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Analysing the spatial dynamics of earthquakes using event synchronization method: Anatolian Case

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Abstract

In this study, an earthquake network was created for the Anatolian region by using the event synchronization method. The prominent earthquake zones in Anatolia and some of their possible network properties have been investigated by using local measurements. As a result of the measurements, some patterns draw attention. One starts from the south of the Marmara Sea and extends to the inner and coastal Aegean region. It can be mentioned that there is an earthquake continuity, and almost every cell on the network acts as a possible bridge for stress transfer in this region. Other prominent patterns arise on the Eastern Anatolian Fault and close to Van. As the same earthquake and stress continuity appear on these regions and cells acts as a bridge. The data used in the analysis cover the period between 1999-2017. Earthquakes with magnitudes ranging from 5.5 to 6.9 occurred after 2017 in some prominent regions. On the other hand, some of them still silent. Results showed that these regions have the potential for future activities. On the other hand, the North Anatolian Fault and the south-west strand of the East Anatolian Fault remained silent. However, the part of the Eastern Anatolian Fault between Bingöl and Pötürge is very active.

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1. Introduction

It is known that Anatolia faces the risk of earthquake hazards. This tectonic region is driven by three major lithospheric plates. The interaction of Eurasian, Arabian and African plates caused many fragments on the Anatolian Peninsula. Due to Eurasian and Arabian plates collisions, the Anatolian plate moves to the west. After the collision with the African plate, it goes down on the African plate along the Aegean subduction zone. These interactions and collisions create one of the most active and complex tectonic regions on Earth. Major faults and systems in Anatolia are given in Figure 1 in order to help to understand and compare network graphs in the next sections. For more information about the tectonic dynamics of the Anatolian Peninsula see [1].

Despite all efforts to explain and predict earthquakes, limited information has been gained, especially in the last century. This is a result of both the complex nature of the earthquakes and insufficient observations of the earth crust. Gutenberg-Richter, Omori and Bath laws are empirical laws and at the centre of this field [2-4]. To better understand this natural phenomenon, studies on to find different laws or scalings are continuing. Due to the complex nature of the earthquake, this challenge is not easy. Maybe our pattern recognition abilities help us to understand nature as our ancient ancestors. We can search for new scaling and patterns by using the advantage of new technologies and new tools. The complex network method is a good candidate for this aim. Network theory has been applied in various areas such as power grid [5], internet [6,7], protein interactions [8], metabolic network [9], neural network [10] and as expected on earthquakes [11,12]. Although a few studies in the literature reveal such patterns, they have several deficiencies. On the other hand, linear analysis methods were generally used in these studies [11,12] (for more information, see [13]).

Very few of them handle the problem by using nonlinear methods. One of the good example of these nonlinear methods is the event synchronization method which will be discussed next section. This study aims to create an Anatolian earthquake network by using the event synchronization method and analyzing the spatial dynamics of this network to investigate possible active regions and pathways of stress transfer. The same method and measurements were used to analyze to earthquake dynamic of Southern California, and remarkable results have been observed [13].

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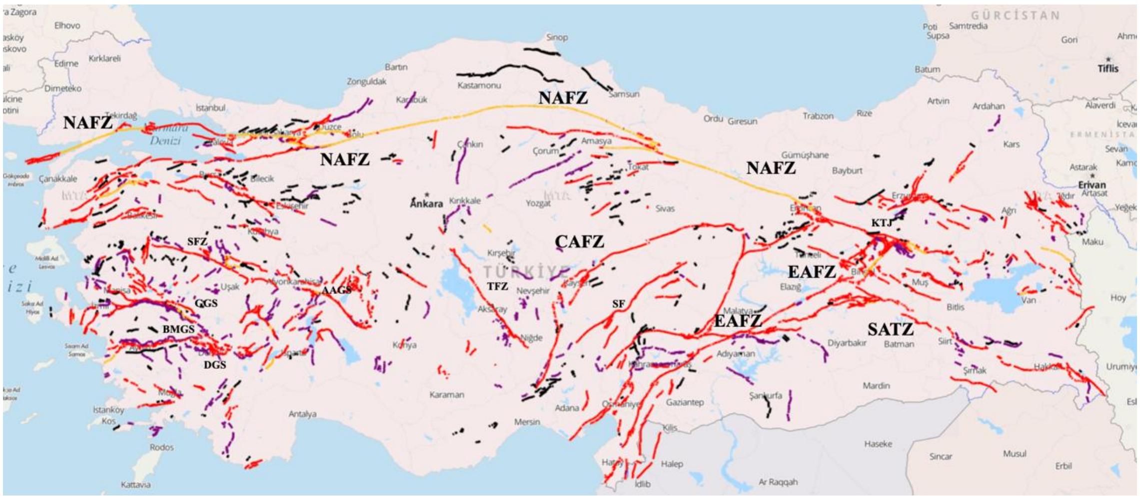

