ISSN 1407-7345

ĢEOMĀTIKA
GEOMATICS

2012

8

RTU Izdevniecība

ISSN 1407-7345 print
ISSN 2255-856X online

Rīgas Tehniskās universitātes zinātniskie raksti

Scientific Journal of Riga Technical University

ĢEOMĀTIKA

GEOMATICS

2012 / 8

Galvenais redaktors Jānis Štrauhmanis

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https://ortus.rtu.lv/science/lv/science/lv/publications/search

Scientific Journal of Riga Technical University. Series: Geomatics are abstracted and indexed in *EBSCO, ProQuest* and *VINITI* database.

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Solid Earth Tides in the Territory of Latvia

Diana Haritonova, *Riga Technical University*

Abstract. **The work provides graphical description of the tide vertical displacements obtained by means of special programmes. An example is given, which vividly demonstrates the differences in the behaviour of vertical displacements under the impact of tide forces at two points in the same longitude. To provide another example, which gives an idea about the nature of the solid Earth tides in the territory of Latvia, 21 LatPos system base stations have been used. The work also provides description of the Earth station displacement calculation, which conforms to the IERS conventions.**

Keywords: **solid Earth tides, station vertical displacements, LatPos, Love and Shida numbers**

I. Introduction

Earth tides and tide deformations are the Earth crust vertical movements with the maximum amplitude of up to 30 cm and the theoretically precisely determined fluctuations. The Earth periodic fluctuations occur, mainly, as a result of gravitation forces between the Earth, the Moon and the Sun and centrifugal forces of the rotation system. The Moon and the Sun tide effect is a significant factor causing the station displacements together with the Earth crust local part.

Graphic depiction of the tide vertical displacements obtained by means of special programmes gives an idea about the nature of the solid Earth tides in the territory of Latvia. 21 LatPos system base stations and one observation point in the territory of Riga have been chosen for this purpose.

It must be noted that, although the aim of this research is directed to the solid Earth tides, and not ocean tides, to characterise the examined problem, sources of some terms have been obtained from the shipping field materials.

II. Solid Earth vertical displacements under the impact of tide forces

With the aim of understanding the behaviour of tide waves in different circumstances, i.e. depending on the time and geographical coordinates, a programme for calculating vertical displacements of solid tides has been used. The programme is based on the tide correction model, which is in conformity with the IERS conventions. The calculation includes both cyclical and permanent or regular tide deformations, with the accuracy of 1 cm. The programme is offered by the University of Bern.

As there was a solar eclipse on 4 January 2011, this date was chosen for the calculation, as well as 12 January, when there were neap tides, i.e. vectors of gravitation forces between the Sun and the Moon were directed perpendicularly. One observation point is located on the equator in the 24° longitude and the second point – in Riga in the 57° latitude and 24° longitude. In Figure 1, the third row of the diagram characterises deformations under the impact of the Sun, the second row – deformations under the impact of the Moon, and the first row of the diagram shows the resulting deformations.

As seen from the diagrams (See the Fig. 1), the nature of the equator waves corresponds to the semidiurnal tide type, which is characterised by the fact that during a lunar day period two elevations and two falls of tide waves can be regularly observed, whereas in Riga both diurnal tides, i.e. one elevation and one fall of waves during a lunar day, and mixed tides can be observed. The behaviour of these tide waves can be characterised by the latitude, where Riga is located.

When analysing the tide deformation values, they do not contradict with the theory in this example which means that the tide force under the impact of the Sun is twice less than that created by the Moon. In the territory of Riga, the amplitude of deformations under the impact of the Sun is 5 cm, and under the impact of the Moon – 10 cm. At the equator, it is correspondingly ± 7 cm and ± 14 cm. This also confirms the fact that tide deformations in the equator area are larger than those in other latitudes. Besides, the conformity of the example to the theory is such that the tide deformation during the syzygy time (in this case, during the solar eclipse) is three times larger than deformations during the quadrature time. Deformation at the equator during the solar eclipse was ± 21 cm, but for the neap tides only ± 7 cm. This relation is not characteristic for the Riga latitude, where the values are correspondingly ± 16 cm and ± 8 cm.

