Federal State Unitary Enterprise «National Research Institute of Physical Technical and Radio Technical Measurements"

Improving software tools for determining global geodynamic parameters using satellite laser ranging at the Federal State Unitary Enterprise "VNIIFTRI"

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ABSTRACT

The results of upgrading software for determining global geodynamic parameters using satellite laser ranging are presented. In order to increase the accuracy and efficiency of determining global geodynamic parameters by satellite geodesy methods, a high-precision orbit integrator (based on implicit Runge-Kutta methods) with a parallelization function and neural network post-processing was developed, which made it possible to obtain accurate orbits of low- and medium-orbit satellites in quasi-real time. The calculated orbits of spacecraft are successfully used at the Federal State Unitary Enterprise VNIIFTRI to determine the parameters of the Earth's rotation and the coordinates of the geocenter, construct a model of the Earth's gravitational field and solve geological problems, assess changes in the level of the Global Ocean and develop models of navigation in gravitational and magnetic fields.

The results obtained demonstrate a high scientific and technical level of development, since the accuracy of determining the coordinates of the Earth's pole is 0.08 mas and 35 μs for the length of day (LOD).

SATELLITE LASER RANGING (SLR) STATIONS

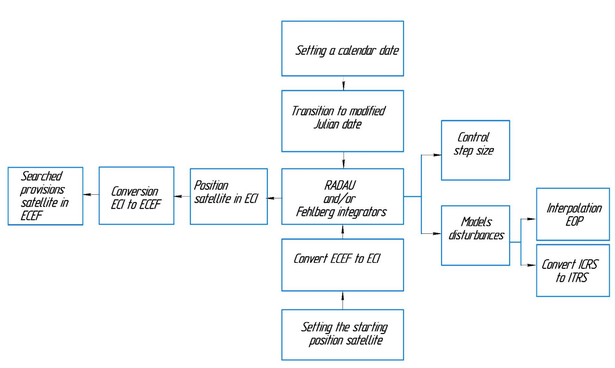
Monument	Code	Monument	Code	Monument	Code	Monument	Code
1868	KOML	7045	APOL	7396	JFNL	7821	SHA2
1874	MDVS	7090	YARL	7403	AREL	7824	SFEL
1879	ALTL	7105	GODL	7406	SJUL	7825	STL3
1884	RIGL	7110	MONL	7407	BRAL	7827	SOSW
1886	ARKL	7119	HA4T	7501	HARL	7838	SISL
1887	BAIL	7124	THTL	7503	HRTL	7839	GRZL
1888	SVEL	7237	CHAL	7701	IZ1L	7840	HERL
1889	ZELL	7249	BEIL	7810	ZIML	7841	POT3
1890	BADL	7306	TKBL	7811	BORL	7941	MATM
1891	IRKL	7394	SEJL	7819	KUN2	8834	WETL

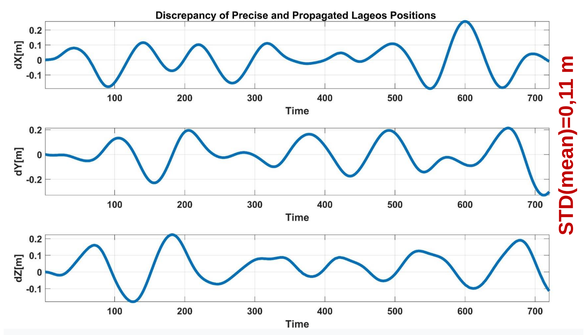
The pictures on the left show MDVS and IRKL stations respectively

DYNAMIC MODEL OF SPACECRAFT ORBIT

Accurate satellite orbits are a prerequisite for determining reliable geodetic parameters from satellite observations, such as station coordinates, Earth Orientation Parameters (EOP), and Earth's gravitational field coefficients. They are also fundamental for solving problems of geodynamics and climatology using satellite geodesy methods. The authors have developed a high-precision adaptive orbit integrator with a parallelization function.

The figures below show the functional diagram of the integrator and the results of calculating the orbit of the LAGEOS 2 satellite (as an example).



