An Implementation of IAU 2000 Resolutions in VLBI Analysis Software

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1 Context

The analysis of an Earth based observation of a celestial object requires an astrometric model to express the transformation from a geocentric terrestrial frame to a geocentric celestial one. The classical transformation refers to the equinox of date and use classical precession and nutation quantities. In a new astronomical modelling approach, we refer to the non-rotating origin on the equator of date, proposed by Guinot (1979) and use the celestial coordinates of the CIP (Capitaine, 1990). One of the resolutions adopted by the XXIV General Assembly of the International Astronomical Union (Manchester, August 2000), recommends the use of this new approach. The two paradigms are detailed in IERS Conventions (1996, 2000), in Capitaine et al. (2000) and in McCarthy and Capitaine (see this volume).

GLORIA (Global Radio Interferometry Analysis) is the Paris Observatory software, developed in the early 90s, to analyse Very Long Baseline Interferometry (VLBI) observations (Gontier, 1993). At that time, the new transformation as well as the classical one was implemented. The agreement between the developments of the celestial pole coordinates (X,Y) as a function of time and as a function of the IAU 1976 precession (Lieske et al., 1977) and IAU 1980 nutation (Seidelmann 1982) arguments have been checked at the level of 10^{-5}" (Gontier, 1990). The partial derivatives of the new transformation with respect to the Earth Orientation Parameters (x_p, y_p, UT1-UTC, X, Y) have also been developed and tested (Capitaine and Gontier, 1991). As partial derivatives were not implemented for the classical procedure, all the results derived until now with GLORIA have been obtained using the new paradigm.

2 GLORIA software update

To comply with IAU resolutions adopted in 2000, we modified the GLORIA software for both the new and the classical transformation following the Chapter 5 of IERS Conventions (2000). The changes consisted in:

For the new paradigm:

- Update of the routine that compute the coordinates (X, Y) of the Celestial Intermediate Pole (CIP) and the quantity **s** using the new developments (Capitaine et al. 2002) based on the IAU 2000 A model for precession-nutation.

For the classical paradigm:

- Implementation of the precession matrix from the angles ϵ_0, ψ_A, ϵ_A, χ_A of Lieske et al. (1977) together with precession corrections and offsets of the direction of the CIP at J2000 in the rigorous form recommended by Wallace (2002).

- Update of the routine that compute the nutation matrix using the IAU 2000 A model (Mathews et al. 2002).
- Modification of GST routine to include the IAU 2000A precession adjustments and complementary terms in the equation of equinoxes (Capitaine et al. 2002, IERS Conventions 2000).
- Implementation of partial derivatives with respect to EOP x_p, y_p, UT1-UTC, $d\psi, d\epsilon$).

Furthermore, in the classical transformation, we have implemented two different ways of computing the Greenwich Sideral Time GST:

- version *a*: implementation of the numerical relation between GST and the Earth rotation angle θ referred to the Celestial Ephemeris Origin (IERS Conventions 2000, chapter 5, equation 29) which includes an update of the "equation of the equinoxes".
- version *b*: modification of the current relationship between Greenwich Mean Sideral Time (GMST) and UT1 (Aoki et *al.*, 1982) to include dGMST (IERS Conventions 2000, chapter 5, equation 30) due to the correction in the precession rate, together with an update of the "equation of the equinoxes".

We could notice that, in practice, any future precession and/or nutation models implementation will introduce less software modifications for the new paradigm than for the classical one.

3 Comparisons

Various tests have been performed to verify the level of agreement between the two paradigms using the same software package GLORIA. Two kind of VLBI program of observations have been analysed to derive EOP series:

- The Iris Intensive sessions (2 hours) consist of 20 daily observations of about 16 sources observed on a single baseline oriented East-West. The program is established for the determination of UT1-UTC only.
- The NEOS sessions consist of weekly 24h of observations using a network of 5 stations. The program is optimized for the determination of the 5 EOP.

Only the Iris Intensive sessions have been used to compare the new paradigm with the two versions (*a* and *b*) of the classical one.
The comparisons of UT1-UTC series obtained by analysing 174 Iris Intensives sessions in 2001 (figure 1) show a constant difference of 7.4 μas between the new and the classical paradigm version *a* and 100.5 μas between the new and the classical paradigm version *b*. The error bars are the standard errors and the mean value for each of the three series is 141 μas.
The constant difference of the order of 100 μas in the estimations of UT1-UTC using the two versions of the classical paradigm (figure 1) can be attributed to the different time scales used for computing the contribution of precession in right ascension in GMST (Capitaine et *al.*, 1986). Version *a* (IERS Convention 2000) refers this computation to TT, whereas version *b* (Aoki et *al.*, 1982) refers to UT1, as TT-UTC is about 64.2 s at J2000 it results a difference of the order of -93 μas on UT1-UTC estimates.

