The combined solution C04 for Earth Orientation Parameters consistent with International Terrestrial Reference Frame 2008

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Abstract

The Earth Orientation Center of the IERS, located at Paris Observatory, SYRTE, has the task to provide to the scientific community the international reference time series for the Earth Orientation Parameters (EOP), referred as "IERS C04" (Combined 04), resulting from a combination of operational EOP series, each of them associated with a given geodetic technique. The procedure developed to derive the C04 solution was recently upgraded back to 1993. The main objective is to insurre its consistency with respect to the newly release ITRF 2008. Due to the separate determination of both terrestrial reference frames and EOP, there has been a slow degradation of the overall consistency since the least ITRF release in 2005, and discrepancies at the level of 50 micoarseconds for x pole coordinate exists between the current IERS C04 and the ITRF realization. We have taken this opportunity to upgrade the numerical combination procedure. Now there are better estimates of the errors of combined values. Individual EOP series have been reprocessed since 1993. Pole coordinates are now fully consistent with ITRF. The new C04 solution, referred as 08 C04, updated two times per week became the official C04 solution since february 2010.

Keywords. Earth rotation, combination, terrestrial reference frame

1 Introduction

The Earth Orientation Parameters (EOP) describe the irregularities of the Earth rotation with respect to a non-rotating reference frame. Two parameters $(dPsi, dEps)$, the celestial pole offsets, correct the precession-nutation model of the celestial pole, one parameter $(UT1 - UTC)$ gives the irregularities of the rotation angle, and the two last one (x, y) describe the polar motion with respect to the crust. They give the full transformation between the International Terrestrial Reference Frame (ITRF) and the International Celestial Reference Frame (ICRF). The reference EOP series computed at the Earth Orientation Center at Paris Observatory is obtained from the combination of "operational" EOP series derived from the various astro-geodetic techniques : Laser Ranging to the Moon (LLR) and to dedicated artificial satellites (SLR), Very Long Baseline Interferometry on extra-galactic sources (VLBI) and more recently from Global Positioning System (GPS) and Doppler Orbitography by Radiopositioning Integrated on Satellite DORIS (Gambis, 2004). The "combination" performed twice a week (Tuesdays and Thursdays) consists in series given at one-day intervals for each of those parameters.

The objective of this paper is to twofold : 1) present the C04 combination procedure and the recent improvements brought in the software code 2) present the new EOP C04 solution, its accuracy, and how it is made consistent with ITRF 2008.

2 Description of the procedure

Step 1 : Selection of a set of operational series, rescaling of the formal uncertainties. After selecting the operational series to be combined, we rescale their formal uncertainties. Applying the "Three-cornered Hat" method (Premoli, Tavella, 1993) involving the whole set we determine the coefficients (one per series) by which the formal uncertainties of the series has to be multiplied in order to get more realistic estimates.

Step 2: EOP series are made consistent with the ICRF and ITRF. One of the main tasks of the combination is to produce EOP series consistent with the International Celestial Reference Frame (ICRF) and the International Terrestrial Reference Frame (ITRF). The operational series are not perfectly aligned with the ITRF and ICRF. They are often referred to different terrestrial and celestial systems, realized by the Analysis Centers. As it can be easily shown, the inconsistency of the EOP series with respect to the ITRF and ICRF produce systematic errors between series (Zhu and Mueller, 1983, IERS Annual Report 2000). In the late eighties, inconsistencies were as large as 1 mas, they are now reduced to 200 μas for (x,y), 10 μs for UT1, and 50 μas for (dPsi,dEps) but they are still significant.

Before the combination is performed, it is necessary to translate all series into the ICRF and ITRF. We assume:

- that the celestial pole offsets (dPsi, dEps) provided by the IVS combined solution give the direction of the CIP in the ICRF without any significant drift ;
- that the UT1 values of the IVS combined solution gives the rotation angle of the ITRF with respect to ICRF without any significant drift from 1993 to 2007;
- that the polar motion (x,y) associated to the ITRF 2008 solution gives the direction of the CIP in the ITRF without any linear trend.

