Planned LLR station in Russia and its impact on the Lunar Ephemeris Accuracy

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INTRODUCTION

- **Precise modern Lunar Ephemerides (DE/LE, INPOP, EPM-ERA) are based on only LLR observations obtained at several LLR ground stations during 1969 – 2013 years:**

LLR station	Time interval	Obs.number
McDonald	1970 March-1985 June	3440
MLRS1	1985 Jan-1988 January	275
MLRS2	1988 August-2012 April	3114
HALEAKALA	1988 August-1990 August	694
CERGA	1985 Jan-2013 February	9599
APACHE	2006 July-2012 August	1576
Total	1970 March-2013 February	18700

- **There are two projects of new LLR stations:**

Altay(Russia) and La Silla(Europe) stations.

Expected impact of new Russian LLR station on the Lunar ephemeris accuracy is the main topic of the presentation.

Altay LLR station

1. Location: Siberia, Altay Optical-Laser Center, approximate coordinates are (51°N, 82°E, 385 m).
2. 3.12 meter telescope (Altay Optical-Laser Center) as probable base telescope for the LLR station
3. Target accuracy of LLR observations (normal point) is about 3mm
4. Meteorological conditions: 1400 clear night hours, 240 nights suitable for LLR observation per year
5. Major project participants: OJC «Research-and-Production Corporation «Precision Systems and Instruments», VNIIFTRI and IAA RAS

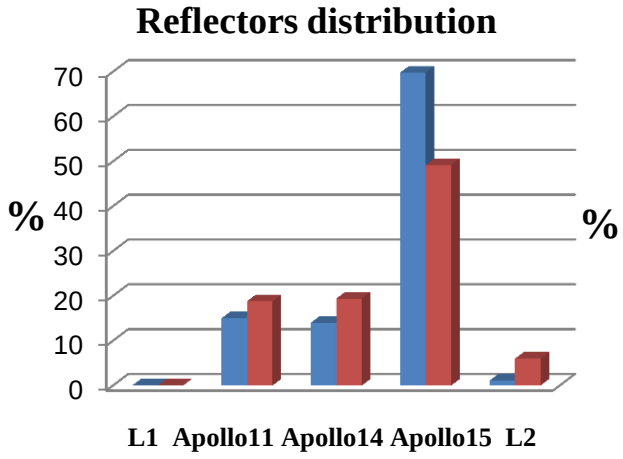
Motivation and methods are presented below:

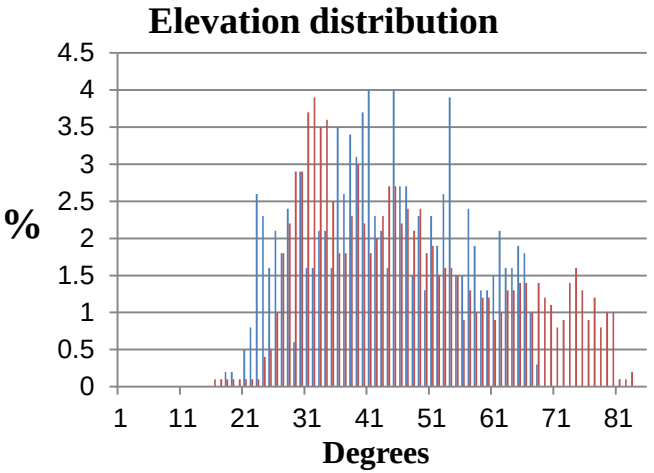
- To check the urgency of the project it should be shown in particular that the accuracy of the lunar ephemeris will visibly increase
- The only way to prove that fact now is the numerical simulation

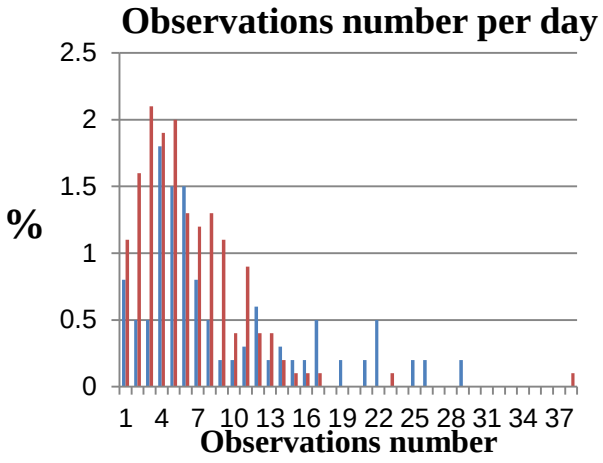
Numerical simulation

1. Distribution of real LLR observations (18700) at interval 1970-2013 have been analyzed depending on LLR station:

- Target reflectors distribution
- Elevation distribution
- Observations per day distribution
- Etc







2. Due to complexity and irregularity of the distributions above it was decided that observation programs of real LLR stations will be used for numerical simulations
3. Observation programs of Apache and Cerga stations have been chosen as the basis to create simulated LLR measurements
4. Special SW was developed for simulation:

- LLR observations simulation for Altay station
- Adjusted parameters estimation using both real and simulated LLR measurements

I.1.18700 real observations **(1970-2013 years) + simulated observations from 2006 till 2013 at Altay station** like it was observed at Apache (Apollo) or Cerga station. (in simulation-"**Apache 2006", "Cerga2006").**

