New Version of EPM-ERA2010 Ephemeris from analysis of LLR data

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INTRODUCTION

MODERN EPHEMERIDES:

JPL, USA: DE403, DE405, DE421;

IMCCE, Observatoire de Paris-INPOP8;

IAA RAS, Russia-EPM-ERA2010

Present analysis of 17131 LLR observations, (time interval 1970-2010).

Model (brief description).
(Krasinsky, 2002)

The dynamical model EPM-ERA has been constructed by simultaneous numerical integration of equations of orbital and rotational motion of the Moon, major planets, biggest asteroids and lunar rotation;

Potential of the Moon is calculated up to 4-th order of the zonal index;

Potential of the Earth includes the 2-th order harmonics C_{20}, C_{22};

Tidal perturbation in the lunar orbital motion (due to tidal dissipation on the Earth's body) and also in rotational Lunar motion (due to tidal dissipation on the Moon's body) computed by the model with a constant lag;

Method of integration : Everhart's method with the constant step of integration.

Partials of lunar ranging respectively to dynamical parameters of the orbital and rotational model of the Moon are mostly computed by integration of variational equations; in a few cases they have been obtained by integration of rigorous system of equations with slightly varied values of the parameter under study (for example, k2 Moon) .

All calculations have been made by system ERA, IAA RAS, Russia .

Station	Time interval	Number LLR observations
McDonald	1970 March-1985 June	3440
MLRS1	1985 Jan-1988 Jan	275
MLRS2	1988 August-2010 April	3066
HALEAKALA	1988 August-1990 August	694
CERGA	1988 August-2010 March	9013
APACHE	2006 August-2009 June	643
Total	1970 March- 2010 April	17131

Table1: Distribution of LLR observations

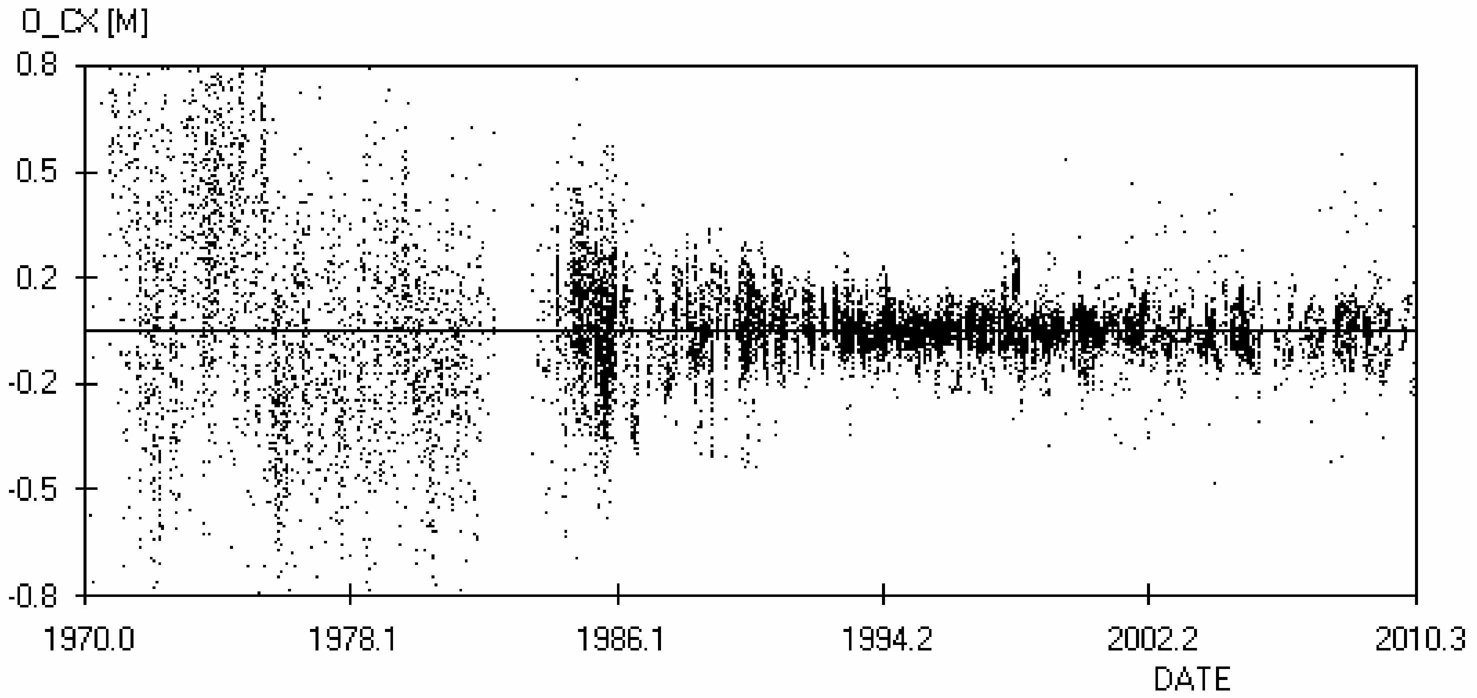
Reflectors:	number of ranging:
1. Apollo-11	1723;
2. Apollo-14	1670;
3. Apollo-15	13231;
4. Lunochod2	486.

