The comparison of the station coordinates between SLR and GPS

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Abstract

The paper presents results of comparison of the station positions and velocities determined by two satellite techniques: SLR and GPS. The coordinates were calculated for the same epochs in the International Terrestrial Reference Frame 2005. The comparison was performed for all stations equipped in the SLR and GPS systems in the period from 1993.0 to 2004.0 without the SLR stations whose system was changed in that time. The final calculations were performed for 12 stations. The coordinates were determined for the epochs on the first day of each month. The analysis included estimation of the station positions stability, and comparison of the positions with those according to ITRF2005, estimation of the station velocities obtained by the two methods SLR and GPS. The NNR-NUVEL1A plate velocity model and ITRF2005 velocities were used for verification of the station velocities. Generally with some exceptions, a good agreement of the station positions and velocities obtained for both techniques. For several stations significant (2-3 cm) differences were detected in the vertical components.

1. Introduction

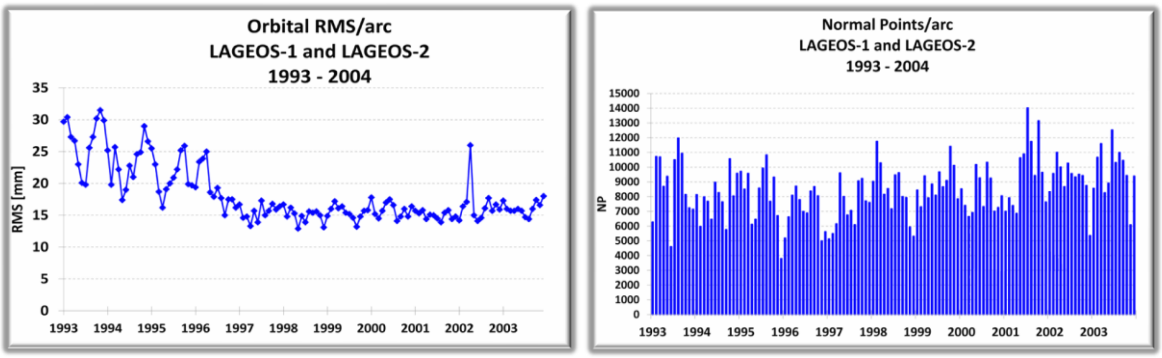
One of the aims of the Global Geodetic Observing System (GGOS) appointed at the International Association of Geodesy (IAG) to be realised within the next 10 years is unification of the methods, models and parameters of the terrestrial studies. The hitherto made comparisons of the measuring methods based on the global mean results, as presented in subsequent ITRF solutions (Altamimi et al., 2002, Boucher et al., 1997, 2004) do not permit a detail analysis of differences between different techniques. To be able to identify and evaluate these differences, a comparison must be made of the results obtained within the same reference system (ITRS) for the same measuring points, the same reference epoch and – if possible- for the same models and parameters. The comparison should be made for the results collected for a long time, at least 5 years, which is particularly important for determination of the station velocity. The aim that should be achieved in the nearest future is determination of the station position at a global accuracy of 1 mm and the station velocity at a global accuracy of 0.1 mm/year. Direct comparison of the results obtained by different measuring techniques permits a detection and elimination of systematic errors brought by individual techniques and stations. Performance of a good comparison requires a correct transformation of results to a common reference system, accurate tie of the reference points of particular techniques at a given station, long-term observation sequences and high quality of measurements in each measuring technique.

The aim of this study was to compare the positions and velocities of a few stations determined by two different satellite techniques SLR and GPS. The analysis was made for the 12 stations carrying out parallel measurements by SLR and GPS in the period from 1993.0 to 2004.0. The laser stations whose laser system was changed in this period were not taken into account.

