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ORIGINAL ARTICLE

17 years of ranging from the Helwan SLR station

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Abstract The satellites laser ranging from Helwan SLR station during the last 20 years are discussed. The internal calibration method used at the Helwan SLR station is explained. The root mean square value of the calibrations carried out during the period from 1991 to 2008 is computed. To clarify the difference in the accuracy of the measurements, the results of the analysis of the data taken for all the satellites after the upgrading (2000) are given and compared with those of the satellites observed before the upgrading (1996). The total number of passes of the satellite observed during the period from 1991 to 2008 is presented and the results are compared with the other SLR stations.

Keywords Satellite laser ranging · Helwan SLR-station · Calibration · Data analysis

1 Introduction

The laser ranging technique is considered to be one of the most accurate methods to track the artificial earth satellites. The primary goal of the satellite laser ranging is the measurement of the time required for pulses emitted by a laser transmitter to travel to a satellite and return back to the transmitting site. The first Helwan SLR station was built in 1974, which was a half-automatic station. It was the only station in Africa. In 1980, a full automatic SLR station was built. Now there are two SLR stations in Africa, the second station is the Harebeesthoek SLR, which exists in South Africa. The improvement in the accuracy of the measurements of the satellites observation using the laser technique gives rise to a development of many recent applications. All the activities are concentrated on the improvement of the performance of the satellite laser ranging stations. There were continuous upgrading of the station (Hamal 1978; Jelinkova 1984; Novotny and Prochazka 1984; Prochazka 1989) provide a continuous improvements in the accuracy of the distance measurements between the satellite and the SLR station from centimeters level to a few millimeters level.

A detailed description of the upgrading, which had been carried out during 1999, is represented (Ibrahim et al. 2001; Tawadros et al. 2000). In addition, there is a new time interval counter of type RS620 with accuracy of 4 psec in measurements, had been installed in the second half of 1999. The aim of this paper is to discuss the results of the last 20 years of ranging from the Helwan SLR station which led to the improvements of the accuracy of the measurements. The data of the observed satellites as well as the calibrations are analyzed and presented. The results of the analysis of the data taken from all the satellites tracked before and after the upgrading are given. For the comparison purposes, the satellite laser ranging data taken from Helwan SLR station are summarized and compared with those obtained from other SLR stations.

2 The calibration of the Helwan SLR station

The Helwan SLR station is calibrated using an internal calibration method. It is accomplished by ranging on a fixed target placed at a distance of 1.01 meter from the laser emitter. The geometry of the calibration setup is shown in Fig. 1(a), which applied to the Helwan SLR station from 1991 till now. For the purpose of the calibration, both the emitter and the

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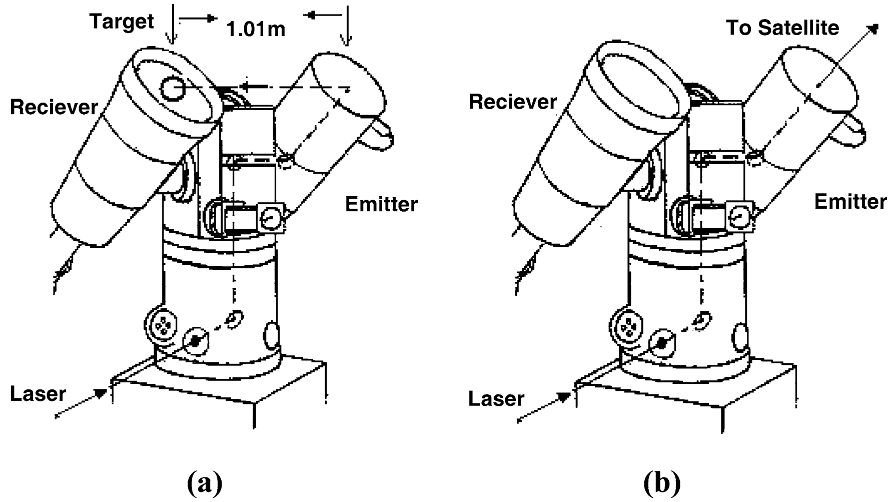

Fig. 1 Three coude mirrors inside the mount to guide the laser beam, for calibration in (**a**) and for ranging to satellites in (**b**)

