ILRS Workshop 19

Impact of atmospheric effects on satellite orbits and geodetic parameters from SLR data

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For the last several decades many satellites for laser ranging have been launched: LAGEOS-1/2, Etalon-1/-2, Stella, Starlette, Ajisai, LARES, BLITS (Table 1). The main goals of these missions are the following:

1. Study of the Earth gravity field;
2. Earth rotation parameters estimation;
3. Determination of terrestrial reference frames;
4. Tides' studying;
5. Relativistic effects studying
6. Testing of new technologies in manufacturing of satellites for laser ranging.

By the way, weekly ILRS solutions are based on observations from the first four satellites due to some objective reasons: orbits of these four satellites are calculated with very good accuracy because of small Earth gravity field attraction and eliminating of atmospheric drag influence. Number of normal points for weekly interval is about 1500 for LAGEOS and 300 – for Etalon.

Adding new satellites to the estimation process could noticeably increase number of normal points for each weekly interval. For example, the number of normal points for a weekly interval for Ajisai, Starlette, Stella satellites is about 2000 NPs for each satellite. For BLITS and LARES this value is smaller: about 500-700 NPs.

The main goal of new satellites adding – decreasing number of gaps in time series of observations. Also it may help for complex studying of different geodetic and geodynamic parameters (stations coordinates, geocenter motion, Earth rotation parameters, Earth gravity field). Another useful thing is that it may help in cases when number of LAGEOS/Etalon observations is quite small.

Several software packages for processing of SLR data have been developed all over the world by the present time (GEODYN, GIPSY-OASIS, BERNESE etc.). Also at the Institute of Astronomy two packages have been developed and used: "PROGNOZ" and "ASTRA". These packages have been developed many years ago and now we have no ability to modify it to make it corresponding to current standards and accuracy levels. So, it was decided to start developing the new software package (GeoIS) for processing of SLR data with taking into consideration modern standards and accuracy levels. The main task of the new software package – ability of joint processing observations from different orbits.

Several atmospheric effects have been studied in this work:

1. First of all three atmosphere models and a wind model have been studied for applying to LEO calculations;
2. Two models of atmospheric tides have been studied for LAGEOS orbit calculation and geodetic parameters estimation (low-frequency earth gravity field coefficients, geocenter coordinates and earth rotation parameters).

Low-Earth orbiting satellites have a serious deficiency – a great influence of atmospheric drag. For calculating the drag values the atmosphere density ρ on the flight's height is needed:

$$\ddot{\bar{r}}_{drag} = -\frac{1}{2} C_D \frac{S}{m} \rho v_r^2 \frac{\bar{v}_r}{v_r}. \qquad (1)$$

It depends on many parameters and is calculated with different atmospheric models. A lot of models have been developed by present time. The most actual models are NRLMSISE-00 [1], JB2008 [2] and DTM2013 [3]. The main advantage of these models is open source code. In eq. (1) one additional parameter deserves special attention – velocity of atmosphere $\bar{v}_a$, which is used to calculate velocity of satellite relative to atmosphere:

$$\bar{v}_r = \bar{v} - \bar{v}_a .$$

Usually velocity of atmosphere is defined as:

$$\bar{v}_a = \bar{\omega}_\oplus \times \bar{r} ,$$

where $\bar{\omega}_\oplus$ – vector of Earth angular velocity and $\bar{r}$ – vector of a satellite's position. Another way to calculate velocity of atmosphere is using different wind model. In our tests HWM07 [4] wind model along with three mentioned atmosphere model have been used.

Two LEO satellites have been used for test: Stella and AJISAI. Observations for 51 weeks have been processed with 3.5 days intervals (Jan/3-Dec/25, 2013). Models and parameters used in the software package are presented in Table 2. RMS residuals for each satellite and each atmosphere model are presented on Fig. 1. Here and after all values are given in meters. All three atmosphere models show almost identical results. But it should be noted that in case of using DTM2013 model calculation time are greater for about 3 times comparing to other models.

