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Development of a software package for determination of geodynamic parameters from combined processing of SLR data from LAGEOS and LEO

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In this study, a method for determination of stations coordinates, Earth rotation parameters and gravity field coefficients in one solution from SLR data from LAGEOS and LEO is presented. A new software package based on the presented method has been developed. All recommendations from IERS Conventions 2010 have been included. In addition, some other perturbations and loading effects are taken into account: atmospheric tides, non-tidal atmosphere and ocean variability, albedo and non-tidal atmospheric pressure loading.

Results of different solutions with the use of only LAGEOS data or LAGEOS plus LEO satellites data are presented. Pole coordinates obtained from both solutions show comparable accuracy relative to IERS 08 C04 solution. As for UT1 corrections in terms of Length-of-Day an additional improvement in accuracy is found: 1.0 ms for LAGEOS and 0.2 ms for the combined LAGEOS + LEO solution. Time series of the estimated degree-2 gravity field coefficients show a very good agreement with results of the Center of Space Research (Austin/USA). As a final remark, some future mandatory steps are outlined.

1. Introduction

For near future, the main tasks in Earth studying are monitoring of water cycle in global and regional scales, studying of sea level and ice mass for registration of small signals of planet changes. Because of very small amplitudes of these changes, a stable and precise reference frame is needed: 1 mm for coordinates and 0.1 mm/year for velocities. This reference frame is the main goal of Global Geodetic Observing System (GGOS) project. In this project, Earth is considered as one system including solid Earth, oceans, atmosphere in static and dynamic. Studying of our planet Earth with geodetic methods means solving three main tasks of geodesy:

- Studying of Earth's geometry through positions of points on its shape;
- Determination of Earth's rotation axis inside the planet's body (pole coordinates) and in space (precession and nutation) and variation of Earth's rotation velocity;
- Determination of static and variable Earth gravity field.

Small changes of sea level, ice mass and global water cycle have an influence on Earth gravity field and its changes in time. Some additional details of gravity field coefficients (GFC) estimation should be noted. When GFC estimated from SLR data, only coefficients of second degree and order are usually considered and only LAGEOS data is processed. Coefficients of higher degrees are estimated from satellite gradiometry/SGG (GOCE project) and satellite-to-satellite tracking/STT (GRACE and CHAMP projects). Compared to SLR, these modern methods have sufficient advantages:

- It does not depend on weather conditions and continuous measurements;
- Precise orbit determination with GPS;
- Sensitivity to high-frequency components of Earth gravity field.

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However, SGG and STT methods have several disadvantages. For example, GOCE gradiometer has a measuring bandwidth from 0.005 Hz to 0.1 Hz (applicable for best measuring accuracy) [1,2]. Because of it, low degrees coefficients are estimated from STT with a help of GPS kinematic orbits. Some problems exist in GRACE project, too: noise in K-band and S_2 orbit aliasing, which influence low-degree zonal GFC [3]. Compared with SLR, one additional disadvantage of SGG/STT is a quite short observation period: no longer than 12 years versus 40 years for LAGEOS.

Because of the items noted above, the task of common estimation and studying of stations' positions, Earth rotations parameters and gravity field coefficients becomes actual and fully coincide with GGOS conception about integrated systems and close connections between Earth geometry, rotation and its gravity field [4]. The primary instruments for solving these issues are additional LEO satellites with different orbital parameters.

2. GeoIS software package

Several software packages (GEODYN, GIPSY-OASIS, Bernese GNSS Software etc.) for processing SLR data have been developed all over the world by the present time. Also at the Institute of Astronomy, RAS, two packages: “PROGNOZ” [5] and “ASTRA” [6] have been developed and used. These packages have been developed many years ago, and now we have no ability to modify it to make it to correspond to current standards and accuracy levels. Table 1 summarizes some parameters available from the software datasheets.

Considering these factors, it was decided to develop the new software package for processing SLR data from different satellites with taking into consideration all state-of-art standards and accuracy levels. The package was named GeoIS (Geodynamic Research in Russian).

The software is designed to solve several main tasks:

1. Numerical simulations of different orbits for investigating various orbital perturbations and loading effects;
2. Processing of LAGEOS data for estimating stations positions and ERP (ILRS products);
3. Combined processing of LAGEOS and LEO satellites for joint estimation of different types of parameters in one solution.

It should be noted that the developed software could be easily modified to process some additional types of measurements (mainly DORIS).

Since the software should meet all modern precision requirements, a wide set of perturbing forces and loading effects should be implemented. The basic document underlying our new software is IERS Conventions 2010 [7]. It describes several standard perturbing, loading sources, and methods for taking it into account during processing of space geodetic measurements (In addition, the following effects are mandatory: Solar System bodies attractions, atmospheric drag and radiation pressure). To make the set more complete, some additional effects have been included into orbit modeling procedure and loading calculations:

1. Earth reflectivity and emissivity (with CERES model [8];
2. Non-tidal mass transport in atmosphere and oceans (AOD1B RL05 product [9];
3. VIENNA atmospheric non-tidal loading [10].

The typical processing workflow with GeoIS software is presented in Fig. 1.

All the data used in the present study has been obtained from stations of the International Laser Ranging Service [11]. It covers 13-years period (from 2001 until 2013) with weekly resolution and includes observations from five satellites: LAGEOS-1/2, AJISAI, Stella, and Starlette. This orbital configuration has been selected because all these satellites have been observed without any gaps during the mentioned time interval. Orbital parameters of the selected satellites are presented in Table 2. As seen from this table, orbital configuration is quite varied: orbits vary in heights, inclinations and longitudes of ascending nodes. Moreover, the selected LEO satellites are spherical and values of cross-section-to-mass ratio are very small. This fact sufficiently reduces possible errors in atmospheric drag modeling for these set of satellites.

To achieve one of the goals mentioned above, the following parameters have been estimated in the presented solution: initial orbital parameters, station coordinates with weekly resolution, Earth rotation parameters with daily resolution and Earth gravity filed coefficients till fourth degree and order with weekly resolution. This configuration of estimated parameters has been found optimal from series of numerical experiments [12], i.e. this solution is sensitive to almost all estimated GFC and the correlations between different types of parameters are quite small. Fig. 2 shows changes in solution's sensitivity to GFC estimates with changing of orbital configuration. Sensitivity depends on values of diagonal terms of normal equations matrix (the higher the value, the more sensitive solution).

One additional solution has been made to verify the combined solution. It includes only LAGEOS observations, only station coordinates, and Earth rotation parameters have been estimated along with initial orbital parameters. This solution is a standard solution in ILRS. However, realization of reference frame was the following: coordinates of twelve core ILRS stations have been fixed to SLRF2008 (instead of loose constraints for 1 m in case of ILRS standard solution).

The total number for used observations – normal points – for each type of satellites with yearly resolution is presented on Fig. 3. It should be noticed that absorbing LEO into processing will increase the total amount of input data by more than two times.

We used two methods of combination: combination on observation level and combination on normal equations level. First of all, parameters are estimated on weekly intervals (or daily intervals for ERP) from processing all five satellites and then gravity field coefficients are estimated on 4-week intervals by combination on normal equations.

Table 1
Comparison of software packages.

Parameter	Software					
	GEODYN	GIPSY-OASIS	Bernese GNSS software	GAMIT	PROGNOZ	ASTRA
SLR data processing	+	+	+	–	+	+
Possible to modify	–	–	+	+	+	+
Documentation	+	+	+	+	–	–
EGM coefficients est.	+	+	–	–	–	–
Availability	–	–	–	+	+	+

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