RESULTS OF MEASUREMENTS OF ULTRA-SMALL DEFORMATIONS OF THE EARTH'S CRUST AT THE TALAYA OBSERVATORY NEAR BAIKAL LAKE

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ABSTRACT

The paper discusses the systematic results of observations of deformation processes in the mountain tunnel (gallery) at the Talaya Observatory using a laser meter for ultra-low deformations of the Earth's crust. The current online and offline processing of incoming data has been completed. The processing of the results of observations and studied the behavior of the deformation process in the Earth's crust has been conducted in a wide frequency range on the eve of earthquakes in order to identify their precursors. A powerful oscillation buildup with periods of 25–60 minutes was found, which was caused by an earthquake with a magnitude of M = 5.2 east of Shikotan Island. The analysis was carried out and the averaged spectra of the main harmonics prevailing in the deformation signal in the range of oscillations with the longest period (ROLP) range were obtained. Harmonics with periods of 205 and 160 minutes are the most evident, which corresponds to the multiplicity to the star day duration. Of particular interest are the 160 minute oscillations, since such oscillations are of a cosmological nature and are found both on the Sun and outside the Solar System.

Keywords: *laser deformograph, short-term precursors of earthquakes, Baikal region, mountain tunnel, modern deformation velocity field*

INTRODUCTION

Regular recording of Earth's crust oscillations under the influence of external gravitational forces allows collecting a lot of information about the crustal structure, processes in it and possible changes [1], [2], [3], [4], [5]. [6], [7], [8]. It also allows to scientists to predict upcoming events, including earthquakes. Unfortunately, not enough monitoring tools for seismic events have been created at present, and with the help of existing and acting tools, not enough information has been collected to predict future seismic events with high confidence, including their level of danger and the exact location of their epicenter. Therefore, it is extremely important to increase the amount of accumulated information and, if possible, to increase the number of collection points for this information. To this end Siberian Branch of the Federal Research Center unified geophysical service of the Russian Academy of Sciences (SIBGSRAS, Novosibirsk, Russia) has developed and manufactured several samples of laser meters for ultra-small oscillations of the Earth's crust in two orthogonal directions [9], [10]. Such devices are installed and operated at several points in Russia and Kazakhstan. This paper reports on some of the studies performed in the mountain tunnel at the Talaya Observatory (South Baikal). An experimental model of a laser measuring instrument for small deformations of the Earth's crust (deformograph) with a measuring base of 25 m is operated there.

STATEMENT OF THE PROBLEM

Using the developed device [11], [12], it is necessary to collect data on Earth's crust oscillations under the action of external gravitational forces (from the Sun and the Moon). The device allows us to record changes in the distance of 25 m between the reflectors, fixed in the rock. Measurements are carried out in two mutually orthogonal directions, namely, in the directions north-south, west-east. In some versions, measurements are also made in the vertical direction. At the same time, increments of the lengths of all specified distances are recorded in the absolute scale and relative to the available reference measurement base, which serves as a reference, since it is not connected with the rock. This method allows us to exclude the influence of the atmosphere and other unaccounted factors on the measurement result. The 24-hours recording of these data allows us to study the spectra of these oscillations, as well as detect relatively short-term changes in these spectra and detect unusual signal bursts, usually associated with significant seismic events, such as an earthquake, even if the measurement point is significantly removed from the epicenter. The collected data are processed in accordance with the theory and accepted practice of processing these data, the results are used by experts for forecasts, as well as for proposals for further modification of the measuring equipment for even more informative measurements.

GEOLOGICAL AND GEOPHYSICAL CHARACTERISTICS OF THE PLACE OF INFORMATION RETRIEVAL

Observatory “Talaya” is located in the southwestern part of the Baikal folded area. Coordinates of the station: 51°40'48.00"N, 103°38'24.00"E. According to the seismic zoning map, this is a zone of possible 8-9-ball earthquakes. About 10 km to the north of the station, the Main Sayan Fault passes, and in 12 km to the south of it there are disruptive violations of the north-western strike. Due to the use of observations on a large number of weak shocks, a rather detailed picture of the stress state of the crust in the main part of the Baikal Rift was obtained. In the overwhelming majority of cases, a consistent orientation of the stress axes is found. The Big Talaya site is located in the northern part of the Slyudyansky industrial mining region.

