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Deformation Analysis of East Mediterranean with Using SSPX Software

Doğu Akdeniz'in SSPX Yazılımı ile Deformasyon Analizi

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Abstract

Global Positioning System (GPS) is an advanced method for determining horizontal and vertical displacement. With the developing technology and data processing techniques, GPS can be used to determine the related/relative position and velocity of a point in millimeter accuracy. Deformation, which is the gradient of the displacement field, can be calculated by using GPS displacement vectors obtained from the measurements made in the interplate and plate boundaries and reveals important information about regional tectonics. Eastern Mediterranean, which has a very active tectonism, was chosen as study area within the scope of this study. In order to be able to examine the tectonic elements in the region, analysis was done in three stages. Deformation analysis was performed for three different areas by using GPS velocities of previous studies. The deformation analysis of the Eastern Mediterranean, which is a larger area, was firstly carried out, and then the area was reduced and the regional results of Cyprus and its surroundings were tried to be reached. Extension, shortening, dilatation and rotation maps of the study area were performed. Obtained deformation analysis results and the relationship between tectonics were interpreted together.

Keywords : *Eastern Mediterranean, Cyprus, GPS, deformation analysis, extension, shortening, dilatation*

Öz

Global Konum Belirleme Sistemi (GPS), yatay ve düşey yerdeğiştirmelerin belirlenmesinde kullanılan gelişmiş bir yöntemdir. Gelişen teknoloji ve veri işlem teknikleriyle birlikte bir noktanın bağıl/göreli konumunu ve hızını mm bazında bulabilme imkanı sağlayan GPS, deformasyon çalışmalarında tercih sebebi haline gelmiştir. Yerdeğiştirme alanının gradyenti olan deformasyon, levha içi ve levha sınırlarında yapılan ölçümlerden elde edilen GPS yerdeğiştirme vektörleri kullanılarak hesaplanabilmekte ve bölge tektoniğiyle ilgili önemli bilgiler ortaya koymaktadır. Oldukça aktif tektonizmaya sahip olan Doğu Akdeniz, bu çalışma kapsamında çalışma alanı olarak belirlenmiştir. Bölgede yer alan tektonik elemanların daha iyi incelenebilmesi için üç aşamada analiz yapılmıştır. Geçmiş yıllardaki GPS çalışmalarına ait hız değerleri kullanılarak yapılan deformasyon analizi, üç farklı alan için gerçekleştirilmiştir. İlk olarak daha büyük bir alan olan Doğu Akdeniz'in deformasyon analizi yapılmış, devamında ise alan küçültülerek Kıbrıs ve çevresine ait bölgesel sonuçlara ulaşılmaya çalışılmıştır. Çalışma alanına ait açılma, kısalma, dilatasyon ve rotasyon haritaları oluşturulmuştur. Elde edilen deformasyon analizi sonuçları ve tektonizma arasındaki ilişki birlikte irdelenerek yorumlanmıştır.

Anahtar Kelimeler: *Doğu Akdeniz, Kıbrıs, GPS, deformasyon analizi, açılma, kısalma, dilatasyon*

1. Introduction

East Mediterranean is a region where Africa, Eurasia and Arabian plates intersects. This triple intersection area is very active in terms of tectonics and contains many tectonic elements. For determining the fixed system elements of the Eurasian plate, the major one Africa plate moves relatively to the north direction and goes under the other element which is Eurasian plate along with the Cyprus and Hellenic arcs; also the third major element Arabian plate moves northward direction and moving faster than the African plate, constitutes the Dead Sea transform fault system at the plate boundary. Apart from these main tectonic elements, the rotation of Anatolian block towards Hellenic arc makes the western part of the study area more complicated. This area, which is contained within Crete Island and the Aegean Sea, has high seismic activity and this region is continuously active in Eastern Mediterranean tectonics. GPS studies in the region [1-2] reveal important findings about regional tectonics and support this tectonic model.

The current tectonism of the Eastern Mediterranean is associated with Eurasia, Africa, Arabian plates, micro plates and blocks. Many small tectonic structures such as collision, subduction, over thrust, transform fault lines, spiral opening are observed in this small area [3]. The main tectonic constructions of the region are given in Figure 1. Different relative motions of Africa and Arabian plates resulted in transform Dead-Sea fault zone, which is one of the earthquake-producing faults in the Eastern Mediterranean. East Anatolia squeezed between the Caucasus and the Arabian Peninsula with the northward relative movement of the Arabian resulted with the East Anatolian Fault Zone and combined with the Dead Sea fault zone in the southeastern Anatolia. Bitlis-Zagros suture belt, another structure formed by the northward movement of the Arabian plate, is one of the important tectonic elements in the region. The westward movement of the Anatolian block caught between the Arab and Eurasian plates constituted transform North Anatolian Fault Zone, this westward movement was broken in the Greek Shear Zone and rotated to the west of Anatolia towards the Hellenic Arc [4-5,6]. There are Helen, Pliny and Strabo trenches on the Aegean which separates the Mediterranean and the Aegean Sea from each other result of faulting [3-6]. This region is very active in seismic terms. It is believed that the Antalya Gulf graben, which is further east of the study area, may be responsible for Neogene-current expansion systems in Western Cyprus but more extensive work is suggested for this region [7-8]. Kyrenia lineament reveals regional uplift due to compression in the region. The Kyrenia lineament terminated by N-S-trending Kormakiti-Anamur fault zone in the west and acting as a transform fault zone and extends towards Syria [8].

