Determination of the SLR station coordinates and velocities on the basis of laser observations of low satellites

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Abstract

The orbits of three low satellites Ajisai, Starlette and Stella have been determined on the basis of the data collected in 2001-2005 from the best 14 Satellite Laser Ranging stations. The positions and velocities of four SLR stations Graz (7839), Greenbelt (7105), Herstmonceux (7840) and Yarragadee (7090) were determined. Additionally, the station velocities were compared with the geological model NNR-NUVEL1A. All calculations have been made assuming the model of the Earth gravity field EIGEN-GRACE02S. All the calculations have been performed with the use of GEODYN-II program. The results presented in this work show that the data from low satellites such as Ajisai, Starlette or Stella can be successfully applied for determination of the SLR station coordinates and velocities.

1. Introduction

The high accuracy of laser observations and large number of observations allow for determination of the stations' coordinates and velocities from orbits of low satellites such as Ajisai, Starlette and Stella. Ajisai was launched by the JAXA on August 12, 1986. It is a spherical satellite covered with 1436 corner cube reflectors for SLR tracking and 318 mirrors for photography. The main purpose of the Ajisai was determination of the position of Japanese islands situated on the border of four tectonic plates Eurasian, Pacific, North American and Philippine and determination of plate motion. The laser data of Ajisai are used for definition and realization of ITRF and determination it changes in time, determination of geopotential coefficients (Bianco et al., 1997) and determination of spin axis of the satellite (Kirchner et al., 2006).

The twins Starlette and Stella with 60 corner cube reflectors were launched by the CNES, on February 6, 1975 and September 26, 1993, respectively. The laser observations to these satellites are used mainly for determination of Earth's gravity field coefficients, investigation of Earth and ocean tides, and determination of Earth rotation parameters (Cheng et al., 1990, Cheng et al., 1991, Schutz et al., 1989). The orbital and technical characteristics of the three satellites are presented in Table 1.
The first promising results of the stations' coordinates determination were obtained for Starlette and Stella (Lejba et al., 2007). In this work the period of the laser data were expanded to 5 years (2001-2005). Such period is taking as a minimum for determination of stations' velocities.

Table 1. Characterisation of the satellites Ajisai, Starlette and Stella.

	AJISAI	STARLETTE	STELLA
Sponsor	JAXA (JAPAN)	CNES (FRANCE)	CNES (FRANCE)
Launch date	August 12 1986	February 6 1975	September 26 1993
ID number	8606101	7501001	9306102
TECHNICAL AND PHYSICAL PARAMETERS			
Number of retroreflectors	1436	60	60
Shape	sphere	sphere	sphere
Diameter [cm]	214	24	24
Centre of mass correction [mm]	1010	75	75
Mass [kg]	685	47.25	48
CSA [m^2]	3.5968	0.0452	0.0452
CSA/Mass [m^2/kg]	0.00525	0.00096	0.00094
ORBITAL PARAMETERS OF THE SATELLITES			
Inclination	50.0°	49.8°	98.6°
Eccentricity	0.001	0.02	0.002
Perigee [km]	1480	810	800
Period [min.]	116	104	101

2. Determination of orbital arcs

The orbits of Ajisai, Starlette and Stella were determined using the program GEODYN-II (Pavlis et al., 1998) in two cases with empirical acceleration coefficients determined every 6 and 12 hours. The perturbing forces, constants and parameters used are listed in Table 3.

The satellites arcs were calculated using the observation data from the 14 best ILRS stations (Table 2), collected during the period from January 1st 2001 to December 25th, 2005 (Pearlman et al., 2002). This period was divided into 130 orbital arcs of 14-days each for Ajisai and 182 orbital arcs of 10-days each for Starlette and Stella. Due to similar orbital and technical parameters the data of Starlette and Stella were combined in the calculations.

Table 2. List of the stations.

	Station	ID Number
1	McDonald	70802419
2	Yarragadee	70900513
3	Greenbelt	71050725
4	Monument Peak	71100411
5	Haleakala	72102313
6	Zimmerwald	78106801
7	Borowiec	78113802
8	Mount Stromlo	78259001
9	Grasse SLR	78353102
10	Potsdam	78365801
11	Graz	78393402
12	Herstmonceux	78403501
13	Mount Stromlo	78498001
14	Wettzell	88341001

472259 normal points of Ajisai, 265282 for Starlette and 133093 for Stella were accepted by the GEODYN. The number of rejected normal points is 2335 for Ajisai and 3729 together for Starlette and Stella. The obtained mean RMS of fit values for the calculated orbits for Ajisai are 1.61 cm and 1.98 cm for 6 and 12-hour interval of empirical acceleration coefficients, respectively. For Starlette and Stella the mean RMS of fit values are 1.15 cm and 1.63 cm, respectively.