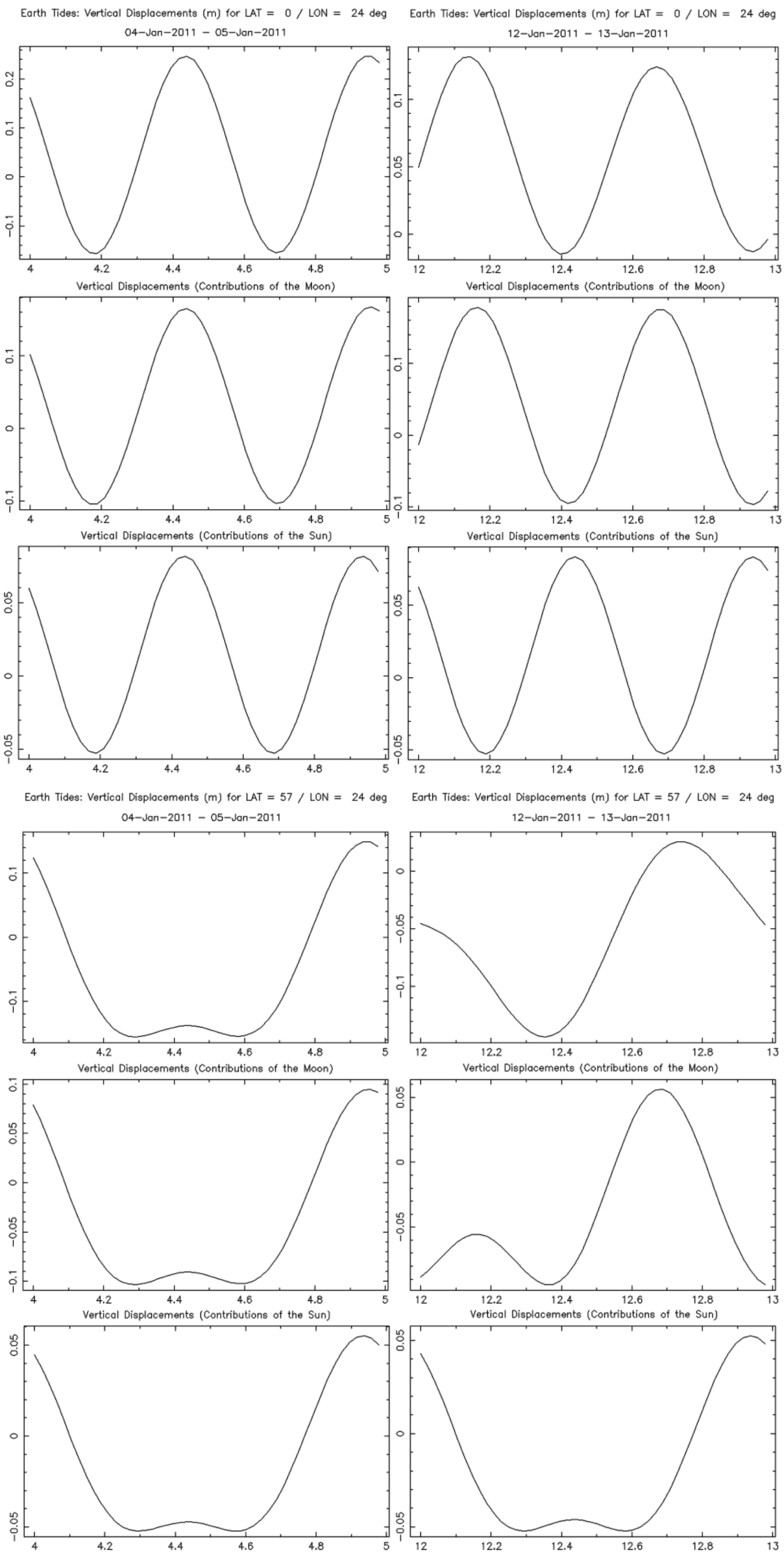

Fig. 1. Solid Earth vertical displacements under the impact of tide forces, depending on the geographical coordinates and epoch.