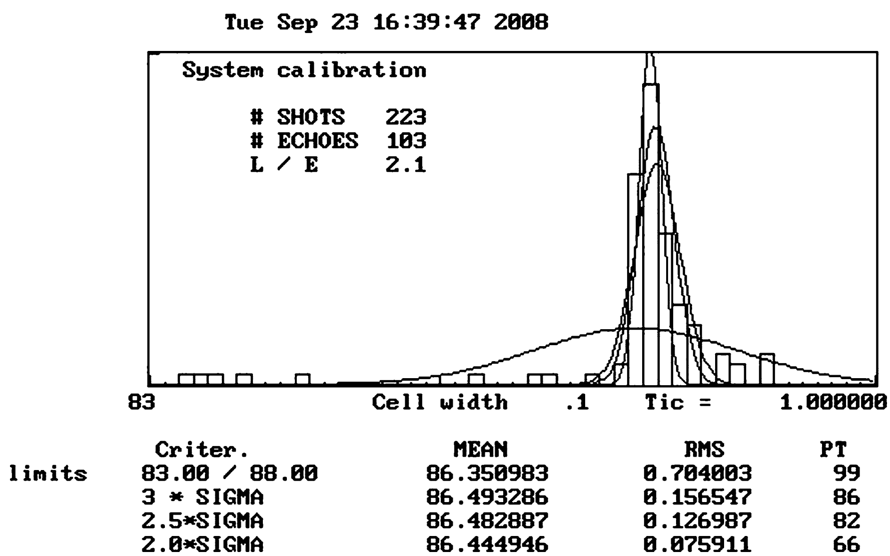

Fig. 2 The calibration of the system using the time interval counter SR620

receiver are covered. The cover of the emitter has a hole followed by mirror to reflect the beam to the direction of the target.

During the calibration, the signal strength is adjusted using a neutral density filters in order to receive the echoes with a known range of the signal to noise ratio. The computation of the calibration constant is the average of nearly 100 returns (echoes) by using the counter SR620, but it was the average of 150 echoes by using the time interval counter of type HP5370B. After a satellite laser tracking, all the ranging data are corrected by subtracting the value of the calibration constant. I concerned on the results of the calibration, which is applied to the Helwan SLR station in two periods. The first period is from August 1991 to September 1997. During that time the photomultiplier (PMT) of type RCA 31034A has been used. Figure 1(b) is a block diagram for ranging to satellite.

Figure 2 shows a typical histogram of the internal calibration of the system carried out on 23 September, 2008, in which the time interval counter of type SR620 is used. The mean value of the calibration is about 86 nsec and the root mean square (RMS) value is about 76 psec. In the figure, the number of laser shots and the echoes, which is the number of returns from the target, are given. L/E is the ratio between them. This ratio is considered a main parameter to adjust the signal strength during the calibration process. For all the calibrations, the root mean square value is selected corresponding to 2 sigma.

Due to the long operating time of that PMT, its sensitivity had been decreased by approximately 3 times (Cech et al. 1998). In May, 1998 the receiver package was completely upgraded and the PMT RCA 31034 was replaced by the PMT Hamamatsu H6533 box with PMT tube 4998. It consists of a PMT tube and high voltage with precise divider. The Tennelec TC 952A high voltage power supply with stable 2500 volts is used as a source for the PMT, to obtain standard parameters. On the other hand, the old preamplifiers HP8447A (400 MHz) and HP8447D (1.3 MHz) have been replaced by EG & G Ortec 1 GHz preamplifier Model 9306. It is a four-stage preamplifier based on Hewlett Packard MMIC chips. The constant fraction discriminator Ortec 646 was replaced by the Quad Tenellec discriminator TC454. The first channel is used for processing the signal from the start detector; the second channel is used for discriminating pulses from the PMT. The time delays of both, i.e. the start and stop channel, were adjusted to the lowest time jitter. The first results show the mean value of the system calibration is about 58 nsec and time jitter is 50 psec, where the counter HP5370B is used as a ranging counter (Cech et al. 1998). Hence, the second period is from May 1998 till December 2008, in which this new PMT is in use.

The calibrations applied to the station within the whole period from 1991 to 2008 are computed and the results are shown in Fig. 3. It is clear that the root mean square (RMS) values of the calibrations produced using the new PMT package are much better than that of the calibration produced using the old PMT. During the first period, there are 2375 calibrations, have been applied. The RMS values of these calibrations are computed and the results are shown

