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Earth crust motion and deformation analysis based on space geodesy methods

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Natural geodynamic processes in the Earth crust become apparent as different types of movement. These movements can be regular when different strata move along fault lines on a local scale or along boundaries of tectonic plates on a continental scale. They can also be abrupt and have the form of earthquakes and other major seismic events. Both forms of movement are irreversible, and thus they can be called deformations. Analysis of Earth crust motion and deformations can be performed by means of seismic soundings, strain-meter and tilt-meter readings, and geodetic methods which are the most significant ones. Geodesy plays a key role in crustal deformation studies by determining the temporal variations of the Earth shape and size at various spatial and time scales. Among modern geodetic methods space geodesy applications are of most importance. Among the latter Global Positioning Systems NAVSTAR-GPS and GLONASS should be pointed out. Current research corresponds an overview of certain GPS applications for Earth crust motion and deformation analysis and geodynamical and geophysical solutions. *KEYWORDS:* geodynamics, space geodesy, crustal deformation analysis, CGPS.

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Natural geodynamic processes in the Earth crust become apparent as different types of movement. These movements can be regular when different strata move along fault lines on a local scale or along boundaries of tectonic plates on a continental scale. They can also be abrupt and have the form of earthquakes and other major seismic events. Both forms of movement are irreversible, and thus they can be called deformations.

The analysis of Earth crust motion and deformations can be performed by means of seismic soundings, strain-meter and tilt-meter readings, and high-accuracy geodetic methods which are the most significant ones. Geodesy plays a key role in crustal deformation studies by determining the temporal variations of the Earth shape and size at various spatial and time scales [*Antonovich,* [2006]. Global Navigation Satellite Systems (GNSS) NAVSTAR-GPS and GLONASS should be pointed out among modern methods of space geodesy.

These methods have become conventional for monitoring and measuring long-term (in the course of a year to decades) deformations of Earth crust at local, regional, and global scales. Such methods include various standard techniques. The most preferred ones for measuring crustal deformations, caused by earthquakes and volcanic activity, are Continuous GPS measurements (CGPS) and Interferometric Synthetic Aperture Radar (InSAR). CGPS methods have been used for measuring aseismic slow earthquakes and the long period components of seismic shaking from large earthquakes [*Langbein and Bock,* 2004].

In contrast to classical geodetic techniques and methods (linear and angular measurements, leveling) GNSS, which in some aspects cannot provide sufficient accuracy (e.g. vertical component determination), has apparent advantages – high operability and efficiency, all-weather survey, high automation rate, etc. But the most significant advantage of this space geodesy method, which is vital for crustal deformation monitoring, is its high temporal resolution [*Dermanis and Kotsakis,* 2005].

Thus GNSS provides continuous monitoring of the Earth crust at regional and global scale. Global monitoring is performed by the International GNSS-Service (IGS). Precise geocentric Cartesian coordinates and velocity components are provided for the stations of the network. IGS also pub-

