Accuracy of proposed corrections to the current precession- nutation models: A first assessment

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Introduction

- **The celestial pole offsets (CPO) are the deviations dX and dY of the coordinates of the actual celestial intermediate pole with respect to its location according to the conventional a priori model IAU2000A/2006 used in their determination from VLBI data**
- **Therefore, the weighted root mean squared (WRMS) of the CPO time series is the main indicator of the variance uncovered by standard models and thus of their accuracy**

Purpose

- **Presenting a first assessment of the extent we can reduce the unexplained variance by applying suitable corrections to the a priori precession-nutation (PN) models and determining the CPO referred to the corrected a priori**
- **Results are derived from well-known VLBI solutions derived by single analysis centres, combined solutions by IERS, and three daily solutions**
  (namely gsf2020a, usn2021c, opa2021a, bkg2020a, ivs20q2X, gsfc20q2, bkg20q2, dgfi20q2, ivs19q4X, iersC04, usno-finals, JPL2)

Correcting precession: Simple linear fit works quite well

We derived corrections to biases and rates of each CPO solution in the period 1984-2021, covering two full oscillations of the lunar node *(but finals starting in 1992, JPL2 in 1998)*

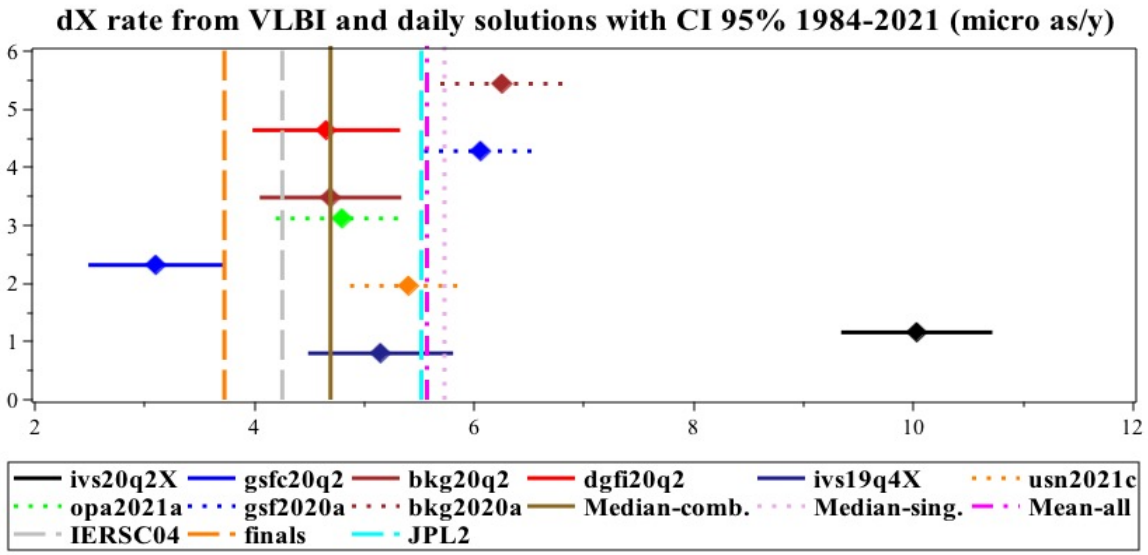
All solutions referred to ITRF14 and ICRF3 *– but JPL2*

CPO	Solution	No. Obs.	Trend µas/y	Offset µas	σ - trend	σ – offset	WRMS raw data	WRMS detrend
dX	bkg2020a	5989	6,253	44,65	0,287	4,03	214,6	172,6
dX	gsf2020a	6431	6,058	22,38	0,262	3,66	196,0	166,1
dX	opa2021a	7027	4,797	-28,26	0,308	4,34	211,1	205,8
dX	usn2021c	5613	5,402	16,64	0,272	3,73	183,4	160,8
dX	bkg20q2	4209	4,691	2,18	0,329	4,10	177,8	167,3
dX	dgfi20q2	4034	4,653	-1,46	0,343	4,40	172,6	162,4
dX	gsfc20q2	4229	3,101	19,95	0,313	4,03	176,9	167,6
dX	ivs20q2X	4266	10,029	-27,55	0,351	4,89	205,0	168,0
dX	ivs19q4X	4215	5,147	16,37	0,337	4,38	173,1	152,9
dX	IERS14C04	13879	4.253	36.01	.166	1.76	180.2	164.8
dX	finals	10910	3.725	-28.73	.175	2.11	150.1	147.0
dX	JPL2	8729	5.518	22.18	.239	3.17	174.6	147.7