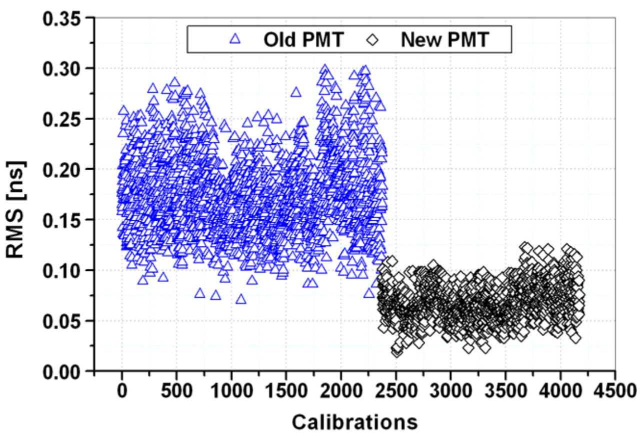

Fig. 3 The calibrations vs. the RMS values for all the calibration carried out in the period from 1991 to 2008

in Fig. 4(a). The average RMS value of the calibrations is found to be 174 psec. Similarly, the results of the calibrations of the system applied during the second period, in which the new PMT package is used, are shown in Fig. 4(b). The total number of calibrations applied in that period is 1794 and the average precision is found to be 68 psec, which is nearly 2.6 times better than the precision of the calibrations produced by the old PMT, which agrees will with the studies in Cech et al. (1998).

3 Helwan satellite laser ranging and data analysis

3.1 The satellites tracked from Helwan SLR during the period from 1991 to 2008

It should be mentioned that the Helwan SLR station was operated completely by a group from Czech Technical University of Prague until 1997. From 1999 the station had been operated completely by the Egyptian scientists all over the year. In this section, the total number of observed satellites from Helwan SLR station during the period from 1991 to 2008 are summarized and the results are shown in Fig. 5. The greatest number of observed satellites (1391 passes) is obtained during 1999. It is also clear that a downturn had taken place during the years after 1999 was due to the shortage of the financial support which is necessary for the operation of the station as well as the little spare parts which in turn affected the station performance (Ibrahim 2005).

3.2 Helwan SLR data before and after the upgrading

The analysis of the data is based on calculating the difference between the observed and the predicted ranges. The principles of the analysis are carried out through main three steps: on-line residuals, off-line residuals, and polynomial fitting of the residuals data (Ibrahim et al. 2001). Ajisai,

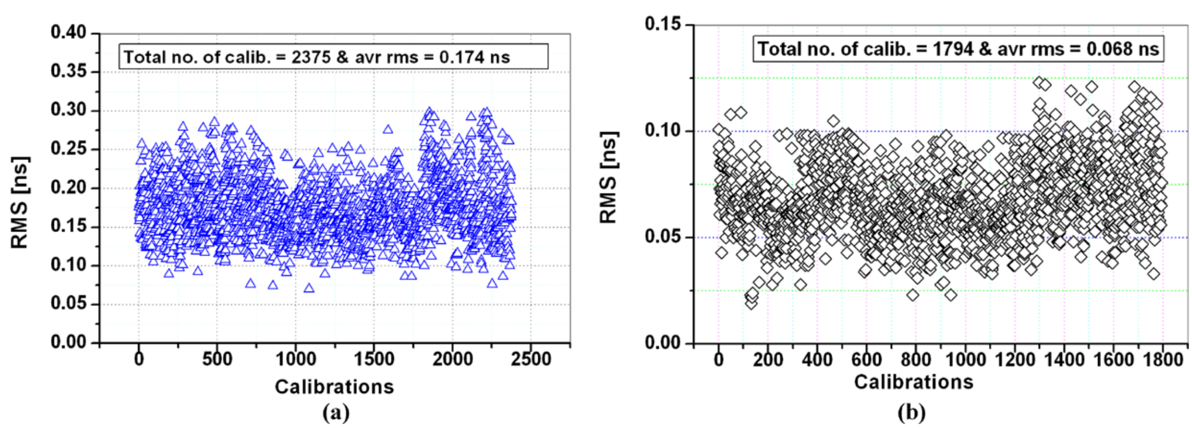

Fig. 4 The RMS values for all the calibrations carried out by the old PMT in (**a**) and by the new PMT in (**b**)

Starlette, Stella and Lageos, are among the satellites under observation. Figure 6 shows the pass of the satellite ERS-2 which observed on 25 October 2000 in (a) and its range residuals (Observed-Computed) in (b). As to its RMS value: it is found to be about 9.45 mm. The number of normal points (Ibrahim et al. 2001) is 18 as computed and presented in Table 1.

On the other hand, Fig. 7 represents the value of the RMS in millimeters as computed for the passes of the satellites Ajisai, which observed during 1996 in (a) and during 2000 in (b).

