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BALKANPROB — Space project for studying the dynamics of the lithosphere of Bulgaria and the Balkans

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I. Introduction

The present state of the space methods and instrumentation provides great potentialities for the study of the global, regional and local dynamics of the lithospheric plates [1,2]. The geodynamic processes are one of the essential precursors of natural phenomena — earthquakes, volcano eruptions, tsunami etc. resulting in the devastation of vast regions and taking a lot of human victims [3,4].

The achieved milimeter accurateness in determining the position of the points from the Earth's surface in the horizontal and vertical direction by laser location of Artificial Earth Satellites (AES), radiointerferometry with very long bases (RIFVLB), and global positioning systems (GPS) provide great potentialities for the study of geodynamic processes, and the study of the correlation of these processes with natural phenomena. This made it possible in the recent years to develop a number of international space projects aimed at the study of the regional shift of the lithospheric plates. Some of these projects are: "WEGENER-MEDLAS" of the West Space Agency (WSA) [6] and "IDEAL" (Study of the Dynamics of Euro-Asian Lithosphere)of the East Space Associasion (ESA) [7,8]. Later, the two committees concluded a contract for joint measurements, processing and interpretation of the results obtained under these two projects.

II. The IDEAL Space project — concept, theoretical provision, and model studies

The development of the project started in 1983 [7—15]. Later, INTERKOSMOS and KAPG adopted it for collaboration between the Eastern

European academies of sciences in the field of global geophysics and space study of the dynamics of the Euro-Asian lithosphere. To this end, the following observatories were appointed on the stable parts of the lithospheric plates of the Alpo-Himalayan orogene: Zvenigorod, Kiev, Riga and Potsdam – for the European zone, and Hart, Heluan and Fort Lami – for the African zone, as well as four stations – Plana, Erevan, Simeiz and Pents – in the mobile belt between the two stable plates (Fig. 1). By measurement, the vectors between the observatories from the mobile and the stable lithospheric plates and their respective yearly modifications with time and space by which the shifts of the mobile plate are characterised.

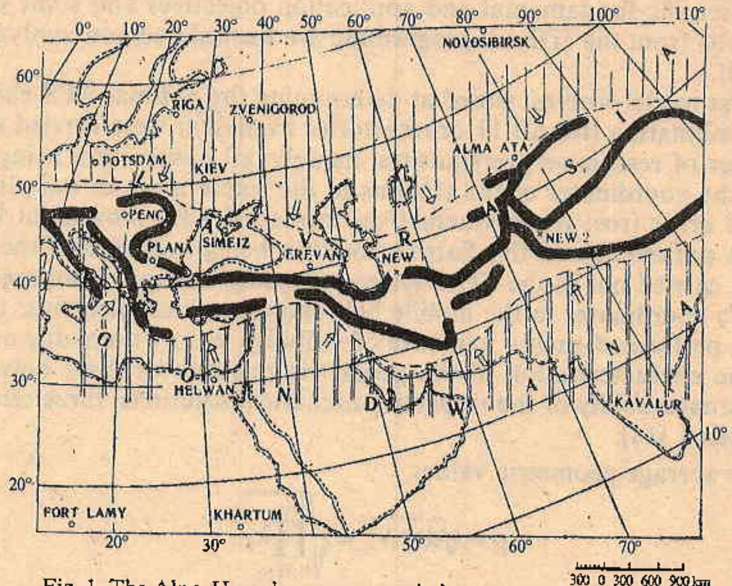

Fig. 1. The Alpo-Hymalayan orogene belt

The region, suggested for studying, comprises part of the Mediterranean Transasian mobile belt which is very interesting in the scientific and practical respect. According to the concept of the new global tectonics, the differential shifts, the significant deformations related with them, and the great tectonic and seismic activity in the Alpo-Himalayan orogene belt result from the complex structural interaction of several big lithospheric plates: the Eurasian – to the north, the African, Arabian, and Indonesian – to the south, and Tibet and Iran – to the east. The shift of the mobile belt thus outlined (Fig.1) is about 5cm/year while to the west, in the region of Gibraltar and the Azores, the shift is 1–1,5cm/year. The greatest shift is the shift of the Turkish lithospheric plate, bordered to the north by the Anadol fault which progresses at the rate of 11cm/year. The whole area is characterized by great deep-focus seismic activity centered concentrated around its northern and southern boundary [16]. The latter fact provides grounds to forward the hypothesis for the availability of two active modern subduction processes in South-Eastern Europe, namely:

i) Gondwan below Laurasia where deep-focus seismic and modern genetic activity is generated in Italy, along the south-west border of the Balkan peninsula, and in the region of the Aegian Sea.

ii) the East-European platform below the northern boundary of the Alpo-Himalayan orogene, generating deep-focus earthquakes.