Table 3. GEODYN II – force models and parameters

Force Model
Earth gravity field: EIGEN-GRACE02S (Reigber et al., 2005), 45x45 solution for Ajisai and 75x75 solution for Starlette and Stella Earth and ocean tide model: EGM96 (Lemoine et al., 1998) Third body gravity: Moon, Sun and all planets – DE200 (Standish, 1990) Solar radiation pressure: C_R coefficient *a priori* 1.13 for Starlette and Stella and 1.0 for Ajisai Earth albedo (Pavlis et al., 1998) Dynamic polar motion (Pavlis et al., 1998) Relativistic correction (Pavlis et al., 1998)
Constants
Gravitational constant times the mass of the Earth (GM): $3.986004415 \times 10^{14}\ m^3/s^2$ (EIGEN-GRACE02S Earth gravity field model) Speed of light: 299792.458 km/s (McCarthy et al., 2004) Semi-major axis of the Earth: 6378.13630 km (EIGEN-GRACE02S Earth gravity field model) Inverse of the Earth's flattening: 298.2570 (EIGEN-GRACE02S Earth gravity field model)
Reference Frame
Inertial reference system: true of date defined at 0^h of the first day of each arc (Pavlis et al., 1998) Stations coordinates and stations velocities: ITRF2005 solution, epoch 2000.0 (Altamimi et al., 2007) Precession: IAU 1976 (Lieske et al., 1977) Nutation: IAU 1980 (Seidelmann 1982) Polar motion: C04 IERS (IERS 2001) Tidal uplift: Love model H2 = 0.609, L2 = 0.0852 (Pavlis et al., 1998) Pole tide (Pavlis et al., 1998)
Estimated parameters
Satellite state vector Station geocentric coordinates Drag coefficients C_D determined every 15 hours for Ajisai and 12 hours for Starlette, Stella Acceleration parameters along-track, cross-track and radial at 6 and 12 hours intervals
Measurement Model
Observations; 30 seconds normal points from Eurolas Data Center Laser pulse wavelength: 532 nm (Zimmerwald 423 nm) Tropospheric refraction: Marini/Murray model (Marini and Murray, 1973) Editing criteria: $5\sigma \approx \pm 11$ cm for arc (Ajisai), $5\sigma \approx \pm 12$ cm for arc (Starlette, Stella) cut-off elevation 10 deg.
Numerical Integration
Integration: Cowell's method Orbit integration step size: 110 sec for Ajisai and 90 sec for Starlette and Stella Arc length: 14 days for Ajisai and 10 days for Starlette and Stella

3. Determination of SLR station coordinates and velocities

The coordinates and velocities of the following stations were determined: Yarragadee (7090), Greenbelt (7105), Graz (7839) and Herstmonceux (7840). These stations provide the best quality of observation results. Besides these stations provided the largest number of normal points of Ajisai, Starlette and Stella in the mentioned period. The calculated X, Y, Z geocentric coordinates referenced to the epoch of ITRF2005 were transformed to the topocentric coordinates N, E, Up. These results were related to ITRF2005. In order to determine the movement of station the calculated X, Y, Z geocentric coordinates were referenced to the epoch of each orbital arc. Also in this case the calculated X, Y, Z components were transformed to N, E, Up components. On figures 1-4 the results obtained from Ajisai data were presented in two cases with empirical acceleration coefficients determined every 6 (blue line) and 12 (red line) hours. The left site of each figure shows determined station coordinates in reference to ITRF2005, the right one the movement of each topocentric component for a given epoch of orbital arc. Analogous results were presented for Starlette and Stella on figures 5-8. The gaps on the figures mean the lack or less than 50 number of normal points of the station for the given orbital arc. The RMS of the determined coordinates amount from 14.7 to 20.1 mm for Ajisai and 9.3 to 17.1 mm for Starlette and Stella depending on the number of the empirical acceleration coefficients. In case of Ajisai results the noticable systematical shifts of Up component for each station are visible. Probably they are caused by the inaccurate definite centre of mass correction of Ajisai. This parameter changes within the range of 5 cm (Otsubo et al., 2003).