The total number of observed satellites is 45 passes in 1996 and 102 passes in 2000. As for the average RMS value, it is about 35 mm in 1996 and about 24 mm in 2000. It is clear that the data obtained during 2000 are much better in accuracy relative to the data obtained during 1996. By the way, Figs. 8 and 9 represent the same behavior for data taken for the satellites Stella and Starlette. The total number of observed satellites is 36 and 22 passes in 1996 for the satellites Stella and Starlette, respectively, and 53 and 56 for the same satellites in 2000.

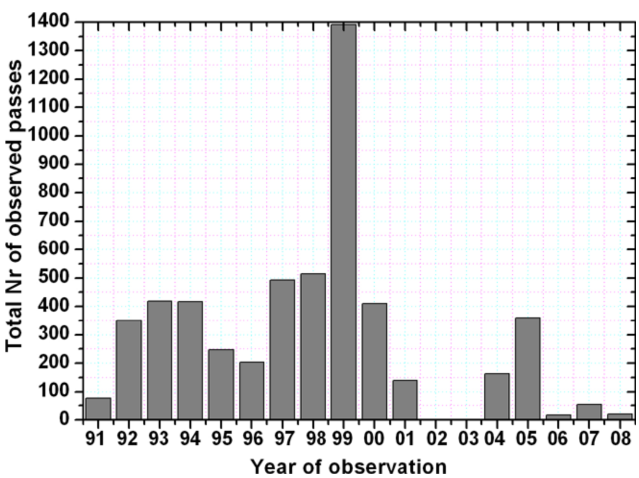

Fig. 5 The total number of tracked satellites from Helwan SLR station during the period from 1991 to 2008

As to the average RMS value: it is about 25 mm for the both satellites Stella, and Starlette, respectively, as computed for the year 1996 and about 12 mm and 11 mm for the same satellites in 2000. It can be also noticed that the accuracy of the measurements for the satellite Ajisai is worse than the accuracy of the measurements of the satellites Starlette or Stella, this is referred to the so-called satellite signature (Appleby 1992; Otsubo et al. 1999).

For a comparison purposes, the results from the satellite laser ranging data taken during the whole year 1996 are compared with the other results for satellites observed during the year 2000. The total number of passes and the average RMS value produced from the analysis of the observed satellites are computed and the results are summarized in Table 2 for the satellites tracked during 1996 in (a) and for the satellites tracked during 2000 in (b). It can be also noticed from Figs. 8 and 9 that the accuracy of the satellite laser ranging measurements below 10 mm is available during the observations carried out at 2000 while such accuracy is not available in 1996. This upturn of the accuracy of measurements is referred to the upgrading of the equipment of the Helwan SLR- station (Ibrahim et al. 2001).

From the tables it is clear that the total number of passes of the satellites tracked during 1996 is 207, and 426 tracked during 2000. It is important to mention that the satellites under observation are chosen to the requested projects and some priorities, which is the reason that some of the satellites tracked during 1996, are not tracked during 2000 and vise versa.

For more clarifications of the comparison, Fig. 10 represents the value of the RMS in millimeters as computed for

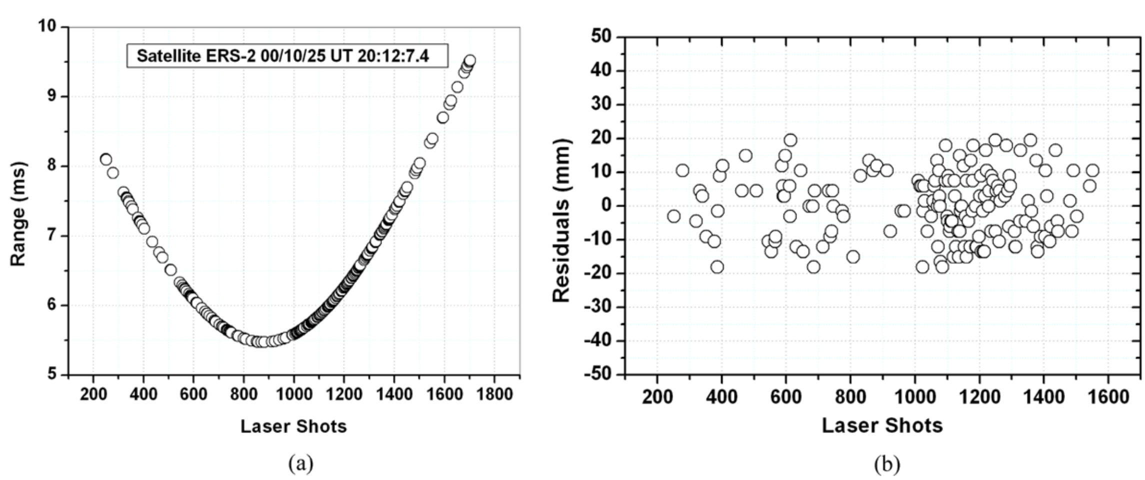

Fig. 6 The number of laser shots as plotted versus the range of the satellite ERS-2 in (**a**) and versus the range residuals in (**b**)