Having in mind the great distance between the stable parts of the lithospheric plates around the mobile belt (about 2000 km), the belt's width (about 1000 km in the region of the Eastern Mediterranean), the availability of significant sea and mountain obstacles, as well as the modern means for high-precision laser location of AES, the IDEAL project was developed based on the laser observatories, located on the mobile and stable lithospheric plates of the Alpo-Himalayan orogene belt (Fig.1).

The scientific-fundamental and application objectives and some of the expected results from the IDEAL programme are formulated and analyzed in detail in [7-15].

The first model studies, aimed at determining the optimal AES-earth observatories combination (for all 11 observatories available) were carried out based on a number of restrictive prerequisites, namely: all observation being of equal precision; the coordinates of the stations in the stable areas of the plates being known and error-free; the mathematical model of AES movement being adequate; the parameters of the Earth's rotation being known and the observations being carried out in the TU 1 system; the only unknown parameters being the station's coordinates in the mobile belt and the orbital elements; the observations are performed each 4 s in case of visibility, at any time, day or night.

For the characterization of the geometric qualities of these networks and for the internal stability of the respective numerical solutions, three criteria have been suggested [14]:

1. The average geometric value:

(1) $$\rho = \sqrt[r]{\det N_r} = \sqrt[r]{\prod_{i=1}^{i=r} \lambda_i}$$

of the matrix's characteristic λ_i numbers

(2) $$N_r = \left\| a_{ij} \right\|; i, j = 1, 2, \ldots, r$$

of the normal equations.

2. Tod's number

(3) $$P = \lambda_{\max} / \lambda_{\min}$$

for the Matrices' N_r substantiation

(4) $$N_r^{-1} = \left\| b_{ij} \right\|; i, j = 1, 2, \ldots, r$$

3. Turing's number

(5) $$M = M(N_r).M(N_r^{-1})/r$$

for the matrices' N_r and N_r^{-1} provision, where the so-called M-normes are represented:

(6) $$M(N_r) = r.\max_{i,j} |a_{ij}|$$
$$M(N_r^{-1}) = r.\max_{i,j} |b_{ij}|$$

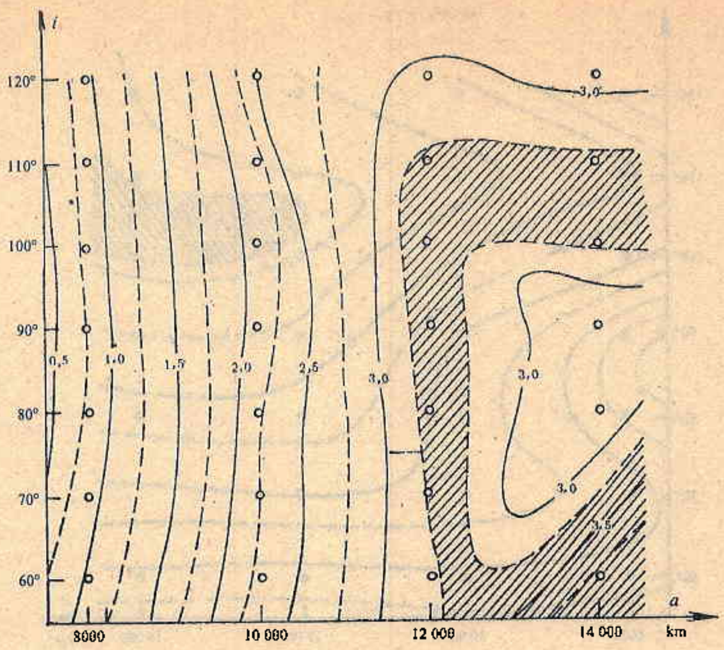

Fig. 2. Map of the values $\rho.10^2$ for the mean-geometric estimate ρ of the eigenvalues of the matrix N of coefficients of the normal equations