Figure 1. Anatolian major faults and systems. FAULTS: NAFZ: Northern Anatolia Fault Zone; EAFZ: Eastern Anatolia Fault Zone; CAFZ: Central Anatolia Fault Zone; SATZ: Southern Anatolia Trace Zone; SFZ: Simav Fault Zone, GGS: Gediz Graben System, BMGS: Büyük Menderes Graben System, DGS: Denizli Graben System, AAGS: Afyon-Akşehir Graben System; TFZ: Tuzgölü Fault Zone, SF: Sarız Fault, KTJ: Karlıova Triple Junction. Lines in different colours represent that; Yellow: Earthquake Surface Fracture, Red: Holocene Fault, Purple: Quaternary Fault and Black: Possible Quaternary Fault or Lineaments. Fault map is taken from [14].

2. Event Synchronization Method and Construction of Adjacency Matrices

Event synchronization has been introduced to analyze rat electroencephalogram and human EEG signals [15]. The method and its fractions have been applied to various fields such as Indian monsoonal rainfall [16,17]. The method has been applied to this geographical region and heavy rainfall events have been used in this version. Contrary to the EEG signals in the original version, earthquakes are discrete events, and they can be handled as a point process as in [17]. This approach gives advantages for the selection of τ, which is a control parameter in time and determines whether selected two events in different time series have synchronization with each other or not.

For simplicity, suppose we have two time series as x_n and y_n $(n = 1, \ldots, N)$ and t_i^x and t_j^y represent the event times in each series. As one can easily guess that these events are earthquakes in our case. If an earthquake occurs at x_n just after an earthquake occurs at y_n, it is called an event pair. τ defines the maximum time interval between these events, which are counted as event pairs. This procedure is given mathematically as;

$$J_{ij}^{\tau} = \begin{cases} 1 & if \quad 0 < t_i^x - t_j^y \le \tau \\ \frac{1}{2} & if \quad t_i^x = t_j^y \\ 0 & \quad else \end{cases} \tag{1}$$

Since the possibility of two earthquakes occurring simultaneously in both series is almost zero, the second condition has been ignored in this study. One can sum event pairs by using the summation rule, which is given as;

$$C^{\tau}(x|y) = \sum_i^{m_x} \sum_j^{m_y} J_{ij}^{\tau}, \tag{2}$$

where $c^{\tau}(x|y)$ stands for an event occurs at x_n just after an event occurs at y_n, and the opposite of this case is represented by $c^{\tau}(y|x)$. The strength of event synchronization between these two series can be given as,

$$Q_{xy}^{\tau} = \frac{C^{\tau}(y|x) + C^{\tau}(x|y)}{\sqrt{m_x m_y}} \tag{3}$$

where m_x and m_y refer to the number of events at time series x_n and y_n, respectively. Q^{τ} is defined in $0 \le Q^{\tau} \le 1$ and $Q^{\tau} = 1$ ($Q^{\tau} = 0$) means that these two time series are fully synchronized (no synchronization). One can find the synchronization level between parts of the interested region under consideration by using this procedure.