Relative plate motions and directions obtained from GPS data are important knowledge in terms of tectonics. In addition, today's software can provide information about the deformation that caused this movement. For this reason, in order to examine the tectonically active Eastern Mediterranean deformation analysis were made using GPS velocities of previous study[2] in the region. As a result of deformation analysis using SSPX software [9] extension, shortening, dilatation and rotational maps of the region obtained. By using these maps, the harmony between the terrain deformations and the zone tectonics was investigated.

2. Material and Method

Deformation analysis studies using GPS data have become widespread in recent years. With the spread of the studies, many software have been developed and the most suitable software for the purpose of research is presented by the researchers. SSPX software was used in this study because of its high analysis power. SSPX is a Macintosh program that can perform strain calculation from two and three dimensional displacement and velocity values. The software calculates the optimal strain tensors with displacement or velocity vectors. SSPX, which can calculate four different deformation types (Extension, shortening, dilatation and rotation), visualizes the results by mapping. SSPX, a document-based software, works equally well for small and large areas and it doesnt have a limitation on the number of data [9]. In addition, the software is easier to use and it has fast calculation ability more than many other softwares.

The displacement vector specifies the position of the body as an origin or reference to the previous position. Consider if G_{ij}, is defined as displacement gradients in the initial position [9] relation between displacement vectors and starting positions be expressed as:

$$u_i = t_i + G_{ij}X_j \;\; ve \;\; G_{ij} = \frac{\partial u_i}{\partial X_j} \quad (1)$$

where G is the Lagrangian displacement gradient tensor [10]. The relationship between the displacement vectors and the final position is determined with the following equation;

$$u_i = t_i + g_{ij}x_j \;\; ve \;\; g_{ij} = \frac{\partial u_i}{\partial x_j} \quad (2)$$

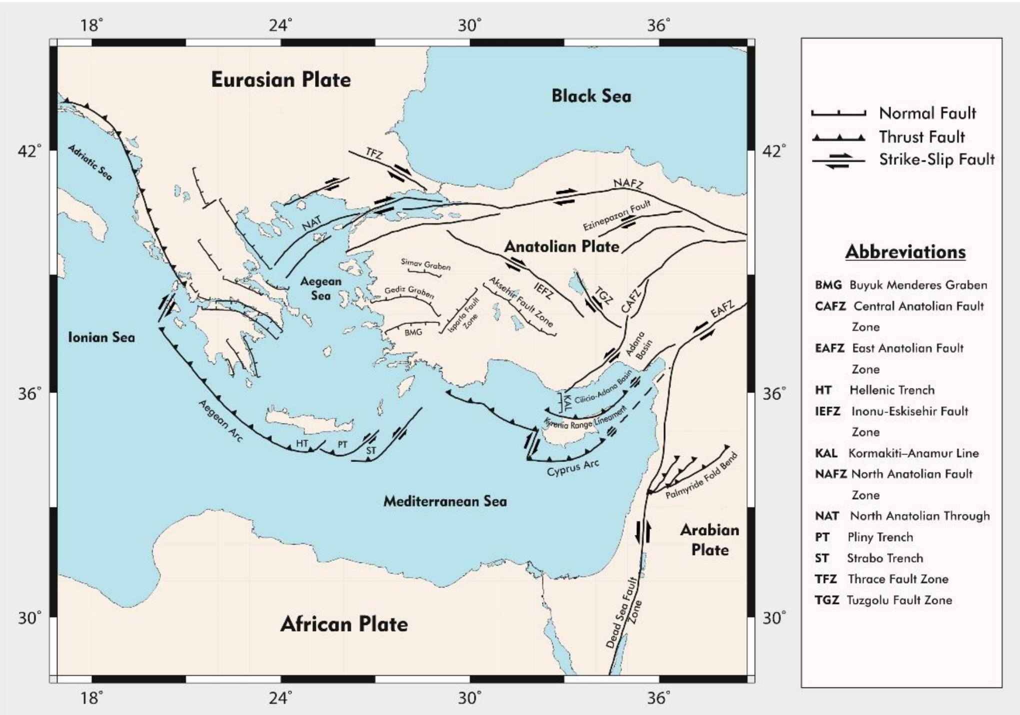

Figure 1. Main tectonic elements of the Eastern Mediterranean (revised from [8-11]).

and g_{ij} is the displacement gradient at the end position. In addition g is called the Eulerian displacement gradient tensor [9-10]. The matrix system for the solution of the equation system created by using these two equations is defined as b=Ap (b: Vector containing displacement values; A: design matrix containing starting positions of stations; p: vector containing unknown model parameters). This equation is based on the distance of the system stations to the calculation point and solved by the weighted least squares method. Then model parameters are found [9].

Strain tensor is calculated by using model parameters and displacement gradients. Lagrangian strain tensor in initial position,

$$E_{ij} = \frac{1}{2}(G_{ij} + G_{ji} + G_{ki}G_{kj}) \quad (3)$$

Eulerian strain tensor in final position,

$$e_{ij} = \frac{1}{2}(g_{ij} + g_{ji} + g_{ki}g_{kj}) \quad (4)$$

are expressed by formulas. The eigenvalues and eigenvectors of strain tensors are used to determine the elongation in the initial or final position [9]. In the initial position,

$$\lambda_i = (1 + 2E_{ii}) \quad (5)$$

or in the final position,

$$\frac{1}{\lambda_i} = (1 - 2e_{ii}) \quad (6)$$

Where λ_i, quadratic (second-order) elongation, S (1 + elongation) is the square of the flexing / pulling [9].