2. SLR and GPS Data

Results of laser observations were taken from the database Eurolas Data Centre (EDC) in the form of two-minute normal points of the LAGEOS-1 and LAGEOS-2 satellites (Pearlman et al., 2002). The orbits were calculated by the orbital NASA GEODYN-II program (Pavlis et al., 1998). Normal equations were calculated for each satellite separately for the same monthly arcs. The points over the criterion of 5 σ for each station as well as those below 10 degrees over the horizon were rejected. Also the passes whose systematic deviation exceeded 2.5 σ from systematic deviations in a given month were rejected. The reference stations for orbit determination were 15-16 of those whose results were characterised by the highest accuracy, a large number of normal points and continuity of observations. Ten of those stations were the same over the period of the 11 years of study, while the others were selected according to the quality of observations in a given year. The station coordinates were determined from the normal equations of the two satellites in each arc for one station, while the coordinates of the other stations were taken from the system ITRF2005 (ITRF2005, 2006). The station coordinates were determined for the first day of each month.

As follows from Fig.1a showing the RMS of fit of each monthly arc, a substantial improvement in the quality of observations is visible beginning from 1996. It is a consequence of significant changes in the equipment of the best laser ranging stations. The considerable deterioration of RMS in April 2002 was most probably a consequence of the collision of a micrometeorite with LAGEOS-1 on April 5^{th}, 2002 over the Pacific (Lemoine et al., 2004). Fig. 1b presents the number of normal points used for determination of the monthly arcs.



a) b)

Figure 1. a) RMS of fit b) number of normal points
LAGEOS-1 and LAGEOS-2 for the monthly orbital arcs

The geocentric GPS coordinates in the ITRS2005 system over the period 1993.0-2004.0 in the form of daytime series per the 2007.0 epoch was obtained from Dr Michael Heflin from JPL/NASA. The reference frame ITRF2005 was established for each day on the basis of the 7-parameter Helmert transformation. The transformation to the 2000.0 epoch (ITRF2005 epoch) was performed using the velocities given for each station by JPL NASA. The common reference point for SLR and GPS was that of the laser station, i.e. the point of intersection of the rotation axes of the telescope. The tie of the geocentric coordinates ΔX, ΔY, ΔZ of the reference points of GPS and SLR for a given station was taken from ITRF2005. The GPS coordinates were determined for the epoch of first day of each month, similarly as for SLR.

From the list of SLR and GPS coordinates only those having the common epoch were selected, therefore, from the maximum number of 132 point that can be determined over 11 years the selected number of common points is much lower (Table 1). Some stations, like e.g. that in Beijing, have a low number of common points as they started the GPS observations much later (Beijing since 2000). The last column gives the period of time of common observations, from the first to the last, particularly important for determination of the station velocity. Except the Beijing station this time was close to 8 years, which is sufficient for accurate determination of the station velocity. Because of the changes in the coordinates of the Arequipa station forced by the earthquake in June 2001, two sets of data were given for this station covering the periods before and after the earthquake. The averaged results are given for the period before the earthquake.

Table 1. List of the SLR – GPS stations whose data were taken into account over the period 1993.0 – 2004.0.

STATION	SLR	GPS	NUMBER OF COMMON POINTS	PERIOD (months)
McDonald	7080	MDO1	111	125
Yarragadee	7090	YAR1	109	131
Monument Peak	7110	MONP	76	109
Beijing	7249	BJFS	34	45
Arequipa	7403	AREQ	56/14	87/30
Borowiec	7811	BOR1	96	111
Grasse	7835	GRAS	68	94
Potsdam	7836	POTS	96	110
Shanghai	7837	SHAO	67	99
Graz	7839	GRAZ	116	132
Herstmonceux	7840	HERS	102	130
Wettzell	8834	WTZR	79	94

3. Positions and velocities of the stations

The geocentric SLR and GPS coordinates calculated for the first day of each month were transformed into the topocentric components in the form of deviations from ITRF2005 in the N-S, E-W and vertical (U) directions (Borkowski, 1989). Exemplary results for the stations Yarragadee (7090) and Arequipa (7403) are shown in Fig. 2.