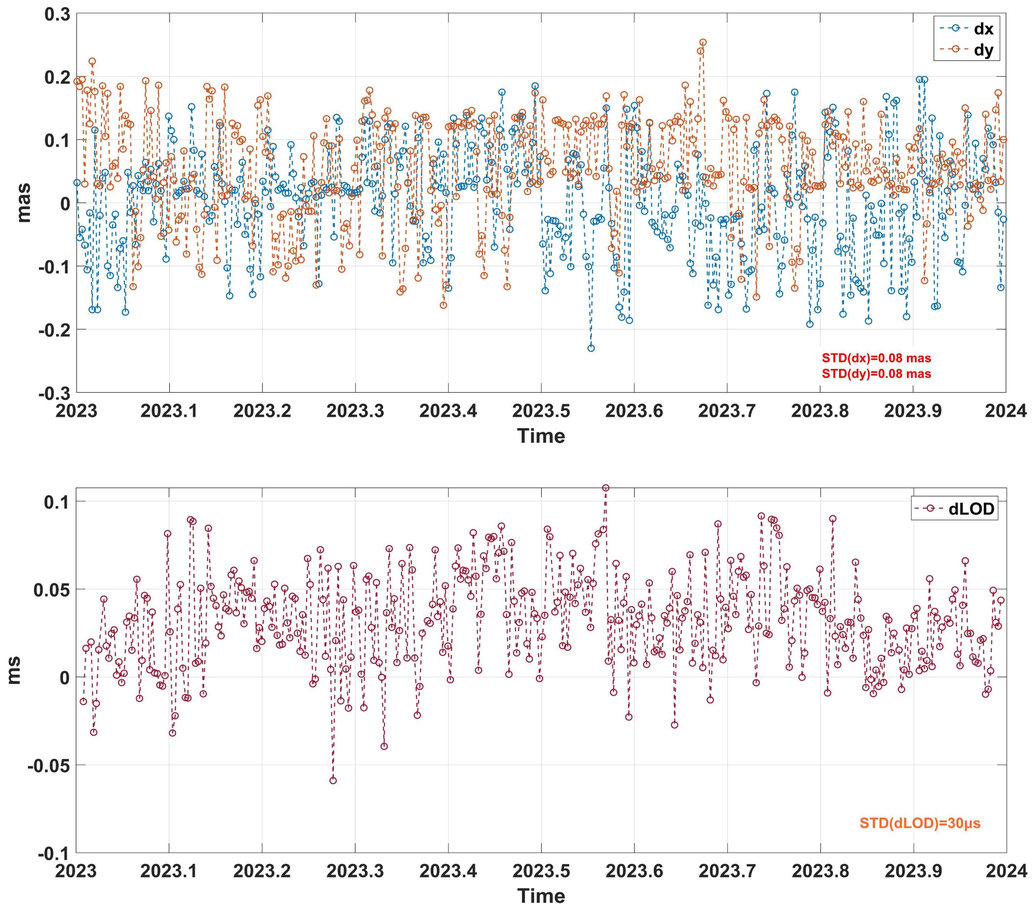


Deviation of the calculated orbit from the reference one for the LAGEOS 2 satellite (before the use of measurement information) on a daily interval

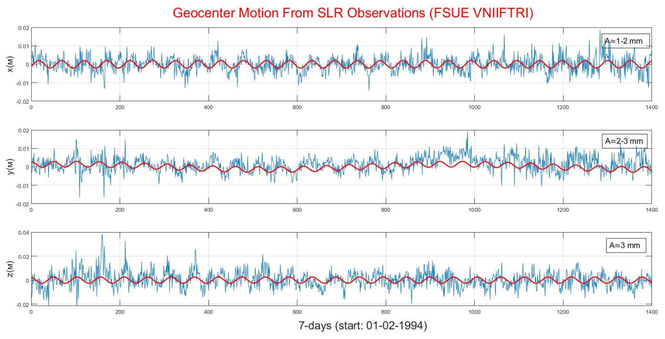
RESULTS OF DETERMINING THE EOP BY THE SLR METHOD (LAGEOS1,2 AND ETALON 1,2)

This section presents the results of the SLR determination of EOP [1] for 2023.