The above steps apply the basic operations of the strain calculation. In addition to these steps, dilation is calculated by using Equation 7 and rotationis calculated from equations 8 and 9 (ε_{ij}: symmetrical tensile tensor; ω_{ij}: antisymmetric tensor) [9].

$$\Delta = S_1 S_2 S_3 - 1 \quad (7)$$

$$G_{ij} = \varepsilon_{ij+}\omega_{ij} \quad (8)$$

$$R_1 = \frac{-(\omega_{23} - \omega_{32})}{2}, \quad R_2 = \frac{-(\omega_{13} - \omega_{31})}{2}, \quad R_3 = \frac{-(\omega_{12} - \omega_{21})}{2} \quad (9)$$

3. Results

Within the scope of the study, GPS velocities from the previous study [2] was used in the region. By using SSPX software [9]; extension, shortening, dilatation and rotation maps were created in the region. When deformation calculations were made firstly, deformation analysis of the Eastern Mediterranean was carried out and furthermore tried to reach more regional results by reducing the area. For this reason different grid spacings and α values (parameter indicating how the effect of a station for the calculated cell will decrease with distance) were used.

192 stations were used while deformation analysis of the Eastern Mediterranean were made and calculations were performed with a grid interval of 47.87 km. The obtained maps which are shortening map in Figure 2, the extension map in Figure 3, the dilatation map in Figure 4, and lastly the rotation map is shown in Figure 5.

Then, deformation analysis results limited with 104 stations and calculations were performed with a grid interval of 46.36 km. The obtained maps which are shortening map in Figure 6, the extension map in Figure 7, the dilatation map in Figure 8, and lastly the rotation map is shown in Figure 9.

Finally, analysis was performed using velocities from 47 stations (grid range 33.46 km). This analysis aims to obtain more detailed results of Cyprus and its surroundings. The results are given in Figures 10, 11, 12 and 13. The figures show shortening, extension, dilatation and rotation maps, respectively.

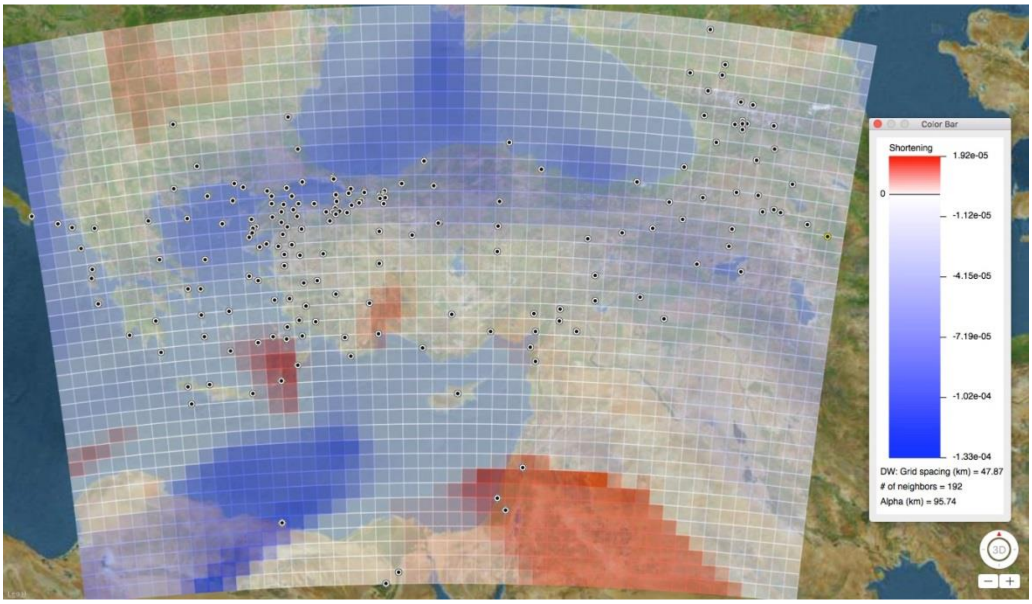

Figure 2. Results of deformation analysis (shortening) using 192 stations.

