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Celestial Pole Offsets: From Initial Analysis to End User

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Abstract

Celestial pole offsets (CPO) are small corrections to the official IAU precession-nutation model needed, in particular, by the users who require highly accurate transformations between terrestrial and celestial reference frames. The CPO time series are initially computed at the IVS Analysis Centers (ACs) as routine products. Each AC computes its own final CPO time series containing results obtained for each processed 24-hour VLBI session and/or computes datum free normal equations for each session. The latter are then used in the IVS Analysis Coordinator's office to derive the IVS combined CPO series. In turn, IERS Combination Centers use original ACs' and/or IVS combined CPO series to derive the IERS combined product. All these transformations between the original series derived by the IVS ACs and the final IERS products that are recommended and usually used by users introduce random and systematic differences between CPO series, which in turn lead to differences and inconsistencies between the results of users' applications. This situation requires clear recommendations on using CPO series.

1. Introduction

Celestial pole offsets (CPO) are small differences between observed and modeled values of the celestial pole position. It is one of the key products of IVS because only the VLBI technique can provide them. CPO are used in many scientific and practical applications, such as highly accurate transformations between terrestrial and celestial reference systems [1]; adjusting precession-nutation model [2, 3]; evaluation of the Free Core Nutation (FCN) model [1, 4]; processing of the VLBI UT1 Intensives [5, 6]; and geophysical studies [7]. The problem is that several CPO series computed at the IERS and IVS Analysis and Combination Centers (AC and CC, respectively) are available for users, and using various CPO series leads to differences in the obtained results. It seems that no clear and unambiguous IERS recommendation exists at the moment, which leads to inconsistency of results obtained by different groups. Evidently, such a recommendation should be based on thorough investigation of the differences between CPO series and the impact of these differences on the results of applications. This paper is an attempt to make a step in that direction.

2. CPO Series

The current CPO series computation technology chain looks as follows:

1. The CPO series are initially computed by the IVS ACs for each processed 24-hour VLBI session in two modes: 'eops' ('eoxy') files with final EOP values and/or datum free normal equations (daily SINEX).
2. The daily SINEX solutions are then used at the IVS CC to compute first individual series in uniform datum and then the IVS combined CPO series, also given for each VLBI session.

3. IERS CCs at the Paris Observatory (OPA) and U. S. Naval Observatory (USNO) use original ACs' and IVS combined series to derive the IERS daily combined products at midnight epochs. It should be noted that OPA and USNO use different data sets and combination methods.

As a result, the following CPO series are available to users:

1. IERS/C04 series computed at OPA, official for applications that are not near-real-time;
2. IERS/NEOS series computed at USNO, official for near-real-time applications and prediction;
3. IVS combined series;
4. Individual series computed at the IVS ACs.

All these series are used in practice for various applications. The problem is that random, and especially systematic, differences between them may lead to substantial differences in obtained results. So, detailed investigation of the consistency of the CPO series is needed. The first of our results in this direction are presented in the next section.

3. Comparison of CPO Series

The following comparisons of CPO series are of interest to us:

1. Individual 'eops' ('eopi') series vs. IVS combined series.
2. IVS combined series vs. C04 and NEOS series.
3. C04 vs. NEOS series.

The CPO series used in this work, together with basic statistics, are shown in Table 1. The time interval MJD=53374...55971 was used. A 2D weighted Allan deviation is computed by [8, 9] and serves as a measure of the smoothness of the series.

Table 1. Compared CPO series with basic statistics: number of CPO estimates in the series and weighted 2D Allan deviation.

AC	Spacing	N	ADEV
	Individual series		
AUS	VLBI sessions	743	189
BKG	VLBI sessions	1034	154
CGS	VLBI sessions	932	143
GSFC	VLBI sessions	1101	131
IAA	VLBI sessions	892	140
OPA	VLBI sessions	1179	137
SPU	VLBI sessions	706	190
USNO	VLBI sessions	979	130
	Combined series		
IVS	VLBI sessions	727	128
C04	daily	2598	45
NEOS	daily	2598	22

Comparison results are presented in Tables 2 and 3. In both tables, the left part is computed from the original CPO series, and the right part is computed after removing the IERS FCN model of S. Lambert [1]. In Table 2, bias between compared CPO series is shown, and Table 3 shows the slope w.r.t. the IAU precession-nutation model. One can see significant differences between series, which has impact on the results of many applications, such as coordinate transformation, satellite orbit orientation, UT1 Intensive determinations, etc. In particular, the difference in slope directly affects the precession rate derived from the VLBI observations.

