Testing the improvement of IAU precession using different J_2 variation with time

Jia-Cheng Liu [1] (jcliu@nju.edu.cn) , Nicole Capitaine[2], Yu-Ting Cheng[1]

[1] Nanjing University, CHINA [2] Observatoire de Paris, FRANCE

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Content

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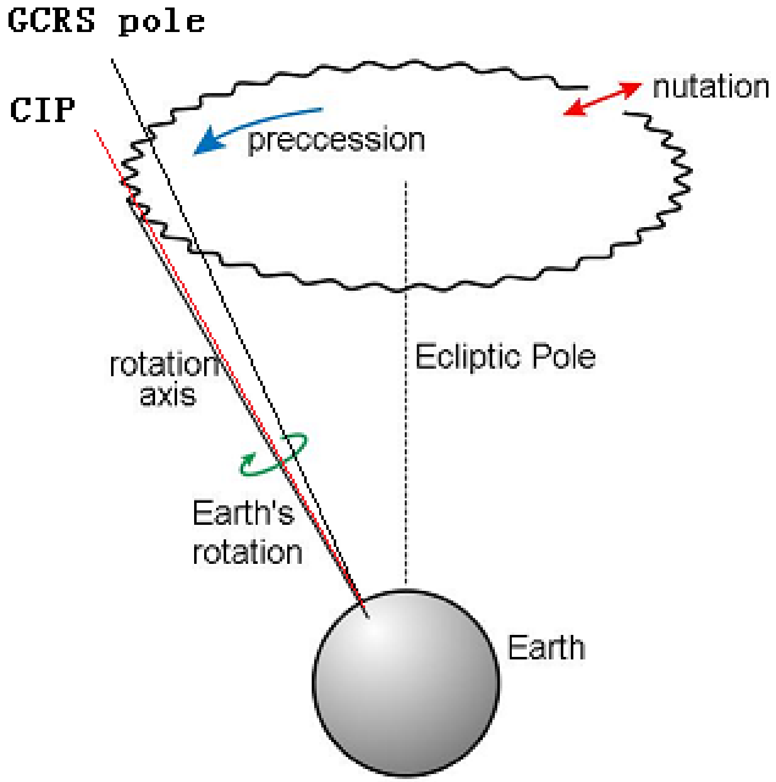
- ✓ Improvement in our 2017 paper (A&A, 597, A83)
- ✓ Effect of considering different J_2 long term variations
- ✓ Conclusion and recommendation



The IAU2006 precession

- ✓ Precession of the ecliptic based on the EMB position of DE406 over 2000 years

- ✓ Precession of the equator used
  - The IAU 2000 precession rates in longitude and obliquity
  - The value $\varepsilon_0 = 84381.406''$ for the mean obliquity of the ecliptic at J2000
  - The precession rates r_ψ, r_ε of non-rigid earth model

    (Williams 1994; Mathews 2002)
  - "observed" effect resulting from changing reference frames
  - *A* J_2 rate value of $\mathrm{d}J_2/\mathrm{d}t = -2.7774 \times 10^{-9}\ \mathrm{cy}^{-1}$

Improvement of the IAU2006 precession (Liu & Capitaine 2017)

✓ Method: similar to P03 (semi-analytical)

✓ Progress in observations and theories after 2003

- Solar system Ephemerides (the accuracy of VSOP2013 is about 100 times better than VSOP87)
- Observational material: VLBI, SLR, LLR (*see Y.-T. Cheng's Poster in Session II*) …
- Progresses in theories

✓ Two aspects of precession:

1. Development of the precession of the ecliptic
2. Integration of the precession of the equator

   More tests on the J_2 long-term variation

Updating the precession of the ecliptic

- New analytical planetary theory VSOP2013 (Simon et al. 2013)
  - Chebyshev ephemerides
  - Poisson series elliptic elements
  - Secular terms of elliptic elements – EMB p, q for precession of the ecliptic
- DE422 and INPOP10a ephemerides over long time interval
  - observational constrains
  - used to eliminate very long period nutation and improve the precession of the ecliptic