The analyse of 28 NEOS sessions in 1999 show differences less than 1 μas on x_p, y_p, $d\psi$ *and* $d\epsilon$ (figure 2 and 3) except for 8 sessions where the differences could reached 81 μas at maximum. The mean values of the standard errors are 69 μas for x_p, 58 μas for y_p, 54 μas for $d\psi$ and 53 μas for $d\epsilon$.

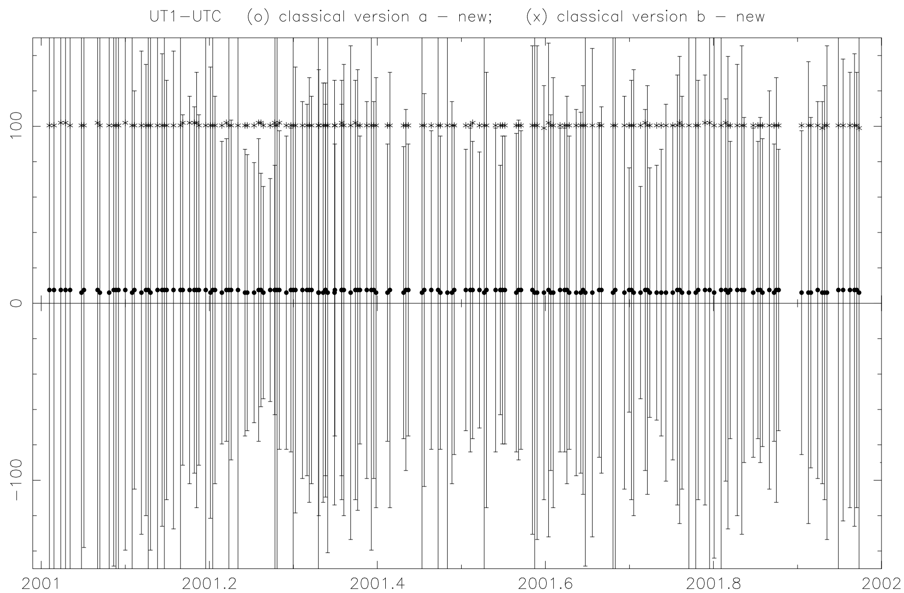

Figure 1: Differences for 2001 between estimated UT1-UTC using the new transformation and the classical one (version *a*: • ; version *b*: ⋆). The plotted error bars are the standard errors of the individual series. Units: μas.

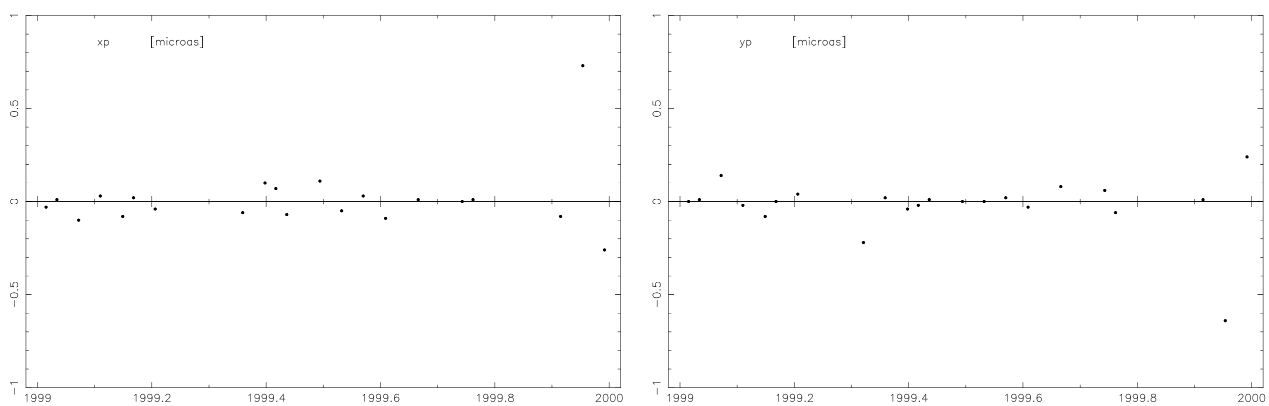

Figure 2: Differences for 1999 between estimated terrestrial pole coordinates (left: x_p, right: y_p) using the classical (version *a*) paradigm and the new one. Units: μas.