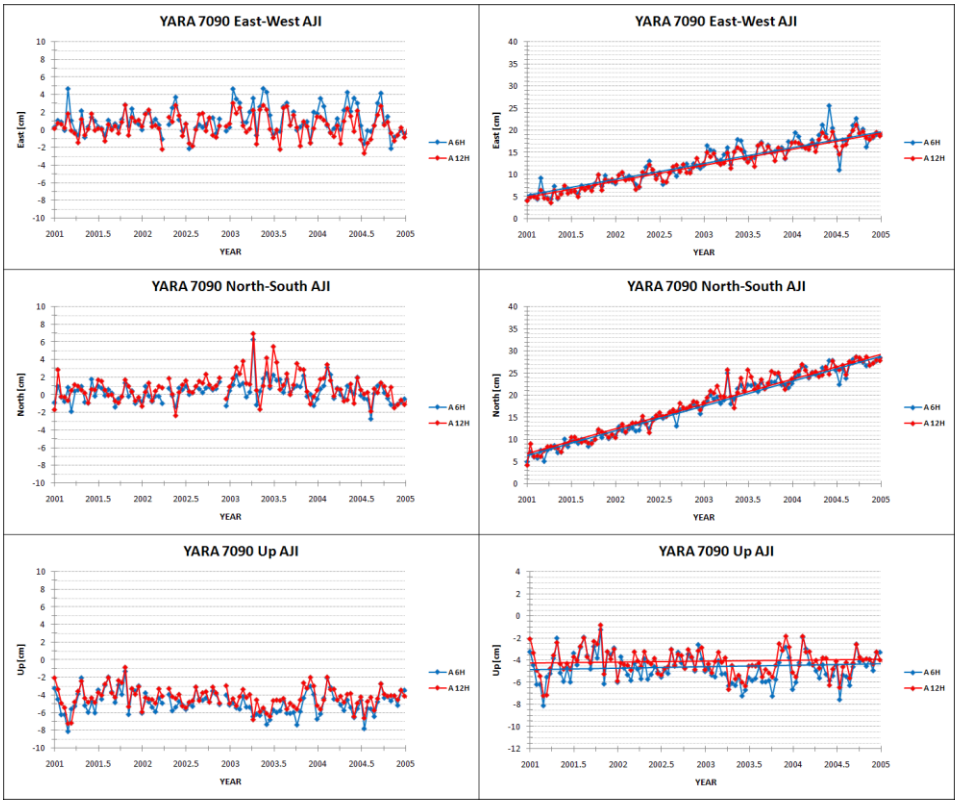

Figure 1. The topocentric coordinates N, E, Up of the station Yarragadee (7090) obtained from laser observations of Ajisai.