BRIEF DESCRIPTION OF THE USED EQUIPMENT

The experimental measuring complex installed in the gallery was made on the basis of two He-Ne lasers interconnected in frequency with accuracy to the phase [12]. The hardware part of the device allows us to receive signals at a carrier frequency of 1 MHz, the phase of which depends on the distance between the mirrors fastened to the rock.

The length of both measurement arms is 25 m. The deformograph signals are recorded using a computer with a sampling frequency of 0.5 Hz. The digital data processing system used below allows you to isolate and analyze the recorded oscillations in any frequency range. The basis of this system consists of two digital filters, an important feature of which is that they do not change the phase of the filtered signals.

Software is a complex of real-time programs that provide interaction between the operator and the computer performing the task. It allows controlling the progress of its execution. On interruptions from the system timer, the software interrogates the phase shift meters and interrogates the seismic sensor and the atmospheric pressure meter using a multi-channel analog-digital converter. The software also performs preliminary processing of measurement results and writes them to a hard disk with simultaneous visualization on the display screen. In addition, the software provides viewing of data for the past 24 hours. For channels recording the deformation, it is possible to view with compensation and without compensation for the influence of the atmosphere on the deformographic data.

RESEARCH RESULTS AND THEIR ANALYSIS

To obtain information about the deformation processes in the gallery, data arrays on the variations of phase signals obtained from two independent measuring channels of the deformograph, a compensation arm and a geophone are analyzed.

Information on the deformation in two independent orthogonal directions is obtained by programmatically subtracting phase signals recorded in digital form in the measuring channels and the compensation arm, with an equalizing coefficient proportional to the ratio of the geometric lengths of the measuring and reference base.

For further processing, the following arrays of deformographic measurements are used.

1. The time series of the deformation process in the first measuring arm of the interferometer.

2. The time series of the deformation process in the second measuring arm (orthogonal to the first).

3. The time series of difference deformation between the first and second measuring arms, obtained by direct subtraction of the phase signals at the corresponding phase shift meter.

4. Time series of seismic sensor signal.

The greatest interest could be only an earthquake that occurred on September 5, 2015 at a distance of 147 km from the observation station. It had an energy class of K = 12.3 and was suitable for the criteria for eliminating regional seismic events that had been developed earlier, however, at that time, preventive work was carried out with the deformograph.

In addition to the round-the-clock recording of signals from the meter, a systematic analysis of the detected deformation signals was carried out, consisting in the study of tidal diurnal and daily deformations, the dynamics of their variations over time, the study of the spectra of the Earth's natural oscillations in a wide frequency range with reference to planetary seismicity and solar activity. As a result, a number of anomalous features in the behavior of the deformation process were found. One of the interesting features is presented as an example in Fig. 1.

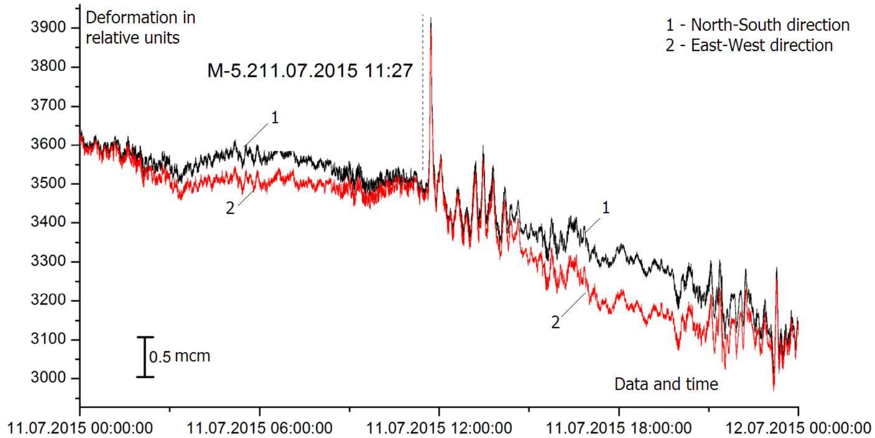

Figure 1: The deformation process, registered during 07/11/2015

The graphs depict unfiltered deformation signals registered in two orthogonal arms from July 11 to July 12, 2015. The figure clearly shows the difference in the character of the deformation signal on the right and left. At 11: 37GMT, there was a sharp synchronous jump in both arms, followed by a powerful buildup of oscillations with periods of 25–60 min. According to the earthquake catalog of the US Geological Survey (USGS), 10 minutes earlier, a large earthquake with a magnitude of M = 5.2 east of Shikotan Island occurred (43.889° N 148.011°E, depth – 40.6 km). Despite the removal of 3500 km, such an earthquake can cause such a buildup. So there is a similar jup in the compensation shoulder of the deformograph, which is consistent with periodically observed earlier similar effects in the behavior of the deformation process after large earthquakes.