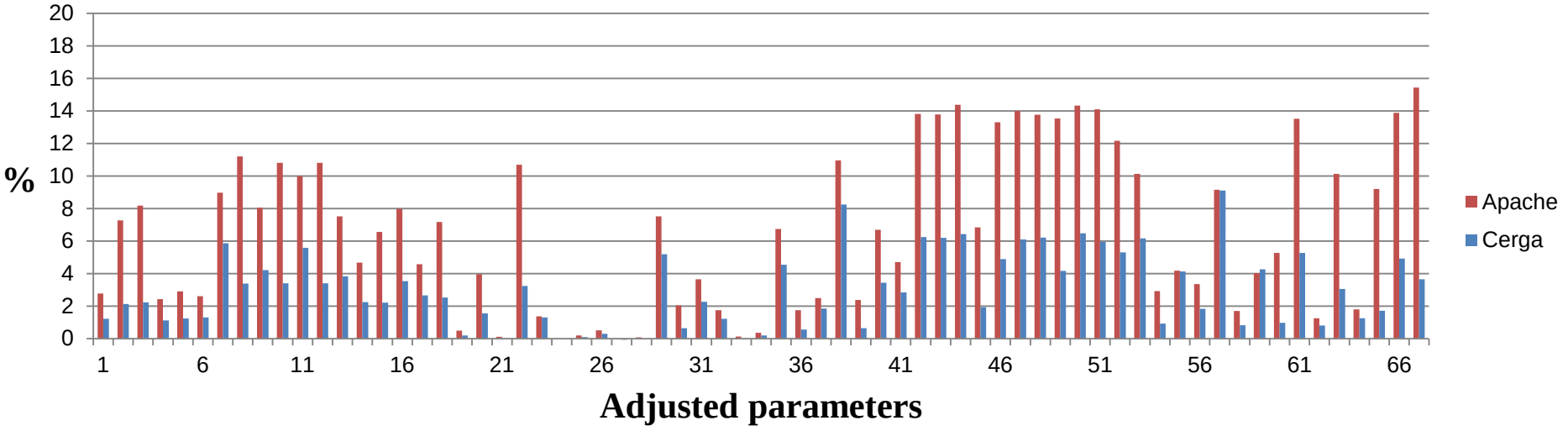
I.2. 18700 real observations **(1970-2013 years) + simulated observations from 2006 (-1 month shift) till 2013 at Altay station** like it was observed at Apache (Apollo) or Cerga station. (in simulation-"**Apache 2006shift", "Cerga2006shift").**

II. 18700 real observations **(1970-2013 years) + simulated observations from 2008 till 2013 at Altay station** like it was observed at Apache (Apollo) or Cerga station. (in simulation-"**Apache 2008", "Cerga2008**").

III. 18700 real observations **(1970-2013 years) + simulated observations from 2012 till 2013 at Altay station** like it was observed at Apache (Apollo) or Cerga station. (in simulation-"**Apache 2012", "Cerga2012").**