Updating the precession of the ecliptic

Results on the Precession of the ecliptic

		unit	t^1	t^2	t^3	t^4	t^5
Fit to DE422	P_A	$''$	4.19903	0.19401	-2.23533×10^{-4}	-1.03944×10^{-6}	2.15694×10^{-9}
	ΔP_A	μas	−65	18	1	−0.1	0.01
	Q_A	$''$	−46.81099	0.05102	5.21368×10^{-4}	-5.5808×10^{-7}	-1.2059×10^{-9}
	ΔQ_A	μas	28	−11	−3	0.1	0.02
Fit to INPOP10a	P_A	$''$	4.19906	0.19400	-2.23575×10^{-4}	-1.02313×10^{-6}	2.26088×10^{-9}
	ΔP_A	μas	−27	17	1	−0.1	−0.001
	Q_A	$''$	−46.81102	0.05102	5.21248×10^{-4}	-5.64478×10^{-7}	5.5757×10^{-10}
	ΔQ_A	μas	−10	−12	−3	0.1	0.02

Effect of using different ecliptics in developing the precession of the equator

$$\Delta\psi_A = -0.003\,t + 0.9\,t^2 + 0.02\,t^3$$
$$\Delta\omega_A = -0.4\,t^2 + 0.006\,t^3.$$

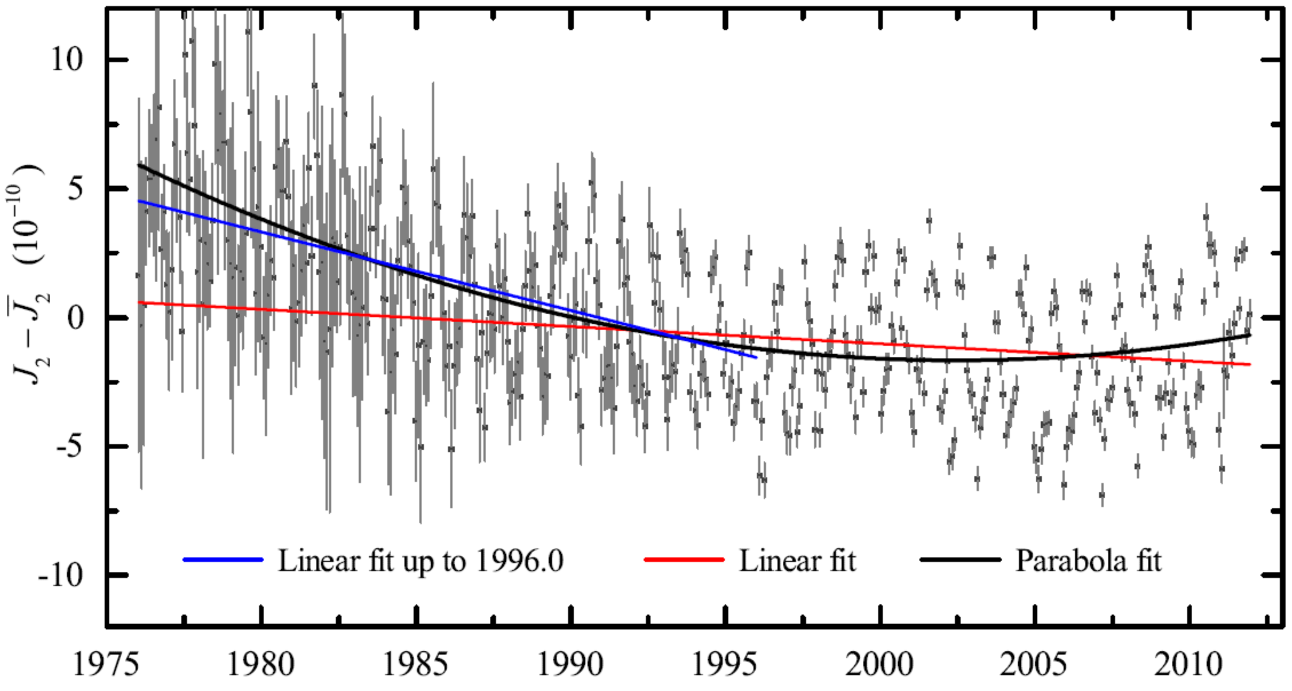
Not very sensitive to the update of the ecliptic precession