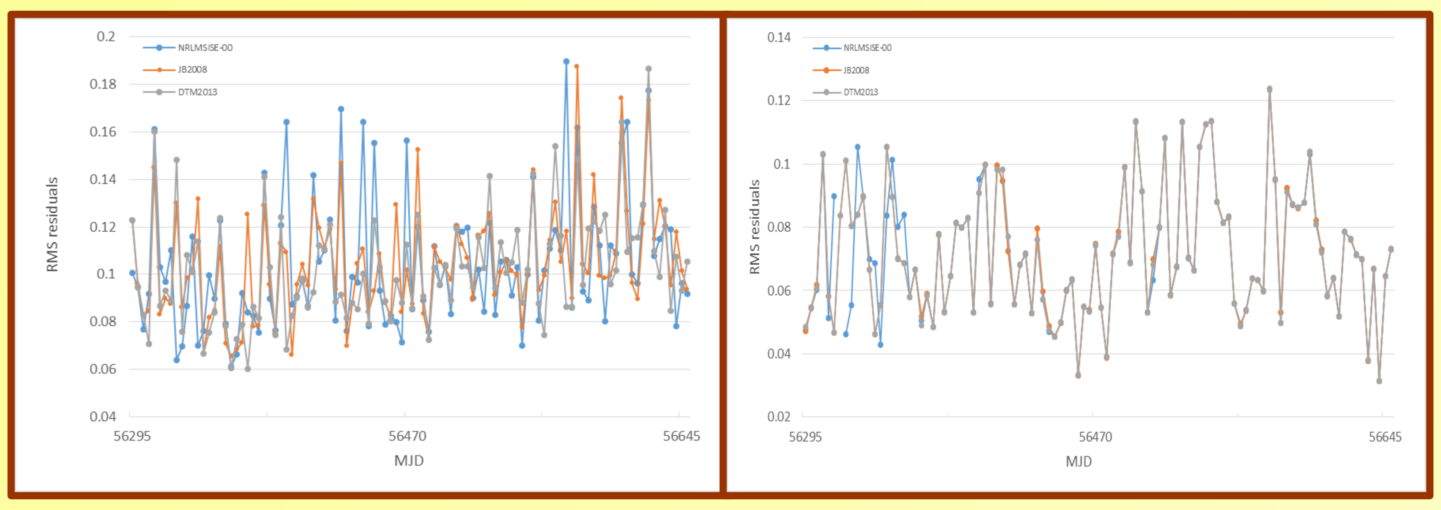

Fig. 1 – RMS residuals for each 3,5-days interval for Stella (Left) and AJISAI (Right) satellites