Simulation results

Impact on parameter's accuracy: "Apache 2006" and “Cerga2006” scenarios

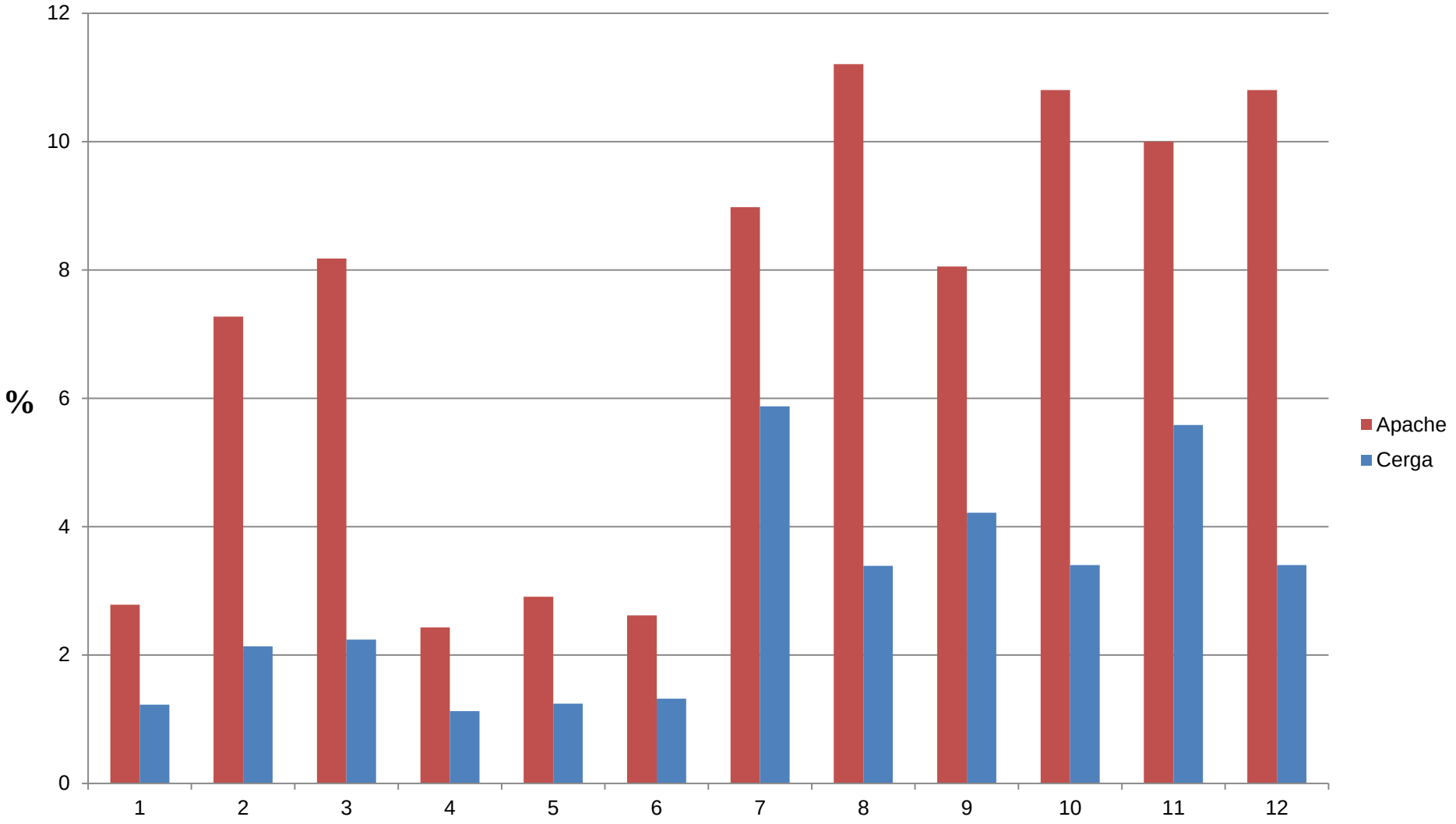


Adjusted parameters

N	Parameter	N	Parameter	N	Parameter	N	Parameter	N	Parameter
1	X Moon	15	A11 PY	29	CERGA PX	42	C_{20}	55	T*sidt Moon
2	Y Moon	16	A14 long	30	CERGA long	43	C_{21}	56	T*deps
3	Z Moon	17	A14 PX	31	CERGA PY	44	S_{21}	57	T*dpsi
4	V_x Moon	18	A14 PY	32	Halaek PX	45	C_{22}	58	deps
5	V_y Moon	19	L2 long	33	Halaek long	46	S_{22}	59	dpsi
6	V_z Moon	20	L2 PX	34	Halaek PY	47	C_{30}	60	Lag Moon
7	Libration Θ	21	L2 PY	35	MLRS1 PX	48	C_{31}	61	k2 Moon
8	Libration ϕ	22	A15 PX	36	MLRS1 long	49	S_{31}	62	A15 long
9	Libration ψ	23	MCD PX	37	MLRS1 PY	50	C_{32}	63	A15 PX
10	Libration dΘ/dt	24	MCD long	38	Apache px	51	S_{32}	64	A15 Py
11	Libration dϕ/dt	25	MCD PY	39	Apache long	52	C_{33}	65	L1 long
12	Libration dψ/dt	26	MLRS PX	40	Apache py	53	S_{33}	66	L1 PX
13	A11 long	27	MLRS long	41	Lag Earth	54	T*sidt	67	L1 PY
14	A11 PX	28	MLRS PY						