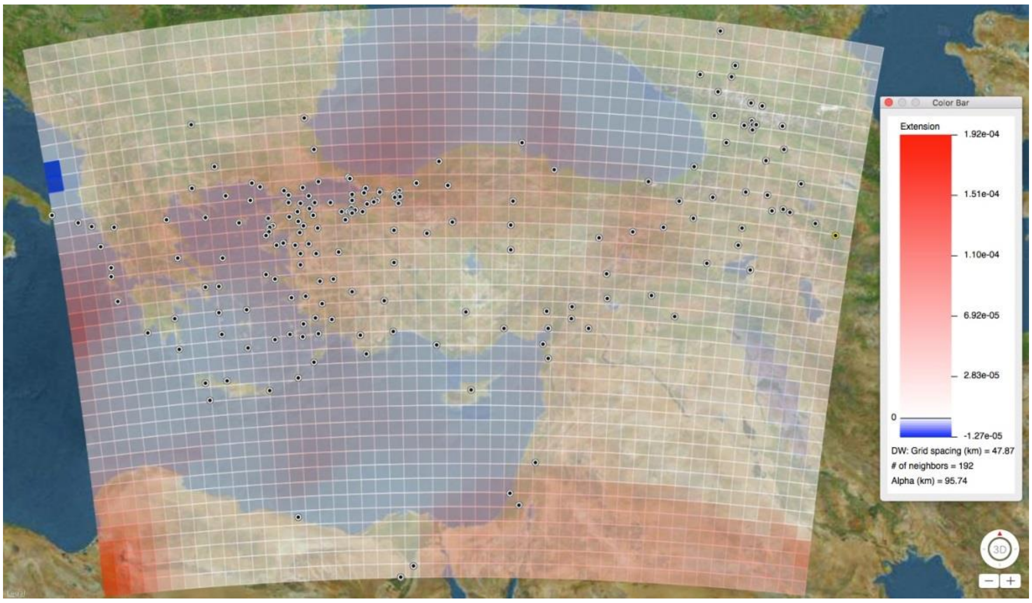

Figure 3. Results of deformation analysis (extension) using 192 stations.

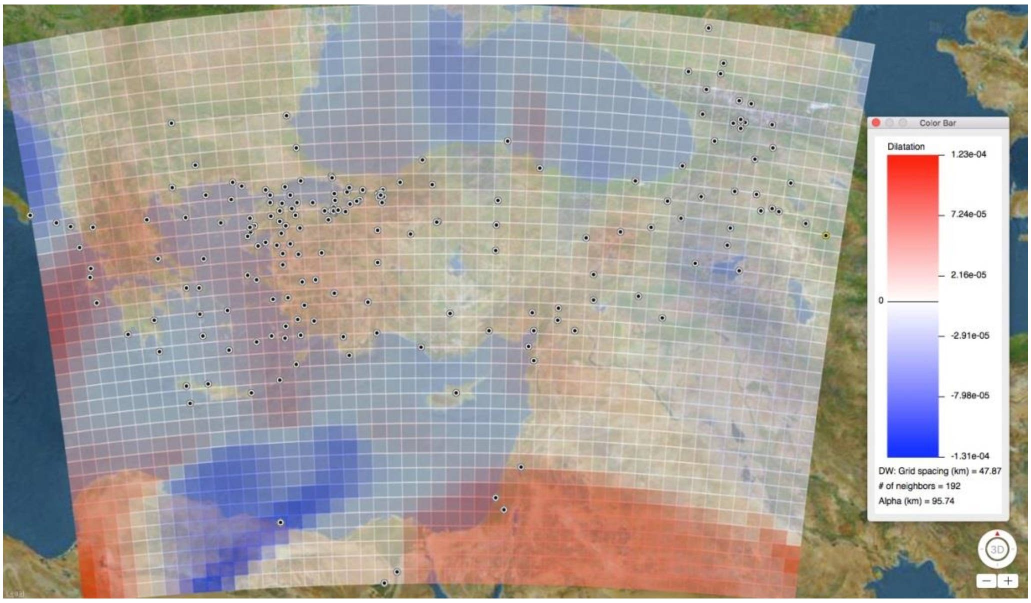

Figure 4. Results of deformation analysis (dilatation) using 192 stations.

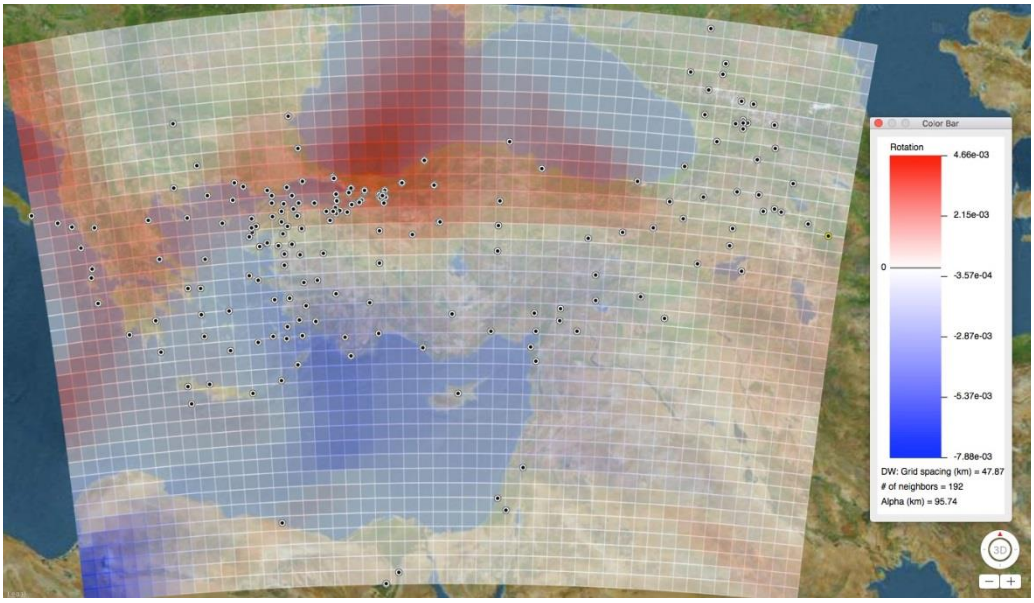

Figure 5. Results of deformation analysis (rotation) using 192 stations (red colour represents clockwise movement and blue represents the movement in the counterclockwise direction).

