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Peculiarities of geodeformation measurements of near surface sedimentary rocks

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Abstract. The results of investigations of the deformation process in the near surface sedimentary rocks are presented. These investigations have been carried out in a seismically active region of Kamchatka peninsula since 2007. The peculiarity of the experiments is the application of a laser strainmeter-interferometer constructed according to the Michelson interferometer scheme.

1 Introduction

Seismotectonic process occurring as the result of accumulation and relaxation of lithospheric stress which is the consequence of motion and interaction of continental and oceanic plates is of great interest for investigation since it plays a significant role in many geophysical processes. To make diagnostics of deformations, we apply different methods of direct measurements by strainmeters. We also investigate such processes as acoustic emission generation, near ground electric field change, and register emissions of different gases.

2 Methods of investigation

One of the effective techniques for direct observations of deformations is the application of laser strainmeters. The operating principle of the simplest devices is that the change of strainmeter base causes additional phase increment in a wave of laser radiation. The method of measurement is as follows. Shift of interferometer mirrors arranged at the ends of a base$l$ by the value $\lambda/2$ results in the change of interference pattern by one band, where λ is the light wave length on which the interferometer operates. Total relative shift equals $\Delta l = N(\lambda/2)$, where N is the number of bands of an interference pattern. The capabilities of the interference method are limited by the measurement accuracy of fraction shifts of a band ΔN which is determined by the parameter of interference pattern sharpness F_k and is characterized by the relation $F_k = \frac{\Delta\lambda}{\delta\lambda}$, that means that it is the relations of the distance between the maxima and maximum half width $\delta\lambda$.

The advantage of laser strainmeters in comparison to mechanic analogies is the absence of a mechanical sensing element. Effect of meteorological parameter variations on the device is reduced to

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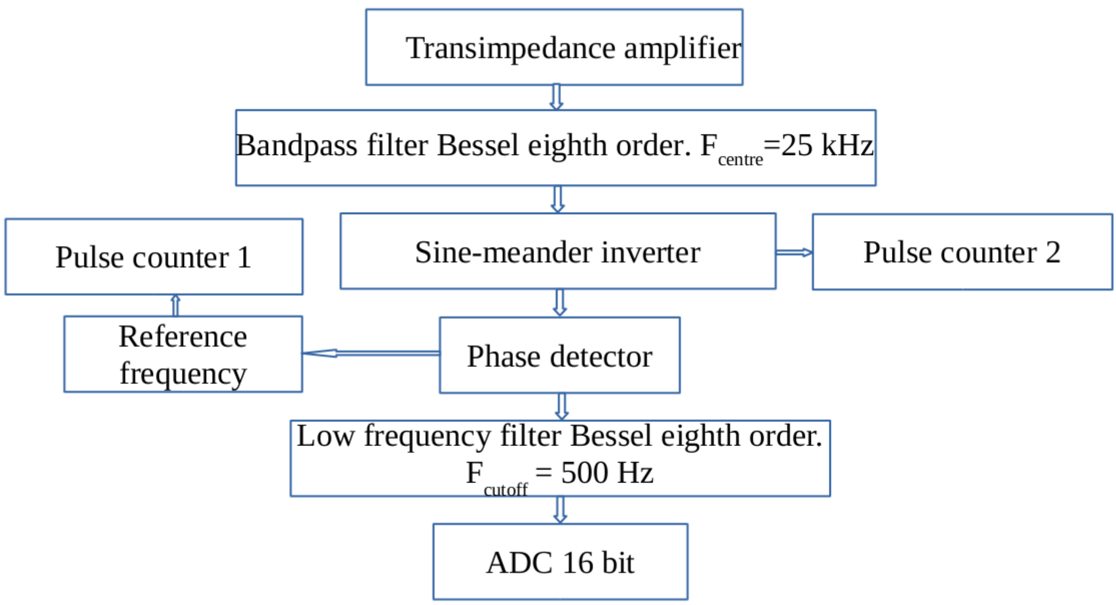

Figure 1. Block diagram of straimeter registration system.