Table 1 The normal point as computed at 25/10/2000 for the satellite ERS-2

#	*H*	*M*	*S*	*R* (ms)	psec	PT/NPT
1	20	12	13.20029	7.90656	63.6	2
2	20	12	25.40029	7.4999	42.4	4
3	20	12	36.20028	7.15953	84.7	5
4	20	12	59.00029	6.51495	40.4	3
5	20	13	10.40029	6.23807	69.1	5
6	20	13	23.8003	5.9591	71	10
7	20	13	40.00029	5.69884	58.4	7
8	20	13	52.00028	5.56701	45.1	6
9	20	14	11.40029	5.47389	12.9	4
10	20	14	29.00029	5.52252	61.1	3
11	20	14	40.60029	5.62262	55.8	8
12	20	14	54.40029	5.80779	61.3	23
13	20	15	7.60029	6.04625	68.1	23
14	20	15	23.00029	6.39104	66.9	23
15	20	15	39.2003	6.81955	64.7	13
16	20	15	53.20029	7.23508	70.4	12
17	20	16	13.60029	7.90109	61.3	7
18	20	16	26.0003	8.33446	42.4	4

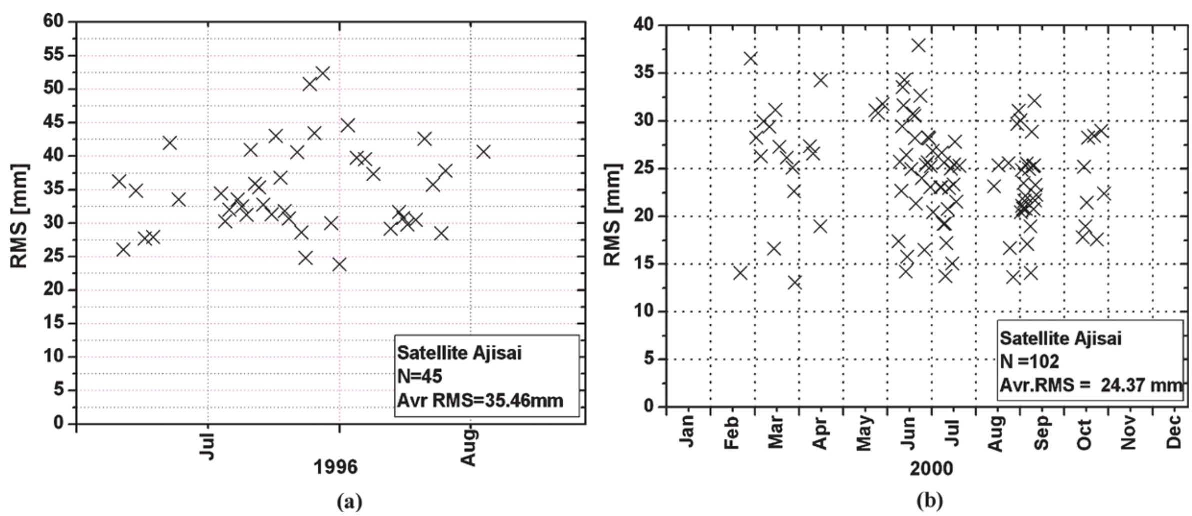

Fig. 7 The RMS in millimeters as estimated for the satellite Ajisai, before the upgrading in (**a**) and after the upgrading in (**b**)

the passes of the satellites Ajisai in (a) and Starlette in (b) which tracked during 2004.

There are 39 passes observed for the satellite Ajisai and 20 passes observed for the satellite Starlette. It is also clear that the value of the RMS is close to the similar satellites observed during 2000. Generally, the satellite laser ranging data taken during the whole year 2004 are analyzed. The total number of passes and the average RMS value produced from the analysis are computed and the results are summarized in Table 3, which shows that the total number of passes of the satellites tracked during 2004 is 163.

3.3 Comparison of the results of Helwan SLR station and other SLR stations

This section deals with the accuracy of the measurements of the data obtained from the observations of the artificial earth's satellites. For instance, Fig. 11 represents the single shot RMS for the satellite Lageos during the fourth quarter of 2000. It is computed for all SLR stations. It can be noticed from the figure that the single shot RMS value is about 19 mm as computed for the Helwan SLR station.

