in-phase values.

On the right part of figure 5, the influence of source coordinates treatment in the determination of the time-varying Free Core Nutation (retrograde 430-day) is shown to be non-negligible in the 1980s. However, it cannot be invoked as a cause for the change in phase and amplitude around 1990. Arguments in favor of an atmospheric origin for this change are given in [2].



Prograde and retrograde components of the annual nutation derived from VLBI observations. The MHB2000 model values are shown as the intersection of the straight lines. Unit: 0.001"



VLBI-derived retrograde component at the FCN frequency (430 days). The origin of phases is J2000.0. Unit: 0.001"

Figure 5. Influence of the modelling of radio source coordinates on the determination of the forced annual and free core nutation coefficients. The blue (darker) lines are for results based on all sources; the pink (lighter) lines are for results based on the stable sources only.

4. Conclusion

While the precision of VLBI-derived precession and nutation amplitude results is at the level of $\pm 10\ \mu$s, these results show clearly that the role of the celestial frame stability is worth analyzing in a rigorous way if further progress is to be made in the understanding of the Earth's precession and nutations.

References

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