The Anatolian earthquake catalogue is analyzed in our case. The data cover the period from 01/01/1999 to 01/01/2017. This data set is downloaded from the https://udim.koeri.boun.edu.tr/zeqdb/ website with the default area option. The area under consideration is divided into cells and earthquakes in each cell are listed as time series. Event synchronization level between any two cells can be measured by using the procedure mentioned above. If event synchronization between them is greater than a threshold, these two cells linked each other. If this procedure is applied between all cell pairs, the adjacency matrix of the network can be created. This matrix is given as,

$$A_{x,y} = \begin{cases} 1 & if\ Q_{xy}^{\tau} > Q_{thr} \\ 0 & else. \end{cases} \quad (4)$$

After constructing the network, the dynamical properties of the region can be observed by using network measurements.

3. Results

The Anatolian region has many faults and faults zones. The most famous one is the North Anatolian Fault Zone (NAFZ). Although the government, almost all media and many other organizations focus on this region; other parts of Anatolia are also at risk. It is vital to consider the whole picture. For this aim, this manuscript focuses on local measurements of the network to investigate active regions, possible pathways and spatial continuity of earthquakes. As mentioned above, the data cover the period from 01/01/1999 to 01/01/2017. Although the catalogue in https://udim.koeri.boun.edu.tr/zeqdb/ web site (Kandilli Observatory and Earthquake Research Institute catalogue) includes data before 1999, that period has some problems such as insufficient data or different magnitude thresholds, especially for early years. In order to include to Gölcük earthquake, the analyzed data set started in 1999. The catalogue includes $M \geq 2.5$ earthquakes for the early years of the analyzed period, but it includes $M \geq 2.0$ for recent years. The minimum magnitude threshold was chosen as $M_{th} = 2.5$ in terms of consistency and completeness of the analyzes.

Earthquake networks have been created for four different parameter combinations. These parameters are cell size, event synchronization, earthquake magnitude and τ values. As seen from Equation 1, τ value defines the maximum time interval between two events in any two nodes to count them as an event pair. τ values were chosen as 10, 30, 180, 365 days. It is known that the aftershock sequence of small earthquakes generally continues less than 10 days. Some small earthquakes can trigger a big one, but this manuscript handles the problem general perspective and does not count into account the behaviour of individual earthquakes. Also, the number of earthquakes in the catalogue does not support to create networks with lower values of τ. Because of these reasons, the lower limit of τ was chosen 10 days. Since the aftershock sequence of almost all earthquakes in the catalogue ends less than one year, the upper limit was chosen 365 days. The lower limit of cell size threshold was chosen as small as possible (0.125°) in order to increase the number of nodes. The upper limit of cell size was chosen as 1°, and this size corresponds to approximately the rapture length of a 7.0 magnitude earthquake [18,19]. Another parameter is the magnitude threshold, and it was chosen as 2.5, 3.0 and 3.5. As explained previously, 2.5 is the minimum magnitude in the analyzed data. Since the number of $M > 3.5$ earthquakes does not support creating a network, the upper threshold was chosen $M = 3.5$. The last one is the event synchronization threshold Q_{th}. The interval of this threshold is 0 to 1.0, and the increments are 0.1. The event synchronization method has been used to study earthquake dynamics of the Southern Californian region [13]. It is found that one of the parameter combinations seems to reveal the dynamics of extraordinary earthquakes. Graphs that are created with this parameter combination will be given in results. On the other hand, other parameter combinations will be discussed.

As same in the Southern California region, some long-range links appear in the network. One can think that these kind of long-range links are not so reasonable. On the other hand, long-range interaction is a popular field of study. Also, the authors show that there is stress-stress interaction between nodes in the California region [20,21]. As mentioned above, this study handles the problem general perspective, and measures do not aim to explain the physical dynamics of interactions. The event synchronization value is chosen high to avoid link inflation, which can be obscure important nodes. These higher thresholds decrease the weight of long-range links in the network. So short-range links are dominant in measurements.

Major earthquakes in the analyzed period are given in Figure 2 for comparison results of measurements.