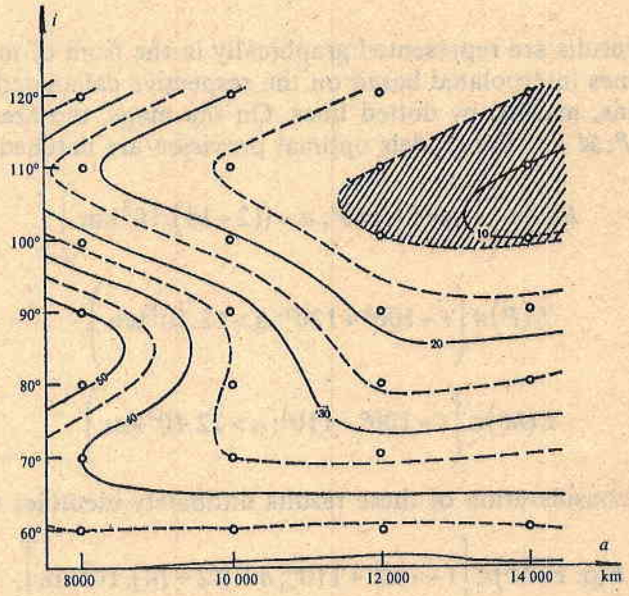

Fig. 3. Map of the values $M.10^{-7}$ for the Turing's M-condition number of the matrix N of coefficients of the normal equations

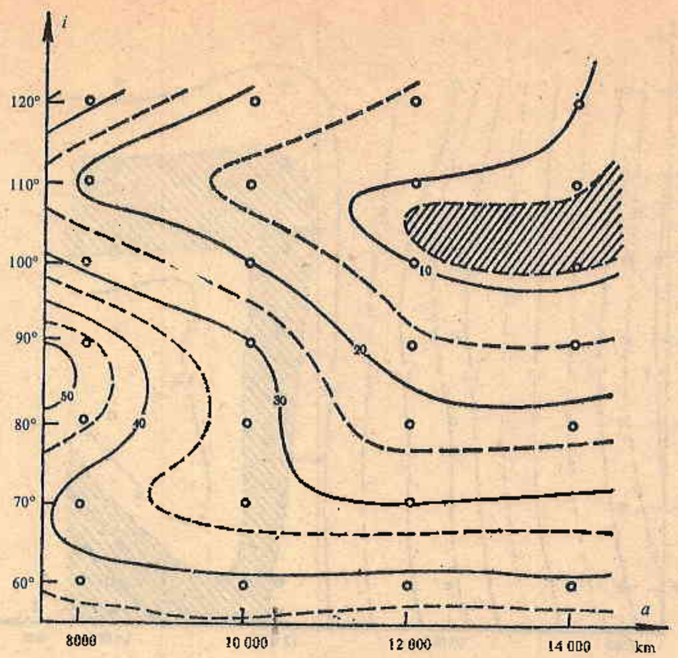

Fig. 4. Map of the values $P.10^{-6}$ for the Tod's P-condition number of the matrix N of coefficients of the normal equations

The obtained results are represented graphically in the form of maps (Figs 2, 3, and 4) by isolines interpolated based on the respective calculated values of the variant solutions, marked by dotted lines. On the maps, the areas $E(k)$ of the criteria $k = \rho, P, M$ for the models optimal provision are hatched, namely:

$$E(\rho) \in \left(i \sim 60° \div 110°;\, a \sim (12 \div 14).\, 10^3 \text{km} \right), \tag{7}$$

$$E(P) \in \left(i \sim 100° \div 120°;\, a > 12.10^3 \text{km} \right), \tag{8}$$

$$E(M) \in \left(i \sim 100° \div 110°;\, a > 12.10^3 \text{km} \right). \tag{9}$$

The joint consideration of these results ultimately identifies the area:

$$E(\rho, P, M) \in \left[i \sim 100° \div 110°;\, a \sim (12 \div 14).\, 10^3 \text{km} \right], \tag{10}$$

where: i and a are the orbit's slope and big semi-axis, respectively.

Without going into any further details, we shall mention, that more than 70 more graphs, maps and tables [7—15] allowing to determine the amount of observations, optimal conditions and precision, needed to be provided by the laser distancemeters for the averagequadratic error to be $m_k \leq 3{,}5$ cm.