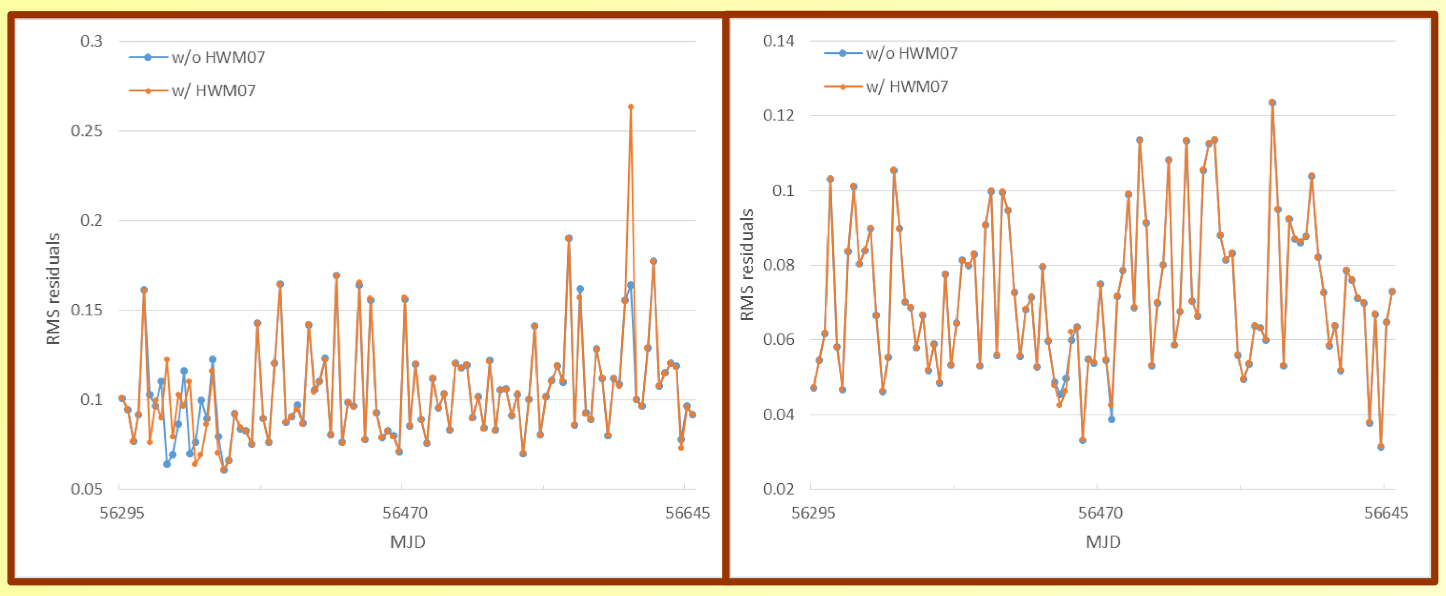

Fig. 2 – RMS residuals for each 3,5-days interval for Stella (Left) and AJISAI (Right) satellites in case of using NRLMSISE-00 atmosphere model and HWM07 wind model

Fig. 2. shows results (RMS residuals) for cases when HWM07 wind model has been used for calculating velocity of atmosphere. Based on the data we conclude that using HWM07 model has no effect in satellite data processing. Also any atmosphere model can be used but NRLMSISE-00 and JB2008 are preferable because of the smaller calculation time.

Table 1 – Geometrical parameters of satellites.

Satellite	ID number	Diameter [cm]	Mass [kg]	CoM [mm]	Height, [km]	S/m ration [m²/kg]
LAGEOS-1	7603901	60.000	406.965	251.0	6000	0.00069
LAGEOS-2	9207002	60.000	405.380	251.0	6000	0.00070
ETALON-1	8900103	129.400	1415.000	576.0	19100	0.00093
ETALON-2	8903903	129.400	1415.000	576.0	19100	0.00093
Stella	9306102	0.240	48.000	75.0	800	0.00094
Starlette	7501001	0.240	47.000	75.0	800	0.00096
AJISAI	8606101	215.000	685.000	1010.0	1500	0.00530
LARES	1200601	0.364	356.800	133.0	1500	0.00029
BLITS	0904907	17.030	7.530	-209.6	800	0.00303

Table 2 – Models and parameters used in the new software package (GeoIS)

Numerical integration:

Integration: numerical integration based on the approximation of differential equations with shifted first order Chebyshev polynomials;

Step size: 80 s (LEO), 120 s (LAGEOS), 180 s (ETALON);

Arc length: 7 days for (LAGEOS/ETALON), 3.5 days (LEO);

Force model:

Earth gravity field: EGM2008 90x90 (LEO), 30x30 (LAGEOS), 30x30 (ETALON);

Earth tides: IERS Conventions 2010;

Ocean tides: FES2004;

Pole tides: IERS Conventions 2010;

Third body gravity: Moon, Sun, Venus, Jupiter – DE421;

Solar radiation pressure coefficient: estimated;

Relativistic correction: IERS Conventions 2010;

Atmospheric density model: NRLMSISE-00, JB2008, DTM2013

Reference frame:

Inertial reference system: true of date defined at 0^h of the middle of the arc;

Station coordinates: SLRF2008;

Precession and nutation: IAU 2006/2000A;

Polar motion: IERS Bul. A;

Earth tidal loading: IERS Conventions 2010;

Range biases: estimated according to ILRS AWG recommendations;

Another investigated effect – atmospheric tides. Atmospheric tides are forced oscillations, produced by lunisolar attraction and changes in Solar radiation, which cause periodical fluctuations in atmospheric temperature and atmospheric pressure and, as a consequence, changes in Earth gravity field. Traditional way to account these effects – through corrections to geopotential coefficients. Using special models. Modern models of atmospheric tides are developed using meteorological data. For example, currently two models are actual: BB03 [5] and RP03 [6]. These models have been created using data from European Centre for Medium-Range Weather Forecasts (ECMWF).

