Bulgarian Academy of Sciences. Space Research and Technology Institute.
Aerospace Research in Bulgaria. 28, 2016, Sofia

APPLICATION OF SPACE TECHNOLOGIES FOR STUDIES AND MONITORING OF SEISMOGENIC ZONES

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Abstract

In the present article are presented the results of studies carried out by the author, or by teams under his supervision and participation, in different seismogenic zones in Bulgaria and abroad. The submitted cases of the application of space technologies Global Navigation Satellite System (GNSS) and Interferometry Synthetic Aperture Radar (InSAR) for investigation and monitoring of seismogenic zones manifest the significance and the advantages of these methods in determination of the regularities in the development of the tectonic processes of accumulation and release of tensions in the seismogenic zones, related to the assessment of the seismic hazard and medium-term forecast of strong earthquakes.

1. Introdution

The Global Earth Observation System of Systems (GEOSS) and Copernicus (formerly the Global Monitoring for Environment and Security – GMES) programs have as a priority the preservation of the environment and the sustainable development of the society, development of instruments for assessment, as well as methods for monitoring and prognosis.

The seismogenic zones are the regions genetically connected to historical and instrumental seismicity, which have potential seismic hazard of strong earthquakes and are identified by seismological, geophysical, and geological data. The Republic of Bulgaria is situated in an active seismogenic zone. This fact results in formulation of one of the main objectives for Bulgarian geophysical science, i.e. to study the processes occurring in these zones which lead to strong earthquakes and to undertake appropriate measures for effective counteraction. This problem is characterized with special topical degree as on a national as on a planetary scale and puts it in the category of priority research trends in the field of Earth sciences.

The application of space technologies Global Navigation Satellite System (GNSS) and Interferometry Synthetic Aperture Radar (InSAR) allow studying the seismogenic zones and the physical processes causing strong earthquakes.

The permanent and periodic high precision measurement with GNSS and the application of the InSAR are the most effective space technics for monitoring and study of the seismogenic zones.

Below are represented the results of the studies carried out during the last 20 years by the author himself, teams under his supervision, or with his participation in different seismogenic zones in Bulgaria and all over the world.

2. Monitoring of the seismogenic zone in the region of Sofia city

The region in south of Sofia city is revealed in structure-geomorphologic, tectonic and seismic approach seismogenic zone where could be expected strong earthquakes [1]. This zone is connected to the so-called *Vitosha fault* dividing *Vitosha* morphoblock from the absorbed under neogenic sediments complex broke up Sofia graben. The surface manifestations of *Vitosha* and *Lozen* faults are presented on the space image by appointed with InSAR method relatively vertical deformations and the network for GNSS monitoring (Fig.1).

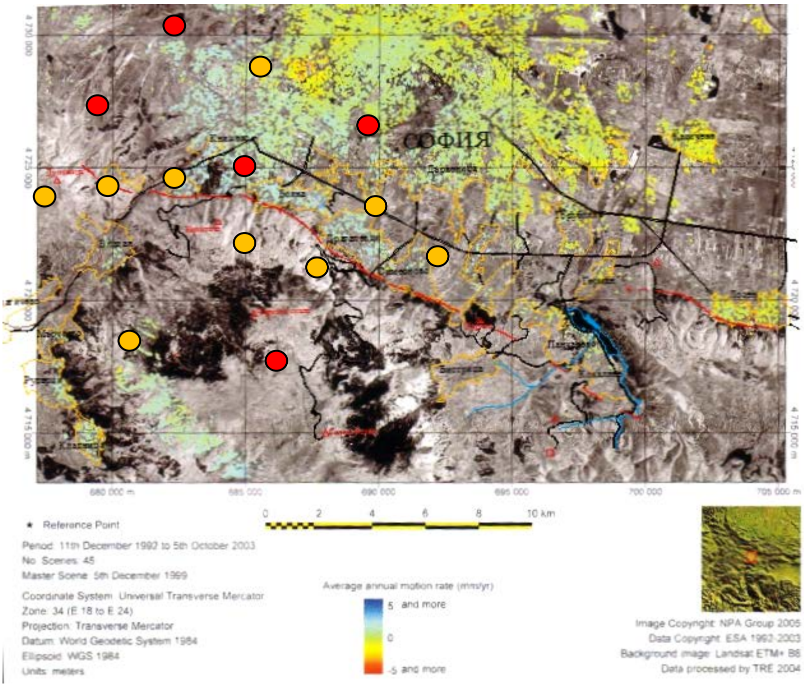

Fig. 1. Network for GNSS monitoring of the Vitosha fault on the space image and the result of the InSAR study of the zone. The permanent GNSS stations are presented with red and the periodic measurements with orange circles.