Updating the precession of the equator

- ✓ Consideration of relativistic aspect of precession: treat geodetic precession as an additional torque (Gerlach, Klioner, Soffel 2012, arxiv:1202.5870v1)
  - contribute ~ 100 µas cy^{-1} to precession rate in longitude
- ✓ Tidal poisson term contribution to precession rate in obliquity (Folgueira et al. 2007, A&A 469, 1197)
  - contribute 88 µas cy^{-1} to precession rate in obliquity
- ✓ Second order torque on tidal redistribution (Lambert, Mathews 2008, A&A 481, 883)
  - -124 µas cy^{-1} to precession rate in longitude (non-linear term)
- ✓ New determination of J_2 variation from SLR observations (*)
- ✓ Effect from global rotation of the ICRS induced by the Galactic aberration
  - About 10 uas cy^{-1} ing precession rate in longitude

Deceleration of the Earth's J_2 (in 2017 paper)

✓ J_2: gravitational degree-2 harmonic, Earth's dynamical oblateness

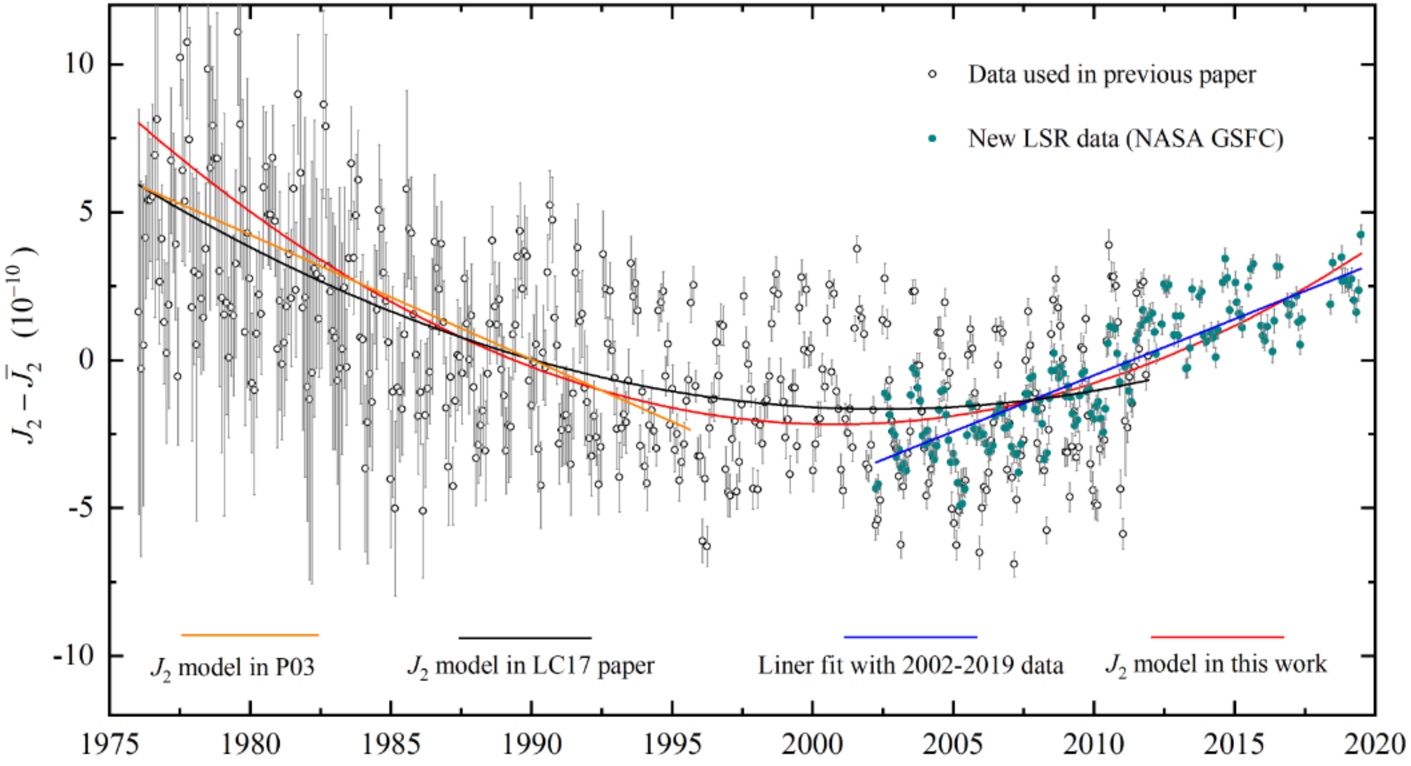


SLR observations (1976-2002)

$\dot{J}_2$ $(10^{-9}\ \mathrm{cy}^{-1})$	Reference
-3.0	Yoder et al. 1983
-2.6	Nerem et al. 1993
-3.0 ± 0.5	Stephenson & Morrison 1995
-3.0	adopted in the IAU 2006 precession
$+3.8 \pm 0.2$	Loomis et al. 2019 (2002-2019 data)

Long-term varition of the Earth's J_2 (c.f. Loomis et al. 2019)

- ✓ Add more data (2002-2019): SLR derived C_{20} estimates



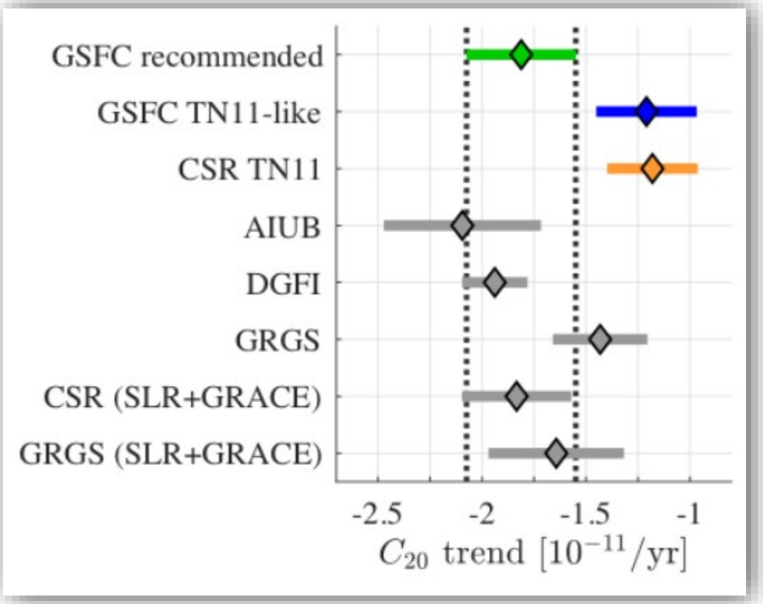
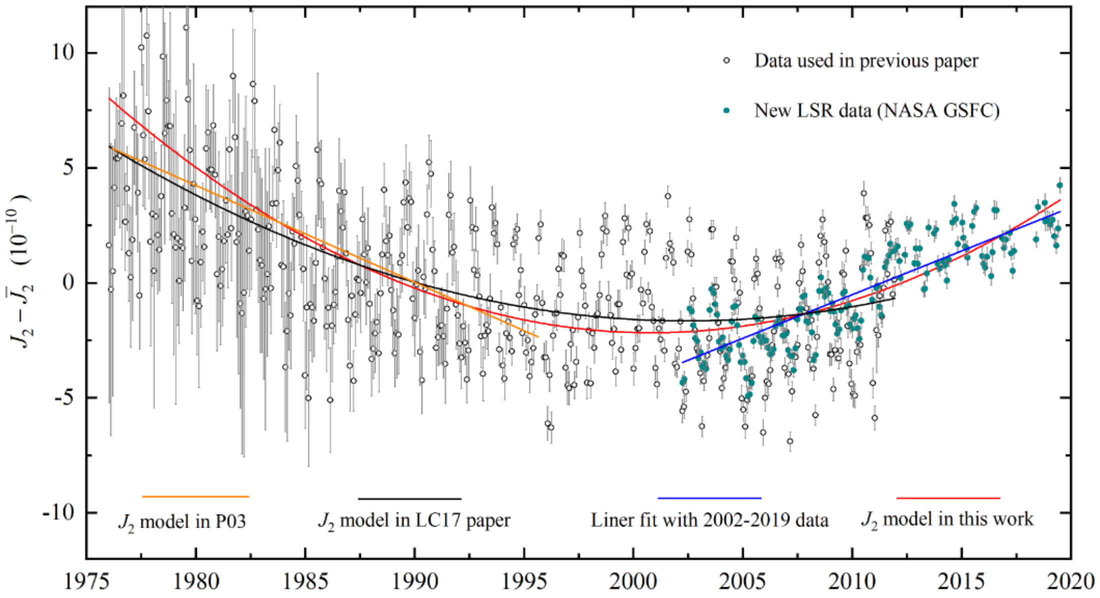