Four-years interval (2010-2013) of LAGEOS data has been processed with estimating $\bar{C}_{20}, \bar{C}_{21}, \bar{S}_{21}$ and geocenter coordinates in the first case and Earth rotation parameters – in the second case.

Fig. 3 shows results of estimating $\bar{C}_{20}$ and its standard deviation with different atmospheric tides models. No significant difference is observed. But after applying discrete Fourier transformation some interesting things should be noted (Fig. 4). Applying BB03 models decrease amplitudes of almost all signals (especially for annual signal). In case of $\bar{S}_{21}$ (Fig. 5) we see the same situation. But in case of $\bar{C}_{21}$ applying BB03 models increase annual signal twice (Fig. 6).

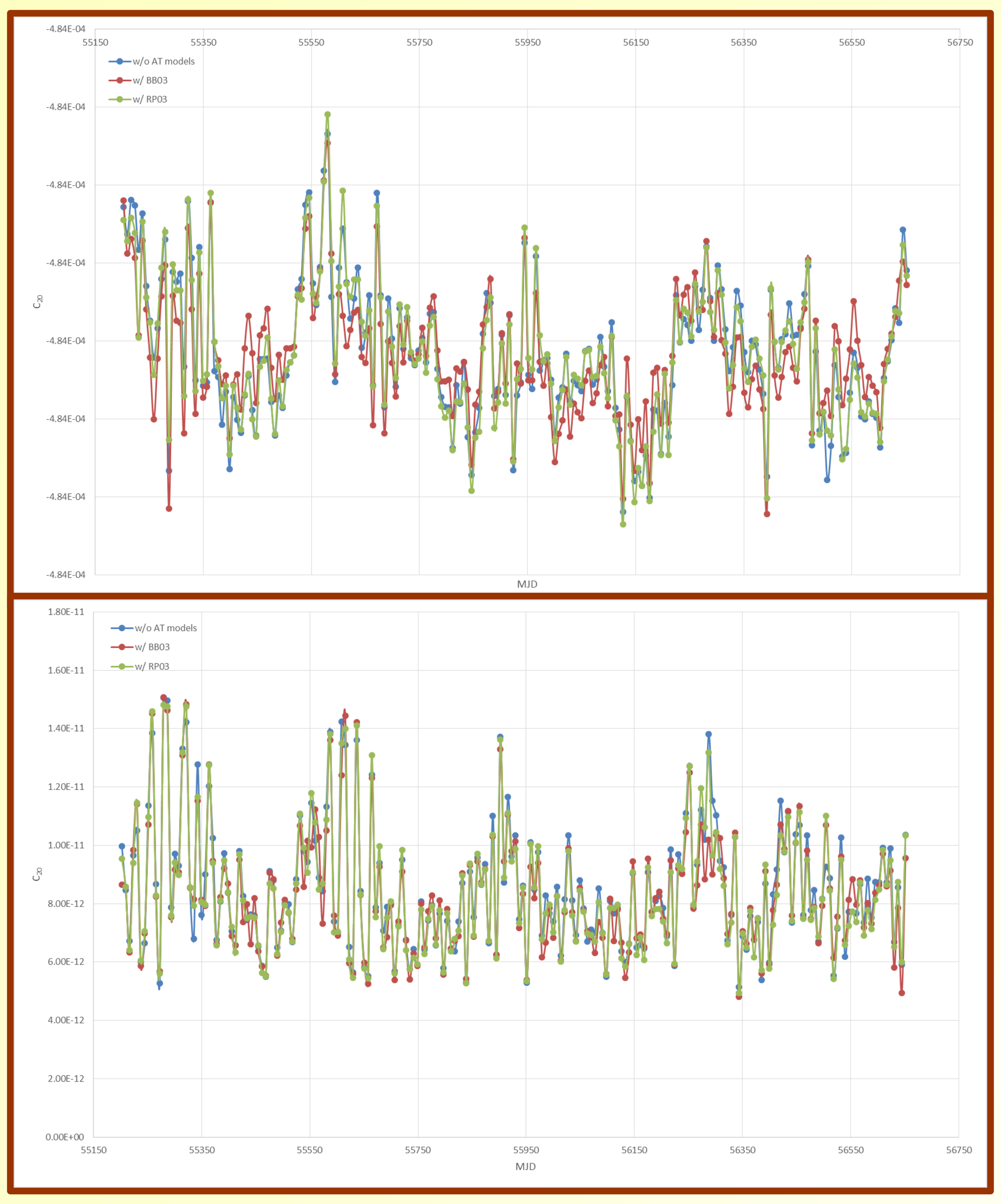

Fig. 3 – $\bar{C}_{20}$ time series obtained with applying different atmospheric tides models (Top) and its standard deviations (Bottom)