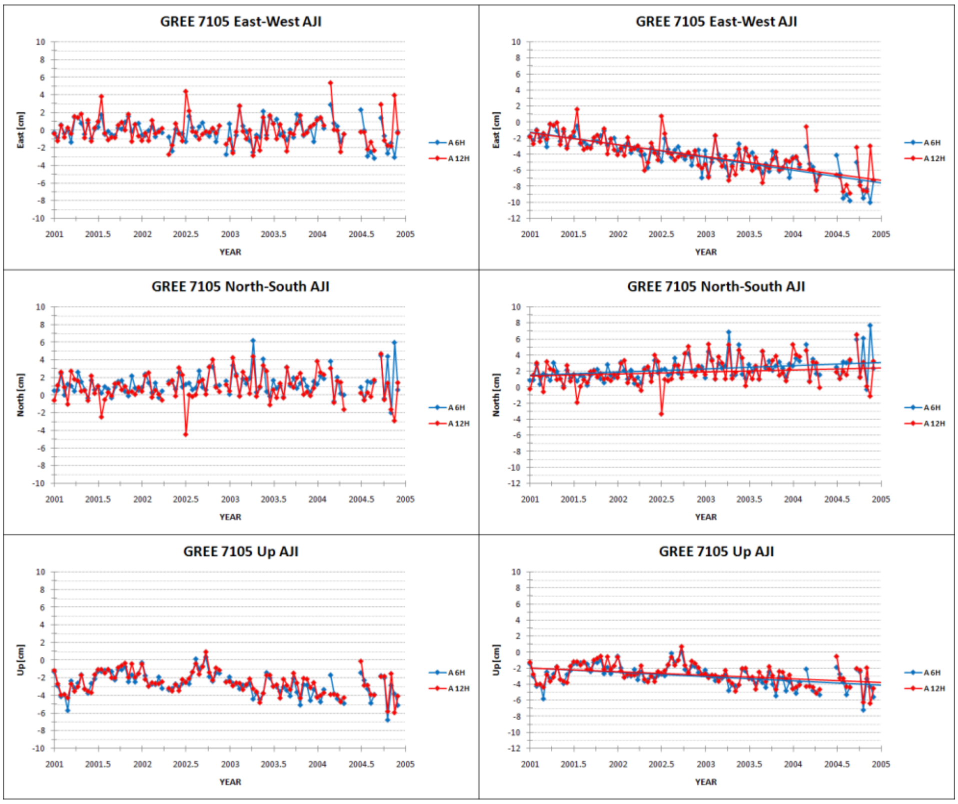

Figure 2. The topocentric coordinates N, E, Up of the station Greenbelt (7105) obtained from laser observations of Ajisai.

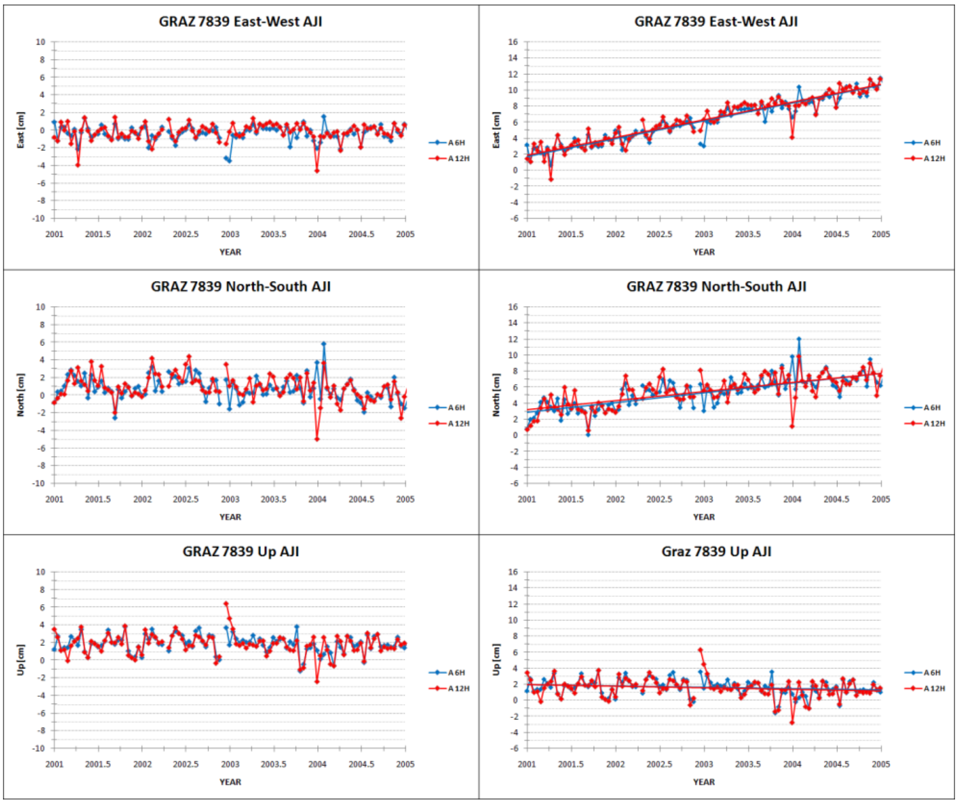

Figure 3. The topocentric coordinates N, E, Up of the station Graz (7839) obtained from laser observations of Ajisai.

Figure 4. The topocentric coordinates N, E, Up of the station Herstmonceux (7840) obtained from laser observations of Ajisai.