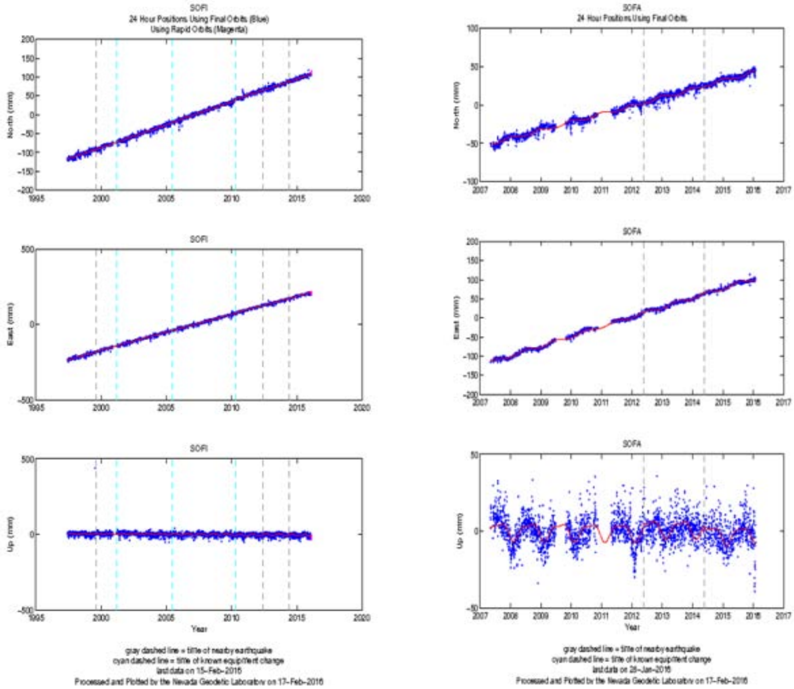

Fig. 2. Components of the absolute velocities from the permanent stations of SOFI and SOFA, on the both sides of the Vitosha fault

The obtained from the monitoring identical velocities of displacements of the permanent and periodic GPS measurement stations (Fig. 2) of the order of 1÷2 mm/yr do not testify for accumulating of considerable tectonic tensions on Vitosha fault. The data from the permanent and periodic re-measurement GPS stations in the regions provide a high-precision monitoring of the movements in this seimogenic zone in connection with the study of tectonic tensions and seismic hazard [2].

3. Studies and monitoring of the seismogenic zone Chirpan – Plovdiv

The application of the space technology GNSS for assessment of the velocities of shifting of geodetic benchmarks in the region allow to study the zone and to determine the geodetic parameters of the main faults, activated in 1928 [3] (Fig. 3). The monitoring of the zone with periodic GNSS measurements (Fig. 4) provides an assessment of the tectonic tensions. Along with paleoseismic studies allows determining the seismic cycle of strong earthquakes in the region [4].

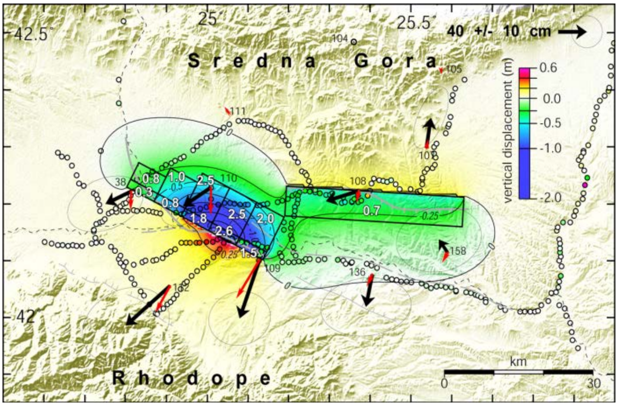

Fig. 3. Main faults, activated during the earthquakes on 14 and 18 April 1928, obtained from modeling of the co-seismic displacements determined by data from GNSS measurements (black arrows)