The station velocity is described by the slope of the time dependence of the coordinate components, shown in Fig. 2. According to the model of the tectonic plate motion, no changes are observed in the vertical component of the station position. The results of a few stations revealed considerable (up to 3 cm) differences in the vertical component between the SLR and GPS data. Particularly important are the differences of the two Moblas stations (Moblas-4, Monument Peak and Moblas-5, Yarragadee). The data from these two stations are of substantial importance for determination of orbits from laser observations. The data from a few other stations shows systematic deviations in the vertical component in some periods (Borowiec, Graz, Grasse, McDonald). The majority of systematic errors in the data obtained by SLR and GPS occur in the vertical direction as it is the fundamental direction of observations. The data for Arequipa (Fig. 2) show a jump change in the horizontal components as a result of the earthquake and a very good agreement in the SLR and GPS results. No jump is noted in the vertical component, but the slow change in the station vertical position is visible for the data obtained by these two techniques immediately before the earthquake.

The quality of the position of a given station can be evaluated on the basis of changes in its coordinates. The change in the position of a station determined for the epoch assumed following from taking into regard the station velocity should be very small, at least for a majority of the stations. The lower the mean square deviation over the period of time studied the more accurate the results of coordinate determinations. The results illustrating the stability of the station position are given in Table 2; the stability of the best stations is at a level of 5 mm. In contrast to the GPS data, the SLR data reveal large differences in the station stability, reaching even up to 3 cm, which is a consequence of the systematic measurement errors of SLR.