Figure credit: https://neptune.gsfc.nasa.gov/gngphys/index.php?section=519

Long-term varition of the Earth's J_2 (c.f. Loomis et al. 2019)



J_2 appears to be more quadratic than linear in nature.

J_2 variation is an important factor in the modern precession model, but it is the main source of uncertainties (Capitaine et al. 2009).

Weighted fits of SLR J_2 observations to straight lines and parabolas.

	Time interval	t^0	t^1	t^2
Linear fit	1976-1996	$1.08263570 \times 10^{-3}$	$(-3.0 \pm 0.3) \times 10^{-9}$	–
Linear fit	1976-2011	$1.08263587 \times 10^{-3}$	$(-0.7 \pm 0.2) \times 10^{-9}$	–
Parabola fit	1976-2011	$1.08263582 \times 10^{-3}$	$(-0.5 \pm 0.2) \times 10^{-9}$	$(1.1 \pm 0.2) \times 10^{-8}$
Parabola fit	1976-2019	$1.08263579 \times 10^{-3}$	$(-0.3 \pm 0.1) \times 10^{-9}$	$(1.7 \pm 0.1) \times 10^{-8}$
Linear fit	2002-2019	$1.08263586 \times 10^{-3}$	$(+0.4 \pm 0.1) \times 10^{-9}$	–

Contribution of J_2 to precession rates

The dynamical equations for precession in equator:

$$\sin\omega_A \frac{d\psi_A}{dt} = (r_\psi \sin\epsilon_A)\cos\chi_A - r_\epsilon \sin\chi_A$$

$$\frac{d\omega_A}{dt} = r_\epsilon \cos\chi_A + (r_\psi \sin\epsilon_A)\sin\chi_A .$$

$$\sin\chi_A \sin\omega_A = P_A \cos p_A + Q_A \sin p_A$$

P_A and Q_A: precession of the ecliptic
p_A: general precession

Theoretical expressions for precession rate in longitude $r_\psi = r_0 + r_1 t + r_2 t^2 + r_3 t^3 + \cdots$

		t^2	t^3
IAU 2006	$r_\psi(J_2)$	-12.7 ± 3.0	0
LC17 paper	$r_\psi(J_2)$	-2.5 ± 1.2	$+50.6 \pm 9$
This work	$r_\psi(J_2)$	-1.4 ± 1.1	$+87.0 \pm 9$
J_2 data (2002-2019)	$r_\psi(J_2)$	$+17.7 \pm 1.0$	0
No J_2	$r_\psi(J_2)$	0	0

Note: J_2 has no effect on the precession rate in obliquity.