III. LAND VERTICAL DISPLACEMENTS AT LATPOS BASE STATIONS

To examine the nature of tide waves in the territory of Latvia, the GNSS system LatPos 21 base stations have been chosen for the calculation (See the Fig. 2).

To determine vertical displacements of the LatPos system base stations caused by the tides, in contrast to the first case, another programme was used for calculating the solid tide deformations (See the Fig. 3). It is based on a similar tide correction model, which is in conformity with the IERS conventions; however, the output data of this programme are the solid Earth tide height and X, Y components, with one minute interval. It must be noted that in both cases the time scale conforms to the GPS time, and not the civil time [1]. The chosen epochs are the same as in the first case – 4 and 12 January 2011.

Fig. 2. LatPos base station locations.

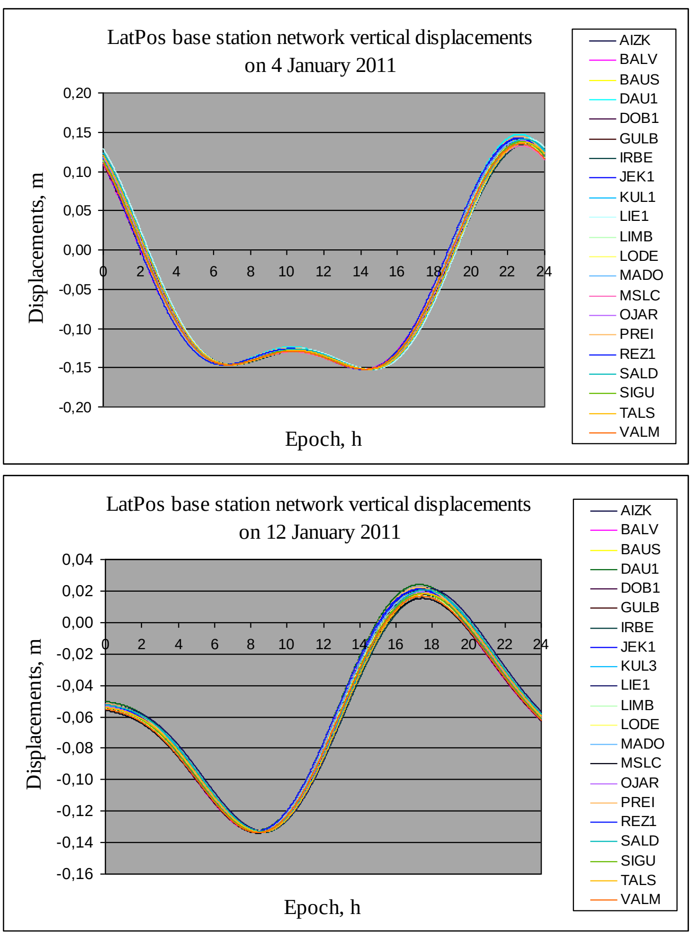

Fig. 3. LatPos base station vertical displacements under the impact of tide forces.

