

Assessing recently improved precession-nutation models

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Introduction

The derivation of corrections to improve the current precession-nutation models was encouraged by Resolution 5 of the 2019 General Assembly of the International Association of Geodesy (IAG) as well as improving the accuracy and consistency of the theories, models and predictions of Earth orientation parameters (EOP)

The 2019 GGOS/IERS Unified Analysis Workshop recommended improving accuracy and consistency of precession-nutation models, and updating nutation amplitudes

Objective

Presenting a first assessment of how much the variance of the celestial pole offsets (CPO) can be reduced by using analytical and empirical corrections to a nutations set recently derived by the authors, and showing a general perspective of the different approaches proposed to this end

Method

Analyzing CPO time series of session-wise VLBI solutions from selected IVS Analysis Centers (AC), and compare the WRMS of residuals for various combinations of theoretical and empirically fit models

Data used for assessing potential corrections to precession-nutation models

- Session-wise VLBI solutions from USNO, GSFC and other ACs
 - Results presented for usn2020a in the main
- Solutions are referred to ITRF14 and ICRF3
- Analyzed period: 1990.0 - 2021.0
 - Mean WRMS of the source USNO series 175 μ as
(dX: 173 μ as, dY 177 μ as)
- Almost no editing (*deletion of worst solutions for equal time-tags*)

First step: Correcting precession by detrending

- It has been shown by several authors in recent papers that fitting a regression straight line to the CPO produces small but statistically significant offsets and rates.
- Examples can be seen in the 2019 Final Report of the SWG 3 of the IAU/IAG JWG TERV by Heinkelmann et al (2019) - available at <https://web.ua.es/en/wgterv/documentos/final-reports/report-of-swg-3-montreal-2019.pdf>
- Detrending produces a mean WRMS drop of $10 \mu\text{s}$ (usn2020a data, period 1990-2020)
- Fit trends are in good agreement for different input data
- Notice that IAU2006 fit (1979-2003) is still quite good

Next steps: correcting nutation models

- After correcting precession, the only possibility for reducing the unexplained variance is improving the nutation component of P-N models
- No corrections to the IAU2000 theory have been recommended by IAU, IAG or IERS so far.
- The only IERS recommendation is using the 2007 Lambert's empirical model intended to remove the effect of free core nutation (FCN); it is updated yearly and described in the IERS Conventions (2010)
- *Next, we compare this simple approach with others that use suitable corrections to the forced nutations amplitudes*

Approach 1: Deriving and removing an FCN model

(Only possibility in current conventions)

- **Pros:** Several models are available, either based on a **sliding window approach** or on the **fitting a small set of arbitrary frequencies around FCN**
- **Cons:** FCN is rather unpredictable, has geophysical excitation sources, and models must be based on past observations
- **Performance:** Final residuals after subtracting the recent **B16-21 model** (*an extension of the 2016 Belda et al B16 FCN model*) have mean WRMS about 83 μs (*mean drop 82 μs*)

Approach 2: Empirical correction of the amplitudes of a set of lunisolar (LS) nutation terms

- Corrections to the amplitudes of various sets of LS nutation terms have been derived in the last years.
- *References and comments can be found in the said report of the SWG3 of JWG TERV. Latter publications are e.g., Nurul Huda et al 2020*
- Most of the corrections limit to a sub-set of the 21 periods used by Herring et al. in the fit of MHB2000 theory

Approach 2: Empirical correction of the amplitudes of a set of lunisolar (LS) nutation terms

Options:

- **Selection of Terms:** < 21 periods in most cases
- **Kind of fit:** Amplitude fits can be either **direct** or **indirect** – re-fitting the basic Earth parameters (BEP) of IAU2000
- **Input data:** interpolated daily data (e.g., *IERS EOP C04*) or non-interpolated VLBI session-wise or global solutions

Performance:

- Using the wider **new set of 28 periods introduced here**, the **mean WRMS drop achieves 22 μ as**

Approach 2: Empirical correction of the amplitudes of a set of lunisolar (LS) nutation terms

Extensions:

- We can **extend the LS correction of this approach 2** with the **new method of removing an *ad hoc* FCN model**, **derived from the residuals** after applying detrending and LS correction

Performance:

- **Supplementing the LS correction with the specific FCN model** derived with that purpose **allows an additional WRMS drop of 60 μas (*Final mean WRMS 82 μas)***

Approach 3: Analytical correction of the amplitudes of a set of planetary (PL) nutation terms