In addition to the deformographic analysis of data, studies of deformational oscillations in the range of 1–5 hours were initiated, which corresponds to the range of oscillations with the longest period (ROLP), on almost the entire array of data obtained in 15 years of observations from 1999 to 2015. Spectral analysis of deformographic data series with the duration of 30 and 60 days was carried out.

A fragment of one of the sections of such rows is shown in Fig. 2. It shows unfiltered records of the deformation process in the two channels of the deformograph, their difference signal, as well as variations in atmospheric pressure, recorded using the compensating arm of the deformograph. As an example in Fig. 2 shows a one-month data set, covering another earthquake (in India). The graphs corresponding to the deformation data and their differences show the moment of arrival of the signal from the catastrophic earthquake that occurred on January 26, 2001 in India, in the state of Gujarat. It happened at 03:16:40 (UTC) and had a magnitude of 7.9. Despite the fact that it naturally influenced the ROLP process in the local time domain, this influence is insignificant when analyzing the ROLP spectrum throughout the entire study area.

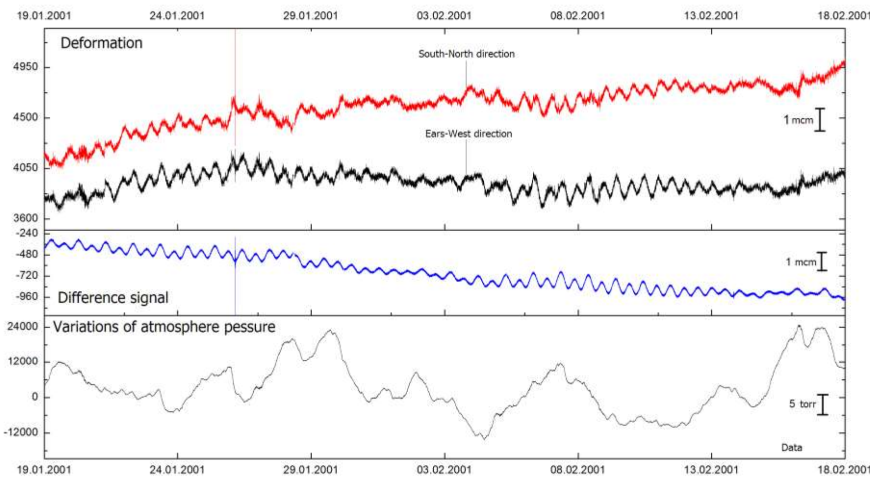

Figure 2: An example of a segment of the deformographic record with a duration of 1 month

In order to reveal the main harmonics dominating in the deformation signal in the ROLP range, the procedure of averaging the spectra obtained from all available continuous sections with the duration of 1 and 2 months was carried out. The averaged spectra obtained are presented in Fig. 3, where the gray graph corresponds to the spectrum of 60 days duration, and the blue graph corresponds to 30 days duration. The 60 days spectrum is noisier compared to 30 days spectrum. This is due to the fact that the number of continuous deformation plots with the duration of 60 days is significantly less than the number of 30 days plots.

In both spectra more than a dozen different harmonics can be clearly distinguished. Their main parts are marked on the figure by arrows, over which the periods of these harmonics are written in minutes. Harmonics with periods of 205 and 160 minutes are the clearest, which corresponds to the multiplicity of the star day (i.e., the period of 24 hours) with coefficients 7 and 9, respectively. In addition, harmonics with periods of 286, 238 and 179, with multiples of star day with the coefficients 5, 6 and 8, also have a high signal-to-noise ratio. Of particular interest are the 160 minutes oscillations, since such oscillations are cosmological in nature and are detected as on the Sun, and beyond the solar system. A similar series of harmonics are distinguished by other researchers in the analysis of seismic noise.

Earlier we revealed the similarity of the spectra of deformation signals synchronously recorded in spaced apart points of the Earth - “Talaya” - “Talgar”. The similarity between the spectra of lithosphere deformations and variations in atmospheric pressure is also shown, and the relationship between their variations in this range is revealed. Based on these assumptions, it was expected to obtain a similarity in the averaged spectra of atmospheric and lithosphere oscillations. A similar comparison is shown in Fig. 4. The following harmonics stand out most vividly in both spectra: 286, 238, 205, 196, 179, 160, 140, 125, 102, 98, 94, 82, 76. In the figure above, these harmonics are marked with dotted lines.