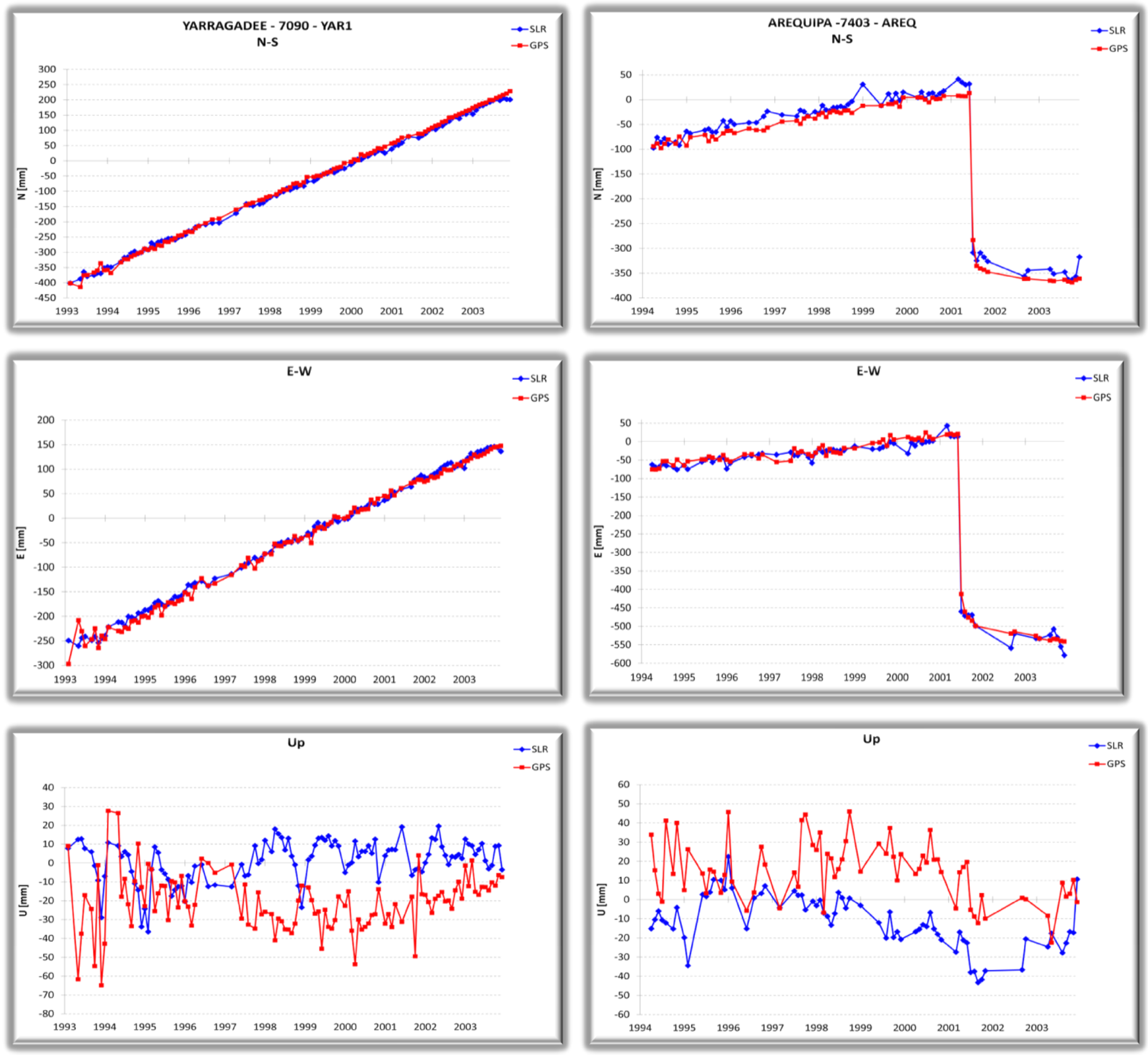


Figure 2. The topocentric coordinates of Yarragadee-left and Arequipa-right (SLR–blue, GPS-red)

Table 2 presents also the differences in the mean coordinates obtained from the SLR and GPS data for the period given in Table 1 for particular stations. The differences expressed in ITRF2005 are also given. The differences between the results of our study and ITRF2005 follow from a bit different period of data averaging, especially for Arequipa, from the differences in data analysis and in criteria of points rejection.

The velocities of the stations were calculated on the basis of the SLR and GPS data by linear regression as the slope of the time dependence of the coordinate components over the time period given in Table 1. The uncertainty of determination of the station velocity ranges from 0.1 mm/year for the best SLR stations and almost all GPS stations to 3 mm/year for the least accurate SLR stations. The results of the station velocities obtained for all stations considered are given in Table 3.

The data presented in Table 3 illustrate a very good agreement between the results obtained by the two methods SLR and GPS for the majority of the stations, the differences do not exceed 1 mm/year. A comparison of these data with those provided by ITRF2005 also indicates a very good agreement, with the differences not exceeding 1 mm/year. No systematic differences are noted in the station velocities determined from SLR and GPS data, both in the geocentric system and horizontal plane.

Table 2. Mean differences in the coordinates obtained by SLR and GPS methods and the stability of the (3D) coordinates determined.

STATION	SLR-GPS [mm]	SLR-GPS ITRF2005 [mm]	STABILITY [mm]	
			SLR	GPS
McDonald	10.3	5.3	8.4	8.2
Yarragadee	13.1	8.5	8.4	11.2
Monument Peak	18.8	8.7	7.6	8.6
Beijing	13.4	13.7	31.6	6.7
Arequipa	18.6	2.9	10.0	10.0
Borowiec	7.0	15.8	17.0	6.4
Grasse	4.4	3.7	10.5	5.9
Potsdam	6.0	4.2	8.4	6.7
Shanghai	18.1	9.5	21.5	9.9
Graz	7.4	2.9	11.7	7.2
Herstmonceux	4.1	11.3	6.8	8.9
Wettzell	3.2	3.7	9.4	5.6

However, there are systematic differences between the velocities of the stations determined by these two methods and those following from the NNR-NUVEL1A plate velocity model (DeMets et al.1994). The NNR-NUVEL1A velocities of all European stations are by 1-2 mm/year lower. The velocities of the Chinese stations are lower by 5 mm/year for Beijing and 10 mm/year for Shanghai. The differences could be explained by the fact that these two stations are localised at the edge of the Eurasia plate or on the Chinese subplate. The analogous differences in the velocities of the stations from the Pacific and Australian plates are small 1-3 mm/year, practically nonexistent for the station from the North American plate. The vertical components of the positions of each station except Beijing change at the velocity below 5 mm/year. No systematic changes are obtained in the velocity of the vertical component depending on the plate. Relatively high velocities obtained for Beijing are a consequence of the short time of measurements (below 4 years) and large systematic errors of this station.