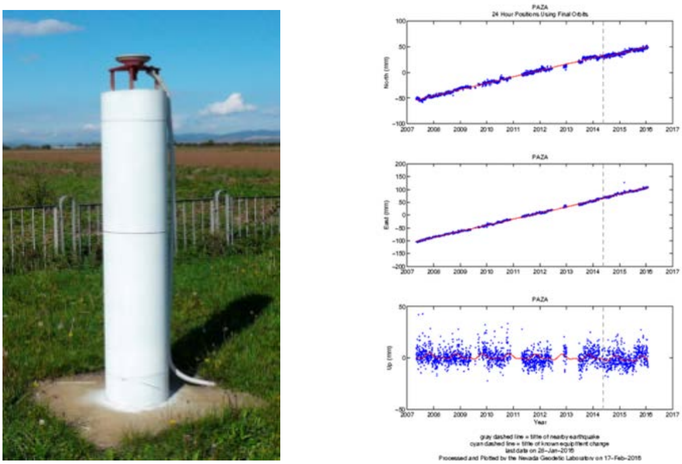

Fig. 4. On the left is a photo of permanent GNSS station in the city of Pazardzhik, and on the right is the components of its time series

4. Studies and monitoring of the seismic zone of Southwestern Bulgaria

The region of Southwestern Bulgaria is known with one of the strongest earthquakes which have struck Europe with a magnitude (M) 7.3 and 7.8 on 4 April 1904 [1]. The long standing monitoring of the zone with permanent GNSS stations and periodic measurements of the local geodynamic network around *Krupnik* fault allow to assess the regional tectonic movements and local tensions around *Krupnik* fault (Fig. 5). According to the data obtained and together with the results from the paleoseimologic studies was determined the seismic cycle of the *Krupnik* fault [5].

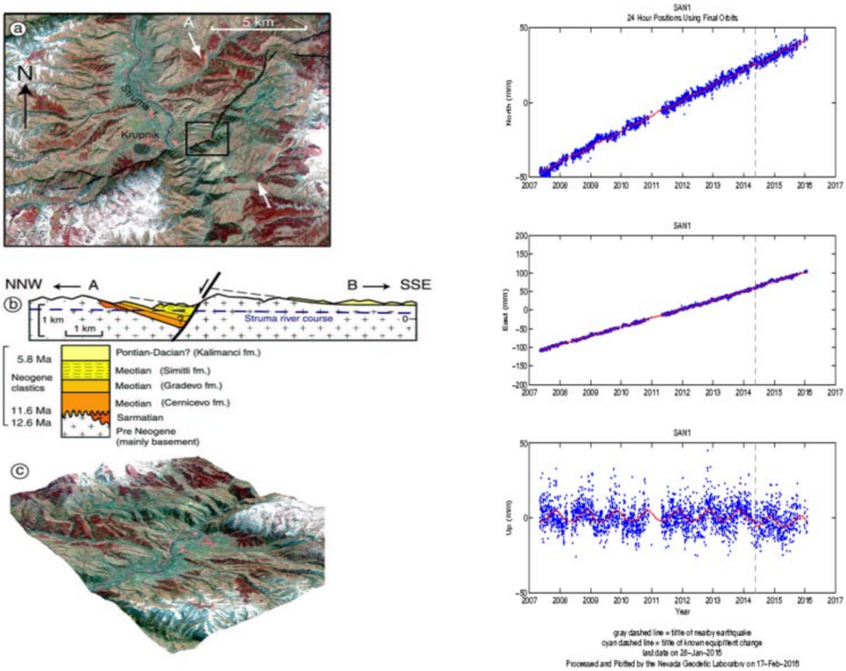

Fig. 5. The Krupnik fault mapping on a space image, geologic cross section, and components of absolute velocities of the permanent GNSS stations in the city of Sandanski

5. Studies of seismogenic zones in Central Greece

The *Corinth* Bay in Central Greece is one of the most seismologically active internal continental structures in Europe [6]. This asymmetric graben is surrounded from active faults causing many catastrophic earthquakes (Aigion, 1861 г. M = 7.0; Corinth, 1981 г. M = 6.7) [7]. Since 1991 in this seismogenic zone is carried out a monitoring of the surface deformations with GNSS network from 22 permanent and 240 periodic pre-measurement stations [8]. It was established a stretching of the bay with medium velocity of 14÷15 mm/yr [8].