In order to ensure these translations, we assume that some "outstanding" series are already consistent with ITRF or ICRF. The drifts between "ITRF/ICRF

EOP	Time interval	Reference Series
dPsi / dEps	1984-1993	IVS combined solution
	1993-2007	id
UT1	1984-1993	IVS combined solution
	1993-2010	IVS combined solution
x,y	1984-1993	IVS combined solution
	1993-2000	EOP ITRF 2008 (IGN)
	2000-2009	id

Table 1: Reference series according to the epoch of the solution

consistent series" and operational series are not perfectly linear over several years, and we model them as broken lines, that are consecutive linear trends. For each operational series we estimate the linear drift (bias + trend) according to the schedule reported in Table 1. The estimated drifts are then removed from the operational EOP, which become "consistent" with the ITRF and ICRF, and are ready for combination.

Step 3: Differences : Operational series - intermediate reference. We do not directly combine the initial values of the series. The more these values vary, the larger will be the error introduced by interpolation, filtering, and any kind of numerical calculation. Therefore, we have to remove from the operational EOP series a well know reference, containing the main part of the signal. This reference is nothing else than the former combined solution obtained in a previous run, extended by a prediction. To achieve this, the reference series are interpolated for each date of the operational series using Lagrange interpolation over four points. The difference between operational series and reference series is then made. The analyses we have performed show that the differences between individual series and the reference is characterized by white noise. The combination process is applied on these differences.

Some characteristics:

- For the offsets of nutation, the parameters of the reference series are dPsi, dEps referred to IAU 2000 precession-nutation model. Therefore all "operational" celestial pole offsets are transformed into (dPsi,deps)/IAU 2000, before differencing.
- UT1-UTC present jumps (because of leap seconds), unconvenient for numerical treatment. Therefore we start to produce the time series UT1-TAI by taking into account all the leap seconds.

Step 4: Trend of LOD determined by satellite techniques is made consistent with UT1 observed by VLBI The trend of the LOD series derived from GPS and SLR series cannot be trusted: because of non-modeled instabilities in the satellite orbits, the *LOD* is severely drifting in an unpredictable

Time interval		x,y	UT1	LOD	dPsi, dEps
1984-1993	Smoothing coefficient	10^2	$10^{0.7}$		$10^{0.5}$
	1% remaining amplitude	2.9 d	4.8 d		5.2 d
	99% remaining amplitude	6.2 d	10.3 d		11.2 d
1993-2010	Smoothing coefficient	10^5	10^5	10^3	$10^{0.5}$
	1% remaining amplitude	0.92 d	0.92 d	2 d	5.2 d
	99% remaining amplitude	2 d	2 d	4.3 d	11.2 d

Table 2: Smoothing coefficient of the EOP

way. This drift is not identical from a series to another one. To determine these spurious drifts, we make use of the LOD_{VLBI}, obtained by time derivation of the UT1 VLBI values and given by the former C04 solution. Drift above 20 days in LOD_{GPS} - LOD_{VLBI} are then computed by low pass Vondrak filtering (99% of the signal is let at 19 days) (Vondrak 1969, 1977) and removed from each GPS series.

Step 5: Sorting by increasing dates. For each EOP, the offsets are chronologically sorted.

Step 6: Running average. The offsets are averaged over successive 0.5 day time intervals. Using Lagrange interpolation we propagate the observed offsets to the averaged date. The average is weighted by the formal errors of the observed values. The averaged error or weight is also computed.

Step 7: Weighting change. We detect the outliers of the averaged series: their weight is divided by 10, and the averaging process of Step 6 is redone. From this gaussian weight we derive formal errors associated to the EOP estimates.

Step 8: High frequency filtering. Vondrak smoothing (Vondrak 1969, 1977) is applied in order to remove high frequency variations. Characteristics of the smoothing, according to the epoch of the solution, are reported in Table 2.