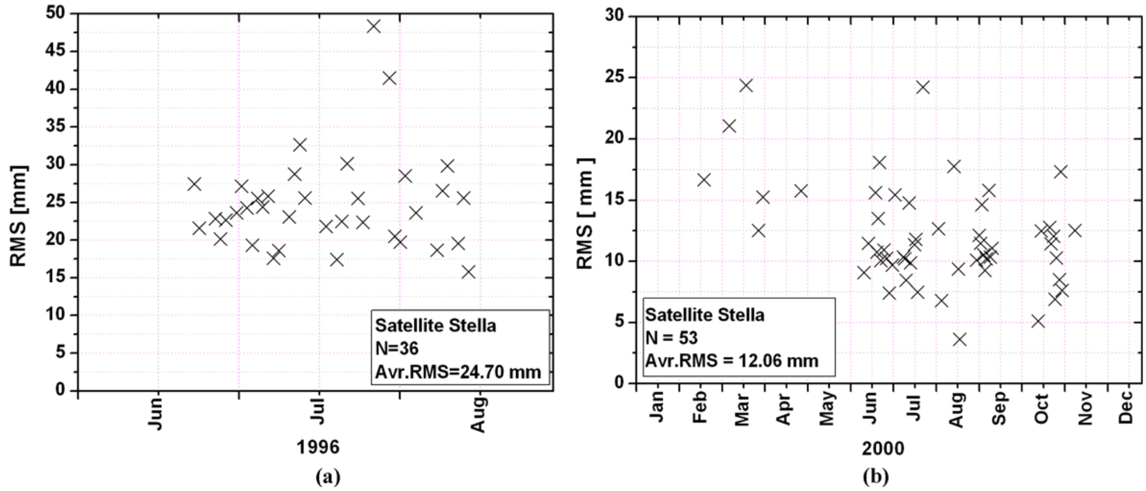

Fig. 8 The RMS in millimeters as estimated for the satellite Stella, before the upgrading in (**a**) and after the upgrading in (**b**)

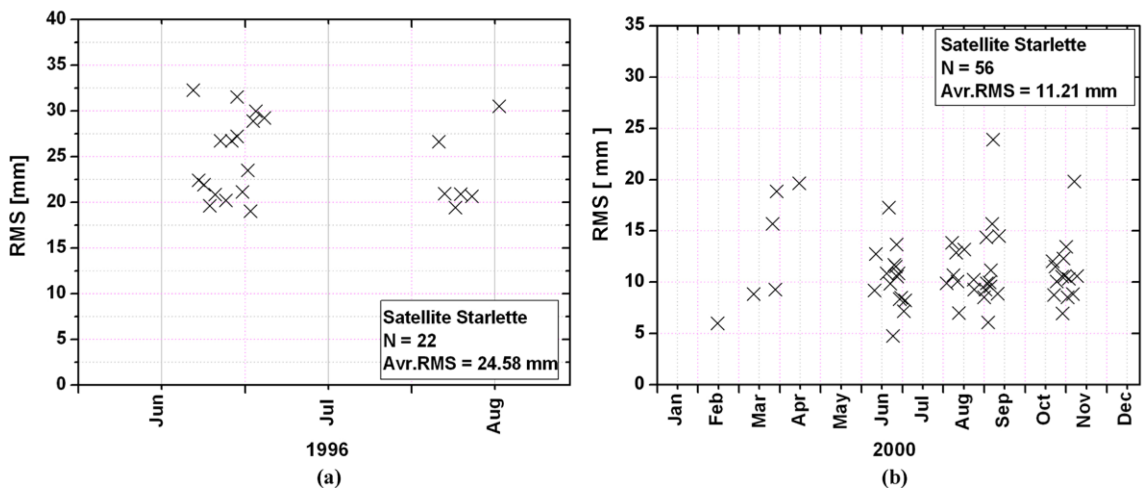

Fig. 9 The RMS in millimeter as estimated for the satellite Starlette, before the upgrading in (**a**) and after the upgrading in (**b**)