5.1. For the **study of the earthquake on 15.06.1995** has been used data from the space methods GNSS and InSAR (Fig. 6). On figure 6 are presented coseismic displacements from the earthquake of 1995 of 24 benchmarks, assessed by GNSS measurements, as well as coseismic deformations from InSAR study. The modeling of the obtained coseismic displacements allows accessing the geometric seismotectonic parameters of the main faults of the main shock [2].

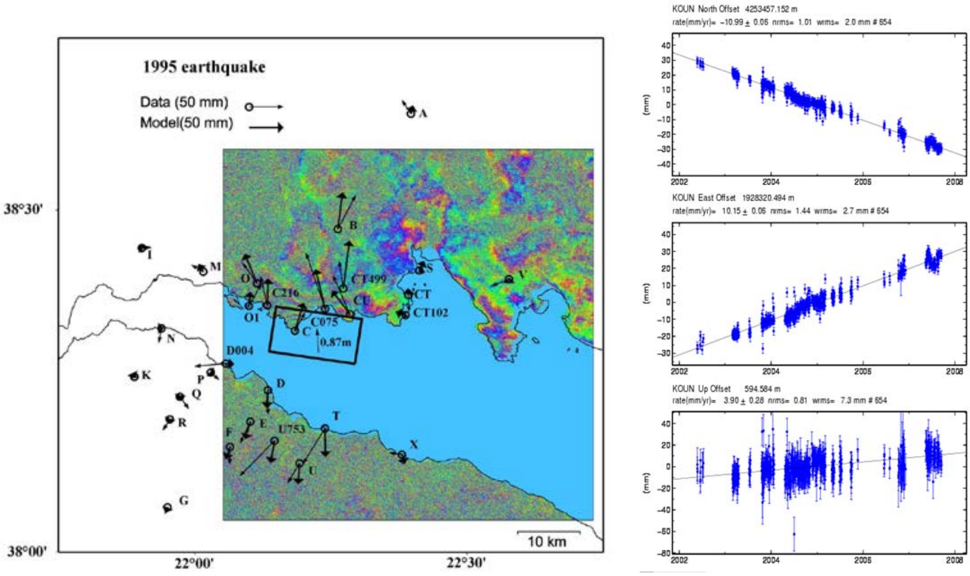

Fig. 6. The region of the earthquake on 15.06.1995 with determined by GNSS and InSAR methods of coseismic deformations. The assessed and modelled displacements are presented respectively by thin and thick arrows. On the right is presented a comparison between permanent stations on the two coasts of Corinth Bay. The space vectors between stations on the two coasts of the bay has been struck.

5.2. In the **study of the earthquake on 26.07.1996 in Konitsa M = 5.3** in Northern Greece was confirmed the possibilities of the method InSAR for the study of the physical mechanisms of medium-strong earthquakes with (Fig. 7).