- Recently, we have derived an **analytical solution for the Oppolzer terms of planetary origin** that generalizes that of Ferrándiz et al (2018) by including anelasticity effects
- Analytical solutions allow the evaluation of amplitudes of terms with close frequencies, whose separation by Fourier analysis is problematic

Performance:

- The implementation of **this correction reduces remarkably the WRMS** with **mean drop of about 25 mas** (dX 20, dY 30)

Approach 3: Analytical correction of the amplitudes of a set of planetary (PL) nutation terms

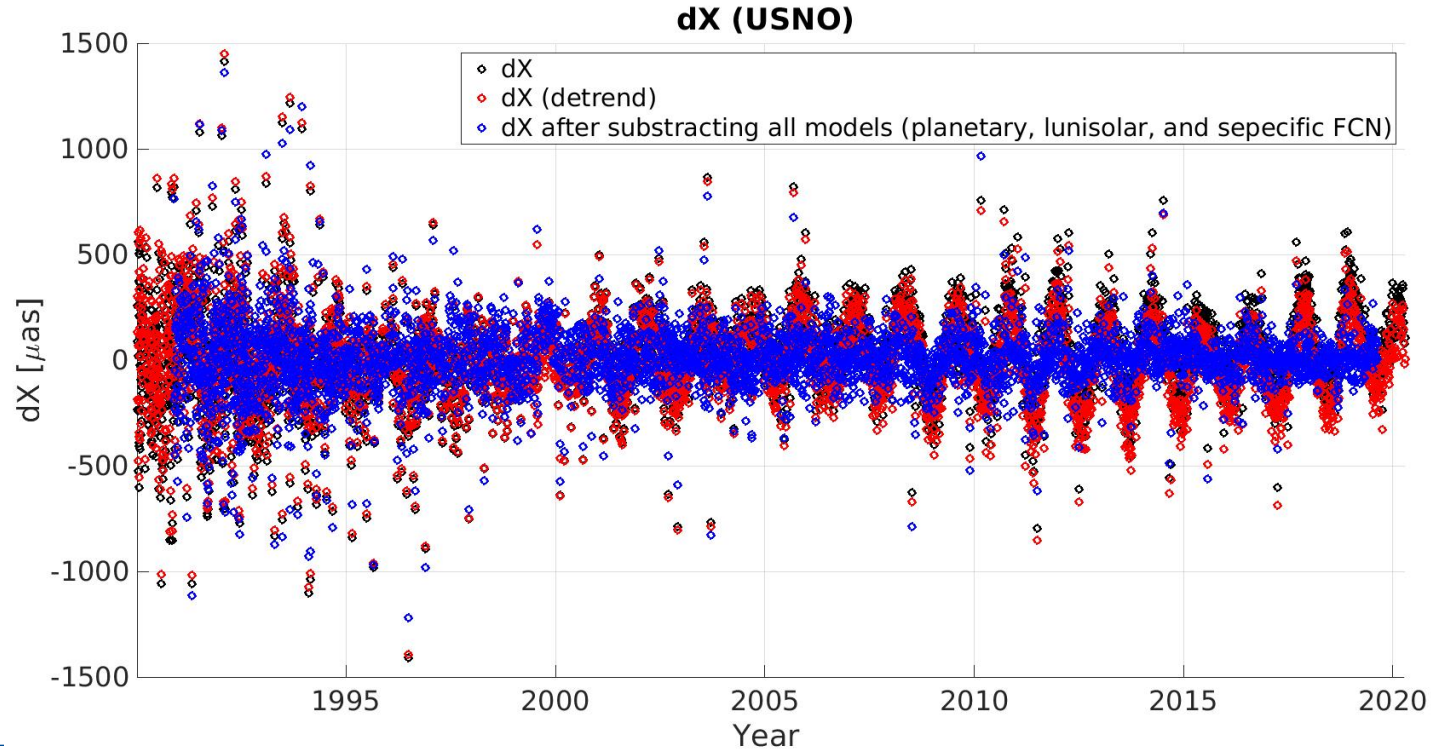
Extensions:

- We can **extend this approach 3** by applying also the two corrections mentioned in approach 2 (**LS, FCN**)