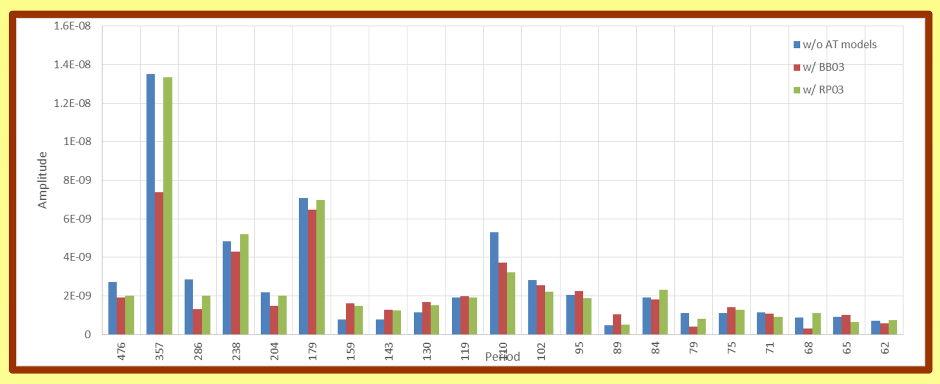

Fig. 4 – Periods and amplitudes of signals in $\bar{C}_{20}$ time series

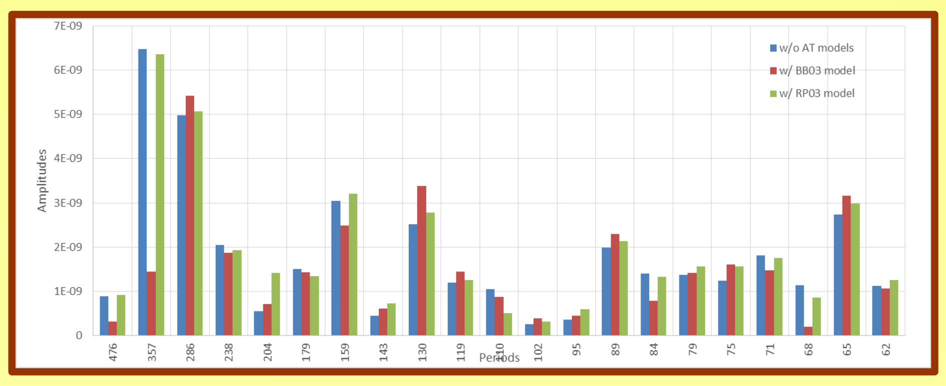

Fig. 5 – Periods and amplitudes of signals in $\bar{S}_{21}$ time series

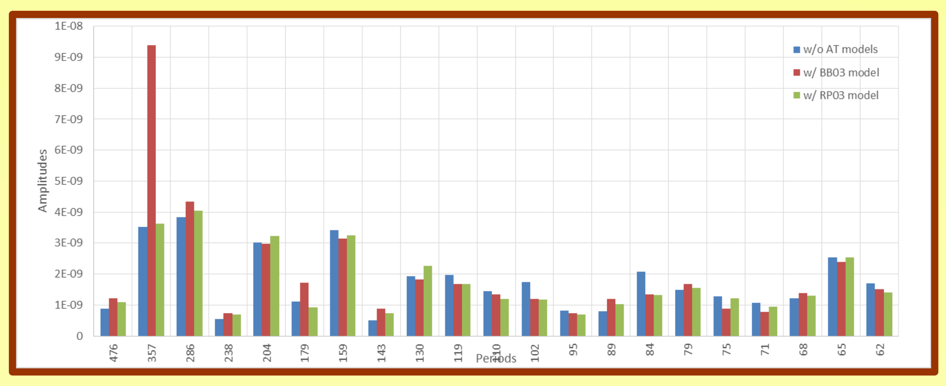

Fig. 6 – Periods and amplitudes of signals in $\bar{C}_{21}$ time series

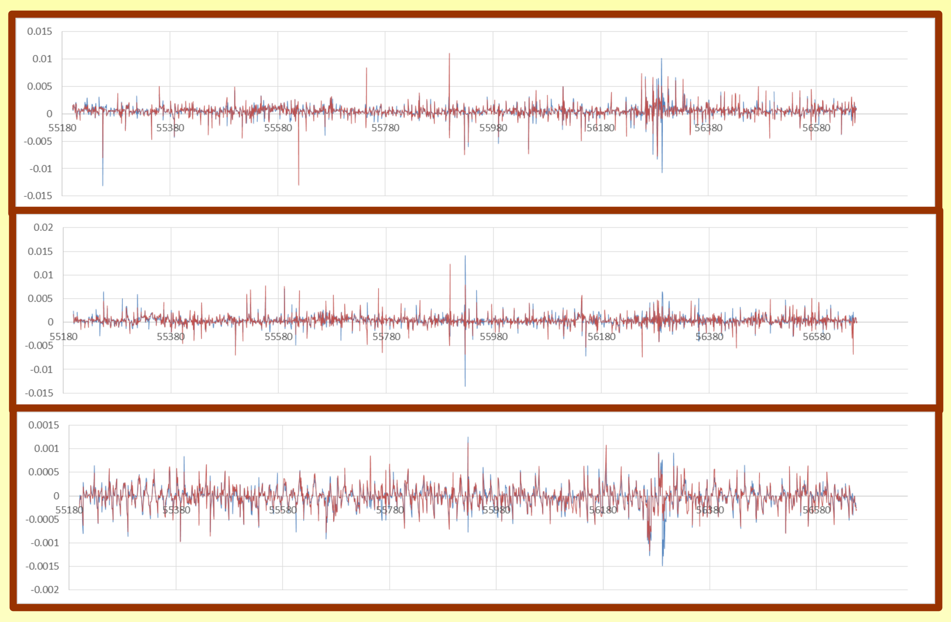

Fig. 7 – Differences between estimated ERP and IERS C04 series(x_p – Top, y_p – Middle, UT1 - Bottom): blue – with BB03 model, red – with RP03 model.

Also ERPs have been estimated with applying different atmospheric tides models. Fig. 7 displayed differenced between estimated ERPs and IERS C04 series for two atmospheric tides models. We can conclude that no significant difference is observed between two models when ERPs are estimated. Also atmospheric models have no effect on ERPs standard deviations (not shown here).

Conclusions:

Three atmosphere models (NRLMSISE-00, JB2008 and DTM2013), two methods of calculating atmosphere velocity (using Earth rotation vector with satellite position and HWM07 model) and two atmospheric tides models (BB03 and RP03) have been investigated using SLR data from LEO and LAGEOS satellites. It was found that the most appropriate atmosphere models are NRLMSISE-00/JB2008. Although all models show similar results these models "work faster".

Also HWM07 model does not help to improve orbits with different altitudes.

Atmospheric tides models show similar results when estimating Earth gravity field coefficients and ERPs. But discrete Fourier analysis shows that applying BB03 model decreases amplitudes of almost all signals in and time series (especially for annual signal), but increases annual signal in time series for two times. At the same time no significant differences in orbit residuals are observed between two cases.

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