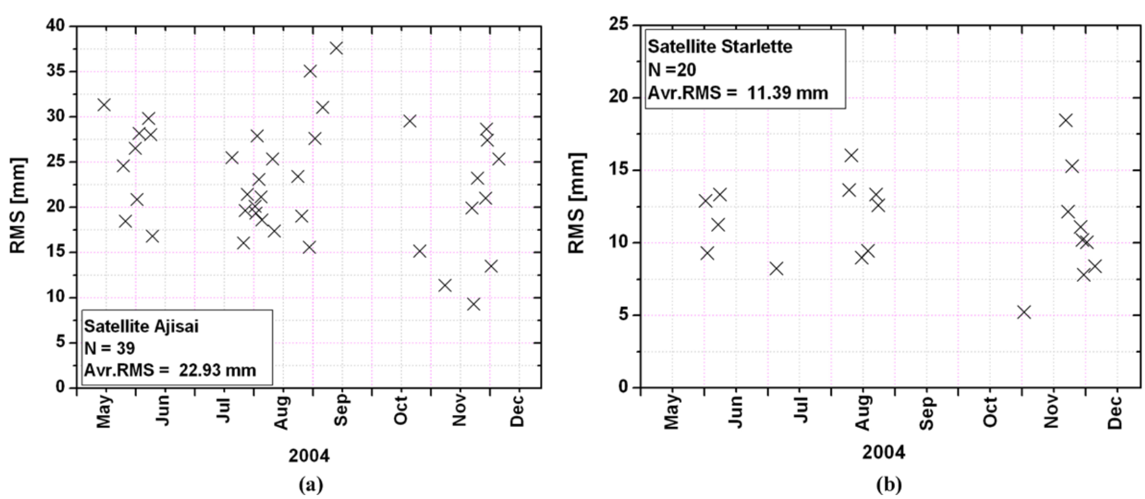

Fig. 10 The RMS in millimeter as estimated for the satellites Ajisai in (**a**) and Starlette, in (**b**) tracked during 2004

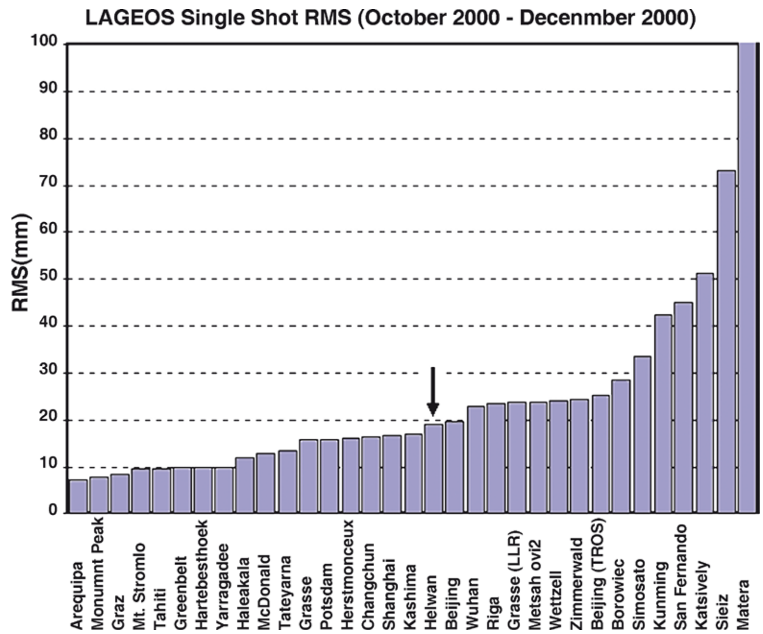

Fig. 11 The single shot RMS as computed for the satellites Lageos from all the ILRS stations during the fourth quarter of 2000

Table 2 Total number of passes and the Average RMS for the satellites tracked during 1996 in (a) and during 2000 in (b)

(a)

Satellite	Nr. of passes	Avr. RMS (mm)
Lageos-1	9	16.21
Lageos-2	6	16.12
ERS-1	3	14.99
ERS-2	34	12.31
Ajisai	102	24.37
Starlette	56	11.21
Stella	53	12.06
Topex	79	18.94
GFO-1	2	10.44
Be-C	82	18.36

(b)

Satellite	Nr. of passes	Avr. RMS (mm)
Lageos-1	3	29.59
Lageos-2	1	27.75
ERS-1	16	24.36
ERS-2	37	25.20
Ajisai	45	35.46
Starlette	22	24.58
Stella	36	24.70
Topex	40	33.60
Resurs	4	19.93
Fizeau	3	29.33

Table 3 Total number of passes and the Average RMS for the satellites tracked during 2004

Satellite	Nr. of passes	Avr. RMS (mm)
Ajisai	39	22.93
Be-C	24	17.04
Envisat	15	13.55
ERS-2	21	13.84
GraceA	7	10.69
GP-B	2	14.55
Jason	2	8.7
Larets	7	11.46
Starlette	20	11.39
Topex	26	20.1

On the other hand, our results are compared with some analysis centers.[1] These analysis centers receive and process information from the data centers and regularly make the results of their analysis available to ILRS participants. They also provide a level of quality assurance on the global data set by monitoring individual station performance via the fitted orbits used in generating the Quick-Look science results. The analysis centers are the Center for Space Research (CSR) at the University of Texas, Delft University of Technology's Quick-Look Data Analysis Center (QLDAC), and the Mission Control Center (MCC) in Moscow and associate analysis centers such as Communication Research Laboratory (CRL) in Japan and other associated centers see footnote 1.