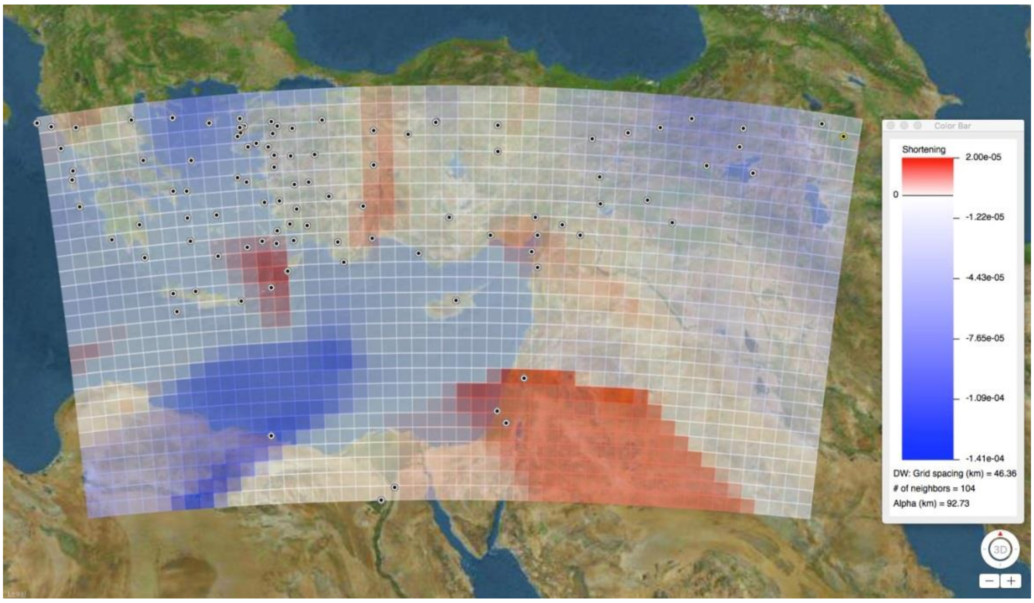

Figure 6. Results of deformation analysis (shortening) using 104 stations.

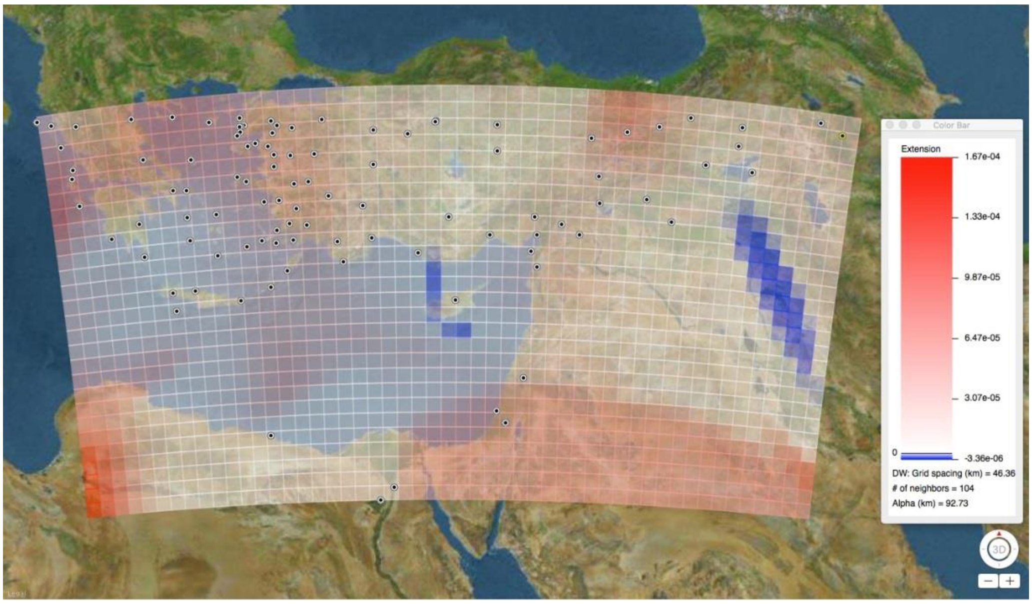

Figure 7. Results of deformation analysis (extension) using 104 stations.