The standard deviation of the calculated EOP values from the EOP C04 data is 0.08 mas for the pole coordinates and 30 μs for the length of day (LOD)

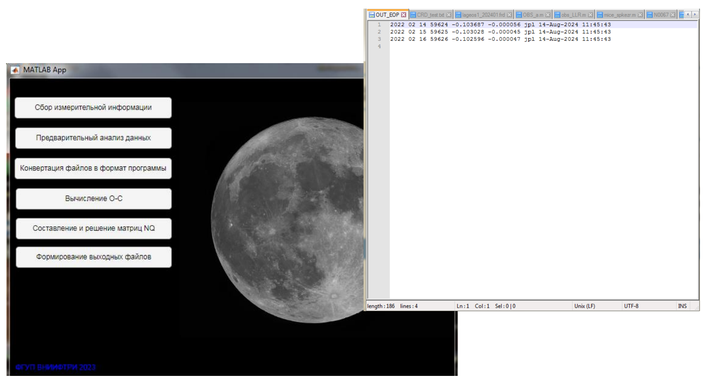


GEOCENTER MOTION FROM SLR OBSERVATIONS (1994-2021)



The Earth's geocenter, as established by SLR observations of the LAGEOS satellites, is rather stable over long time spans (years to decades). Variations in the SLR-derived time series are within ±1 cm for the *x*- and *y*-components and within about ±1.5 cm for the *z*-component.

CREATION AND DEVELOPMENT OF SOFTWARE AND HARDWARE FOR PROCESSING LUNAR LASER RANGING DATA



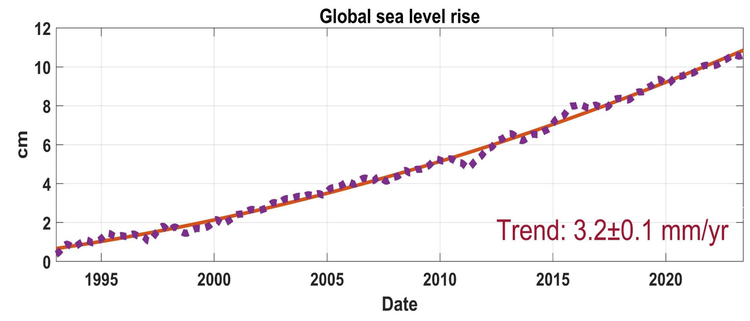
Since 2014, LLR measurements have been processed in order to determine EOP(dUT1). Deviation of calculated values from IERS EOP C04 data 40-60 μs

The pictures on the left show the program interface and output file

DETERMINATION OF THE PARAMETERS OF THE EARTH'S GRAVITATIONAL FIELD AND ASSESSMENT OF CHANGES IN THE LEVEL OF THE GLOBAL OCEAN

Determining the physical surface and gravitational field of the Earth in a single coordinate system is the main task of geodesy. To solve this problem, global gravimetric data is needed. Since most of the Earth's surface is ocean (more than 70%), then determining the heights of the geoid and the altitude of the ocean is an important section of geodesy. In this case, satellite altimetry plays an indispensable role.

In solving the problems listed above (in this section of the report), SLR is used to clarify the dynamic orbits of LEO satellites. The deviation of the updated dynamic orbits of LEO satellites from the reference ones does not exceed 12 cm



Change in mean sea level is an essential indicator of our evolving climate, as it reflects both the thermal expansion of the ocean in response to its warming and the increase in ocean mass due to the melting of ice sheets and glaciers. Long-term and interannual variations in sea level are observed by satellite altimetry at both global and regional scales. In coastal areas, sea level variations are superimposed on the vertical land motion (either subsidence or uplift) and threaten ecosystems and communities. Long-term sea level rise is expected to aggravate coastal erosion, coastal flooding, and saltwater intrusion into coastal aquifers.

The figure on the left shows an estimate of changes in global sea level. The obtained (FSUE VNIIFTRI) results are consistent with data from international data analysis centers.

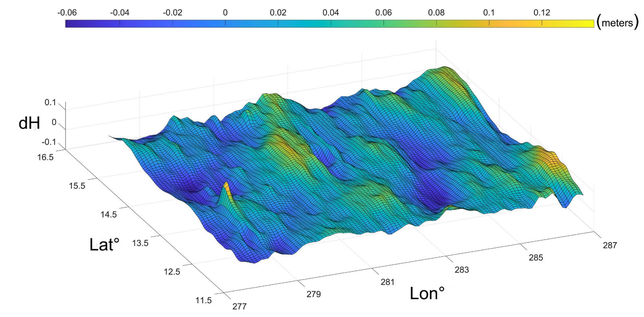
As the temperature of the Earth changes, so does sea level. Temperature and sea level are linked for two main reasons:

1.Changes in the volume of water and ice on land (namely glaciers and ice sheets) can increase or decrease the volume of water in the ocean.