The new precession of the equator is based on:

- ecliptic precession derived from VSOP2013 and DE422/INPOP10a ephemerides
- updated integration constants* (P03 and P04 approaches to deal with the "observed effects" and frame bias)
- Various contributions to precession rates including J_2

Precession expressions and celestial pole offsets derived by VLBI

The solution for the main precession quantities:

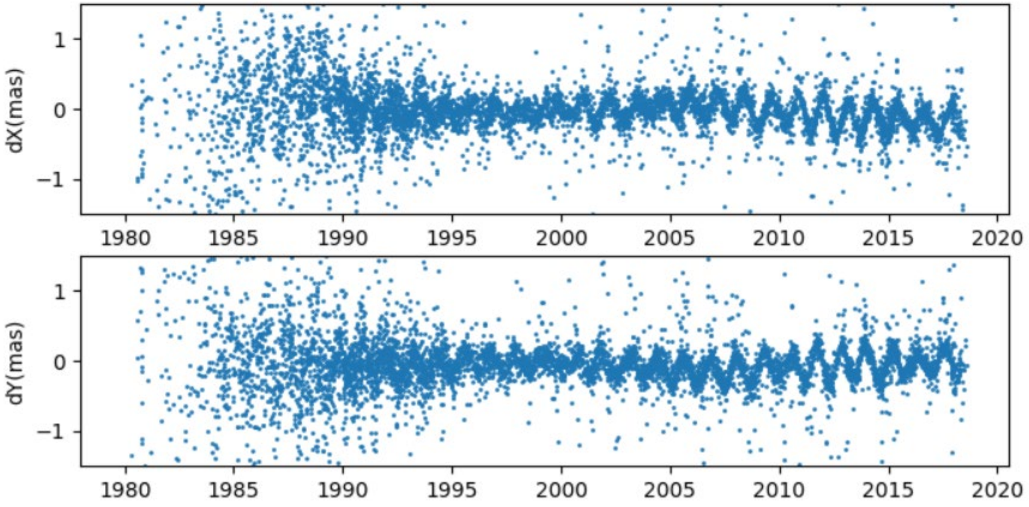
$$\psi_A = 5038''.482041\,t - 1''.072687\,t^2 + 0''.0278555\,t^3 + 0''.00012342\,t^4 - 0''.0000001096\,t^5$$

$$\omega_A = \epsilon_0 - 0''.025754\,t + 0''.0512626\,t^2 - 0''.0077249\,t^3 - 0''.000000086\,t^4 + 0''.000000221\,t^5$$

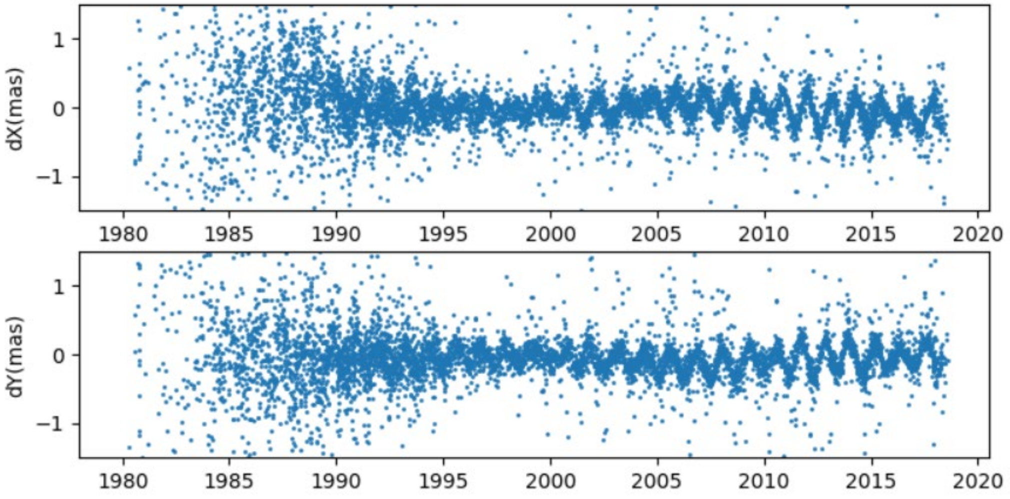
Precession expression ψ_A minus the IAU 2006 model.