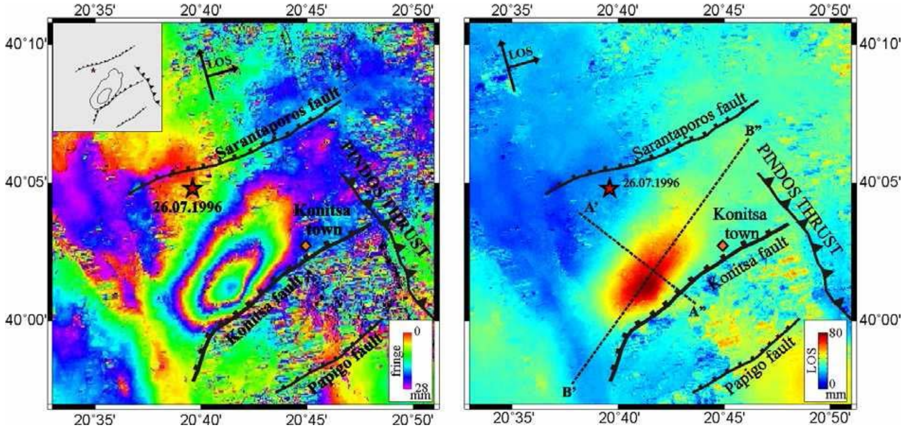

Fig. 7. Seismogenic zone of town of Konitsa and the faults activated with the assessed coseismic deformations with InSAR of the earthquake of 1996

5.3. The study of the earthquake of 2003 in Lefkada M = 6.3 with InSAR and modeling of coseismic deformations (Fig. 8) shows the possibilities of this method for assessment of the place and the seismotectonic parameters of the activated sea faults [9].

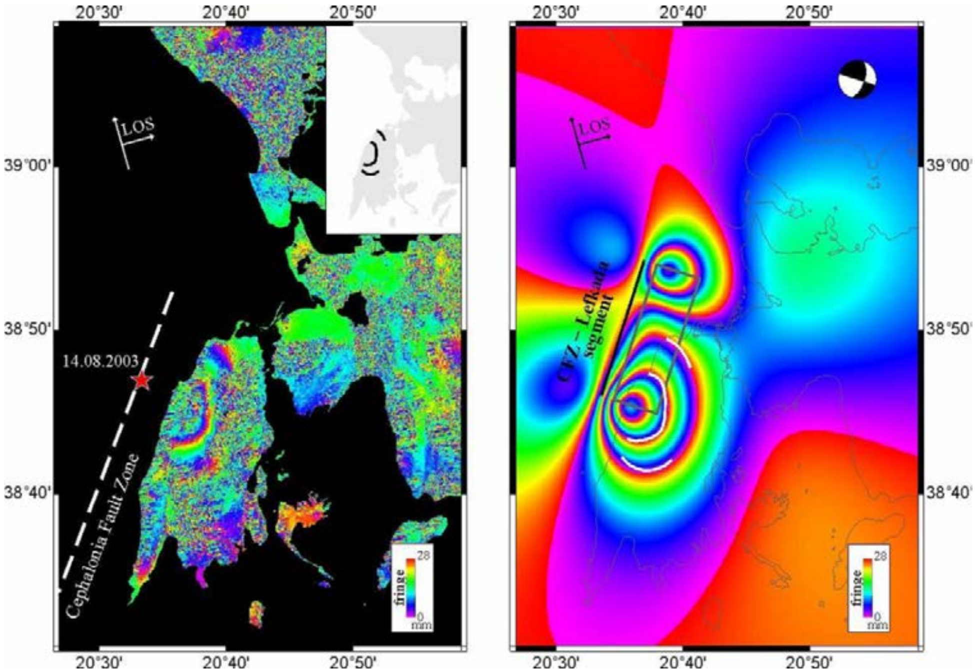

Fig. 8. On the left – Isle Lefkada with the assessed by the method InSAR coseismic deformations and the fault activated during the shock of 2003. On the right – the model of coseismic deformations.

6. Study of the zone of the earthquake of 1835 in Central Chile

The seashore line of Chile is one of the most seismogenic zones in the world. Here approximately at every ten years occur strong earthquakes with magnitude M > 8. The region is situated between 35° and 37°S and is known with its very strong earthquake in February 1835 [10] with M = 8.5 [11] (Fig. 9).

In this region was stabilized and assessed in 1996, 1999, and 2002, with a GNSS network of 41 points which allow considerable displacements of monitoring stations, reflection of the accumulation resulting from the subduction interseismic tensions.