[1] http://ilrs.gsfc.nasa.gov/reports/analysis_report/index.html, http://ilrs.gsfc.nasa.gov/reports/ilrs_reports/ilrsar_2000.html.

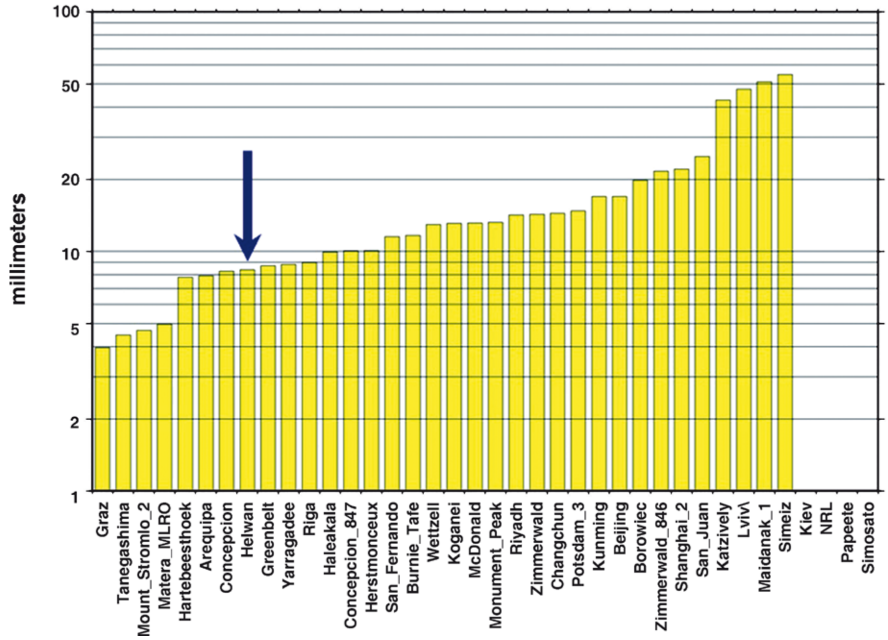

Fig. 12 Starlette RMS for all SLR stations from October 1 to December 31, 2007

It is worth mentioning that the average precision of satellites Lageos-1 and Lageos-2 that were observed during 2000 is found to be about 16 mm, which is nearly the same as the results obtained from the center of space research, Austin, University of Texas. Similarly, the average precision estimated for satellites Ajisai, Starlette, and Stella tracked during 2000 are found to be about 24 mm, 11 mm, and 12 mm, respectively. These results agree well with the precision estimated for the same satellites as at the (CRL) in Japan.

It can be also clearly seen that the accuracy of the distance measurement below 10 mm becomes available since the upgrading of the station applied at 2000. As can be seen from Fig. 12, it shows the RMS values of the satellite Starlette which observed from all the SLR stations through the fourth quarter of 2007. It is clear that the RMS is about 8 mm as computed for the Helwan SLR station.

4 Conclusion

The analysis of the data obtained from Helwan SLR station confirms the good performance of the station. The study concerned on the calibrations of the Helwan SLR station applied in two periods. The first period is carried out with using the old PMT, from 1991 to 1997. The second is carried out during the period from May 1998 till 2008. The average RMS value for the old PMT is found to be about 174 psec, while for the new PMT is about 68 psec. This means that the precision of the Helwan SLR station in system calibration has been improved by nearly 2.6 times.

To show the difference in the accuracy of the measurements due to the upgrading of the Helwan SLR station, I analyzed the data taken for all the satellites observed before the upgrading (1996) and the satellites observed after the upgrading (2000). It is found that there are remarkable differences in the accuracy of the measurements before and after the upgrading. The average RMS value of all the satellites observed during 1996 is nearly 27 mm, while it is about 16 mm for those observed at 2000. For a more logical comparison: the average of the RMS value of the European satellites ERS-1&2, is about 25 mm while it is about 14 mm after the upgrading at 2000. It is also found that the accuracy of the distance measurement below 10 mm becomes available at 2000, while it is never reached at 1996.

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