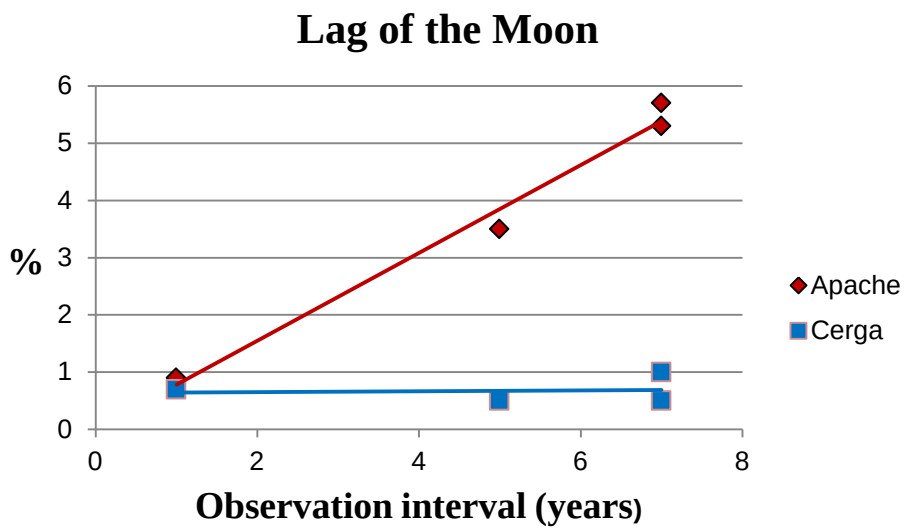
Impact on the Lunar ephemeris accuracy

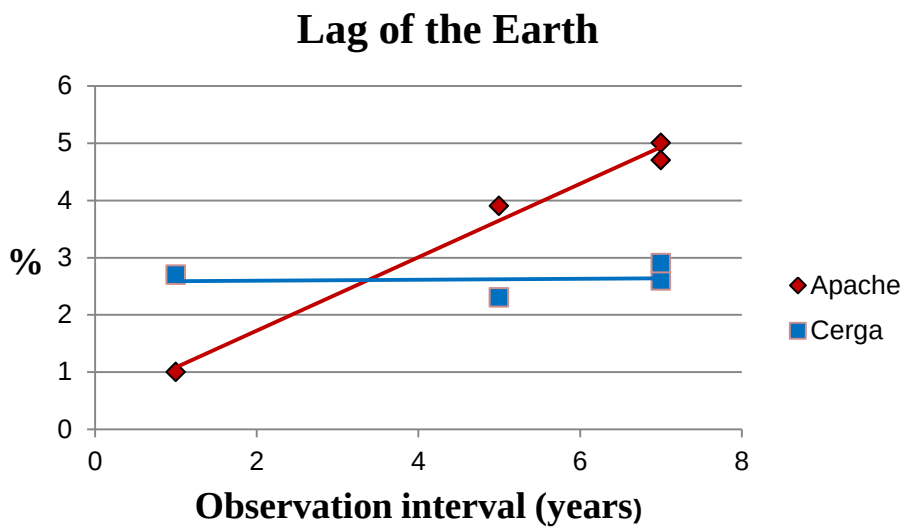
"Apache 2006" and “Cerga2006” scenarios

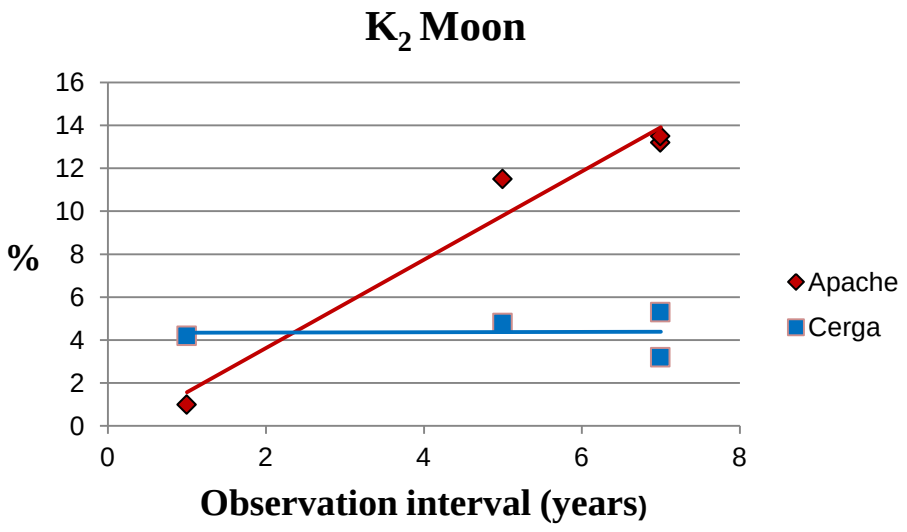


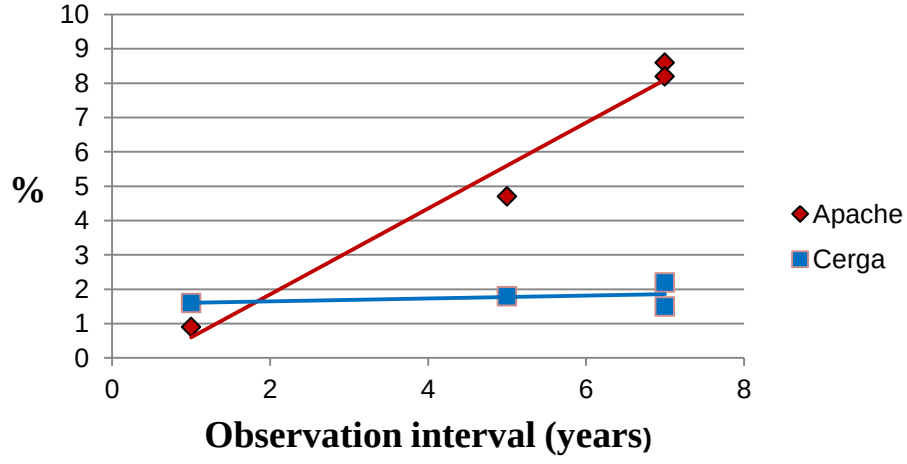
Adjusted parameters: initial Lunar state vector and libration angles