their impact on the change of a laser beam optical path. When applying sealed vacuum-processed light guides, the accuracy for the measurement of relative deformations of the Earth's crust is 10^{-10} – 10^{-11} for best interferometers. Accuracy constraints determined by the effect of weather parameter variations are applied to the measurements carried out by "open" strainmeters without light guides. Wind, precipitation, air temperature and pressure have the strongest effect [1]. To exclude the wind and precipitation effect, we use special cover. Air pressure and temperature changes are quite slow processes which occur within several hours which allows us to make estimates of more fast deformation processes. Based on the calculated data, a strainmeter installed in such conditions has the accuracy of relative deformation measurements not less than 10^{-8}. As the observation results show, during the deformations of such order and more, the effects in sedimentary rocks generate acoustic signals in the frequency range from tens of hertz to the first ten of kilohertz [2–4].

Since 2007, the Laboratory of Acoustic Research of the Institute of Cosmpphysical Rasearch and Radio Wave Propagation (IKIR) FEB RAS has carried out geodynamic observations of the near surface sedimentary rocks as they are characterized by weak strength, high plasticity and are the most available to investigate deformation processes [3]. A laser strainmeter-interferometer of unequal-type constructed according to Michelson interferometer scheme developed at TOI FEB RAS was used to register deformations until 2013 [2, 4].

Due to the breakage of some key elements, a new strainmeter-interferometer was developed at the Laboratory of Acoustic Research of IKIR. It was constructed according to the same optical scheme and was put into operation in 2016. The block diagram of the strainmeter registration system is shown in Fig. 1.

The electric signal corresponding to the change of light intensity in the interference pattern is formed on a photodiode which is thereupon transformed into voltage and amplified on a transimpedance amplifier. A frequency range carrying the useful information is separated from the spectrum of the obtained electric signal by a band filter of the 8-th order. The pick of a pass band corresponds to the modulation frequency of 25 kHz. Then a signal is transformed into a square signal as long as the amplitude in this case does not carry any useful information. After the transformation, the signal comes to a pulse counter 2 and on input 2 of a phase detector. The reference signal modulating the phase shift between the reference and the measuring laser beams comes to the pulse counter 1 and on input 1 of the phase detector. The phase detector generates a signal proportional to the phase difference within 2π between the reference and the interference signals. The number of phase shift transitions across 2π is determined by the difference of readings of pulse counters 1 and 2. To digitize a signal formed by the phase detector, we use a 16-bit ADC together with LF filter of the 8-th order with the cut-off frequency of 500 Hz. The ADC sampling rate is 1 kHz.

In the result of digitization, two files are formed in a PC. One of them contains a signal from the phase detector. The other contains the number and the direction of phase transition across 2π. Then, taking into account the data of phase transitions, a processing program removes them from the initial signal of phase detector and forms daily files of absolute deformation changes.

It is generally accepted in data interpretation to apply dimensionless quantities of relative deformations that is why the data on graphs are shown relatively a strainmeter gauge length. In the analysis of weather parameter effects, we used the data from a temperature sensor fixed directly on the basis of the strainmeter optical system and from a weather station located at the distance of 20 m from the strainmeter. Such parameters of the environment as air temperature, humidity, and pressure change slowly during a day and do not affect fast deformation processes. Wind velocity makes significant effects on the strainmeter readings which appear as increases of signal amplitude oscillations.

3 Results of the investigation

The main direction in the investigation of near surface sedimentary rock deformations is the relation of local deformation process and its derivatives, such as generation of acoustic emission, near ground electric field changes and so on. In the previous papers of the author [2–5] such a relation was confirmed. Thus, in the construction of the strainmeter, a simple scheme of strainmeter-interferometer of the first generation with a frequency-stabilized laser was chosen.

Fig. 2 and 3 show examples of registration of seismic events of different energy classes which occurred at about the same distance from "Karymshina" observation site. To determine the earthquakes characteristics, the data of Kamchatka Branch of the Geophysical Service RAS were applied.