Observations obtained by FTP servers:
ccdisa.gcfc.nasa.gov/pub /slr,
Oca.eu/gemini/donnes/las_lune,
Partly by private correspondence

N	Parameters estimated
1-6	Lunar orbital state vector for the epoch JD 2446000.5
7-12	Euler's angles and their time derivatives for the same epoch
13-18, 22-24	Coordinates of reflectors A11, A14, L2
20	X coordinate for reflector Apollo 15 (A15)
25-42	Coordinates of 6 observational stations
44	Lag of Earth's body tides
48-51	Secular trends in siderial angles of the Earth and Moon
55	Lag of Moon's body tides
52-54, 59-63	Harmonics of lunar potential from C_{20} to S_{33}
56-58	Lunar Love numbers k_2, h_2, l_2
64-65	Secular trends of the corrections to the parameters of Earth's equator ε, Φ

wrms (cm) O-C	residuals	Number of observations	Observational stations	Interval of observations
31.5	31.5	3399	McDonald	19700415.0 - 19850630.0
12..2	12..2	275	MLRS1	19850301.0 - 19880127.1
5.1	5.1	8996	CERGA	19840407.2 - 20100121.2
13.6	13.7	694	Haleakala	19841113.1 - 19900830.1
6.7	6.7	2808	MLRS2	19880229.0 - 20100405.1
5.7	5.7	643	Apache	20060407.1 - 20090615.1
6.8	6.8	16823	(All stations)	

EPM-ERA2010 ephemeris, statistics of residuals



EPM-ERA2010, residuals (laser ranging)

O-C and residuals for DE ephemerides compared with EPM-ERA2010

Ephemeris	O-C Wrms (cm)	Residuals Wrms (cm)	Number of observations	Number of deleted observations
DE403	22.2	5.2	16827	304
DE405	258.2	5.6	16837	294
DE421	561.8	5.7	16833	298
EPM-ERA 2010	6.8	6.8	16823	308

