GeoTerrace-2023-011

Differentiation of recent geodynamic processes within the Carpathian Mountains based on GNSS data

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SUMMARY

This work presents the results of the analysis of data from 50 continuous GNSS stations located in the Carpathian Mountains to study recent geodynamic processes of this region. Determine the value of the linear velocity of horizontal movements of selected continuous GNSS stations and perform their analysis. An analysis of recent geodynamic processes was performed and the main extreme zones of geodynamic processes have been identified.

Keywords: continuous GNSS stations, Carpathian Mountains, horizontal movements, area strain, maximum shear strain
Introduction

The Carpathian Mountains are the second-longest mountain system in Europe, covering an area of about 210,000 square kilometres. Carpathian Mountains, are a geologically young European mountain chain forming the eastward continuation of the Alps Mountains. From the Danube Gap, near Bratislava (Slovakia), they swing in a wide crescent-shaped arc some 900 miles (1,450 km) long to near Orșova (Romania), at the portion of the Danube River valley called the Iron Gate (Kondracki, 2023). According to Márton et al. (2009), the Carpathian Mountains belong to the European mountain system, which was formed during the convergence and collision of the European and African plates. The Carpathian Mountains are the result of the evolution of continental units and oceans from the Triassic to the Tertiary period. The continental units consist of the inner Tyso-Dacian and Alpine-Carpathian-Pannonian (ALCAPA) blocks, as well as the outer European-Scythian-Mesian continental foreland, which forms the arc-shaped shape of the Carpathians (Sandulescu, 1988; Ismail-Zadeh et al., 2012). Since the Carpathian Mountains are a young mountain system, its study is of considerable scientific interest. There are enough examples of conducting geodynamic studies of separate parts of the Carpathian Mountains using the currently popular GNSS technologies. Such studies confirm the presence of active recent geodynamic and seismic processes within the Carpathian Mountains (Brusak & Tretyak, 2020, 2021). However, for a comprehensive understanding of such processes, as well as the development of strategies for minimizing risks, and protecting the population and infrastructure from emergencies, it is necessary to study the Carpathian Mountains as a whole. So, in this work, we carry out a study of recent geodynamic processes within the whole Carpathian Mountains.

Data

The initial data for conducting research are time series of daily solutions of continuous GNSS stations located within the Carpathian Mountains, as well as adjacent territories, obtained from the Nevada Geodetic Laboratory in 2023 (Blewitt, Hammond & Kreemer, 2018). Continuous GNSS stations with a long measurement period (more than 3 years), whose time series of daily solutions are homogeneous, without long breaks and gross errors, were selected for the study. As a result, 50 continuous GNSS stations were selected for this study. (Figure 1).

Figure 1. The location map of selected continuous GNSS stations within the Carpathian Mountains

Analyzing Figure 1, it can be noted that the network of continuous GNSS stations within the Carpathian Mountains is quite dense and homogeneous, with an average density of 1 station per 4200 square kilometres. The average distance between neighbouring continuous GNSS stations is 150 kilometres, minimum distance is 20 kilometres, and the maximum distance does not exceed 300 kilometres.
Method

This study followed a three-step approach, including the determination of horizontal velocity, calculation of strain rate parameters, and analysis of the obtained data. Numerical computations, data interpretation, and visualization of outcomes were carried out using MathCad v15 and Generic Mapping Tools v6.4.

The horizontal velocity of continuous GNSS stations was determined by solving a system of linear equations of the form:

\[ f(t_i) = v(t_i - t_0) + y_0 \]  

(1)

where, \( t_i \) – observation epoch, \( v \) – the linear velocity of the station and \( y_0 \) – the intercept (at epoch \( t_0 \) – start epoch).

In this work, we decided to analyze two strain rate parameters, namely area strain and maximum shear strain. According to Savchyn & Vaskovets (2018), and Savchyn et al. (2020 and 2021) these parameters provide an opportunity to visualize recent geodynamic processes quite accurately. The following functional relationships were used to determine these parameters:

\[ e_{area} = e_{xx} + e_{yy} \]

\[ e_{max\ shear} = \sqrt{\left(\frac{e_{xx} - e_{yy}}{2}\right)^2 + e_{xy}^2} \]  

(2)

It is known that the determination of strain rate parameters is based on the components of the two-dimensional (Lagrangian) strain rate tensor. The components of the strain rate tensor were determined as follows (Shen et al., 1996; Sagiya et al., 2000):

\[ e_{xx} = \frac{1}{\Delta t} \frac{\partial u}{\partial x} \]

\[ e_{yy} = \frac{1}{\Delta t} \frac{\partial v}{\partial y} \]

\[ e_{xy} = e_{yx} = \frac{1}{2\Delta t} \left( \frac{\partial u}{\partial y} + \frac{\partial v}{\partial x} \right) \]  

(3)

where \((u, v)\) are the movements at the epoch GNSS stations during the time interval \( \Delta t \) in the directions of \((x, y)\).

Results

Using the selected data and the described mathematical apparatus, the necessary calculations were performed and quite interesting data were obtained. In the first stage, the values of the linear velocities of the horizontal movements of the continuous GNSS stations located in the Carpathian Mountains have been obtained. Figure 2 shows the map of the obtained horizontal velocity distribution. Analyzing the map (see Figure 2), it can be noted that the direction of the vectors of linear velocities of horizontal movements of continuous GNSS stations is oriented to the northeast. The values of the horizontal movements’ vectors range from 25.05 to 28.02 mm/year, and the average accuracy of their determination is 11% of the vector length (2.87-3.03 mm/year). It is interesting to note that the range of the vectors is quite small. The maximum vector value of 28.02 mm/year was identified at TGMS (Târgu Mureș, Romania) continuous GNSS stations, while the minimum value was 25.05 mm/year at FAGA (Făgăraș, Romania) continuous GNSS stations.
At the next stage, based on the determined linear velocities of horizontal movements, the area strain and maximum shear strain were determined. The distribution of the determined values within the Carpathian Mountains is shown in Figures 3 and 4, respectively.

The results obtained (see Figures 3 and 4) confirm the presence of recent active geodynamic processes within the Carpathian Mountains. Analysing Figure 3, it can be noted that the distribution of area strain values in the Carpathian Mountains is not uniform, area strain values range from -0.0079 to 0.0052 micro-strain/ year. Zones with maximum positive values of area strain (extension) are identified in the Western Romanian Mountains. Zones with maximum negative values of area strain (compression) are identified in the northern part of the Outer Eastern Carpathians.

Analysing Figure 3, it also can be noted that the distribution of the maximum shear strain values in the Carpathian Mountains is not uniform, maximum shear strain values range from 0.00010 to 0.0051 micro-strain/ year. The lowest values are concentrated in the Serbian Carpathians and the highest in the Outer Eastern Carpathians.
Conclusions

The study and brief analysis of recent geodynamic processes within the whole Carpathian Mountains are presented. The study is based on the processing and analysis of freely available time series of continuous GNSS stations located within the Carpathian Mountains. In total, continuous 50 GNSS stations were processed, and linear velocities of their horizontal movements were obtained, which indicate a north-east direction with velocities of 25-28 mm/year. Analysis of the distribution of velocities confirmed the presence of recent active geodynamic processes. Also, the main extreme zones of geodynamic processes have been identified.

References