Table 2. Bias of CPO series w.r.t. the IAU model, μas.

Series	Original series		After removing FCN	
	dX	dY	dX	dY
Individual series				
AUS	146.4 ± 7.0	-232.2 ± 7.2	143.3 ± 4.7	-247.8 ± 4.6
BKG	75.3 ± 5.5	-92.0 ± 6.2	73.6 ± 3.3	-104.7 ± 3.4
CGS	85.1 ± 5.4	-147.6 ± 6.0	80.3 ± 3.3	-165.4 ± 3.3
GSFC	99.4 ± 5.2	-136.0 ± 5.6	96.0 ± 2.8	-142.1 ± 3.0
IAA	112.3 ± 5.7	-182.6 ± 6.1	108.6 ± 3.4	-197.1 ± 3.6
OPA	92.9 ± 5.0	-126.9 ± 5.5	88.7 ± 2.8	-133.7 ± 2.9
SPU	137.8 ± 7.1	-236.4 ± 7.4	138.3 ± 4.8	-244.0 ± 4.8
USNO	95.4 ± 5.2	-128.4 ± 5.7	89.6 ± 2.9	-136.6 ± 3.1
Combined series				
IVS	84.5 ± 7.9	-170.1 ± 6.6	84.2 ± 4.3	-189.1 ± 3.8
C04	70.0 ± 3.6	-81.6 ± 4.3	73.8 ± 2.0	-95.8 ± 2.2
NEOS	11.7 ± 3.3	-39.0 ± 3.9	15.4 ± 1.5	-118.8 ± 1.8

Table 3. Slopes of CPO series w.r.t. the IAU precession-nutation model, μas/yr.

Series	Original series		After removing FCN	
	dX	dY	dX	dY
Individual series				
AUS	-11.7 ± 3.9	-3.2 ± 4.0	-10.9 ± 2.6	0.0 ± 2.6
BKG	-1.5 ± 2.8	29.7 ± 3.0	-4.3 ± 1.7	19.5 ± 1.6
CGS	-4.5 ± 2.7	14.2 ± 2.9	-3.8 ± 1.6	11.6 ± 1.6
GSFC	-6.1 ± 2.5	23.4 ± 2.7	-7.8 ± 1.4	18.8 ± 1.4
IAA	-9.1 ± 2.8	5.2 ± 3.0	-10.6 ± 1.7	9.1 ± 1.7
OPA	-3.5 ± 2.5	20.0 ± 2.6	-5.8 ± 1.4	41.3 ± 7.8
SPU	-15.4 ± 4.2	0.4 ± 4.5	-14.5 ± 2.8	1.0 ± 2.9
USNO	0.7 ± 2.7	21.0 ± 2.9	-4.6 ± 1.5	16.2 ± 1.5
Combined series				
IVS	-16.4 ± 3.3	28.2 ± 3.2	-14.6 ± 1.8	24.3 ± 1.8
C04	-15.1 ± 1.8	59.6 ± 1.8	-12.0 ± 1.0	35.6 ± 0.8
NEOS	-1.1 ± 1.6	50.9 ± 1.7	-7.6 ± 0.7	25.8 ± 0.8

One can also find systematic differences between series computed with Calc/Solve (BKG, CGS, GSFC, and USNO) and OCCAM software (AUS and SPU). IAA results computed with OCCAM–GROSS software are generally between Calc/Solve and OCCAM ones.

Figure 1 shows three combined CPO series used in this study. It demonstrates in more detail the main differences between them that are already shown in tables above: different degrees of smoothness of the C04 and NEOS series and systematic differences between them, which are especially large around 2009.0. One can also notice abovementioned global shifts between the two IERS series.