Based on the results, obtained by the model studies, the conclusion was made that, if 1,5—2 month-long observation sessions be made, in 3—4 years it will be possible to determine platform shifts of the order of 1 cm. These were the grounds for the preparation of joint observations between the West Space Agency (the WEGENER-MEDLAS project) and the East Space Association (the IDEAL project) Unfortunately, notwithstanding the theoretical and model studies, the available laserlocation equipment and the undertakings of the two committees, for a number of economic and technical reasons, the initiated experiments for studying the dynamics of the Alpo-Himalayan orogene belt were interrupted.

III. The BALKANPROB Space project — objectives and prospects in studying the dynamics of Bulgaria and the Balkans

It should be noted that, in the development of the BALKANPROB project in 1991—1992, the authors [17—20] were not only concerned about the major fundamental-scientific and application-scientific objectives but they also accounted for the prospects and economic potentialities for the project's implementation, in relation with which the features of the supportive geodetic networks were analysed.

The vertical shifts of the earth's crust in our country are studied best, their greatest velocity (reaching up to 5,9 mm/year) being recorded in the thick Tectonic zones (the Rhodopes and the Serbian-Macedonian massif). Moderate shift values (up to 2 mm/year) were recorded in large areas of the Moesian platform in the fore-Balkan, Sredna Gora, Kraishte and Strandja [1, 17, 21].

Accounting for the considerations stated above, it was decided that the efforts during the first stage be directed at the design and implementation of four traverses for identification of the vertical shifts of the earth's crust on the territory of Bulgaria, a 150—200 m wide polygon, starting at the Danube and reaching as far as the Greek boundary to the south. This allows for the polygon's extension furthermore to the south — on Greek territory, and to the north — on Roumanian territory.

The worked out neo-Tectonic map (Fig.5) allows for increase of the available geologic information, since the materials already known were supplemented with newly-revealed space-lineaments and ring arch-block structures, unknown so far.

In parallel with the polygons' design, the velocity of the vertical shifts along the traverses was calculated, including references of the 1-st and 2-nd class in such a way that the meridianal paces of Nos 1, 2, 3, and 4 (Fig.5), crossing the outlined thrusts be outlined. In the selected levelling paces, 2 to 4 measurements are included, performed in the years 1924—1929, 1956—1960, 1975—1976, and 1987. The number of measurements is greatest along paces Nos 1 and 2, the essential fact about them being that traverse No 2 crosses regions with the greatest number of thrusts and highest seismic activity.