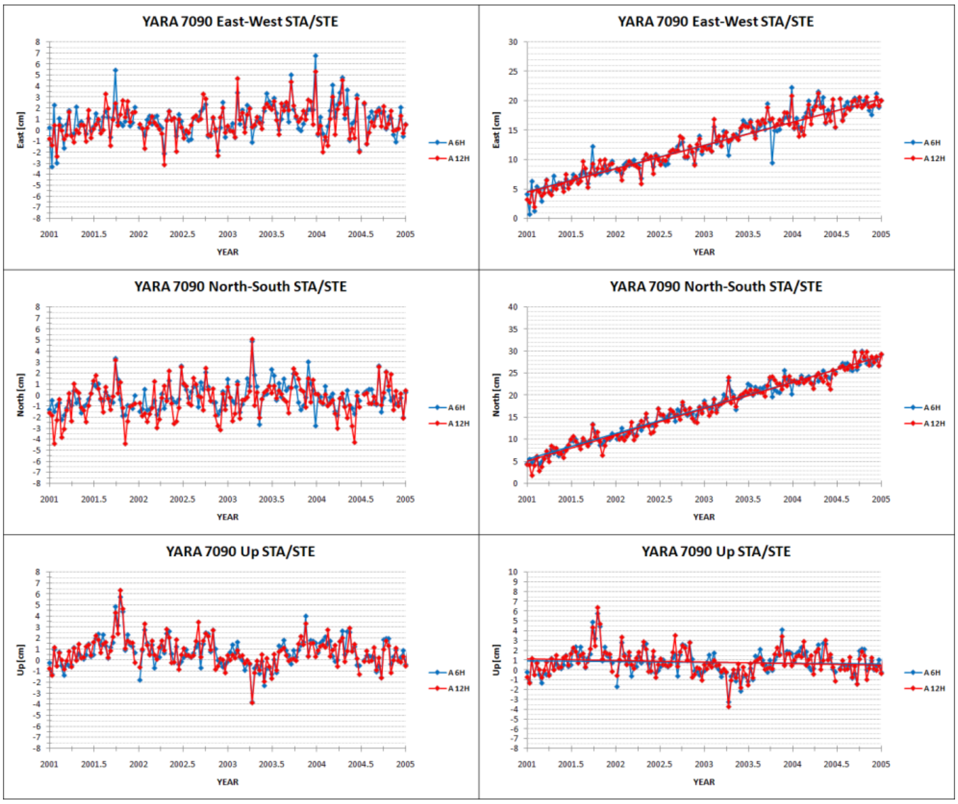

Figure 5. The topocentric coordinates N, E, Up of the station Yarragadee (7090) obtained from laser observations of Starlette and Stella.

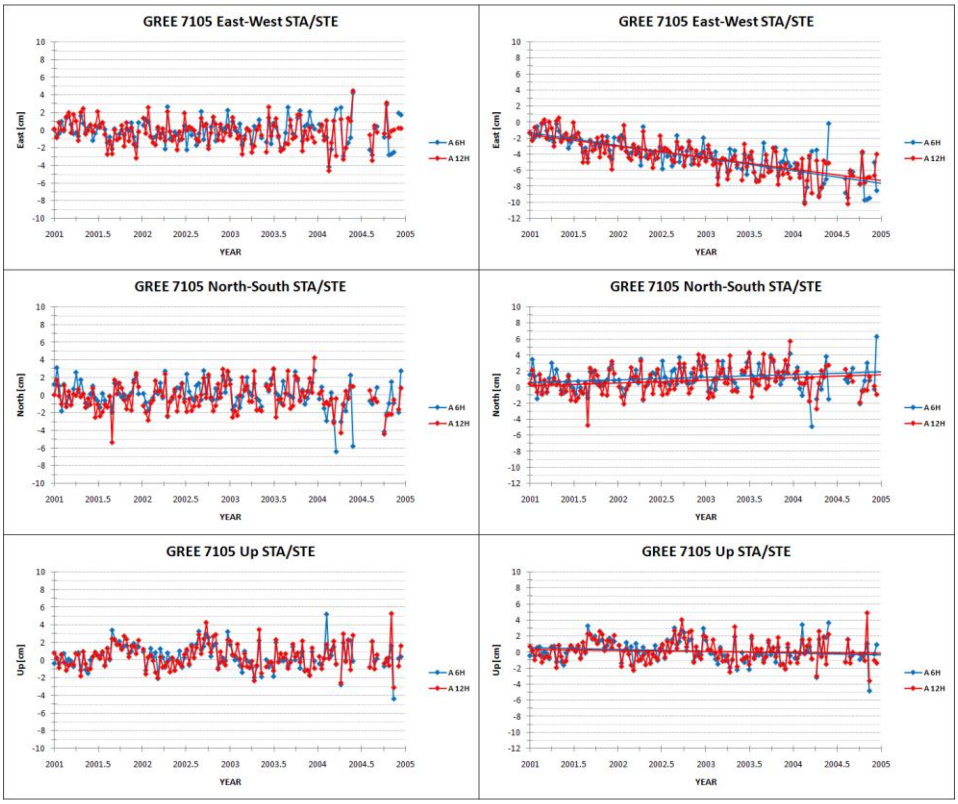

Figure 6. The topocentric coordinates N, E, Up of the station Greenbelt (7105) obtained from laser observations of Starlette and Stella.