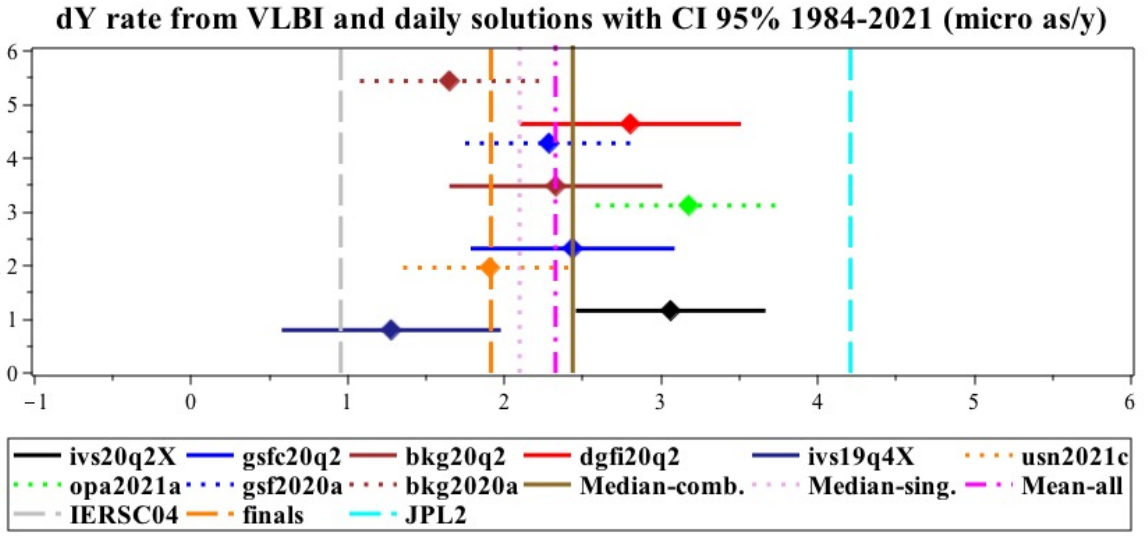
A sample of results for only dX

The lowest WRMS after detrending, in each category, are highlighted

Precession correction: mean dX variance reduction is about 20% (dY->12)



dX	Mean - VLBI only	Median – VLBI only	Mean - all	Median - all	*Min.*	*Max.*
WRMS – raw data	190.1	183.4	184.6	179.0	*172.6*	*214.6*
WRMS detrended	169.3	167.3	165.3	165.5	*152.9*	*205.8*
% variance lowering	20	22	19	19	*5*	*35*
Rate (µas/y)	5.57	5.15	5.30	4.97	*3.10*	*10.03*
Bias (µas)	7.2	16.4	7.9	16.5	*-28.3*	*44.65*



dY	Mean - VLBI only	Median – VLBI only	Mean -all	Median - all	*Min*	*Max*
WRMS – raw data	183.2	183.4	179.2	176.4	*172.6*	*214.6*
WRMS detrended	171.3	172.8	166.4	167.0	*152.9*	*205.8*
% variance lowering	12	12	14	13	*1*	*19*
Rate (µas/y)	2.32	2.33	2.33	2.31	*0.96*	*4.21*
Bias (µas)	-83.6	-85.9	-86.5	-87.3	*-129.6*	*-14.4*

Correcting nutation: options at hand

There are two basic options that may work together:

- **Improving the amplitudes of the forced nutations, either by:**
  - **updating VLBI estimates for a group of selected main nutation periods *(as done in the empirical IERS 1996 model, or as a final step of MHB2000 fit), e.g. Belda et al 2017*, or**
  - **refitting basic earth parameters of MHB2000 *(fitted to VLBI estimates till 1999), e.g. Zhu et al 2021***
  - **Deriving an updated, consistent, and more accurate theory *(no proposal yet)***
- **Using FCN (free core nutation) models, with two main possibilities:**
  1. **Most common: Fit a time-varying amplitude to the FCN oscillation by a sliding window approach (SLA) *(e.g. Lambert's, Malkin's or Belda et al's models)*, or**
  2. **Fitting constant amplitudes for a chosen set of frequencies in a band around FCN (BA) *(e.g. L Petrov 2007 or Nurul-Huda et al 2020)***