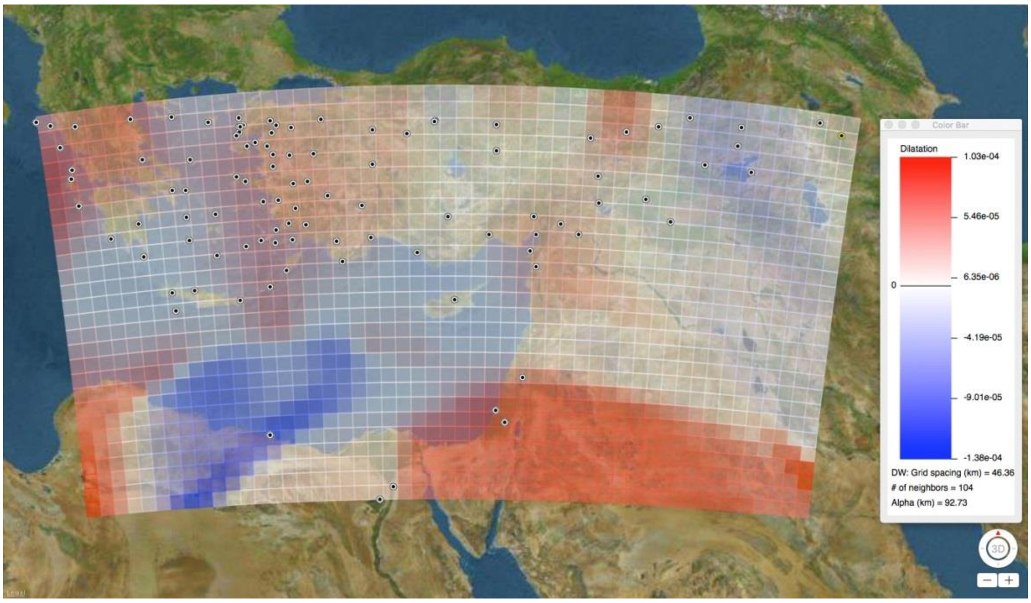

Figure 8. Results of deformation analysis (dilatation) using 104 stations.

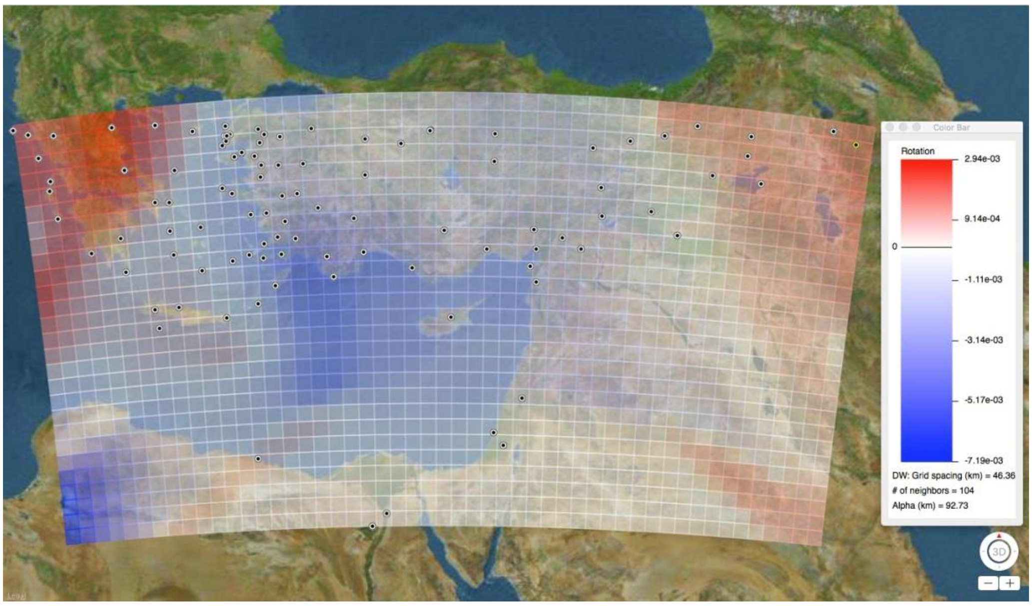

Figure 9. Results of deformation analysis (rotation) using 104 stations (red colour represents clockwise movement and blue represents the movement in the counterclockwise direction).

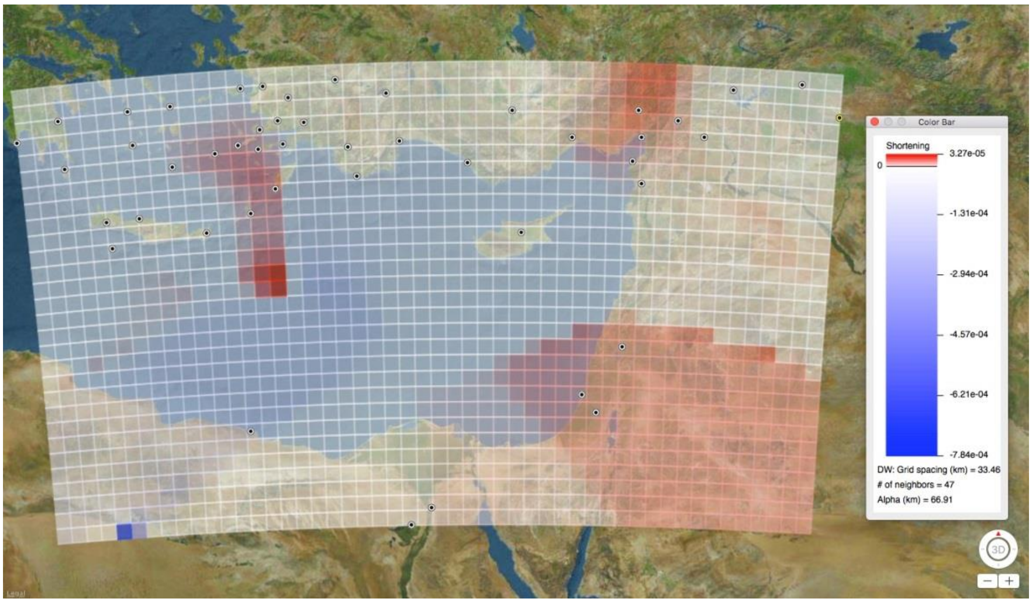

Figure 10. Results of deformation analysis (shortening) using 47 stations.