The strainmeter data are shown with the recording frequency of 1 kHz. The second channel of registration is used to display the data. Geoacoustic emission signals are registered with the frequency of 44 kHz. Fig. 2 and 3 illustrate only its low-frequency part. It is clear from the figures that the most powerful earthquake has the strongest signal at both measurement systems. These data allow us to estimate the correctness of adjustment and operation of the strainmeter registration system.

In the case of the earthquake on March 14, 2016, an increase in the deformation process rate was observed. A hydrophone installed in the intermediate vicinity from a reflector of the strainmeter measuring arm registered the increases of the amplitude and the number of acoustic pulses in the frequency range of 70-200 Hz (Fig.4). No wind, precipitation, sudden changes of air pressure and temperature were registered during this period. It allows us to consider this case as a local process of stress accumulation in rocks before the earthquake.

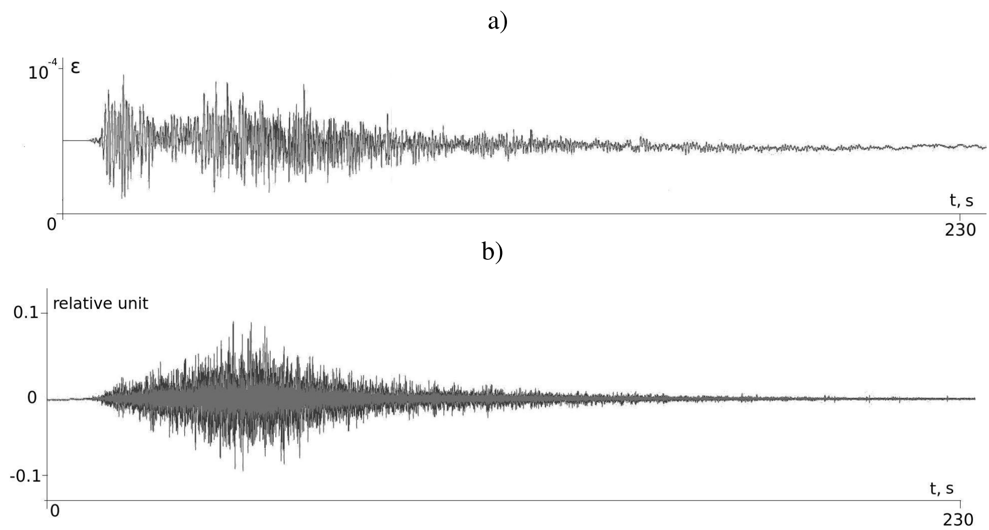

Figure 2. Seismic event on January 30, 2016 at 03:25 UT, energy class is 15,7, distance to the station is 129 km. a) Strainmeter, b) Geoacoustic emission.