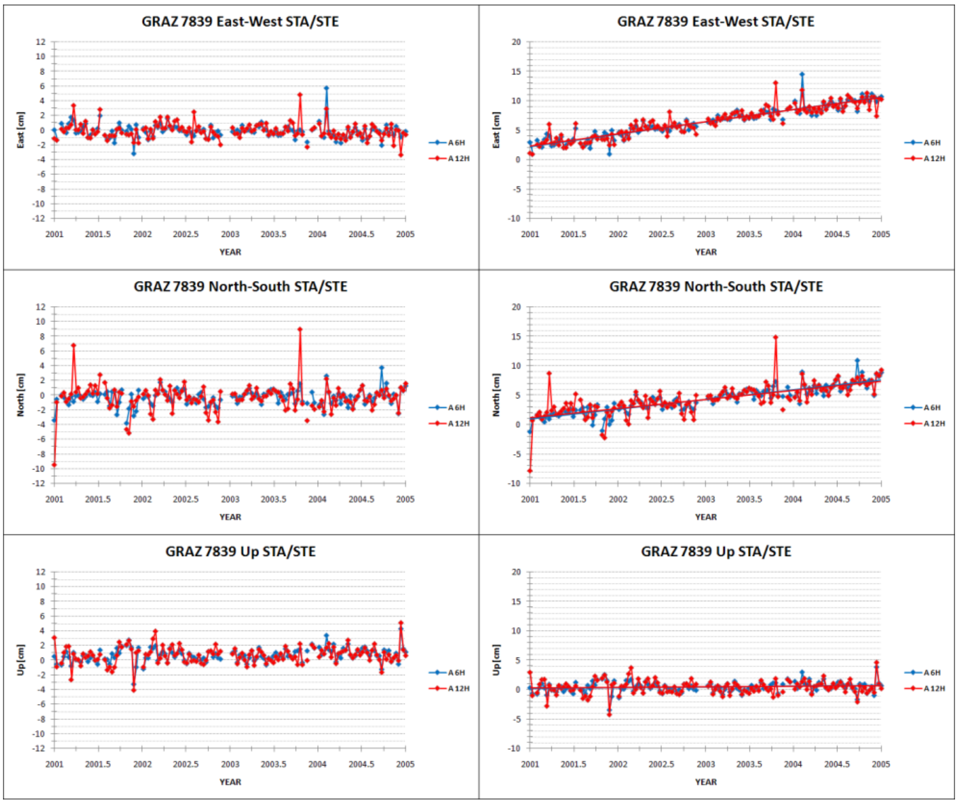

Figure 7. The topocentric coordinates N, E, Up of the station Graz (7839) obtained from laser observations of Starlette and Stella.