Accuracy vs observation interval



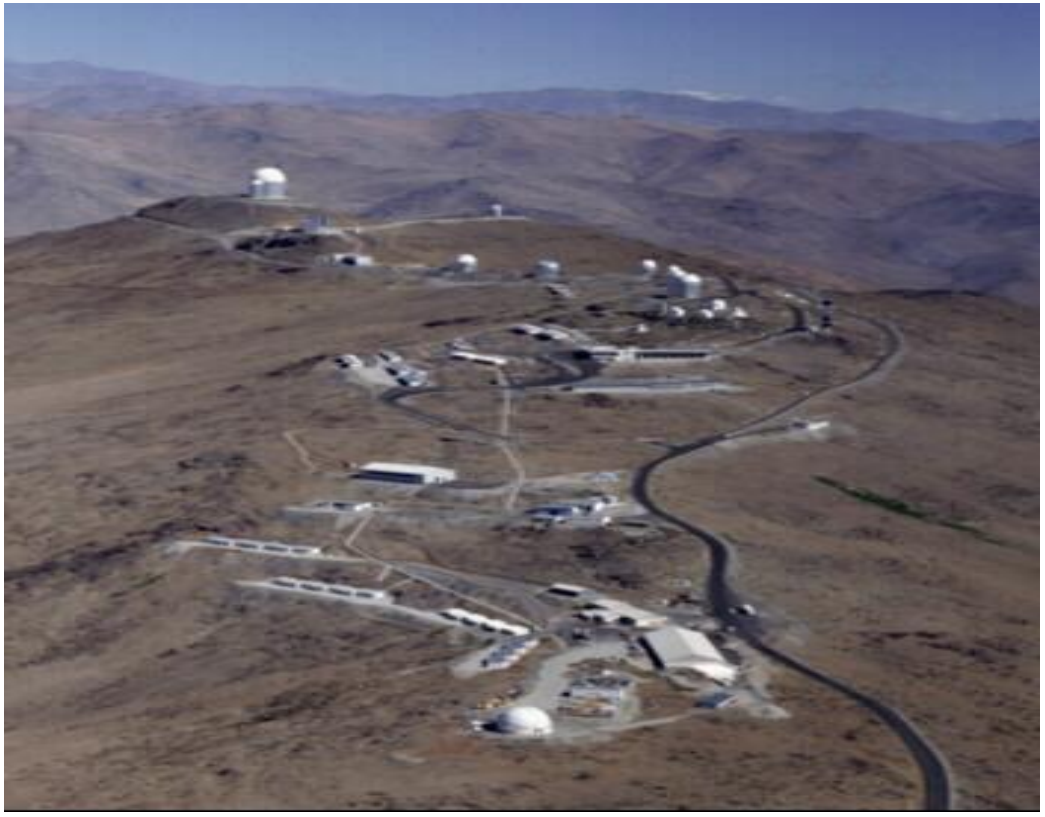




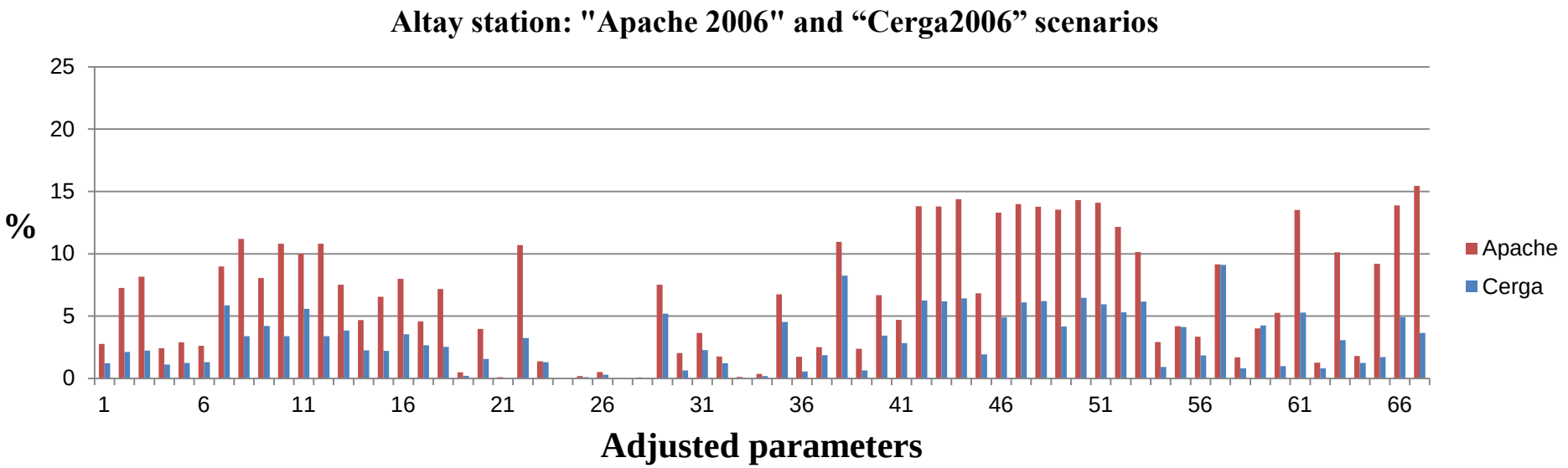


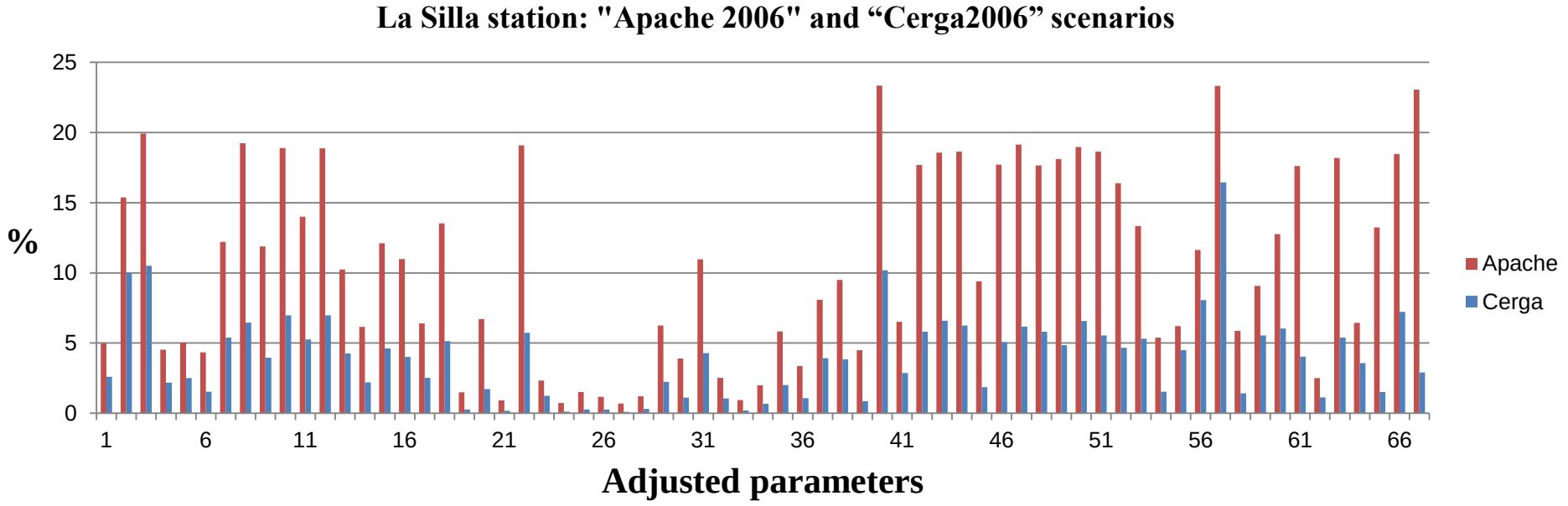
La Silla LLR station

1. SHELLI (Southern Hemisphere Lunar Laser Instrument) project, location: ESO, La Silla, Chile (29°S, 70°W, 2400m)
2. NTT telescope (3.6 meter) as proposed base telescope for the LLR station
3. As a twin of Apache Point in terms of quality and regularity of the produced data
4. Meteorological conditions: ESO, bordering the southern extremity of the Atacama desert in Chile
5. Probable project participants: ESO, Geoazur (OCA), INSU



