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Global deformations of the Eurasian plate and variations of the Earth rotation rate

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ABSTRACT

Strain data recorded by two laser interferometer–strainmeters operating in the Baksan (Russia) and Gran Sasso (Italy) underground observatories, and the length-of-day (LOD) data describing the variable rate of the Earth's rotation are used to study the relation between the deformation processes in the lithosphere and the global geodynamics of the Earth over short time intervals. The methods applied are based on analysis of the coherence of the studied processes, and correlation analysis. A significant (90%) correlation is revealed between the local deformation fields at two remote observation stations, which proves the existence of a global (at least on the scale of the Eurasian plate) component in the Earth's deformation field that manifests itself at characteristic time intervals of up to 1–2 months. At the same level of significance, the correlation between the local deformation fields and variations in the rate of the Earth's rotation has also been identified. The found correlations in the tidal low-frequency range are caused by the direct impact of the long-period tidal loading (M_f and M_{tm} waves) on the lithosphere and the length-of-the-day (LOD). On the contrary, the significant correlation in the non-tidal range is probably linked to irregular perturbations of the continental character, which create a coherent interference in the studied processes. The global mechanism that causes this coherent noise requires further study.

1. Introduction

The conception of the existence of large-scale perturbations of the Earth's deformation field has initially been formulated in works devoted to plate tectonics (Morgan, 1968; Le Pichon, 1968; Isacks et al., 1968). One of the conception postulates assumed the existence of deformation waves of global and regional scales which can be generated on the borders of lithospheric plates, on the lithosphere–asthenosphere contact, as a result of mutual displacements of these plates. Such deformation waves can initiate a sequence of strong earthquakes lengthways along a fault zone.

On the other hand the analysis of the relationship between the global seismicity and the variations in the rate of the Earth's rotation, or the length-of-day (LOD) variations, has shown that such a relation exists at time intervals of 3–5 years and is different at different latitudes (Gorkavyi et al., 1994). A global component caused by the diurnal variations in the Earth's rotation rate has also been revealed in the seismic process (Fridman and Klimenko, 2003).

Finally, the question of correlation between crustal deformations and variation in the LOD of the Earth has been already considered. A significant correlation was found between these processes on decadal time scales (Wang et al., 2000). Nevertheless, the question of existence of the global deformation component remained open as long as the analysis was done on the basis of strain observations from only one station.

The factor responsible for the coherent deformation processes in the lithosphere should be a global mechanism driving the changes in the stress–strain state of the lithosphere. In principle, there are only two possible mechanisms responsible for the correlation between LOD variation and crustal deformation: first, variations in crustal deformations are induced by variation in the Earth's rotation rate or LOD. Second, the correlated variations in LOD and crustal deformations all originate from the same dynamic process within or outside the Earth.

This global component of the deformation field can be recognized by the system of space separated strainmeter stations that are situated far enough from each other. In recent work by some of the authors (Milyukov et al., 2011) the relation between local deformation fields and variations in the rate of the Earth's rotation has been studied on the basis of the original data from two Russian strainmeter stations: Baksan (the Northern Caucasus) and Protvino (the Central Russian Plain). The existence of a global component in the Earth's deformation field with characteristic manifestation times of up to 3–4 weeks has been proven at the statistically significant level. The correlation between the local deformation fields and the variations in the rate of the Earth's rotation has also been identified.

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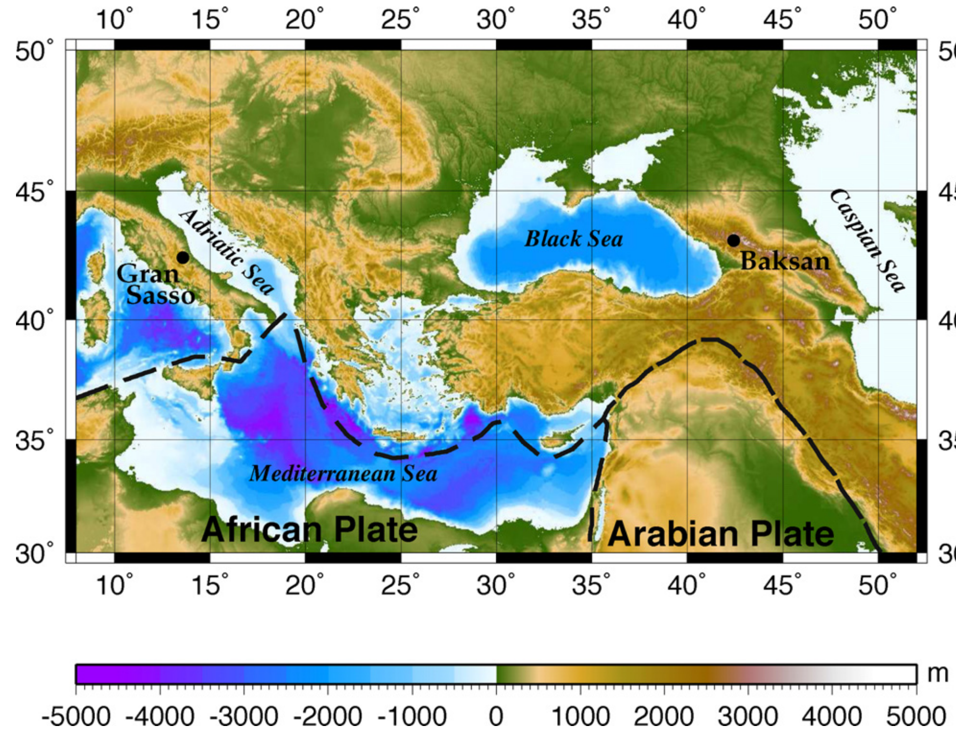