Step 9: Interpolation (Lagrange). The filtered series are interpolated at 1 day intervals.

Step 10: Adding back the intermediate series. The final values are obtained by adding to the filtered and interpolated offsets i) the "intermediate" reference series, which had been removed in the Step 3 ii) the removed models during this step ("zonal tides" on UT1-TAI/LOD, precession-nutation offsets). The values UT1-TAI are then translated into the discontinuous series UT1-UTC.

Step 11: Prediction and recording storage in the database. The next solution needs reference values covering the dates of the new observations. Therefore we extend the present series by a prediction, which is not described in this report. The solution associated with its prediction over 180 days is archived.

3 Consistency with ITRF and ICRF

A fundamental issue was solved : due to the separate determination of both celestial and terrestrial reference frames and EOP, there had been a slow degradation of the overall consistency. This has caused discrepancies at the level of 300 micro-arc-seconds between the current IERS C04 and the current ITRF realization. This was largely solved in the new solution by re-setting the C04 on the system linked to the newly issued ITRF2008 (Altamimi, 2007). Different hypotheses are adopted (see table 1) :

- UT1 and the celestial pole offsets (dPsi, dEps) provided by the IVS are consistent with the ICRF from 1984 to 2007.
- the polar motion components associated with the ITRF 2008 solution gives the direction of the CIP in the ITRF without any linear trend.

The differences between 08 C04 solution and the former solutions are displayed on the Fig. 1.

4 Other recents improvements

In the Fortran code for computing the C04 we introduced the following changes : i) model for nutation and UT1/LOD tidal variations have been updated according to the last IERS conventions (2003) : MHB 2000 for precession-nutation, Defraigne and Smits model (1999) for tidal variation in UT1/LOD (Step 3) ; ii) dimensions of tables have been significantly increased and computation are done with 16 significative numbers - this allows solution to be performed over 30 years in one run ; iii) a new approach for combination of LOD (GPS/SLR data) was developed, compatible with UT1-UTC (Step 4); iv) formal errors on EOP are estimated (Steps 6/7) ; v) the solution is automated.

Performances are significantly improved. This is illustrated by better RMS agreements of the differences between individual and the combined solution. We gain about 10 μas for long-term polar motion 3-4 μs for UT1, and $40 - 50$ μas for nutation offsets.

The possibility to make long-term computation over 20 years leads to an improved consistency and long-term stability of the solution.

5 Operational C04 solution

The C04 solution is computed every Tuesday and Thursday for the last 365 days. We update only the last 30 days. This last part, undergoing changes from a