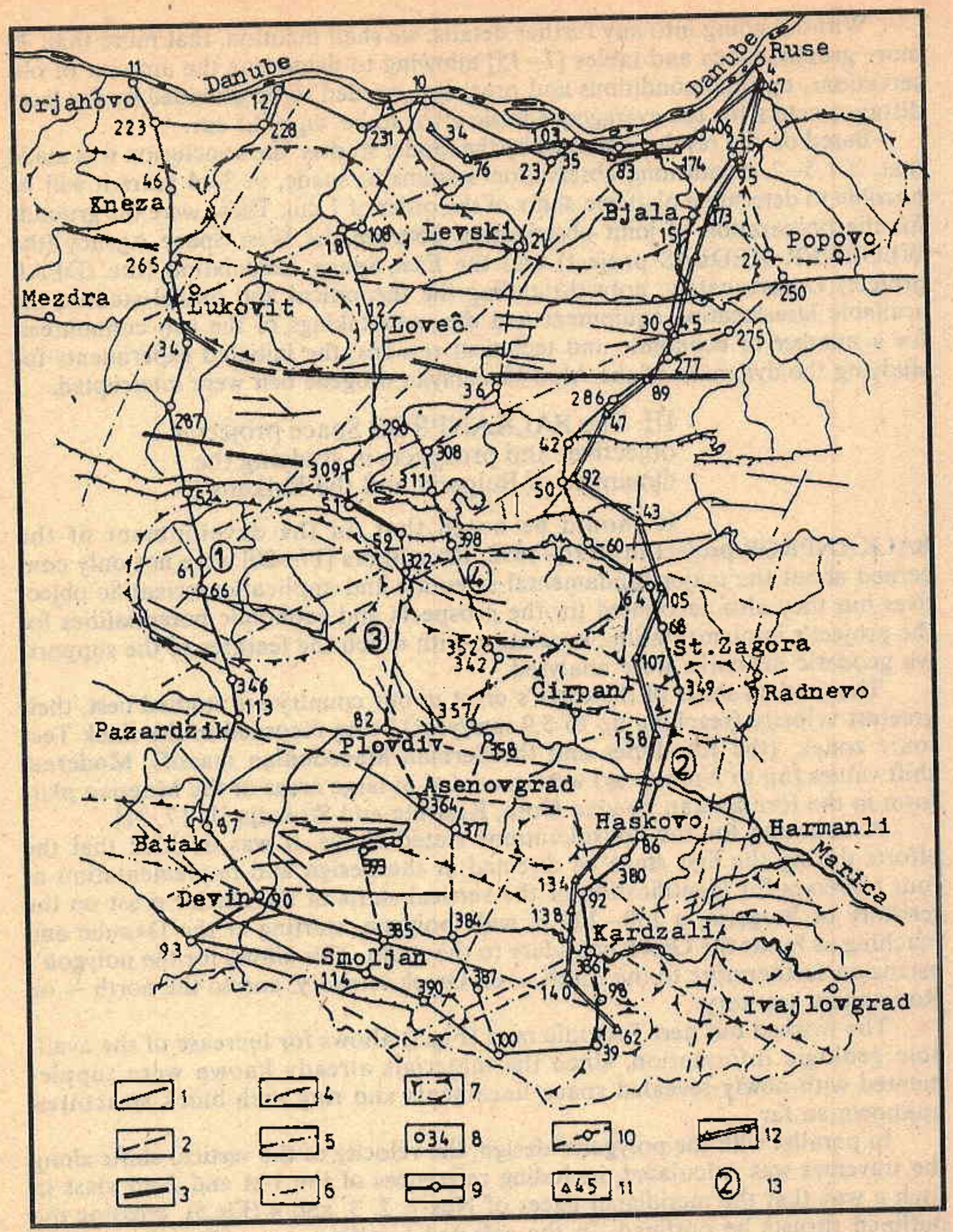

Fig.5. Neotectonic sketch with plotted levelling lines
Faults: 1 — proven fault, 2 — suggested fault, 3 — flexures, 4 — overthrust, 5 — space lineament, 6 — suggested space lineament, 7 — ring, oval and arch block structures, 8 — levelling point with number, 9 — first class levelling line, 10 — levelling line, 11 — triangular point with number, 12 — triangular line, 13 — number of levelling line

From the analysis of the supportive (triangular) network, identifying the points in the lateral respects, it was established that the measurements performed during the initial stages of its design cannot satisfy the precision needed for determination of the horizontal shifts. Reliable results are possible to be obtained only recently, by the classical universal instruments which determine with great precision the horizontal angles and the distances between the supportive points. In the proposed traverse, points from the available state supportive network are also included [21].

A number of experiments have been made for studying the horizontal shifts by immediate measurements for at least two epochs. One of them is the Chirpan region with measurements in 1921—1935 and 1950, and another one — the Strajitsa region with more than one measurement. Naturally, these preliminary studies, based on information obtained by classic measurements are regarded only as an approximate estimation of the horizontal shifts of the earth's crust in the respective region.

In studying the geodynamic processes along the traverse, data for the seismicity was used, which was obtained by the network of seismologic observatories [22, 23]. Of particular interest for the suggested project are the Plovdiv and the Gorno Oriahovo seismic regions.

The major considerations underlying the suggestion of BALKANPROB are:

1. The chosen polygons cross major thrusts on the territory of Bulgaria, namely: the South-Moesian, Bresnik-Preslav, Stara Planina Over-Balkan, and Maritsa ones.

2. The implementation of the project needs minimum finance since all identification works are planned to be carried out by classical technical means or by GPS measurements, if possible.

3. The traverses are outlined in such a way so as to use the available stable references from the state levelling network and the precisely determined triangular points from the supportive network since the measurements made in a particular epoch can be adopted as initial "zero" epochs.