Fig. 1. Geographical positions of the stationary deformation stations Baksan (Russia) and Gran Sasso (Italy). (For interpretation of the references to color in this artwork, the reader is referred to the web version of the article.)

It has been shown that the global deformation component and the relationship between the deformation fields and LOD in the low-frequency tidal range is the severe regular long-period tidal loading (M_f and M_{tm} wave groups) that acts directly on the lithosphere and on the LOD. Thus, it is the second type of mechanism: correlation is caused by dynamic processes outside the Earth.

To further develop the work of the cited paper, in the present work we will study the relation between the local deformation fields related to the large tectonic structure, the Eurasian plate (Baksan station, Russia, and Gran Sasso station, Italy), and variations in the Earth's rotation rate. Special attention will be given to the non-tidal range of frequencies.

2. Experimental data

Original data of the lithospheric deformations were obtained by the long-base high-sensitivity laser interferometer–strainmeters operated in the Northern Caucasus, Russia (Baksan station) and in the Central Apennines, Italy (Gran Sasso station). The geographic locations of the stations are shown in Fig. 1.

Baksan station is located in the Greater Caucasus ridge, one of the most geodynamically active regions of Russia, in the Baksan gorge, 18 km from Mount Elbrus. The interferometer is mounted at a level of 650 m and a depth of 400 m inside the main gallery of the Baksan Neutrino Observatory, Institute of Nuclear Research, Russian Academy of Sciences. The coordinates of the interferometer are (43°12′N, 42°43′E) and its azimuth is 150°37′ (from north). The baseline of the interferometer is approximately perpendicular to the local direction of the Greater Caucasus.

The Baksan laser interferometer–strainmeter is a Michelson two-beam unequal-arm interferometer operating in the regime of separated beams. The length of its larger (measuring) arm is $L = 75$ m (accordingly, its optical length is 150 m), and the length of the minor (reference) arm is 0.3 m. An electronic recording system ensures operation of the interferometer in a wide range of frequencies from ultralow (limited only by the time interval of continuous observations) to thousands of hertz. In a standard regime, the lithospheric strains are monitored with five frequency channels. The instrumental resolution of the interferometer is 2.3×10^{-13} for crustal strain measurement. In terms of design and technical performance, the Baksan laser interferometer is intended for a wide range of high-precision geophysical and geodynamic measurements (Milyukov et al., 2005, 2010).

The Gran Sasso station is located in an active tectonic region in the Central Apennines in the Gran Sasso massif. As well as the Baksan interferometer, two Gran Sasso interferometers are installed beside the tunnel of the underground Gran Sasso laboratory for Particle Physics and Astrophysics (INFN – Laboratori Nazionali del Gran Sasso) at about 5 km from the east entrance and at least 1400 m under the free surface. The coordinates of the interferometers are (42°27.06′N, 13°33.79′E). Two interferometers, referred to as “BA” and “BC”, are oriented at a right angle to each other. Their azimuths are 66° (from north) and 156° respectively. The baseline “BC” is approximately perpendicular to the local direction of the Apennines and the baseline “BA” is approximately parallel to it.

Each interferometer is based on the classical unequal-arm Michelson set-up and compares the optical length (i.e. the length expressed in terms of the light wavelength) of a longer measurement arm (90 m in length) and a shorter fixed reference arm (0.2 m in length). The instruments are characterized by instrumental resolution $\approx 3 \times 10^{-13}$, a wide frequency band (from DC up to hundreds of Hz), and a large dynamic range limited only by the capability of maintaining optical alignment. The interferometer–strainmeters are intended for monitoring crustal deformation processes related to a wide range of phenomena such as regional strain accumulation and release, coseismic steps, slow earthquakes, and earth tides (Park et al., 2008; Amoruso and Crescentini, 2009).

The arrangement and orientation of instruments and their technical characteristics are identical in many aspects. The laser interferometer–strainmeters are mounted in underground observatories, and the azimuth of the Baksan interferometer coincides practically with the direction of the Gran Sasso “BA” device whose