Correcting nutation: Models assessed here

We present results for the former input data that include:

- **First step: detrending *(always done)***
- **Next steps: Correcting nutations with three different procedures:**
  1. **Fitting only a reduced set of 15 periods of lunisolar origin (forced nutation model Fn 1)**
  2. **Fitting a wider set of 21 periods of various origins (forced nutation model Fn 2)**
  3. **Using forced model Fn 1 jointly with an FCN model (Fn 1 + FCN)**
- **Results are summarized in a table displaying both CPO and WRMS for uncorrected and all corrected cases.**

Considering the mean of VLBI solutions scatters, the WRMS of raw series may be about halved by correcting the amplitudes of 15 periods and using an FCN model (results in next slide are for a band approach FCN model)

Correcting nutation: WRMS for various data and models

Input data		dX WRMS					Input data	dY WRMS				
	No obs	Raw	Detrend	Det + fn1	Det + fn2	Det + fn1+FCN		Raw	Detrend	Det + fn1	Det + fn2	Det+ fn1+FCN
usn2021c	5613	183.4	160.8	150.7	141.8	91.5	usn2021c	176.6	165.2	151.9	143.4	93.2
gsf2020a	6431	196.0	166.1	156.0	145.5	94.8	gsf2020a	184.5	172.8	158.7	149.5	96.7
bkg2020a	5989	214.6	172.6	163.1	153.0	105.5	bkg2020a	176.1	175.6	163.6	154.0	105.9
opa2021a	7027	211.1	205.8	196.0	190.0	155.2	opa2021a	223.1	201.1	192.9	185.4	150.3
gsfc20q2	4229	176.9	167.6	157.8	149.8	100.1	gsfc20q2	190.8	177.8	161.0	152.8	109.3
bkg20q2	4209	177.8	167.3	159.8	149.8	100.3	bkg20q2	186.2	174.9	160.3	150.8	104.0
dgfi20q2	4034	172.6	162.4	154.4	144.6	96.5	dgfi20q2	179.0	168.8	154.0	144.6	96.0
ivs20q2X	4266	205.0	168.0	133.1	119.5	86.4	ivs20q2X	158.2	145.9	130.4	119.4	73.2
ivs19q4X	4215	173.1	152.9	129.1	116.4	84.0	ivs19q4X	174.0	159.3	135.0	122.7	84.4
IERS14C04	13879	180.2	164.8	157.8	153.9	115.0	IERS14C04	173.2	163.2	154.6	151.9	114.9
finals	10910	150.1	147.0	141.3	131.8	75.9	finals	156.3	138.3	125.2	92.9	75.5
JPL2	8729	174.6	147.7	139.1	131.2	54.2	JPL2	172.3	154.0	140.1	134.4	54.9
From 8 VLBI solutions:							*From 8 VLBI solutions:*					
MEAN		187.4	164.7	150.5	140.1	94.9	MEAN	178.2	167.5	151.9	142.2	95.3
Std Dev		*15.9*	*6.0*	*12.6*	*14.1*	*7.3*	*Std Dev*	*9.9*	*10.7*	*12.5*	*13.6*	*11.9*
COMPARISON WITH Fits20 solution as reported in Zhu et al (2021), period 1984-2020. *Our forced nutation models 1 & 2 behave better for ivs19 and C04, but used BA FCN looks worse than SLA below*												
ivs19q4X	4216	173.2		154.1		68.9	ivs19q4X	173.9		160.7		71.0
IERS14C04	13465	171.7		161.0		108.8	IERS14C04	175.1		163.5		106.1

Conclusions and outlook

- **The use of certain sets of semi-empirical corrections to the precession and forced nutation models IAU2006 and IAU2000 may bring the WRMS of each CPO from over 170 μas to about 120 μas, for combined IVS solutions,**
- **Agreeing and implementing a suitable set should not take long**
- **Using supplemental FCN models the WRMS lowers to about 84 to 70 μas, also depending on the used model**
- ***Our tests bolster than a more complete physical background of models helps to explain more variance, either for forced or free nutations***

Take away message:

- ***WRMS may be halved by correcting CPO this way***