A study was made of the behavior of the spectra throughout the year depending on the month of observation. For this, the energy of the spectrum was calculated for each of the 80 continuous deformographic regions with the duration of 1 *month*.

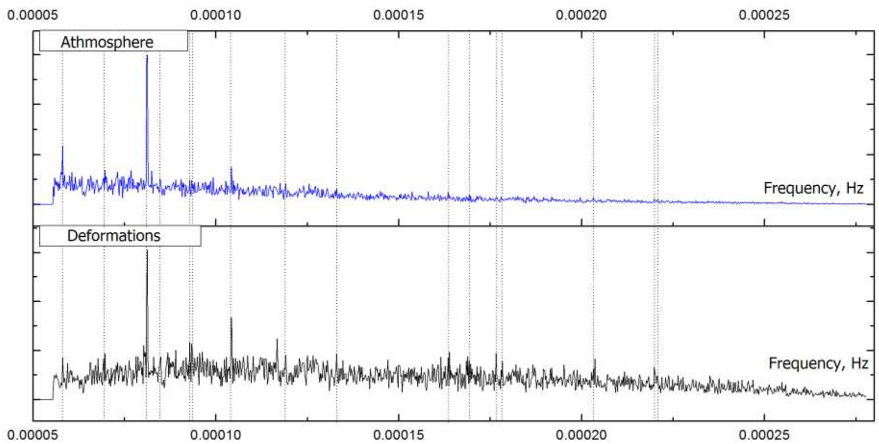

Figure 3: Averaged deformation spectra

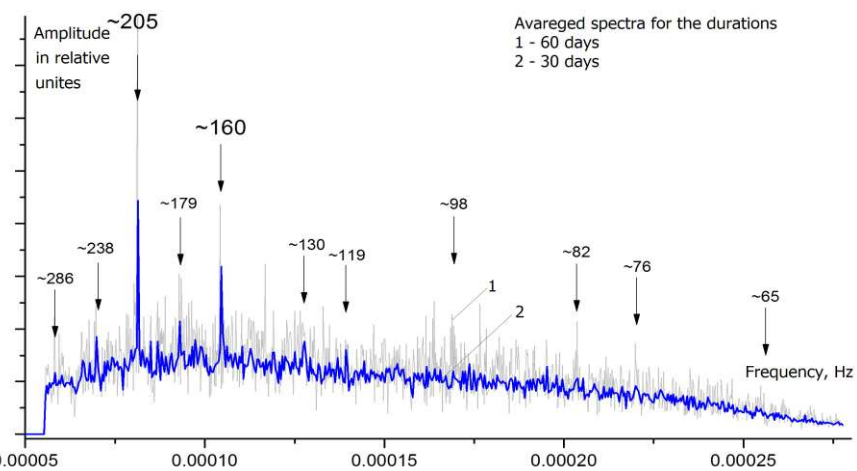

Figure 4: Comparison of averaged spectra of atmospheric and lithosphere oscillations

The obtained results are marked with dots in the corresponding column in Fig. 5. The averaged value for the three neighboring months is shown by crosses, and the continuous line is the resulting smooth curve. The graph shows that the energy of the spectra changes during the year depending on the month, and in summer it is more than in winter, and the maximum falls in June-July, i.e. the changes are clearly seasonal.

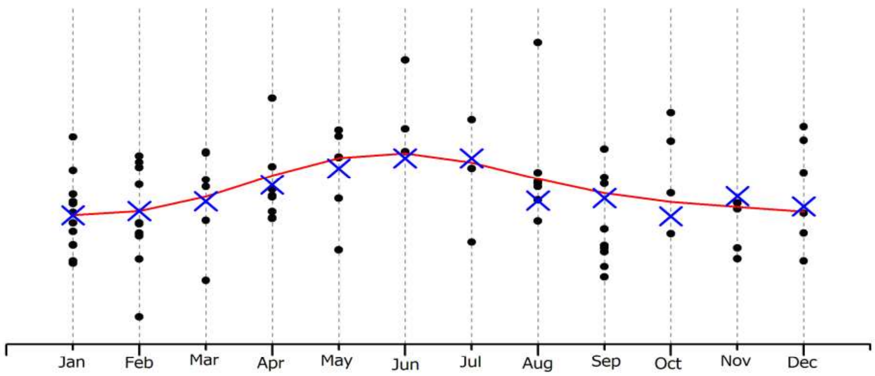

Figure 5: The energy distribution of the spectra of deformagrams depending on the month of observation

In order to look at the behavior of specific harmonics during the year, the procedure of averaging the spectra of 30 daily portions of the deformographic data recorded in different years, but starting in one month, was carried out. Thus, for each month of the year, an average spectrum of deformation oscillations was obtained in the range from 1 to 5 *hours*. The resulting spectra are shown in Fig. 6.