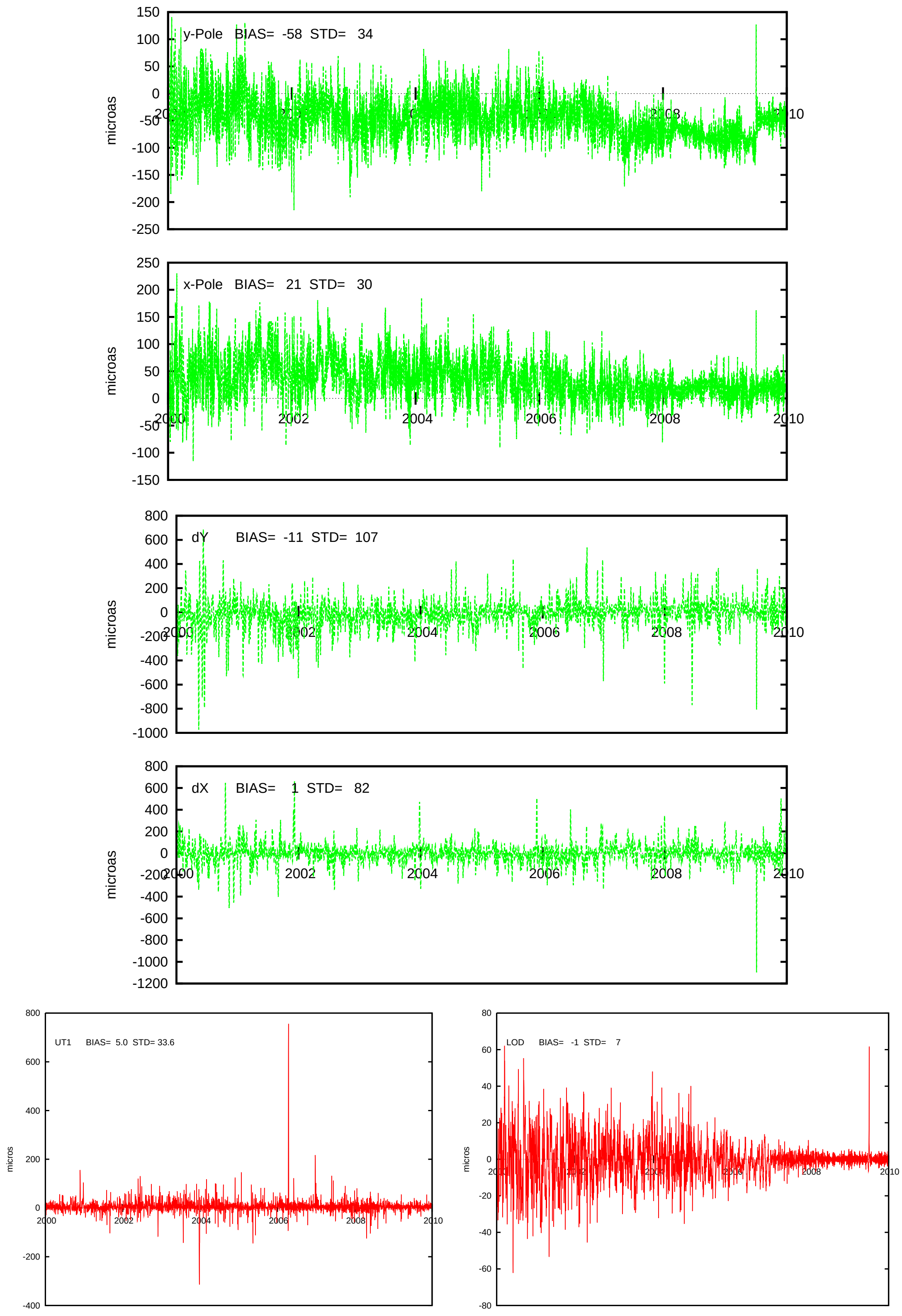

Figure 1: Differences 08 C04 - 05 C04 from 2000 to 2010 for the Earth rotation parameters x, y, LOD, $UT1$, dX, dY.

IVS combined solution
IVS OPA solution
VLBI intensive BKG
GPS IGS-Rapid
GPS IGS-Final
Combined Laser ASI

Table 3: EOP series used for the operational C04 solution

computation to another, is called "operational C04 solution".

In table 3 we check the series entering our present combination. Note that except for SLR, the combination is not restricted to intra-technique combined series. We are not using IVS solution for 2 reasons :

- IVS combined latest value is several days late
- IVS combined does not take intensive sessions into account
- Our combination for the parameters dPsi,dEps and UT1 seems to present closer agreement with IVS operational series than IVS combined series, according to the RMS value previously shown.

We do not combine exclusively IGS-Final or IGS-Rapid solutions because the last IGS-R values is available with a one day delay. CODE and GFZ provide the pole coordinates and LOD in a quasi real time.

6 Summary

The C04 solution has been improved back to 1993 : the pole coordinates are consistent with ITRF 2008. Pole motion and LOD is are as good as those of the official IGS combined series (30 μas for pole motion, 15 μs for LOD). The parameters $UT1$ / $d\psi * \sin\varepsilon_0$ and $d\varepsilon$ are surprisingly in better agreement with VLBI series than the previous IVS official combined VLBI solution, especially for UT1. Their present accuracy is about 6 μs for $UT1$ and 70 μas for nutation offsets.

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