Geophisical Applications of Laser Interferometers: Long-Term Monitoring Crustal Deformations

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Abstract

The wide-band laser interferometer with a measurable armlength of 75m is used for monitoring crustal deformations in the North Caucasus (Russia). Unique geodynamical features of the region, the proximity of the Elbrus volcano and existing long-term wide-band and high-quality observed time-series of deformations allow to study a wide class of geophysical phenomenae.

1. Introduction

A wide frequency range of the laser interfrometric gravitational antennae opens the possibility for an additional "geophysical" use of the device for observations and measurements of global geodynamical processes, seismic events and tidal deformations. In this case the gravitational wave interferometer was considered as a differential tiltmeter in the very low frequency range $10^{-3} - 10^{-5}$ Hz, what is placed far from the zone of gravitational wave interest, $10 - 10^{3}$ Hz. This "double use" of the laser interferometric antennae was proposed and calculated at Sternberg Astronomical Institute of Moscow University [1]. The realization of the "geophysical application" of the gravitational interferometer has to be provided by a deep underground location of the device where low-frequency noises are strongly suppressed.

Sternberg Astronomical Institute has designed and implemented a long-base laser interferometer which has been installed in the underground tunnel of the Baksan Neutrino Observatory (the North Caucasus, Russia).

The northern part of the Great Caucasus Ridge is one of the most active in geodynamic respect among the Russian regions characterized by intensive movements of the Earth's crust. The recent studies give evidence concerning high vulcanic hazard of Caucasus region. The greatest European volcano, Elbrus, is supposed to be classified as an active volcano with clearly dated historical eruptions in the Holocene.Therefore the region of the interferometer location is the unique natural "proving ground" for geophysical researches.

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2. Baksan Laser Interferometer (BLI)

The optical scheme of interferometer is the two passes (N=2) Michelson-type interferometer with unequal arms working in regime of space separated beams. The measurable arm lies along the tunnel and has the length 75 m, the length of small (reference) arm is 0.3 m The mirrors and the beam splitter are placed in vacuum tanks, which are installed on concrete foundations untied from tunnel's bottom and rigidly connected with the fundamental rock. The light source used is the commercial frequency-stabilized He-Ne laser, the radiation wavelength is 0.63 μm, the power output is 2 mW. The radiation of the laser is modulated at the frequency of 60 kHz.

The read-out system provides the monitoring of the interferometer output signal in a wide frequency band, from ultra low frequency up to thousands Herz, in the three channels: the low-frequency channel (from 10^{-6} up to 0.1 Hz); the seismic channel (in the bandwidth of 0.5 Hz around 30 Hz, the monitoring of quadrature components); and the high-frequency channel (in the bandwidth of 0.5 Hz around frequency 1.62 kHz) [2].

3. Observation of Free Oscillations of the Earth

For the first time the free oscillations of the Earth (FOE) have been observed for great earthquakes in Kamchatka (1954), Chile (1960), the Kurile Islands (1963) and Alaska (1964). The evolution of both instrumental techniques and analytical methods made possible to observe the excitation of free oscillation due to earthquakes with magnitude as small as 6.

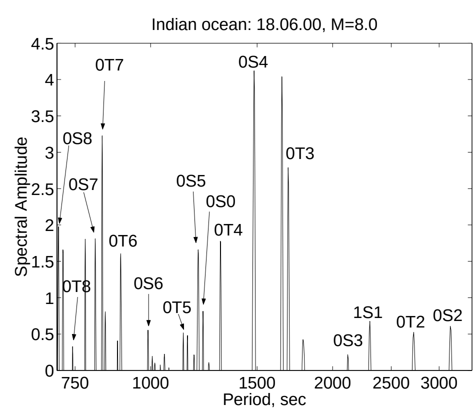

Fig. 1. Amplitude spectrum of FOE excited by Indian Ocean earthquake

From the large number of seismic events, which were registered by BLI during 1999-2000, four earthquakes were selected and analized: South Indian Ocean (18.06.2000, Mw 8.0); Sakhalin Island (04.08.2000, Mw 6.8); the Eastern

Table 1. Observed periods of FOE excited by earthquakes: (1) Turkey, (2) Eastern Caucasus, (3) Sakhalin, (4) Indian Ocean. $P_{obs} - P_{th}$ is difference between observed and theoretical values.