$\Delta\psi_A$	t^1	t^2	t^3
IAU 2006	0	0	0
LC17 paper	532	5767	16847
This work	534	6320	28995
J_2 data (2002-2019)	534	15862	-5
No J_2	534	7012	-2

CPO series for precession without J_2 variation



CPO series for precession with quadratic J_2 variation



Check the precession models using VLBI data

Fits of empirical models to VLBI celestial pole offsets (OPA2018a, 1979-2018) corresponding to different precession models The unit is micro-arcsecond.

Model	t^0	t^1	t^2	$\sin\Omega$	$\cos\Omega$	$\mathrm{WRMS}_{\mathrm{pre}}$	$\mathrm{WRMS}_{\mathrm{post}}$
IAU 2006	13 ± 1	382 ± 12	--	36 ± 1	-18 ± 1	126	116
	2 ± 1	-90 ± 23	4436 ± 184	54 ± 1	-31 ± 1	126	115
LC17 paper	9 ± 1	-210 ± 12	--	48 ± 1	-31 ± 1	128	115
	6 ± 1	-353 ± 23	1355 ± 184	54 ± 1	-35 ± 1	128	115
This work	9 ± 1	-330 ± 12	--	52 ± 1	-36 ± 1	135	115
	8 ± 1	-391 ± 23	579 ± 184	54 ± 1	-38 ± 1	135	115
Positive J_2 rate	-2 ± 1	-503 ± 12	--	61 ± 1	-37 ± 1	152	115
	3 ± 1	-301 ± 23	-1884 ± 184	54 ± 1	-31 ± 1	152	115
No J_2	6 ± 1	82 ± 12	--	47 ± 1	-26 ± 1	152	115
	3 ± 1	-92 ± 23	1635 ± 184	54 ± 1	-31 ± 1	152	115

Correlations between fitted parameters

Term	t^0	t^1	t^2	$\sin\Omega$
t^1	-0.7			
$\sin\Omega$	$+0.0$	$+0.4$		
$\cos\Omega$	$+0.2$	-0.3		-0.0
t^1	-0.1			
t^2	-0.3	-0.8		
$\sin\Omega$	-0.2	-0.3	$+0.5$	
$\cos\Omega$	$+0.2$	$+0.3$	-0.4	-0.2

Two functions to interpret the long wavelength curvature in the VLBI residuals:
(1) Straight line + 18.6-year nutation
(2) Parabola + 18.6-year nutation

We have noted the difficulty of interpreting the fit of a linear term or a parabola, plus a term with a 18.6-yr period over using only 28yr of accurate VLBI data.

Concluding remarks and recommendation

- ✓In this study we have investigated the possibility of improving the IAU 2006 precession model (Capitaine et al. 2003) by updats in our 2017 work (Liu & Capitaine 2017), with:
  - (i) introducing an empirical expression for J_2 based on the most recent and accurate determination of the J_2 variations before integrating the precession equations for the equator
  - (ii) adding 2 years of VLBI data for comparing the fits of the precession models to observations.
- ✓A serious study of the latest results on the J_2 variations with time is very interesting and would be required before introducing a so different representation in a precession model.
- ✓To retain IAU 2006 as standard model is a good choice before these corrections are significant and robust.

Thank you for attention!