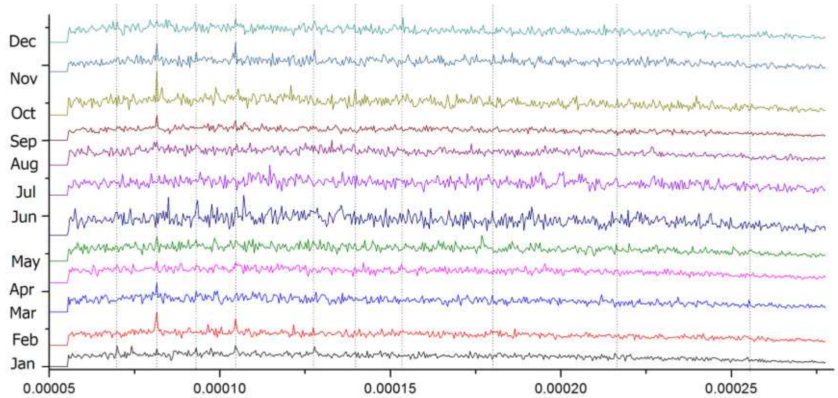

Figure 6: Averaged spectra of ROLP depending on the month of observation

For convenience of comparison, this figure shows a series of vertical straight lines tied to some distinct harmonics, which clearly change their behavior depending on the month of averaging. In particular, the harmonic with a period of 205 *minutes* is clearly distinguished from February to May and from September to November, the rest of the time it is slightly noticeable against the background of neighboring harmonics. Another bright harmonic having a period of 160 *minutes* is best distinguished between November and February.

CONCLUSION

The paper presents the obtained systematic series of observations of deformation processes in the tunnel at the Talaya Observatory using a He-Ne laser deformograph. The current online processing of incoming data has been completed. The processing of the results of observations and studied the behavior of the deformation process in the Earth's crust in a wide frequency range on the eve of earthquakes in order to identify their precursors has been conducted.

A powerful oscillation buildup with periods of 25–60 min was found, which is caused by an earthquake with a magnitude of M = 5.2 east of Shikotan Island (43.889°N 148.011°E, depth is 40.6 km). The analysis was carried out and the averaged spectra of the main harmonics prevailing in the deformation signal in the ROLP range were obtained. Harmonics with periods of 205 and 160 minutes stand out most clearly, which corresponds to the multiplicity of the sidereal day. Of particular interest are the 160 minutes oscillations, since such oscillations are of a cosmological nature and are found both on the Sun and outside the Solar System.

The spectra of deformation signals synchronously recorded in spaced points of the Earth - "Talaya" - "Talgar" are investigated. A similarity is obtained in the averaged spectra of atmospheric and lithosphere oscillations. The following harmonics stand out most clearly in both spectra: 286, 238, 205, 196, 179, 160, 140, 125, 102, 98, 94, 82, 76.

It was found that the energy of the spectra changes during the year depending on the month, and in summer it is more than in winter, and the maximum falls in June-July, i.e. the changes are clearly seasonal. It was found that the harmonic with a period of 205 minutes is clearly distinguished from February to May and from September to November. Another bright harmonic having a period of 160 minutes is best distinguished between November and February.

Analysis of laser deformograph records obtained after a catastrophic earthquake in Japan (March 11, 2011, M = 9.1), allowed us to determine the values of the natural oscillation periods of the Earth. In the spectra, frequencies of torsion and spheroid oscillations with periods of 57 min are distinguished as well as with periods 35.5 min.; 25.8 min.; 20 min..; 13.5 min.; 11.8 min.; 9.0 min.; 6.1 min.; 4.9 min.; 4.2 min., 3.8 min. and 3.6 min. Different frequency intervals are determined by the properties of different areas of the Earth's interior. It is shown that a laser deformograph can serve as an important part of the instrumental complex for studying the natural oscillations of the Earth.

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