Conclusion

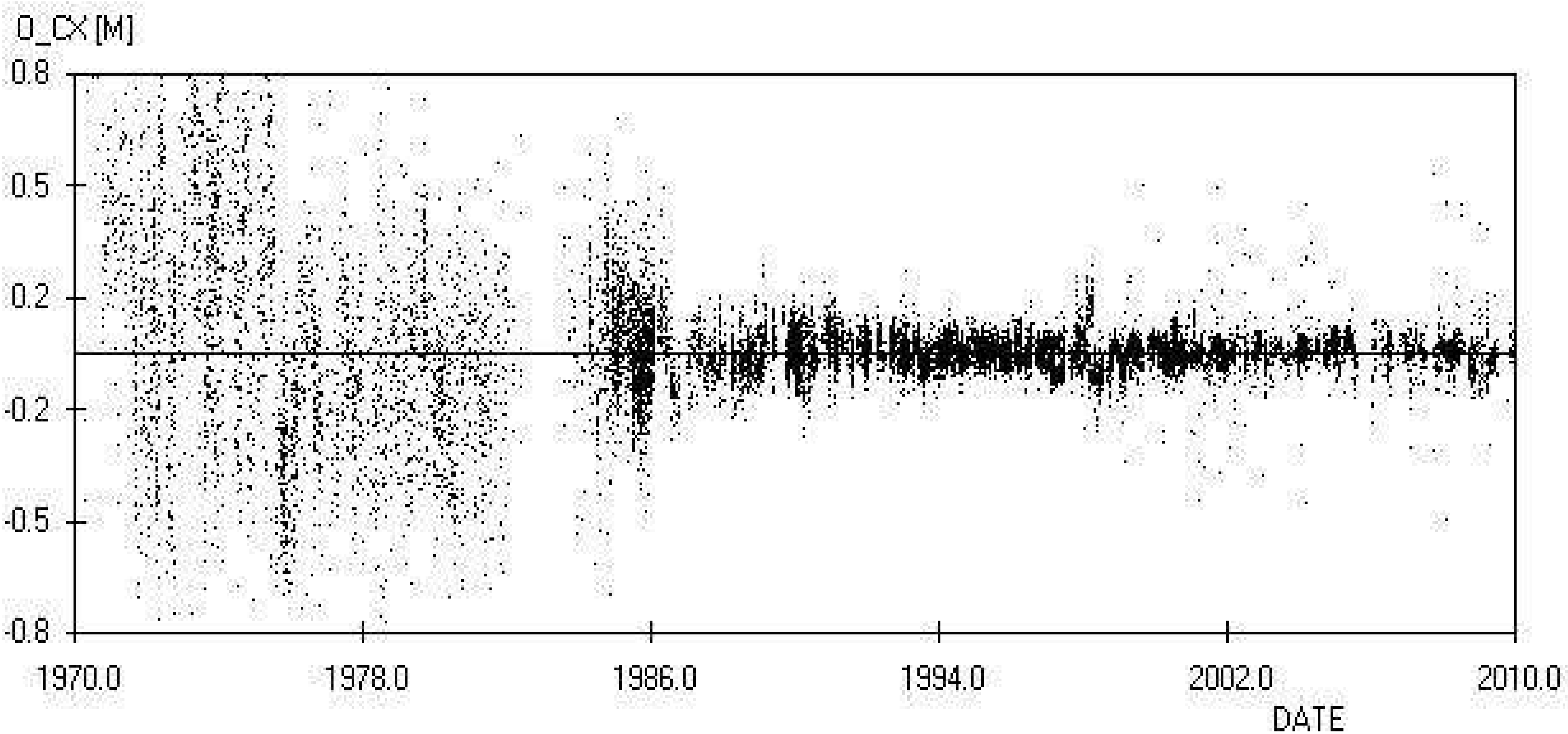
- **The investigation shows that inner accuracy of DE ephemerides (5.4-5.7cm) is a slightly better than that of EPM-ERA2010 (6.8 cm). But this accuracy of DE ephemerides cannot be used by independent researcher because it is not possible to feed back the corrected values of parameters.**

- **In the current version of EPM-ERA2010 ephemeris, the attempt to improve the model of the tidal perturbations in the rotational motion of the Moon (due to dissipation in the Moon's body) is carried out. The expansion of the retarded function in a power series of delay is used. This part of the model needs further improvements.**

- **Thank you very much for your attention!**

wrms (cm)		Number of observations	Observationa stations	Interval of observations
O-C	residuals			
39.3	30.3	3411	McDonald	19700415.0 - 19850630.0
10.7	7.2	275	MLRS1	19850301.0 - 19880127.1
16.4	4.1	8996	CERGA	19840407.2 - 20100121.2
14.3	7.2	694	Haleakala	19841113.1 - 19900830.1
17.6	5.6	2808	MLRS2	19880229.0 - 20100405.1
39.5	3.4	643	Apache	20060407.1 - 20090615.1
22.2	5.2	16827	(All stations)	