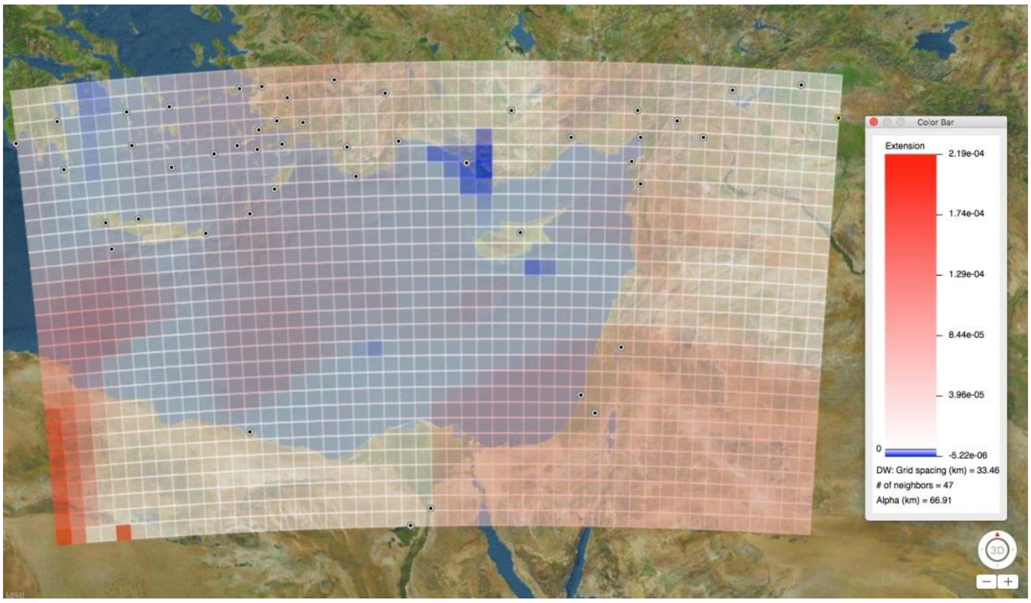

Figure 11. Results of deformation analysis (extension) using 47 stations.

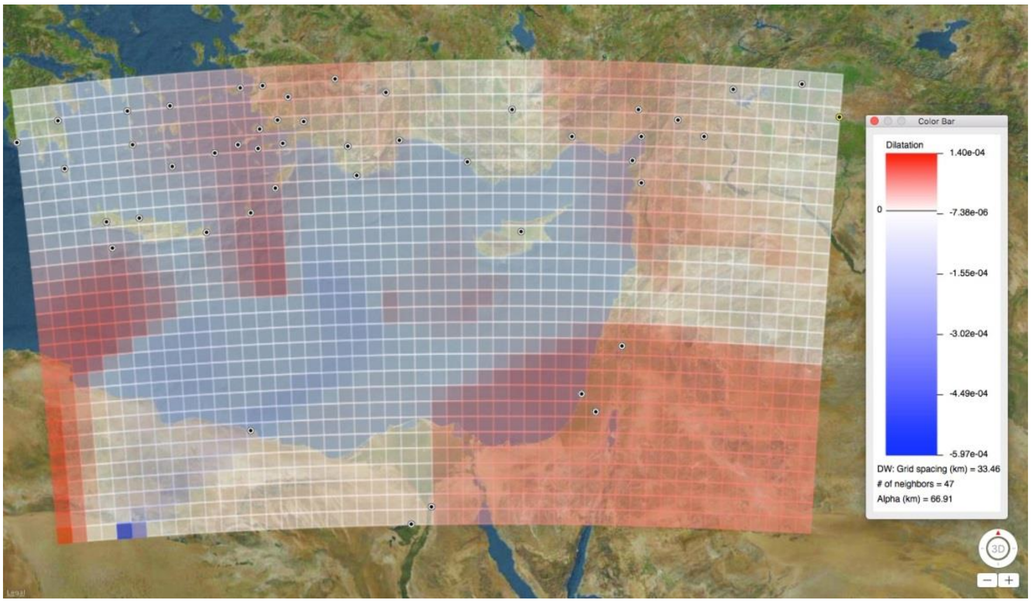

Figure 12. Results of deformation analysis (dilatation) using 47 stations.