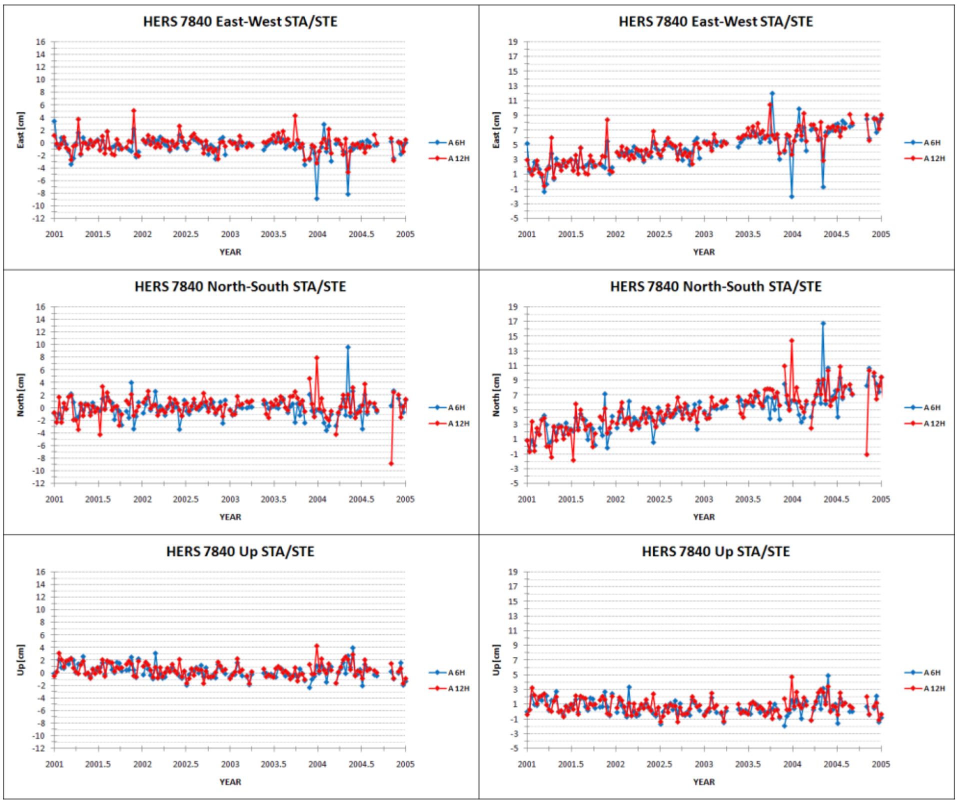

Figure 8. The topocentric coordinates N, E, Up of the station Herstmonceux (7840) obtained from laser observations of Starlette and Stella.

Table 4. The velocities in horizontal plane of the stations determined for Ajisai, Starlette/Stella, LAGEOS, ITRF2005 and geological model NNR-NUVEL1A.

	V 2D [mm/rok]				
	AJISAI	STARLETTE STELLA	LAGEOS	ITRF2005	NNR NUVEL1A
Yarragadee	66.5 67.0	65.7 71.5	68.3	68.1	66.6
Greenbelt	16.1 15.0	16.2 14.7	15.6	15.7	15.4
Graz	25.3 25.0	26.7 25.8	26.6	26.7	24.8
Herstmonceux	22.8 23.4	22.7 23.3	23.3	23.4	23.3

Table 4 shows the velocities of the stations in horizontal plane determined for Ajisai and Starlette and Stella in comparison to the same results obtained for LAGEOS, ITRF2005 and geological model NNR-NUVEL1A (DeMets et al., 1994). In case of LAGEOS the velocity of the station were computed for the period 1999-2004 (Schillak, 2008). For Ajisai and Starlette and Stella two values of the V2D velocity were presented. The upper value is in Table 4 for variant with empirical acceleration coefficients determined every 6 hours. For this solution the differences come from 0.4 to 2.6 mm/year. The bottom is for variant with empirical acceleration coefficients determined every 12 hours. For this solution the differences don't exceed 1.6 mm/year for Ajisai and 4.9 mm/year for Starlette and Stella. The fastest station is Yarragade moving about 7.0 cm/year in North-East direction. The European stations like Graz and Herstmonceux 2.5 and 2.3 cm/year in Nort-East direction, rspectively. The slowest is Greenbelt moving in North-West direction about 1.5 cm/year.

5. Summary and conclusions

The results presented in this work show, that observations of low satellites such as Ajisai, Starlette and Stella can be used for determination of the SLR station coordinates and velocities. The obtained results permit verification of results derived from the LAGEOS observations are in a good agreement with those determined from LAGEOS observations, for ITRF2005 and geological model NNR-NUVEL1A. The stations' coordinates and velocities were counted for 5-years period. Approximately 0.5% of all normal points of Ajisai were rejected by the orbital program and about 1% for Starlette and Stella. The RMS of fit is on the level 1.61-1.98 cm for Ajisai and 1.15-1.63 cm for Starlette and Stella. The RMS of the calculated coordinates amount from 9.3 to 20.1 mm depending on the number of the empirical acceleration coefficients. The stations are moving in horizontal plane from 1.5 to 7.0 cm/year. These results show, that the laser observations of low satellites could be included to the global solution of the stations' coordinates and velocities.

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References

Altamimi, Z., Collilieux, X., Legrand J., Garayt B., Boucher C., ITRF2005: A new release of the International Terrestrial Reference Frame based on time series of station positions and Earth Orientation Parameters, J. Geophys. Res., 112, B09401, 2007.