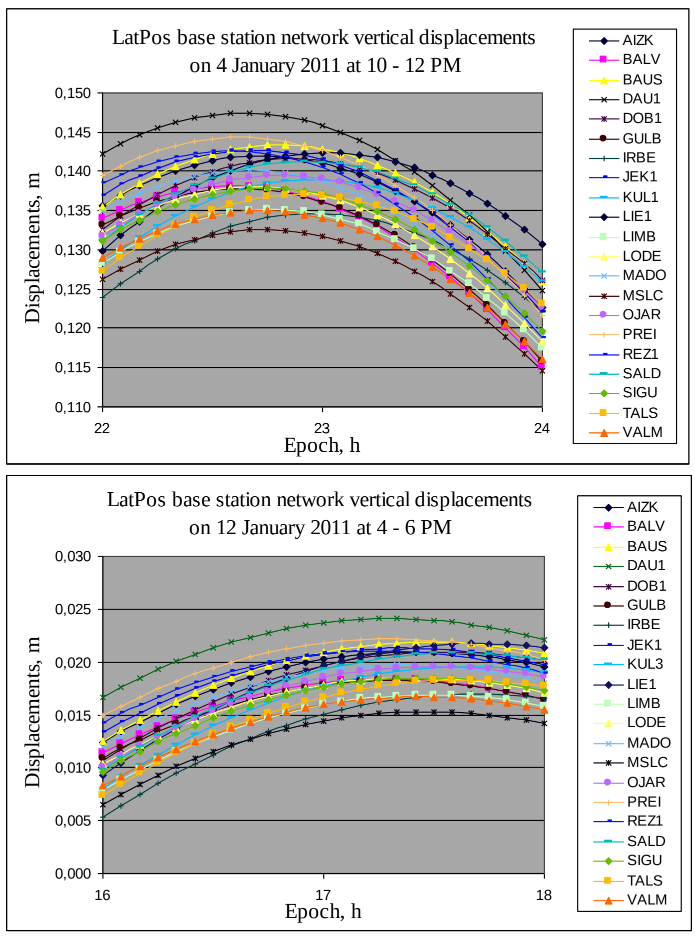

Fig. 4. Vertical displacements of the LatPos base stations under the impact of tide forces at the two hours interval.

Figure 4 provides LatPos base station vertical displacements under the impact of tide forces in every 5 minutes. The Figure 4 graphs demonstrate the Figure 3 data with the two hour intervals, when the station vertical displacements have the maximum dispersion.

The graphs allow seeing that with decrease of the latitude degree, where the LatPos base station is located, the vertical displacement caused by tides is increasing. The maximum displacement is for the DAU1 station, as it is located in the lowest latitude degree, in comparison with other LatPos stations. The next station after DAU1, which is located closer to the equator, is the PREI station, and its vertical displacement curve is located immediately under the DAU1 station curve. Whereas, the MSLC station, which is located in the highest latitude degree, in comparison with other LatPos stations, has the smallest vertical displacements. The vertical displacement curve of the OJAR station is in the middle of this dispersion.

The neap or spring tides, obviously, occur later at the stations located in the highest degree of the geographical longitude, than at the stations located closer to the west. This can be well seen in Graph for 4 January of Figure 4.

The dispersion of vertical displacements of all stations during the syzygy time (4 January) is located at the 1.5 cm interval, and for the neap tides (12 January) this value is 0.9 cm.

IV. Calculation of the Earth station displacements

The effect of the Moon and the Sun tides is a significant factor, which causes the station displacements together with the Earth crust local part.

The station displacements can be characterised in the following way [2]:

$$\Delta\vec{r} = \sum_{j=2}^{3} \frac{GM_j R_e^4}{GM_{\otimes} R_j^3} \Big\{ h_2 \hat{r} \Big(\frac{3}{2} (\hat{R}_j \cdot \hat{r})^2 - \frac{1}{2} \Big) + 3 l_2 (\hat{R}_j \cdot \hat{r}) \big[\hat{R}_j - (\hat{R}_j \cdot \hat{r}) \hat{r} \big] \Big\} + \sum_{j=2}^{3} \frac{GM_j R_e^5}{GM_{\otimes} R_j^4} \Big\{ h_3 \hat{r} \Big(\frac{5}{2} (\hat{R}_j \cdot \hat{r})^3 - \frac{3}{2} (\hat{R}_j \cdot \hat{r}) \Big) + l_3 \Big(\frac{15}{2} (\hat{R}_j \cdot \hat{r})^2 - \frac{3}{2} \Big) \big[\hat{R}_j - (\hat{R}_j \cdot \hat{r}) \hat{r} \big] \Big\} \quad (1)$$

where

- GM_j – gravitational parameter for the Moon (j = 2) or the Sun (j = 3);
- $GM_{\otimes}$ – gravitational parameter for the Earth;
- $\hat{R}_j$, R_j – unit vector from the geocenter to the Moon or the Sun and the magnitude of that vector;
- R_e – the Earth's equatorial radius;
- $\hat{r}$, r – unit vector from the geocenter to the station and the magnitude of that vector;
- h_2, h_3 – nominal degree 2 and degree 3 Love numbers;
- l_2, l_3 – nominal degree 2 and degree 3 Shida numbers.