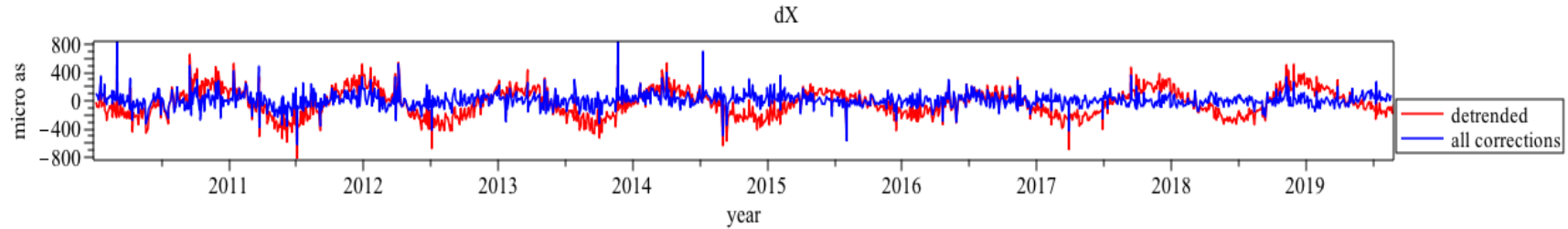
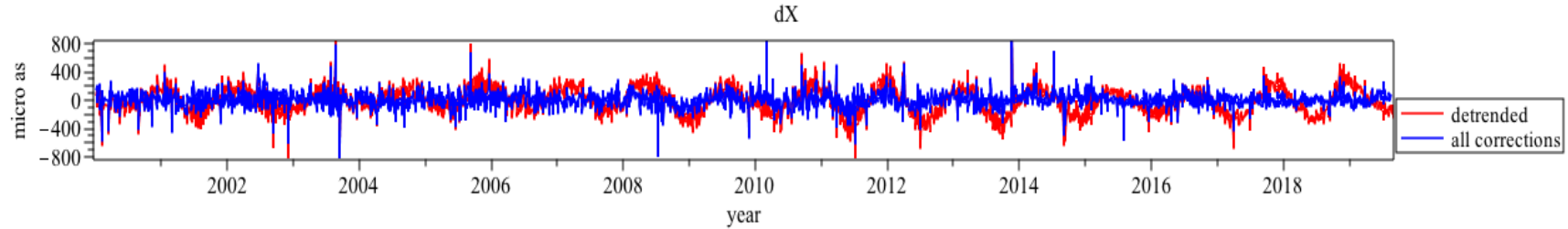
Performance:

- Combined with the LS nutations correction, the mean **WRMS lowers to 119 μas** (accumulated **LS+PL 45 μas**)
- Finally, proceeding as in approach 2, i.e., **supplementing the LS+PL correction with a specific FCN model**, the **mean WRMS gets down to 80 μas**

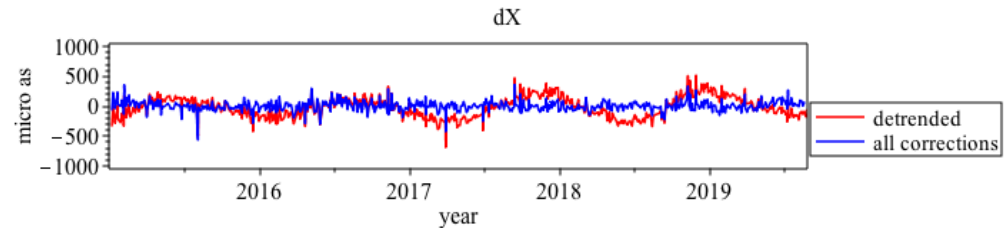
Graphics of the CPO input data and residuals after corrections of approach 3