Spheroidal oscillation			Toroidal oscillation		
mode	P_{obs}	$P_{obs} - P_{th}$	mode	P_{obs}	$P_{obs} - P_{th}$
${}_0S_0$	$^{(3)}1225.8 \pm 4.6$	-3.0			
${}_0S_2$	$^{(3)}3224.6 \pm 15.2$	-1.3	${}_0T_2$	$^{(4)}2618.3 \pm 13.7$	-11.0
${}_0S_3$	$^{(2)}2144.5 \pm 5.5$	+8.9	${}_0T_3$	$^{(2)}1706.2 \pm 3.9$	+4.2
${}_0S_4$	$^{(3)}1546.2 \pm 3.5$	-1.0	${}_0T_4$	$^{(4)}1304.4 \pm 2.1$	+0.7
${}_0S_5$	$^{(2)}1200.1 \pm 3.8$	+8.7	${}_0T_5$	$^{(4)}1072.3 \pm 1.8$	-3.4
${}_0S_6$	$^{(3)}965.2 \pm 1.1$	+0.9	${}_0T_6$	$^{(2)}926.3 \pm 1.7$	+0.5
${}_0S_7$	$^{(1)}813.0 \pm 1.3$	+0.5	${}_0T_7$	$^{(2)}819.2 \pm 0.8$	+0.9
${}_0S_8$	$^{(2)}710.0 \pm 0.8$	+2.1	${}_0T_8$	$^{(2)}736.8 \pm 0.7$	+0.1
${}_0S_9$	$^{(4)}634.5 \pm 0.7$	+0.6	${}_0T_9$	$^{(4)}671.4 \pm 0.6$	-0.6
${}_0S_{10}$	$^{(2)}580.2 \pm 0.5$	+0.8	${}_0T_{10}$	$^{(1)}620.0 \pm 0.8$	+0.8

Caucasus (25.11.2000, Mw 6.3); and Turkey (17.08.1999, Mw 7.6). For estimate of free oscillation mode parameters (frequencies, RMS, Q-factors) the special method of analysis were developed [3]. The parameters estimates were founded for each pointed earthquake. Table 1 contents the observed periods of spheroidal and torsional fundamental modes with $n \leq 10$. The spectrum of the low frequency modes estimated for the Indian Ocean earthquake is shown in Figure 1.

4. Studying Resonant Properties of Magmatic Structures of the Elbrus Volcano

Geophysical and geological researches carried out in Elbrus region confirm the existence of some low-density zone in the crust at the dept of 20-30 km. This zone may be associated with upcoming from the asthenosphere melted material that accumulates in a shallow magmatic structures within the upper crust. Upon incidence of a broadband seismic signal (for example, from strong earthquakes), mentioned structures are responsible for generation of secondary seismic wave fields containing information about resonant properties of inhomogeneities [4]. Therefore monitoring resonant effects, accompanying low-frequency seismic influence upon magmatic structures from distant earthquakes provides experimental data needed to understand dynamic of volcanic processes.

Lithosphere deformations caused by 44 distant earthquakes with magnitude >Mw 6.7 (Mw - moment magnitude) and registered by BLI during 1998-2001 were studied and analized. In Figure 2 is shown typical spectrums for the

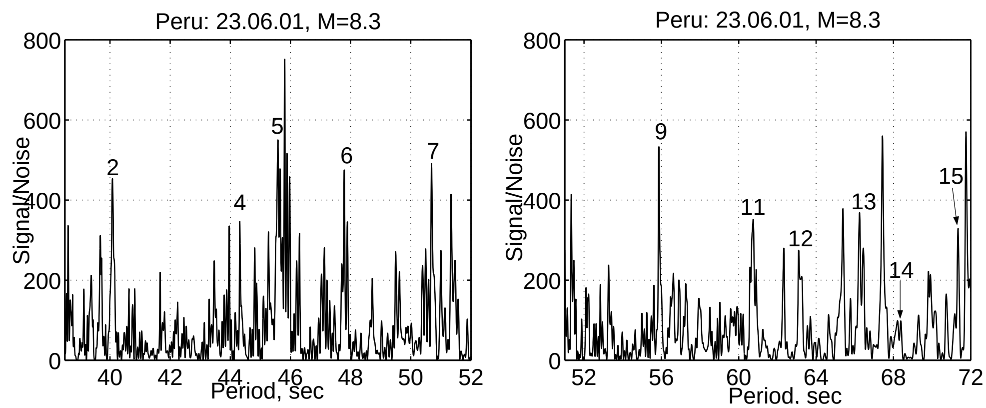

Fig. 2. Resonances of geophysical media excited by Peru earthquake. The numbers indicate resonances which can be associated with magmatic structure of Elbrus.

great distant earthquake with significant signal to noise ratio (Peru earthquake, 23.06.2001, Mw 8.3). Quantitative estimations of parameters of resonant modes in the geophysical medium at the point of observation, excited by the listed earthquakes in the frequency range 0.025 - 0.003 Hz (40-300 s) have been obtained. The resonance modes which can be associated with local inhomogeneities are summerizes in table 2 [5].

Table 2. Period values of resonance modes associated with magmatic source of Elbrus. Mode numbers correspond to numbers of spectrum peaks in Figure 2.

mode	1	2	3	4	5	6	7
Mean value, s	39.4	40.5	42.5	44.0	45.7	48.3	49.9
RMS, s	0.3	0.3	0.2	0.5	0.4	0.7	0.5

mode	8	9	10	11	12	13	14	15
Mean value, s	52.2	56.6	59.4	61.9	64.0	66.0	68.2	70.7
RMS, s	0.5	0.8	0.4	0.4	0.4	0.5	0.4	0.4

This work is supported by the Russian Foundation for Basic Research under grant No. 03-05-96053.

5. References

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