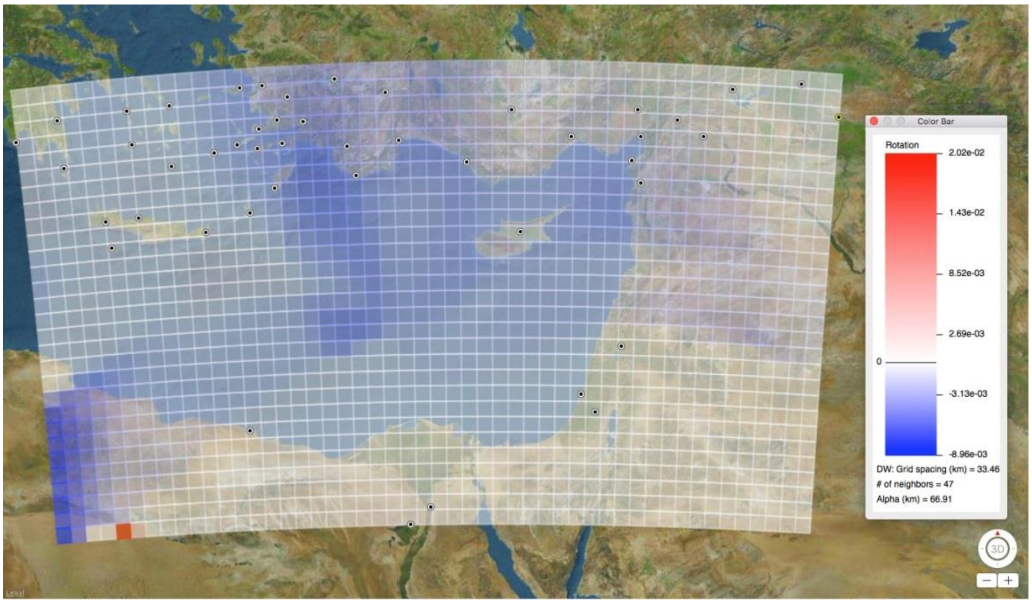

Figure 13. Results of deformation analysis (rotation) using 47 stations (red colour represents clockwise movement and blue represents the movement in the counterclockwise direction).

4. Discussion and Conclusion

When Figure 2 is examined, first the high deformation in the region of Helen, Pliny and Strabo trenches forming the eastern part of the Aegean arc is noteworthy. In the analysis made, the region in terms of tectonics, one of the most active regions of the Eastern Mediterranean is striking as a zone with high deformation rate. Starting from the region between Egypt and Libya and extending towards the coast and in the southern part of the fault of Dead Sea (Israel and its surroundings) areas with high deformation are observed in Figure 2. The region south of the Dead Sea fault is compressional, and the region extending from Egypt-Libya to the Mediterranean is depicted by expansion.

However, the stations fewer in number in this region reduces the resolution and accuracy of the solution, and it is thought to provide general information about the region. A deformation line starting from the Black Sea and reaching the Aegean Sea through the Marmara Sea can be seen in the north of the map in Figure 2.

This high deformation line, which is defined as the expansion zone, is thought to indicate the general stress in the North Anatolian Fault Zone. This line is also clearly visible on extension and rotation maps (Figures 3 and 5). Plurality of stations around the Marmara Sea providing positive contribution of this line and it should be taken into consideration. In addition, lower amplitude deformation zones are observed around Antalya and the Adriatic Sea (Figure 2). The given rotation map in Figure 5 the red colour represents clockwise movement and blue represents the movement in the counterclockwise direction.

The northern branch of the North Anatolian fault, which is a right-strike fault zone and the fact that it has clockwise rotation reveals the correspondence between tectonic and rotation analysis. The most dominant rotation value in the study area is determined in this region.

The maps of deformation analysis for the Eastern Mediterranean on a large scale are given in Figures 2, 3, 4 and 5. When these maps are examined, the high deformation in similar regions is striking. If the tectonics of the region (Figure 1) and the results of previous GPS studies [1-2] are evaluated together, it is seen that the Aegean and Cyprus Arcs, the North Anatolian Fault Zone, the Dead Sea Fault Zone and the Bitlis-Zagros thrust belt, which the African Plate goes under the Anatolian block, are tectonically active. Therefore, high deformation is expected in these regions. As a result of the deformation analysis (Figs. 2, 3, 4 and 5), the high deformations in the regions where the tectonic elements are located are outstanding.

Deformation analysis results limited with 104 stations are shown in Figure 6,7,8 and 9. It is observed that the deformation areas in the south are similar to those in the first analysis. In this analysis, observation has been provided where the stations in the north are not used, the dominant effect of the North Anatolian Fault Zone is to be left in the middle parts of Anatolia, in the Bitlis-Zagros thrust belt area, and in the deformation areas around Cyprus. Examination of Figure 7 reveals that the Bitlis-Zagros thrust line extends to the southeast and the compression regime in the region is represented by blue color.

In the same way, the high deformation area in the region of the Cyprus Arc, which is located in the south of Cyprus, is striking and the compression line on the Kormakiti-Anamur fault (Figure 1) extending between N-S between Anatolia and Cyprus (Figure 7).

The results of the analysis in order to reduce study area to 47 stations are shown in Figure 10, 11, 12 and 13. Decreasing the number of stations and the greater occupancy of the seas seem to reduce the power of analysis. The dominance of compression values in the vicinity of the Strabo trench and the deformation in the area where the Adana basin is located can be seen in Figure 10. In this region where the Adana basin is located, there is the Kyrenia Range Lineament's northeastward extension (Figure 1).

The results obtained from the analyzes show that the findings are consistent with the tectonics of the region. The regions with active tectonics have a high deformation rate as expected. Important tectonic elements such as the Aegean and Cyprus Arcs, Dead Sea, Eastern Anatolia and North Anatolian Fault Zones in the study area have dominant deformation rates, and therefore a significant portion of the deformation of local tectonic elements is thought to be obscured. Also, the size of the area covered by the sea in the study area, inadequate number of stations, especially in the south of study area, has had a negative effect on the solutions. Therefore, this study should be repeated with GPS data obtained with current measurement networks. Renewed GPS data and previous and current deformation areas should be reinterpreted and regions with high risk of earthquakes should be examined. In addition, it is necessary to increase the numbers of bedrock featured GPS stations in order to carry out more reliable deformation analysis in Cyprus and surroundings.

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