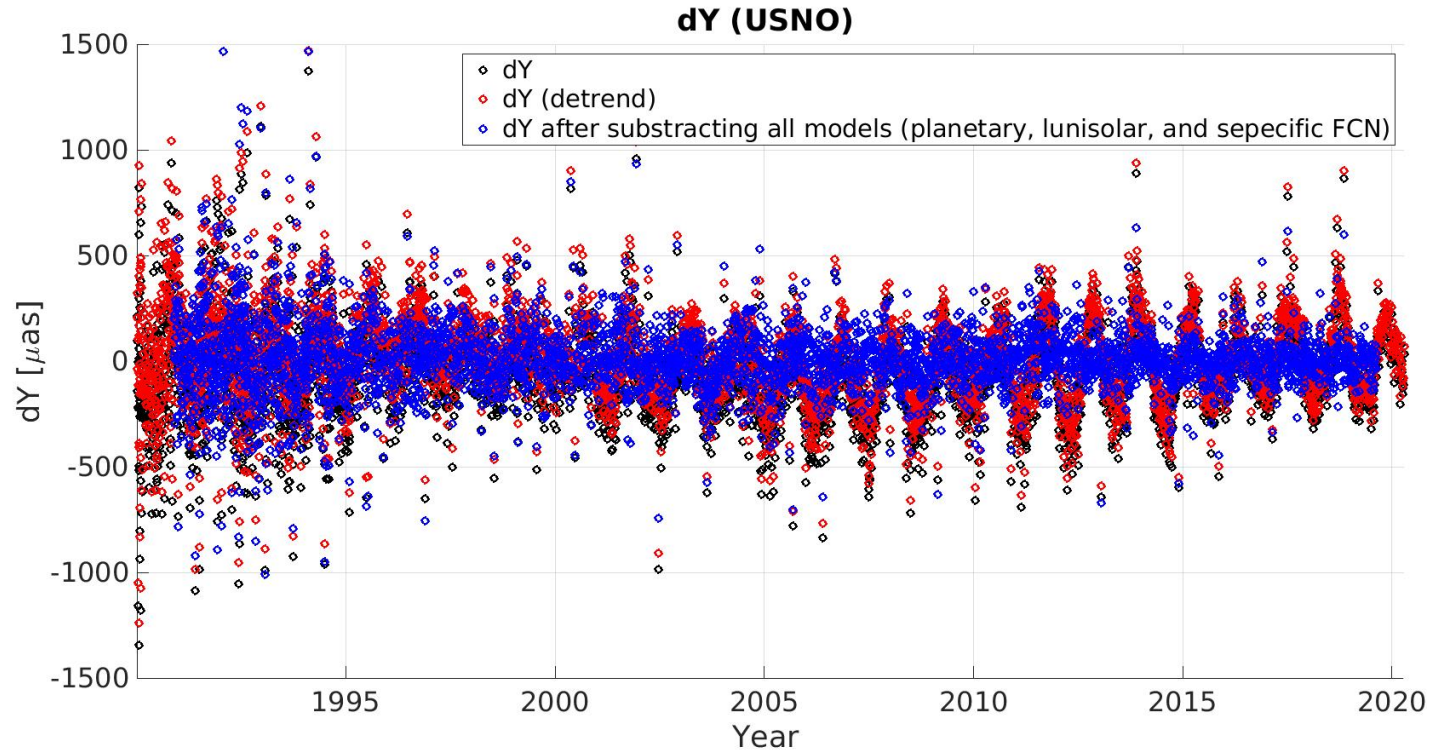
Details of detrended and corrected dX series in shorter time intervals



(vertical display range limited)



Graphics of the CPO input data and residuals after corrections of approach 3



Summary

Reduction of the unexplained variance of CPO time series: approaches and mean WRMS drop		
Test source data: usn2020a session-wise solution, Jan. 1990 – Dec. 2020. WRMS (dX, dY) = (173, 177) μs		Initial mean WRMS : 175 μs
DETRENDING (linear regression). WRMS of residuals mean drop: 10 μs (dX, dY) = (161, 167) μs		Mean WRMS of res.: 164 μs
<i>CURRENT CONVENTIONAL PROC.</i>	<i>COMMON RESEARCH APPROACH</i>	<i>FULLY NEW APPROACH</i>
A. Applying NO CORRECTION to IAU2000/2006	A. EMPIRICAL CORRECTIONS to NUTATION AMPLITUDES of LUNISOLAR BLOCK (LS)	A. ANALYTICAL CORRECTIONS to NUTATIONS AMPLITUDES of PLANETARY BLOCK (PL)
Mean WRMS of residuals: 164 μs	Drop with new 28 periods set: 22 μs Mean WRMS of residuals: 142 μs	Mean drop with 15 periods: 25 μs (dX,dY)=(20,30) μs
B. REMOVING FCN MODEL derived from detrended CPO	B. REMOVING FCN MODEL derived from residual after LS correction	B. EMPIRICAL CORRECTIONS to NUTATIONS AMPLITUDES of LUNISOLAR BLOCK (LS)
Drop of 82 μs with the new B16-21 model	Additional drop of 60 μs	ACCUMULATED WRMS mean drop : 45 μs Mean WRMS of residuals: 119 μs
		C. REMOVING FCN MODEL derived from residual after PL+LS correction Additional drop of 40 μs
FINAL MEAN WRMS of residuals: 82 μs	FINAL MEAN WRMS of residuals: 82 μs	FINAL MEAN WRMS of residuals: 80 μs

Conclusions

- In the analyzed case, by combining detrending + analytical corrections to planetary nutations + empirical corrections to lunisolar nutations, the **WRMS of IAU2000/2006 residuals can be reduced drastically, dropping from 175 to 120 μ as.**
- Correcting the amplitudes of forced planetary nutations is as relevant as doing it for lunisolar terms.
- Suitable specific **FCN models allow additional WRMS lowering till near 80 μ as.**