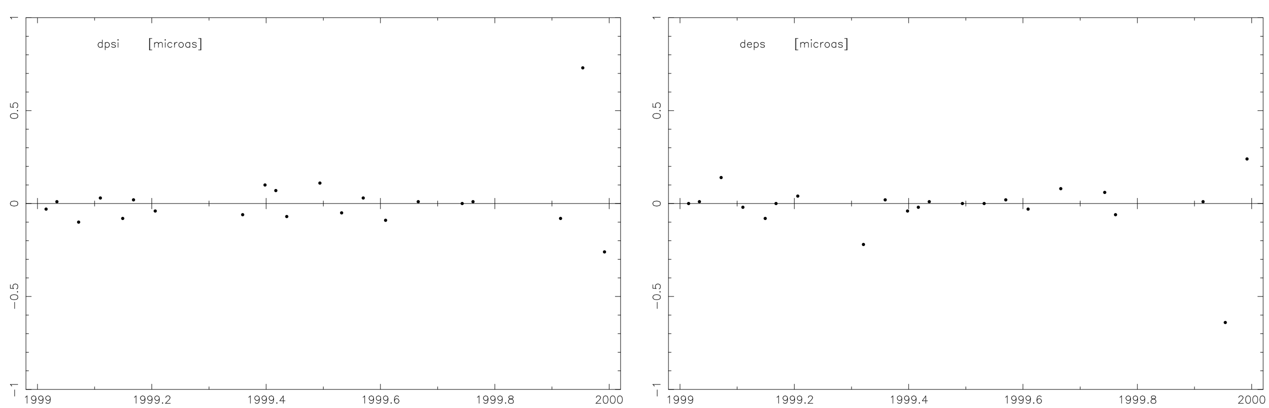

Figure 3: Differences for 1999 between estimated celestial pole offsets (left: $d\psi$, right: $d\epsilon$) using the classical (version *a*) paradigm and the new one. Units: μas.

A difference of 8 μas between the new transformation and the classical one version a is shown on figure 4 for the UT1 parameter. The series have a mean standard errors of 53 μas. The remaining small differences between the new and the classical version a paradigm are under investigations.

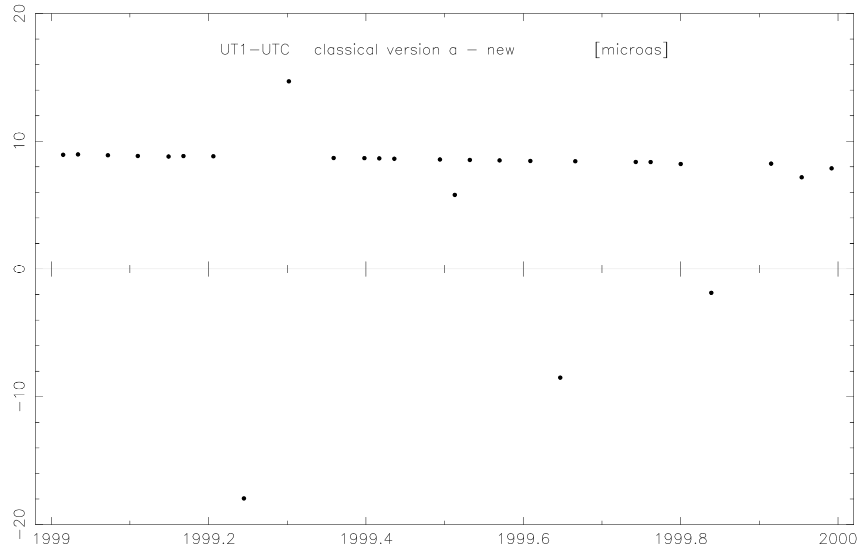

Figure 4: Differences, for the 1999 NEOS sessions, between estimated UT1-UTC using the classical (version a) paradigm and the new one. Units: μas.

4 Conclusions

To comply with the IAU resolutions adopted in 2000, we have to modify softwares that compute the transformation between terrestrial and celestial reference frame. The identification of each pieces of software where the modification/update have to be made is the most important and non-trivial step of this process.

Today, with GLORIA we have experienced that the implementation of the new paradigm will require as much work as the correct update of the different part of the classical one. In the future, any changes of precession and/or nutation models will require only the replacement of the provided developments of the celestial pole coordinates (X, Y) and **s** for the new transformation instead of modifying precession and/or nutation and GST computations for the classical one.

The new transformation have been successfully implemented and used in at least two VLBI software STEELBREEZE (S. Bolotin, 2002) and GLORIA. Routines to compute the partial derivatives of the new transformation with respect to the EOP are available for the user community.

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