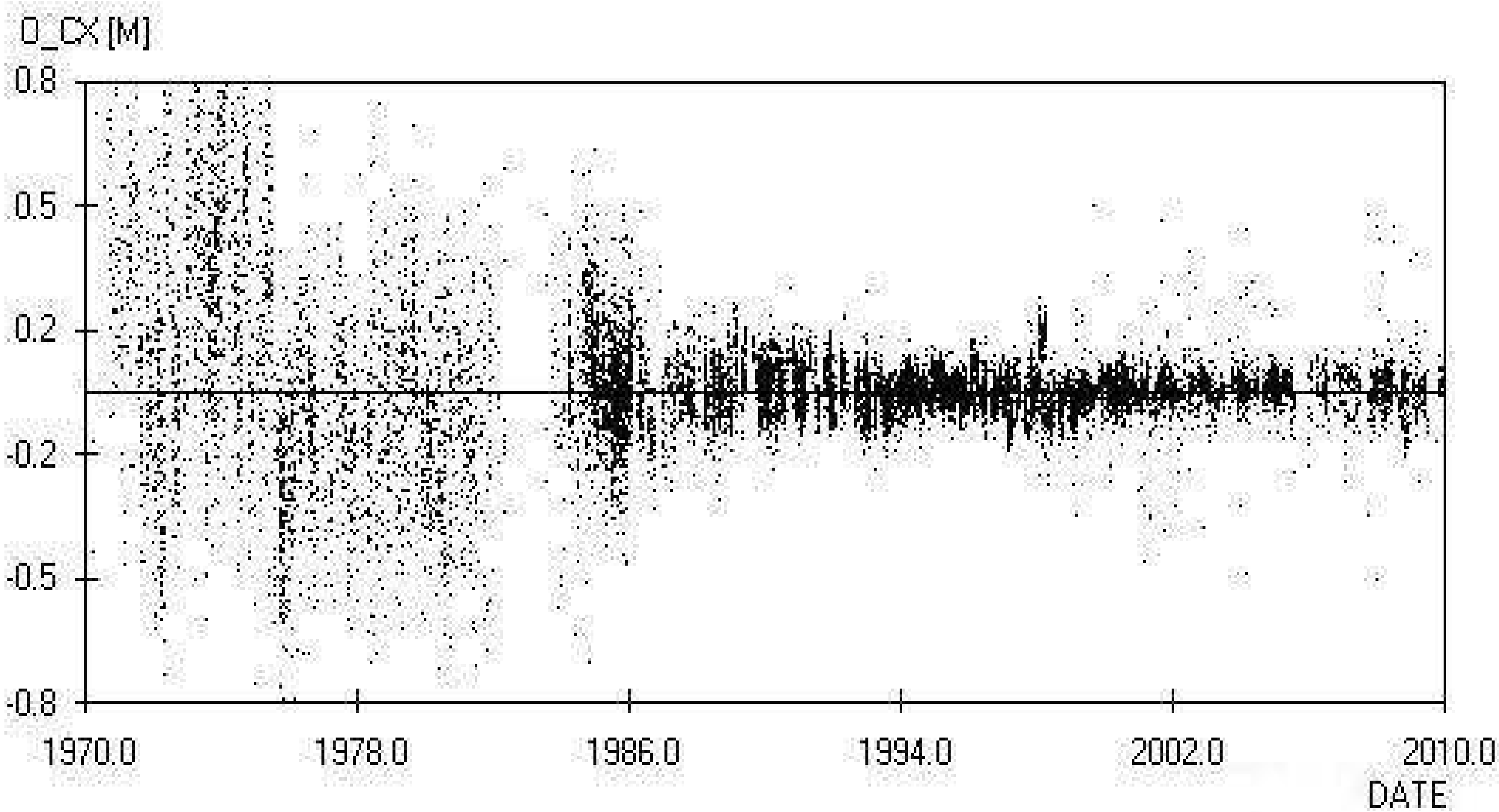
DE403 ephemeris, statistics of residuals in LLR



Ephemeris DE403, residuals (laser ranging)

Wrms (cm) O_C	residuals	Number of observations	Observational stations	Interval наблюдений
267.9	28.9	3416	McDonald	19700415.0 - 19850630.0
227.6	7.5	275	MLRS1	19850301.0 - 19880127.1
246.9	4.5	8998	CERGA	19840407.2 - 20100121.2
133.8	7.6	694	Haleakala	19841113.1 - 19900830.1
215.0	5.8	2811	MLRS2	19880229.0 - 20100405.1
348.6	4.7	643	Apache	20060407.1 - 20090615.1
258.2	5.6	16837	все станции	