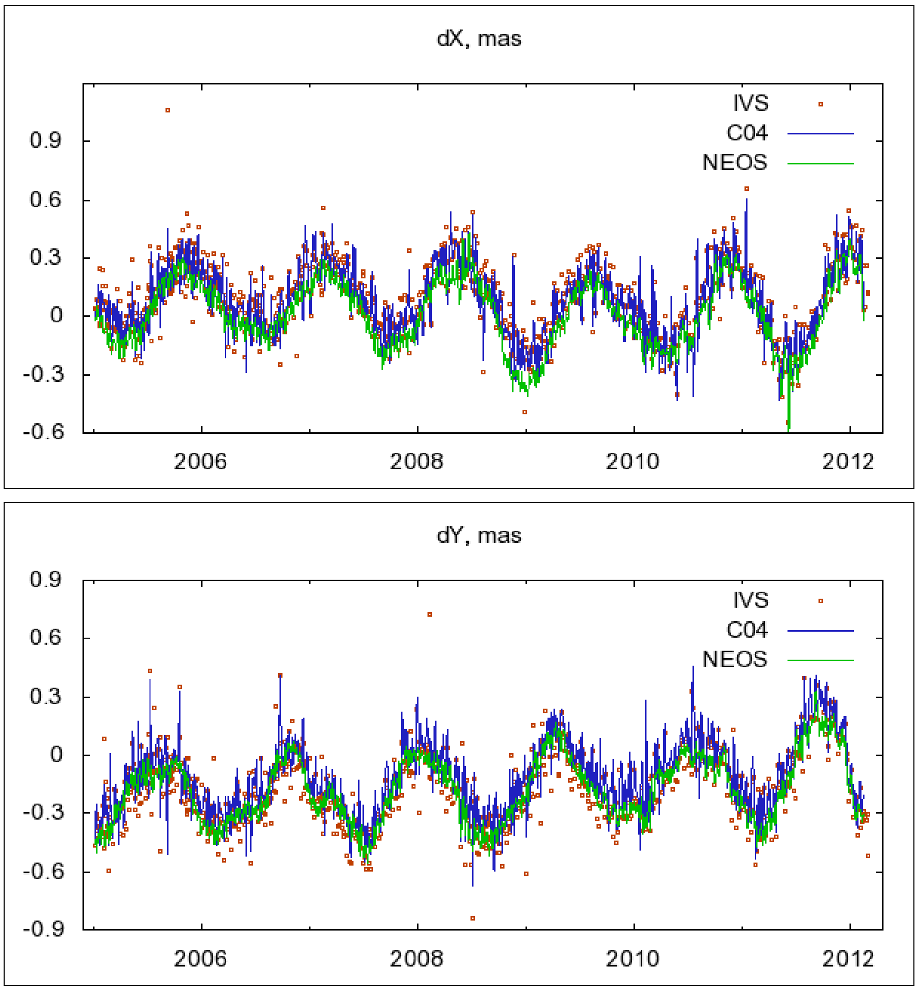

Figure 1. IVS, C04, and NEOS CPO combined series.

4. Concluding Remarks

This study shows that significant stochastic and systematic differences do exist between the individual and combined CPO series from both the IVS and the IERS. These discrepancies affect the results of space geodesy data processing, such as the VLBI UT1 Intensives and satellite applications, the accuracy of the VLBI-derived precession-nutation model, or the FCN models.

This situation requires more careful investigation and perhaps more coordination between the IVS and the IERS. In particular, more specific IERS Conventions recommendations on the CPO issues are very desirable for applications requiring microarcsecond-level accuracy.

It should be noted that the quality of the IERS combined CPO series depends on the selection of the individual series used for combination, as well as on interpolation and smoothing algorithms. For this reason, the IVS series may be preferable for some applications, such as the improvement of precession-nutation and FCN models or other applications that do not require equally spaced input data.

Individual CPO series computed at the IVS CC from daily SINEX solutions in uniform datum were not considered here. Although these series are publicly available they are, in fact, internal IVS products. Nevertheless, their comparison with the 'eops' ('eopi') series may be also interesting for assessment of the accuracy of the IVS CPO series because the IVS ACs' and IVS CC's solutions differ not only by datum, but also by other analysis options, such as modeling (primarily geophysical) and parameterization.

On the other hand, there should not be any significant systematic differences between AC-computed and CC-computed CPO series. ACs compute EOP using own datum, either the ITRF and ICRF or station and source catalogs linked to the ITRF and ICRF using NNT and NNR constraints. So, ACs and CC use, in fact, the same datum for computation of EOP.

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