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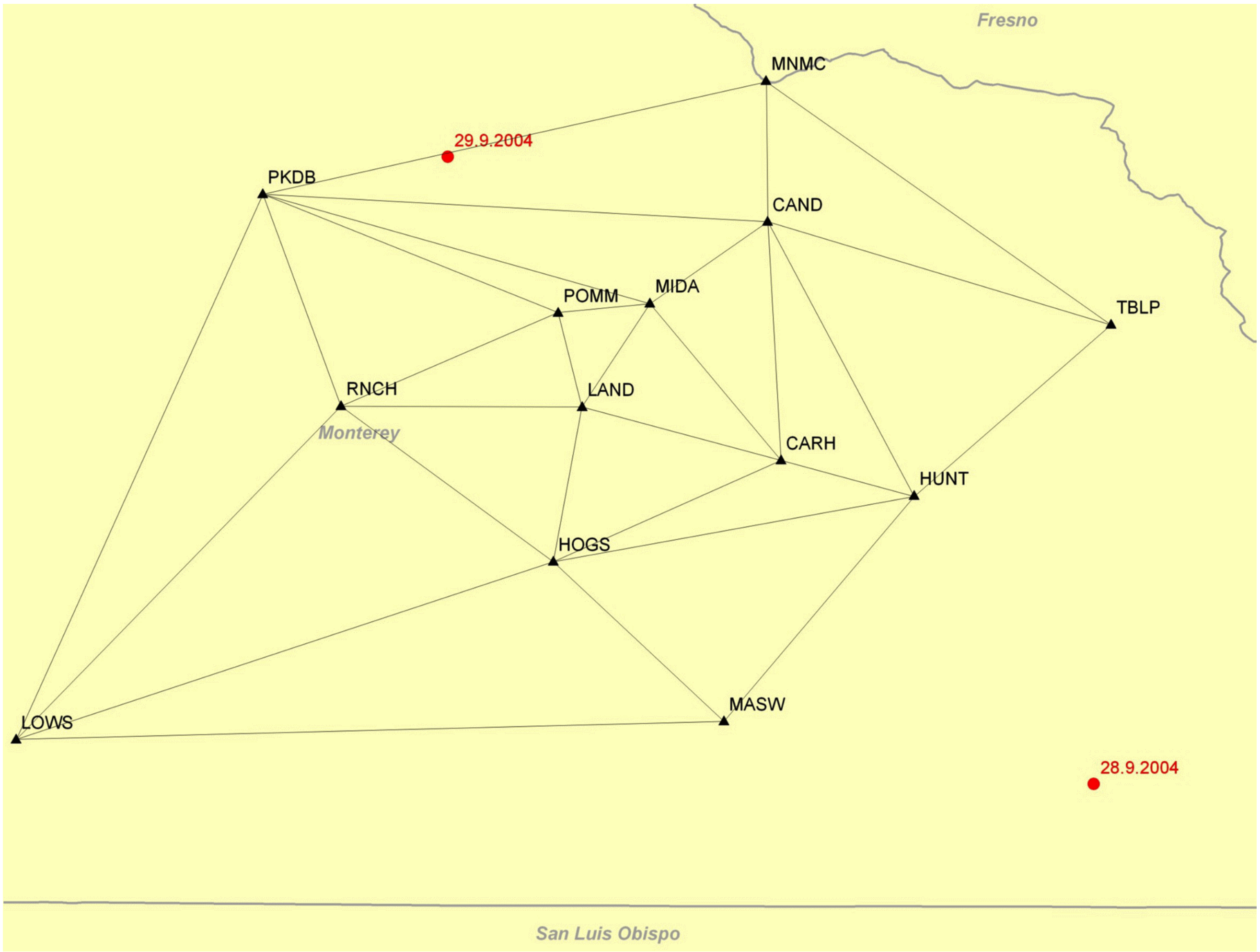

Figure 1. Network of 13 CGPS stations in the vicinity of Parkfield, California.

lishes different "products" including GPS satellites' precise ephemeris and Earth rotation parameters.

As an example of regional GNSS services with well-developed infrastructure two networks should be marked out – Southern California Integrated GPS Network (SCIGN) in the US and National GPS Array (NGA) in Japan. Apart few IGS and EUREF stations and several departmental and commercial GNSS networks crustal deformation monitoring within the territory of Russia is provided by the Northeast Eurasia Deformation Array (NEDA) [*Antonovich,* [2006].

Being a seismically active region with a dense CGPS array of networks Southern California in the US is a preferable region for crustal deformation analysis. For the effective response following the 16 October 1999 Hector Mine earthquake, M=7.1, the mentioned above SCIGN array should be pointed out. The interseismic station velocities, coseismic positional jumps and postseismic transient deformations were efficiently detected by SCIGN station [*Hudnut et al.,* 2001]. This network provides valuable data required for geophysical modeling of deformation processes occurring within certain seismic events.

Within the author's thesis work a network of 13 continuously operating GNSS stations is analyzed. These stations were installed near the town of Parkfield, California, by PBO (Plate Boundary Observatory). The selected network is dense (baselines 1–14 km) and its stations are located on the both sides of the San-Andreas Fault. On 28 September 2004 a large earthquake, M=6.0, occurred in this region [*Johnson et al.,* 2006]. The earthquake focus was located in the vicinity of the selected network. Moreover, the network stations have been operational for a long period of time which enables the analysis for this region for several years before and after the earthquake. 30 baselines were selected to obtain an even network of triangles (Figure 1).

Previous analysis of geodetic stations' displacement vectors of a geodetic quadrangle within the selected network showed a peculiar phenomenon of dispersive signal-to-noise ratio growth as approaching the earthquake [*Dokukin and Kaftan,* 2008]. This result enabled further research into the deformations prior to significant seismic events in this region in order to define spatiotemporal laws of their progress.

RINEX files downloaded from the SOPAC (Scripps Orbit and Permanent Array Center) ftp-server were processed. Daily measurements were taken with a five-day interval. The analyzed period included five years since 2002 to 2006. Measurements were processed with Topcon Tools v.7 software suite. Baselines were processed independently without adjustment. As a result vector components in WGS-84 system and their covariance matrices were obtained.

Further process includes baseline increments calculation and adjustment. Then deformation tensor components are to be defined using finite elements method. Detailed analysis of these parameters is to be implied.

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