In this expression, it is important to note nominal Love and Shida numbers. These are accepted to characterise elastic properties of the Earth. The Love and Shida numbers are the parameters which reflect reaction of the Earth to different perturbations. These observe reaction of the Earth to the deformations characterised by degree 2 and degree 3 spherical harmonics.

The part proportional to *h* gives the radial (not vertical) component of the tide-induced station displacement, and the terms in *l* represent the vector displacement transverse to the radial direction (and not in the horizontal plane).[2]

It is important to note that for the station displacement created by the tide causing degree 3 potential, it is sufficient to observe only the impact of the Moon. The maximum vertical displacement caused by the Sun tides is 0.002 mm, which is two orders less than the Moon component.

In the first expression, the Love and Shida numbers do not depend on the tide wave frequencies. To observe dependence of these values on the frequency, it is required to introduce corrections in the radial and transverse components [3]:

$$\delta r = \begin{pmatrix} \delta R_f \sin 2\varphi \sin(\theta_f + \lambda) \\ \delta T_f \cos 2\varphi \sin(\theta_f + \lambda) \\ \delta T_f \sin\varphi \cos(\theta_f + \lambda) \end{pmatrix} \quad (2)$$

where

- δR_f, δT_f – coefficients of the radial and transverse component corrections;
- θ_f – tide argument for tidal constituent with the frequency *f*;
- φ – geocentric latitude of the station;
- λ – east longitude of the station.

Correction coefficients of the radial and transverse components depend on the Love and Shida numbers of the frequency *f* deflection from their nominal values.

The resulting expression of the station displacement caused by the solid body tides is:

$$\Delta\vec{r}_{set} = \Delta\vec{r} + R\delta\vec{r} \quad (3)$$

where *R* is the transformation matrix of the spherical coordinates to the rectangular coordinates [3]:

$$R = \begin{pmatrix} \sin\phi & \cos\phi & 0 \\ \cos\phi\cos\lambda & -\sin\phi\cos\lambda & -\sin\lambda \\ \cos\phi\sin\lambda & -\sin\phi\sin\lambda & \cos\lambda \end{pmatrix} \quad (4)$$

V. Conclusions

The nature of tide waves in the territory of Latvia conforms to the diurnal and mixed tide types. The amplitude of vertical displacements under the impact of tide forces during the syzygy time (in this case, during the solar eclipse) in the territory of Latvia is 15 cm and during the quadrature time – 8 cm. The maximum vertical displacement is for the DAU1 station, and the minimum one – for the MSLC station, which does not contradict to their geographical coordinates. Dispersion of the LatPos station vertical displacements during the syzygy time (4 January) is within the interval of 1.5 cm and for the neap tides (12 January) this value is 0.9 cm.

The Earth station displacement, which is caused by the solid body tides, is the correction which must be observed for determining the Earth station's position. This correction is based on conventional parameters.

On the one hand, observations of the Earth solid surface tide waves allow judging on elasticity of the Earth substance, which, in its turn, gives an idea about the Earth structure, but, on the other hand, local properties of the Earth internal structure encumber research of the Earth tides.

ACKNOWLEDGEMENT

I would like to express my gratitude to Prof., Dr.sc.phys. Janis Balodis for suggesting the theme of this research and necessary support.

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Diāna Haritonova. Cietās Zemes plūdmaiņas Latvijas teritorijā