2.As water warms, it expands slightly—an effect that is cumulative over the entire depth of the oceans .

Changing sea levels can affect human activities in coastal areas. Rising sea level inundates low-lying wetlands and dry land, erodes shorelines, contributes to coastal flooding, and increases the flow of salt water into estuaries and nearby groundwater aquifers. Higher sea level also makes coastal infrastructure more vulnerable to damage from storms.

The sea level changes that affect coastal systems involve more than just expanding oceans, however, because the Earth's continents can also rise and fall relative to the oceans. Land can rise through processes such as sediment accumulation (the process that built the Mississippi River delta) and geological uplift (for example, as glaciers melt and the land below is no longer weighed down by heavy ice). In other areas, land can sink because of erosion, sediment compaction, natural subsidence (sinking due to geologic changes), groundwater withdrawal, or engineering projects that prevent rivers from naturally depositing sediments along their banks. Changes in ocean currents such as the Gulf Stream can also affect sea levels by pushing more water against some coastlines and pulling it away from others, raising or lowering sea levels accordingly.

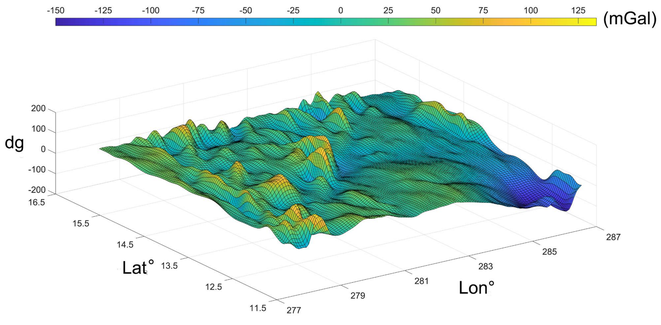


Currently, it is possible to approach the study of the structure of the tectonosphere of the entire Global Ocean within the framework of information contained in the gravitational and magnetic fields. This opportunity arose after the launches of special geodetic spacecraft equipped with an altimeter, providing a qualitatively new type of information - data on the excess of the ocean surface above the ellipsoid of relevance, and thereby characterizing the surface of the geoid, coinciding with the equipotential surface of the Earth's gravity field.

Earth's gravity field data obtained from satellites, along with advanced geophysical methodologies, provide an unambiguous picture of the Earth's geological features. Many geological features, such as seafloor spreading ridges, pre-Cenozoic basement fault systems, and the distribution of sedimentary basins, are identified through the interpretation of gravity anomalies, etc.

FSUE "VNIIFTRI" has developed software for determining the parameters of the gas zone using the satellite altimetry method. The standard deviation of gravity anomalies from EGM2008 data does not exceed 4 mGal in the open sea and 14 mGal in the coastal zone [2,3,4].

The figures above and on the right show the deviations of geoid heights *dH* and gravity anomalies *dg* (calculated at FSUE VNIIFTRI) from the EGM2008 model for the Caribbean Sea.



CONCLUSION

1. In Russia, the responsibility for determining the parameters of the Earth's rotation, according to Decrees of the Government of the Russian Federation No. 225 and No. 323, is assigned to the State Service for Time, Frequency and Determination of the Earth's Rotation Parameters .

The software package developed at FSUE VNIIFTRI allows solving a wide range of problems related to processing satellite laser rangefinder measurements. The results of testing and practical calculations of the EOP showed that the calculated EOP are accurate at the modern level. Regular operational calculation of EOP with a minimum time delay combined with high accuracy has been organized. Work to improve software for processing measurement information from SLR stations continues.

2. The Marine Geoid model is used to create mathematical models of navigation along the Earth's gravitational field and solve the problem of V.V. Fedynsky. and Arkhangelsky A.D. (search for oil and gas fields in the Global Ocean using gravitational anomalies).

REFERENCES

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2.*Tsyba E.N., Vostrukhov N.A.* Construction of a model of the Earth's gravitational field within the Caribbean Sea using satellite altimetry data//Measuring equipment. 2023. No. 3. P. 16-20.

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