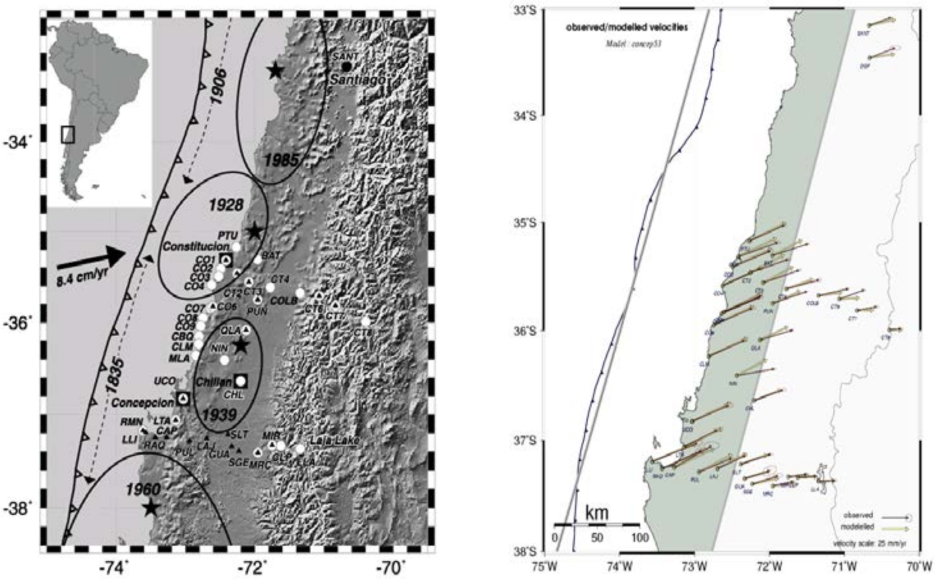

Fig. 9. On the left – Geodynamic GNSS network of 41 points in the seismogenic zone of Central Chile with the results of monitoring from 1996, 1999, and 2002. On the right (in grey) – the zone of collision of the Pacific Nazca Plate with this in South America, obtained from the modeling of interseismic displacements.

The analysis of the results from three cycles of measurements determinates considerable interseismic movements with velocity from 34 to 45 mm/yr on coastline and from 10 to 20 mm/yr on the mountain range of Andes in comparison with the stable part of the South American continental Plate (Fig. 9). Namely the considerable difference between velocities of movement of the benchmarks stabilized on the coastline and those on the mighty mountain range of Andes is the reason for the accumulation of the seismogenic tensions in the area up to the contact zone. The data obtained allow assessing exactly the place and parameters of insertion: Azimuth N 19°; gradient 16°; sliding 67 mm/yr and depth of shock 55 km. The results show that the earthquakes in this zone are not simply a kind of subduction; and between the subduction zone and the mighty mountain range of Andes are accumulated tensions, increasing the danger of a new strong earthquake [12].

According to the parameters obtained has been calculated the accumulated tectonic tension in the region of the last strong earthquake in 1835 with M = 8.5, on the basis of which was made a prognosis for an expected strong earthquake in the zone with M > 8.5 [12]. The forecast of the occurring in the study zone earthquake in March 2010 with M = 8.8 was cited in [13] as "*a good example and successful forecast of strong earthquakes on the basis of scientific data and methodology*".

6. Conclusion

The examples presented of the application of the space technologies GNSS and InSAR for study and monitoring of seismogenic zones show their importance and advantages in establishing of regularities in the development of slow and fast motions in the seismogenic zones, in revealing the developing tectonic processes and namely the accumulation and delivering of tectonic tensions, related to the assessment of seismic hazard and the forecasting of strong earthquakes.

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ПРИЛОЖЕНИЕ НА КОСМИЧЕСКИ ТЕХНОЛОГИИ ЗА ИЗСЛЕДВАНЕ И МОНИТОРИНГ НА СЕИЗМОГЕННИ ЗОНИ

Д. Димитров

Резюме

В настоящата статия са представени резултатите от изследвания, осъществени от автора или от колективи под негово ръководство или с негово участие, в различни сеизмогенни зони у нас и по света. Представените примери от приложението на космическите технологии GNSS (Global Navigation Satellite System) и InSAR (Interferometry Synthetic Aperture Radar) за изследване и мониторинг на сеизмогенни зони показват значението и предимствата на тези методи при установяване на закономерности в развитието на тектонските процеси на натрупване и освобождаване на напрежения в сеизмогенните зони, свързани с оценката на сеизмичният риск и средносрочното прогнозиране на силни земетресения.