It might be expected that the BALKANPROB project, suggested according to the frame contract, concluded in 1991 between the Space Research Institute at the Bulgarian Academy of Sciences and the Military Topographic Office at the Ministry of Defense of the Republic of Bulgaria will be accomplished successfully since, during the analyses performed with the participation of both institutions, it was decided to perform as well GPS measurements along the traverse with relative error of the order 10^{-6}—10^{-7} [24].

In the recent years, a number of institutions and private companies in Bulgaria bought some of the most modern and high-precision GPS equipment of the type of "Wild System 200" — 15 pieces, "Trimble" — 6 pieces, etc. These technical means undoubtly revealed great potentialities for the implementation of diverse scientific and application problems in the field of the study of geodynamic process. This provided grounds for an international team of Bulgarian and German experts to carry out a GPS campaign in 1992 [25] for measurements by the established through the assistance of WTS supportive network of 15 points, covering uniformly the territory of Bulgaria. The aim was to develop a modern supportive network in the country and to reveal prospects for local geodynamic measurements under the EUREF-BUL'92 project [25]. This was really a very good initiative since it provided the first actual results from GPS measurements under a definite project.

The results from the carried out GPS campaigns were suggested and accomplished not only by the EUREF-BUL'92 project but also by BULREF'93 and BULREF'95. Based on the information obtained by remote sensing aerospace methods about lineaments and ring arch-block structures, unknown so far [26], a supplementation and further development of the above-mentioned projects can be proposed, namely the BALKANPROB project where new supportive points are added. We believe that it will provide for a more detailed study of the velocities of the vertical and horizontal shifts in typical Tectonic regions with clearly outlined thrusts, namely: the Rhodope and the Serbo-Macedonian massives, remote from the Stara Planina segment, large regions of the Moesian platform, the fore-Balkan, the Sredna Gora region, Kraishte and Strandja. In contrast to the prevailing total uplift of the Balkan peninsula, some relatively lowered regions can be outlined, comprising parts of the Moesian platform, the Sredna Gora region and the Eastern Rhodopes.

If the results from this GPS network prove to be reliable, the network will be enlarged to encompass other regions of the Balkan peninsula, accounting for their Tectonic and geodynamic features.

In conclusion, we shall formulate the fundamental scientific problems that we expect to be solved by the accomplishment of the BALKANPROB project:

— identification of the modern mutual shifts of the local and microlocal blocks along the traverse and on the whole territory of Bulgaria and the Balkans, namely: between the heterogeneous geostructural elements on the Balkans — the Dynarides and the Balkanides, the Serbo-Macedonian massif, and the Rhodope massif, delimited from each other by thrust faults;

— study of the neo-Tectonic structures and geodynamic processes on the territory of the Balkans which comprise large areas from the Alpo-Himalayan orogene and the territory of Bulgaria along the traverse crossing successively the Tectonic zones of the Moesian platform, the fore-Balkan, the Sredna Gora region and the Rhodope massif.

— control of the internal stability of the regional and local lithospheric blocks in Bulgaria;

— determination of the peripheral deformations on the territory of Bulgaria, the Serbo-Macedonian and the Rhodope massives, the fore-Balkan, the Sredna Gora region, Kraishte and Strandja;

— contribution to the study of the dynamic processes in the Alpo-Himalayan orogene.

The scientific-application objectives comprise the following problems:

— evaluation of the seismic risk and forecasting of the deep-focus earthquakes, using seismicity's subduction and slip-collision models by empiric kinematic verification;

— determination of the relative shifts of large blocks of the earth's crust in big rift or thrust zones of the orogene belt, of interest to the forecast of low-focus earthquakes, as well as to the design, construction and operation of important engineering equipment.

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БАЛКАНПРОБ — космически проект за изследване на динамиката на литосферата на България и Балканите

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(Резюме)

Съвременното ниво на космическите методи и техническите средства дава големи възможности при изследването на глобалната, регионалната и локалната динамика на литосферните плочи. Геодинамичните процеси са едни от съществените предвестници на природни феномени като земетресения, изригвания на вулкани и др.

На базата на анализа на резултатите и опита от редица регионални и локални геодинамични проекти — и преди всичко на проекта ИДЕАЛ, в статията се мотивират целите, фундаменталните и научно-приложните задачи, очакваните резултати, както и перспективите на предложения проект БАЛКАНПРОБ за територията на България и Балканите с помощта на GPS-измервания.