Bianco, G., Devoti, R., Fermi, M., Luceri, V., Rutigliano, P., Sciarretta, C., Estimation of low degree geopotential coefficients using SLR data, Planet Space Sci., vol. 46, no.11/12, pp.1633-1638, 1997.

Cheng, M.K., Shum, C.K., Eanes, R.J., Shutz, B.E. and Tapley, B.D., Long-Period Perturbations in Starlette Orbit and Tide Solution, Journal of Geophysical Research., 95, B6, pp. 8723-8736, 1990.

Cheng, M.K., Shum, C.K., Eanes, R.J., Schutz, B.E. and Tapley, B.D., Observed temporal variations in the Earth's gravity field from 16-years of Starlette orbit analysis, Processing XX General Assembly of the IUGG, IAG Symp. No. 3, Vienna, Austria, August, 1991.

DeMets, C., Gordon, R. G., Argus, D. F., Stein, S., Effect of recent revisions to the geomagnetic reversal time scale on estimates of current plate motions, Geophysical Research Letters, 21, pp. 2191-2194, 1994.

Kirchner, G., Kucharski, D., Cristea, E., Hausleitner, W., Spin Parameters of GP-B and AJISAI with Kilohertz SLR Data, 15th International Workshop on Laser Ranging, Canberra, Australia, October 15-20, 2006.

Lejba, P., Schillak, S., Wnuk, E., Determination of orbits and SLR stations' coordinates on the basis of laser observations of the satellites Starlette and Stella, Advances in Space Research, Volume 40, Issue 1, p.143-149, 2007.

Lemoine, F.G., Kenyon, S.C., Factor, J.K., Trimmer, R.G., Pavlis, N.K., Chinn, D.S., Cox, C.M., Klosko, S.M., Luthcke, S.B., Torrence, M.H., Wang, Y.M., Williamson, R.G., Pavlis, E.C., Rapp, R.H., Olson, T.R., The development of the joint NASA GSFC and the National Imagery and Mapping Agency (NIMA) Geopotential Model EGM96, NASA/TP-1998-206861, Goddard Space Flight Center, Greenbelt,1998.

Lieske, J. H., Lederle, T., Fricke, W., Morando, B., Expression for the precession quantities based upon the IAU (1976) system of astronomical constants, Astronomy & Astrophysics, 58:1-16, 1977.

McCarthy, D. D., Petit, G., IERS Conventions 2003, Frankfurt am Main, 2004.

Otsubo, T., Appleby, G. M., System-dependent center-of-mass correction for spherical geodetic satellites, Journal of Geophysical Research, 108(B4), 2201, doi:10.1029/2002JB00-2209, 2003.

Pearlman, M.R., Degnan, J.J., and Bosworth, J.M., "The International Laser Ranging Service", Advances in Space Research, Vol. 30, No. 2, pp. 135-143, July 2002, DOI:10.1016/S0273-1177(02)00277-6.

Pavlis, D. E., Luo, S., Dahiroc, P., McCarthy, J. J., Luthcke, S. B., GEODYN II System Description, Hughes STX Contractor Report, Greenbelt, Marylnad, July, 1998.

Reigber, C., Schmidt, R., Flechtner, F., Koenig, R., Meyer, U., Neumayer, K.H., Schwiatzer, P., Zhu, S.Y., An Earth gravity field model complete to degree and order 150 from GRACE: EIGEN-GRACE02S, Journal of Geodynamics 39 (1): 1-10, 2005.

Schillak, S., The comparison of the reference frames ITRF2000 and ITRF2005 in the determination SLR station positions and velocities, European Geosciences Union, General Assembly 2008, Vienna, Austria, April 13-18, 2008.

Schutz, B. E., Cheng, M. K., Shum, C. K., Eanes, R. J., Tapley, B. D., Analysis of Earth Rotation Solution from Starlette, Journal of Geophysical Research 94, pp. 10167-10174, 1989.

Seidelmann, P. K., 1980 IAU nutation: The final report of the IAU Working Group on nutation, Celestial Mechanics, 27:79-106, 1982.

Standish E.M., The observational basis for JPL's DE200, the Planetary Ephemerides of the Astronomical Almanac, Astron. Astrophys., Vol. 233, pp. 252-271, 1990.