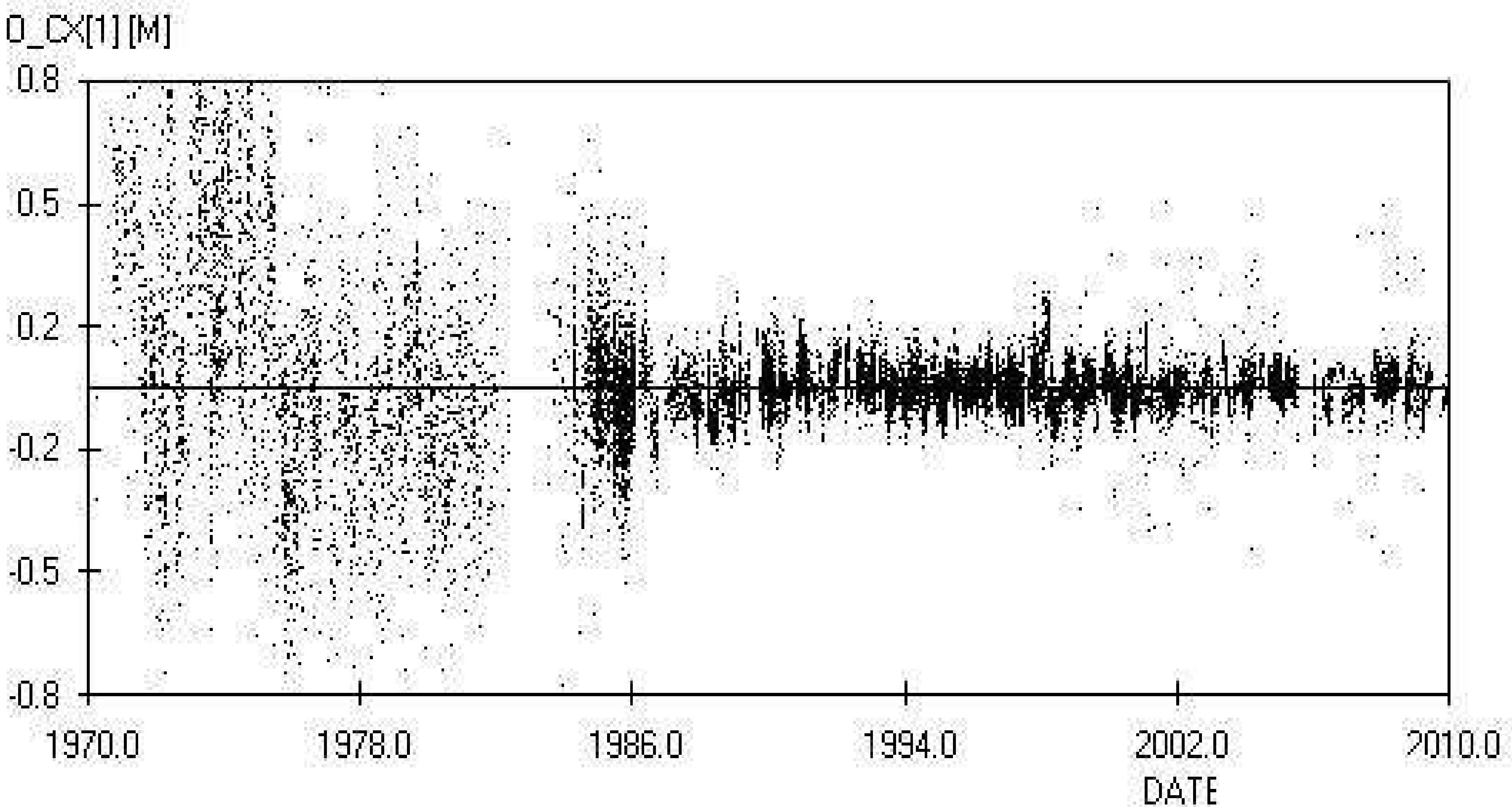
DE405 ephemeris, statistics of residuals in LLR



Ephemeris DE405, residuals (laser ranging)

Wrms (cm) O-C	residuals	Number of observations	Observational stations	Interval of observations
577.7	29.5	3411	McDonald	19700415.0 - 19850630.0
533.9	6.5	275	MLRS1	19850301.0 - 19880127.1
535.7	4.6	8999	CERGA	19840407.2 - 20100121.2
288.8	8.3	694	Haleakala	19841113.1 - 19900830.1
483.2	6.1	2811	MLRS2	19880229.0 - 20100405.1
750.4	3.9	643	Apache	20060407.1 - 20090615.1
561.8	5.7	16833	(All stations)	

DE421 ephemeris, statistics of residuals in LLR



Ephemeris DE421, residuals (laser ranging)

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(model) (programming) (databases)

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