Table 3. The velocities of the stations.

STATION	PLATE	V_{XYZ} [mm/year]		V_{XYZ} ITRF2005 [mm/year]		V_{NE} [mm/year]		V_{NE} NUVEL [mm/year]	V_U [mm/year]	
		SLR	GPS	SLR	GPS	SLR	GPS		SLR	GPS
Herstmonceux	Eurasia	24.0	24.3	23.8	23.8	24.0	24.2	23.2	-1.1	2.2
Grasse	Eurasia	26.8	26.0	26.0	26.0	26.7	26.0	24.7	2.3	0.3
Graz	Eurasia	27.7	26.5	26.4	26.9	27.4	26.5	24.7	-4.0	1.2
Wettzell	Eurasia	25.5	25.7	25.2	25.6	25.1	25.7	24.3	4.4	1.1
Potsdam	Eurasia	24.4	24.8	24.1	24.2	24.5	24.7	23.9	-0.7	1.8
Borowiec	Eurasia	25.8	25.4	24.7	24.7	25.8	25.4	24.1	-1.5	1.2
Beijing	Eurasia	32.2	31.0	32.2	32.4	29.2	30.6	25.6	-13.5	5.4
Shanghai	Eurasia	33.3	34.5	34.6	34.0	34.5	34.5	25.7	-4.5	0.5
Yarragadee	Australia	68.2	69.7	69.6	69.6	68.4	69.9	71.0	1.3	0.0
Monument Peak	Pacific	43.7	42.3	42.4	42.4	43.6	42.3	46.6	0.4	0.2
McDonald	N. America	14.2	13.1	13.5	13.2	14.1	13.0	13.9	-1.3	1.5
Arequipa	S. America	19.6	19.3	18.9	18.9	19.6	19.4	10.0	-2.0	0.5

4. Conclusions

Analysis of the results obtained by the two satellites methods SLR and GPS has revealed significant differences in the range 1-3 cm in the vertical component of the positions of five stations: Yarragadee, Monument Peak, Arequipa, Shanghai, Herstmonceux (over the period 1999-2004). As the data from these stations are important for the calculations of the satellite orbits the explanation of the origin of these differences has great significance. Similar differences had been noted earlier for different stations but were later eliminated (Grasse 1995-1998, Graz 1993-1996, Beijing 2000-2002, McDonald 1993-2001). An interesting observation is similar change in the station vertical position of Arequipa station prior to the earthquake for results from both techniques GPS and SLR (Fig. 2). The horizontal components of the station position obtained from the SLR and GPS results for all the stations studied are consistent to 5 mm. The coordinates calculated on the basis of the SLR results have shown considerable differences in the station stability, depending on the system.

The station velocities determined on the basis of the data collected by the two methods compared have shown a very good agreement (to less then 1 mm/year), this agreement was also good with the ITRF2005 results. No systematic shift was found between the station velocities calculated on the basis of the data collected by the two methods. Moreover, these station velocities were in good agreement with those following from the NNR-NUVEL1A plate velocity model, although the velocities of the European stations determined according to NNR-NUVEL1A are systematically lower by 1-2 mm/year. The differences in the velocities of the European stations reaching up to 3 mm/year can be considered as real because of their agreement with the analogous differences between those following from NNR-NUVEL1A and ITRF2005. The velocities of the two Chinese stations, Monument Peak and in particular Arequipa differ from those following from NNR-NUVEL1A, however, these differences can be explained by the position of these stations at the edges of the plates.

Further efforts should concern the explanation and elimination of the 2-3 cm differences in the vertical component of the station position between the results calculated from SLR and GPS data. A new system of ITRF coordinates should facilitate solution of this problem.

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