Altay vs La Silla station





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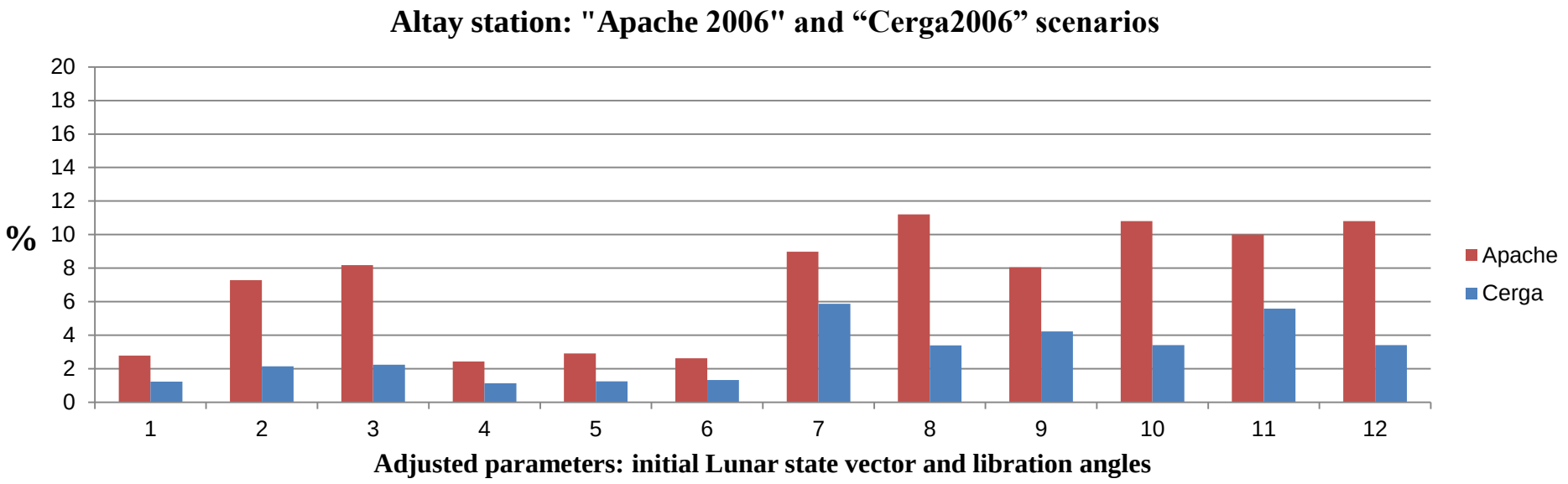
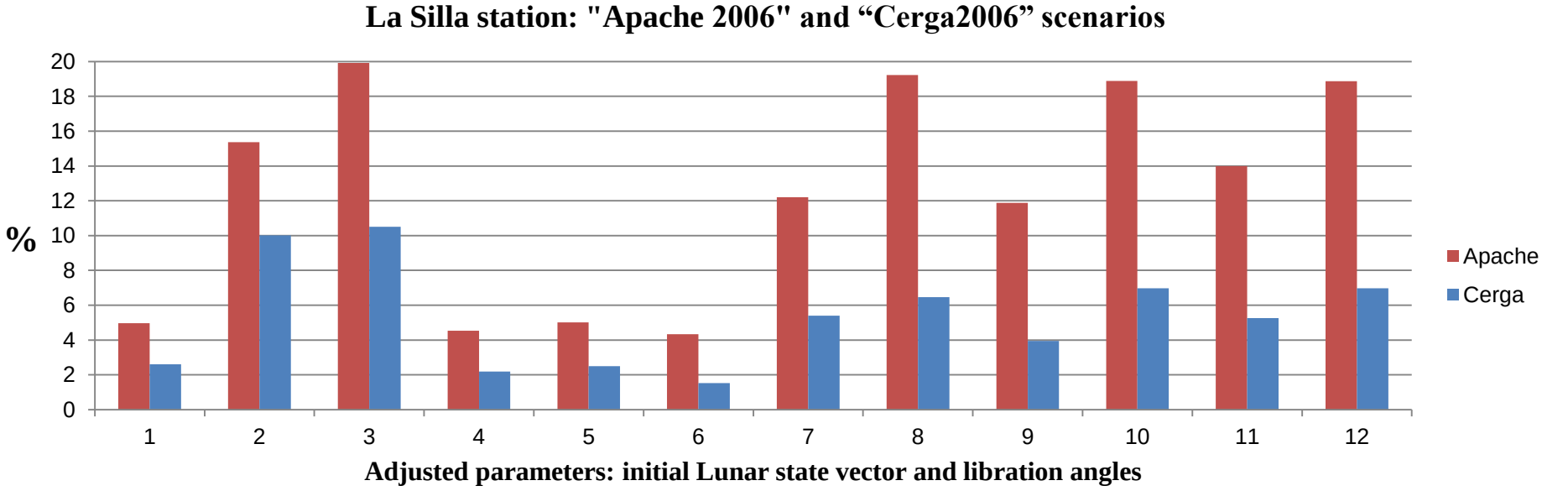
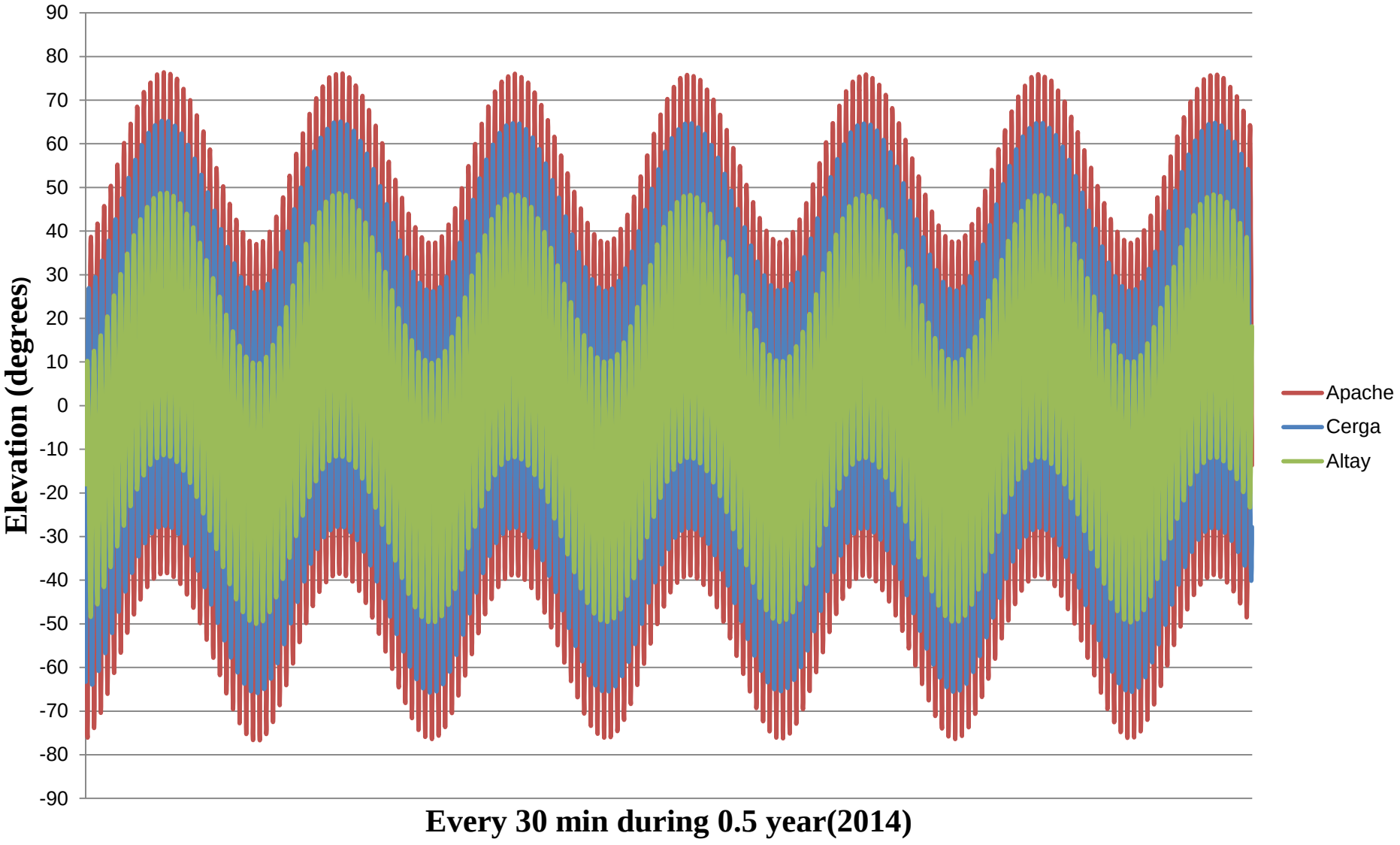