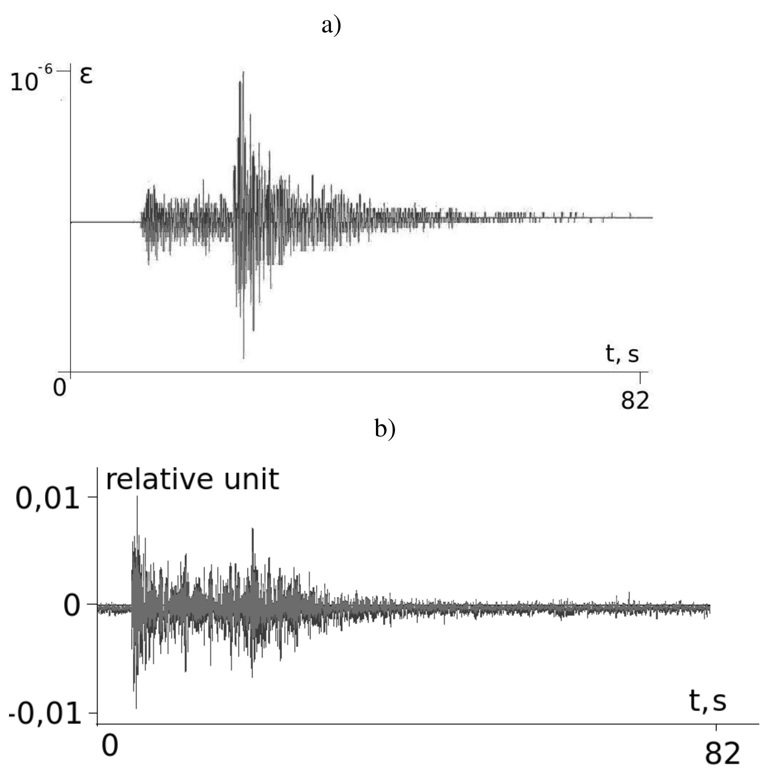

Figure 3. Seismic event on March 14, 2016 at 21:50 UT, energy class is 11,2, distance to the station is 133 km. a) Strainmeter, b) Geoacoustic emission.

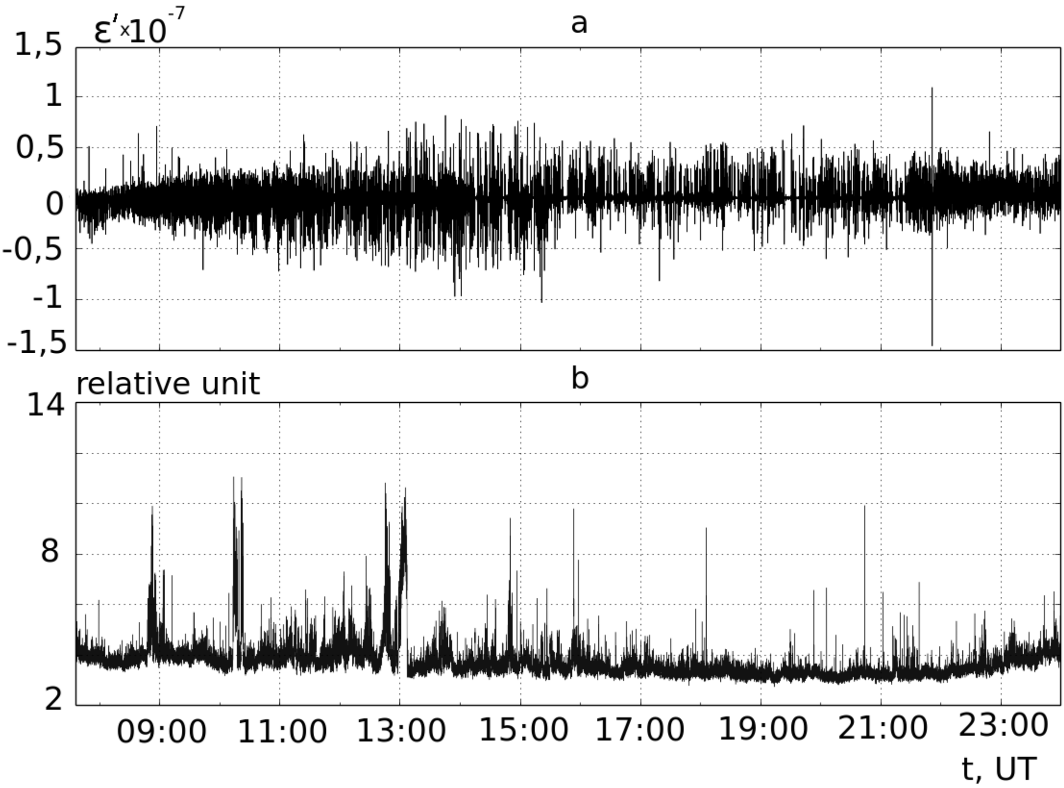

Figure 4. Period from 7:30 to 24:00 UT on March 14, 2016. a) Deformation rate, b) Geoacoustic emission in the frequency range of 70-200 Hz.

4 Conclusions

Thus, it has been shown that deformation measurements at "Karymshina" observation site have been resumed to their full extent which allowed us to investigate deformations at different stages of seismic activity during fair weather conditions.

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