Ar mērķi noteikt plūdmaiņu viļņu uzvedību dažādos apstākļos, t.i., atkarībā no laika un ģeogrāfiskajām koordinātām, tika izmantotas programmas cieto plūdmaiņu vertikālo pārvietojumu aprēķinam. Programmu pamatā ir plūdmaiņu korekciju modelis, kas ir saskaņā ar IERS konvencijām. Aprēķinā ietilpst gan ciklisko, gan permanento vai pastāvīgo plūdmaiņu deformācija. Rakstā ir dots plūdmaiņu vertikālo pārvietojumu grafiskais attēlojums. Ir dots piemērs, kas uzskatāmi parāda vertikālo pārvietojumu uzvedību atšķirības plūdmaiņu spēku ietekmē divos punktos vienā meridiānā; viens no tiem atrodas uz ekvatora, otrs – Rīgas teritorijā. Rīgas teritorijai Saules ietekmē deformāciju amplitūda ir 5 cm, bet Mēness ietekmē - 10 cm. Uz ekvatora atbilstoši – ± 7 cm, un ± 14 cm. Uz ekvatora pie Saules aptumsuma deformācija bija ± 21 cm, bet pie kvadratūru plūdmaiņām tikai ± 7 cm. Punktam, kas atrodas Rīgas teritorijā, šīs vērtības atbilstoši ir ± 16 cm un ± 8 cm. Citam piemēram, kas dod priekšstatu par cietās Zemes plūdmaiņu raksturu Latvijas teritorijā, kalpoja GNSS sistēmas LatPos 21 bāzes stacija. Tika izanalizētas vertikālo pārvietojumu raksturlīknes un noteikta staciju pārvietojumu izkliede sizigiju un kvadratūru laikā. Latvijas teritorijas plūdmaiņu viļņu raksturs atbilst diennakts un jaukto plūdmaiņu tipiem. Vertikālo pārvietojumu amplitūda plūdmaiņu spēku ietekmē Latvijas teritorijai sizigiju laikā (šajā gadījumā Saules aptumsuma laikā) ir 15 cm un kvadratūru laikā – 8 cm. Maksimālais vertikālais pārvietojums ir stacijai DAU1, un minimālais – stacijai MSLC, kas nav pretrunā ar to ģeogrāfiskajām koordinātām. LatPos staciju vertikālo pārvietojumu izkliede sizigiju laikā atrodas 1,5 cm intervālā un pie kvadratūru plūdmaiņām šī vērtība ir 0,9 cm. Zemes stacijas pārvietojums, kuru izsauc cietķermeņu plūdmaiņas, ir korekcija, kuru ir nepieciešams ievērot stacijas pozīciju noteikšanā. Darbā ir arī aprakstīts Zemes stacijas pārvietojuma aprēķins, kas ir saskaņā ar IERS konvencijām.

Диана Харитонова. Твёрдотельные приливы на территории Латвии

С целью определения характера приливных волн при различных условиях, т.е. в зависимости от времени и географических координат, были использованы программы для расчёта вертикальных перемещений твёрдотельных приливов. В основе программ лежит модель по коррекции приливов, которая соответствует конвенциям IERS. В расчёт включена деформация как цикличных, так и перманентных или постоянных приливов. В работе приведено графическое отображение приливных вертикальных перемещений. А также приведён пример, который наглядно отображает различия между характерами вертикальных перемещений под воздействием приливообразующих сил для двух точек, расположенных на одном меридиане; одна из которых находится на экваторе, другая – на территории Риги. Амплитуда деформаций для территории Риги под воздействием Солнца – 5 см, а под воздействием Луны – 10 см. На экваторе, соответственно, – ± 7 см, и ± 14 см. На экваторе во время солнечного затмения деформация была ± 21 см, а во время квадратурных приливов только ± 7 см. Для точки, которая находится на территории Риги, эти значения, соответственно, – ± 16 см и ± 8 см. Для другого примера, который даёт представление о характере твёрдотельных приливов на территории Латвии, служила 21 базовая станция GNSS системы LatPos. Были проанализированы характерные кривые вертикальных перемещений и определена дисперсия перемещений станций во время сизигий и квадратур. Характер приливных волн для территории Латвии соответствует суточному и смешанному типам приливов. Амплитуда вертикальных перемещений под воздействием приливообразующих сил для территории Латвии во время сизигий (в данном случае, во время солнечного затмения) – 15 см, и во время квадратур – 8 см. Максимальное вертикальное перемещение наблюдается у станции DAU1, а минимальное – у станции MSLC, что не противоречит их географическому расположению. Дисперсия вертикальных перемещений станций LatPos во время сизигий – 1,5 см, а во время квадратурных приливов – 0,9 см. Перемещение наземной станции, которое вызвано твёрдотельными приливами, – это коррекция, которую необходимо учитывать при определении позиций станции. В работе также описан расчёт вертикльных перемещений станций, который соответствуют IERS конвенциям.