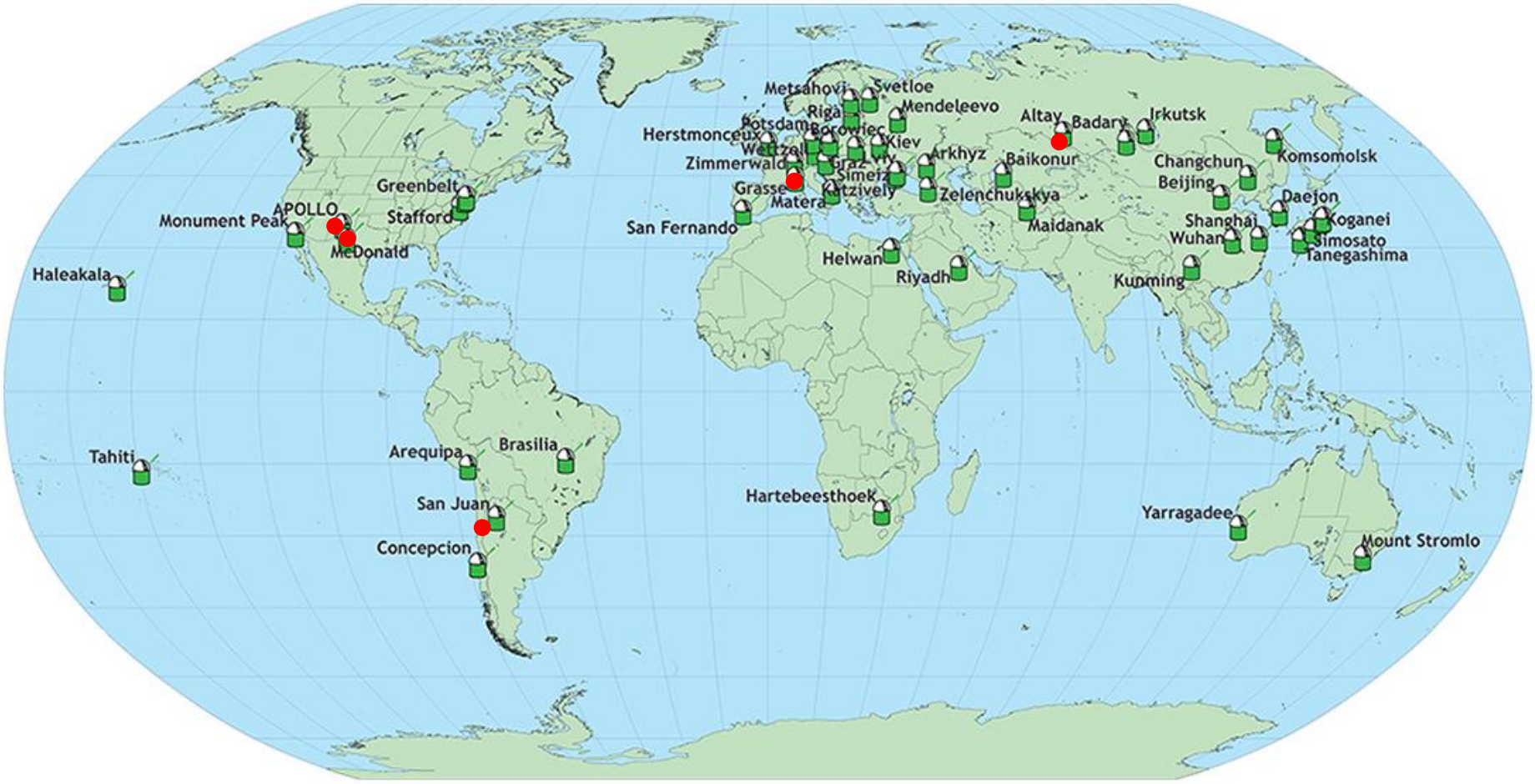


Observation conditions: latitude dependence

Elevation of the Moon: Apache, Cerga, Altay



LLR observations: geography



Conclusions

- **According our simulations new Russian LLR observations will provide visible accuracy improvement of the Lunar ephemeris and corresponding physical models: about 2-16% depending on the adjusted parameter.**

- **Simulation SW was developed estimating the impact of new LLR stations on the accuracy of Lunar ephemeris.**

- **Russian LLR station (Altay) has observational limitation due to geographical position. So, its observation program should be very intensive to provide the impact comparable with other modern LLR stations.**

- **The received result are in good agreement with analogous works (for example, the paper French colleagues about proposal of installation LLR device at 3.6 m telescope in Southern Hemisphere, La Silla).**

- **Russian LLR station can give contribution into the common world database of LLR observations.**

Thank you for attention