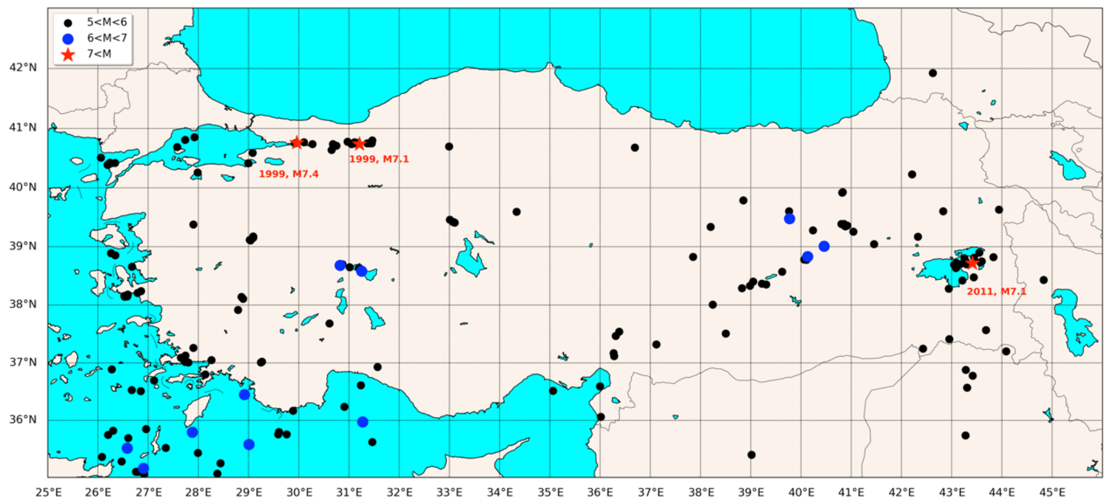

Figure 2. $M \geq 5.0$ Earthquakes between 01/01/1999-01/01/2017 in Turkey and surrounding region.

3.1. Degree centrality

Degree centrality is a good candidate for the observation of active regions. Since any node's degree centrality is related to the number of links of that node, this measurement is an indicator of that node's importance from the network point of view. It is given mathematically as;

$$C_j^D = \frac{\sum_{i=1}^{N} A_{ij}}{N-1} \quad (5)$$

where N is the number of nodes, and A_{ij} is the adjacency matrix. As seen from the equation, any node's degree centrality is the ratio of links of that node to that node's total possible links.

As seen from Figure 3, prominent regions generally correspond to regions where $M > 5.0$ magnitude earthquakes occurred in recent years in Figure 2. The well-known one of these earthquakes is Van Earthquake (October 2011; $M = 7.1$). The aftershock regime of this earthquake increased the activity of the near part region. This activity increases the chance of these cells becoming a part of the network. This situation shows itself as clustering around the northeast at the Van Lake. Another prominent structure in Eastern Anatolia shows itself as a line. This pattern starts close to Karlıova/Bingöl, follows the Eastern Anatolia Fault Zone (EAFZ) and ends close to Pötürge/Malatya. It is the evidence of activity of the EAFZ in that region. Bingöl earthquake (May 2003, $M = 6.4$), occurred close to the starting point of this pattern. Karlıova Triple Junction (KTJ) is a part of this region, and it is well-known as an active region. This well-known activity has been clearly demonstrated in the network with degree centrality measurement. As same Sivrice earthquake recently happened at the point where this pattern ended. It should be noted that Karlıova-Pötürge part of this fault clearly shows itself in the figure. This fault bifurcates after Çelikhan. The main EAFZ starts from Karlıova and reaches Antakya. It includes the southern strand of the EAFZ. The northern strand between Çelikhan to Iskenderun Gulf called Sürgü-Misis fault system. Both northern and southern strands after Pötürge weekly show themselves in Figure 3. This week representation is a result of relatively few earthquakes on these strands of the fault system. This difference between the two areas of the same fault system can be interpreted as the southwestern part of the fault has not yet taken action, and attention should be paid to this area in the future.

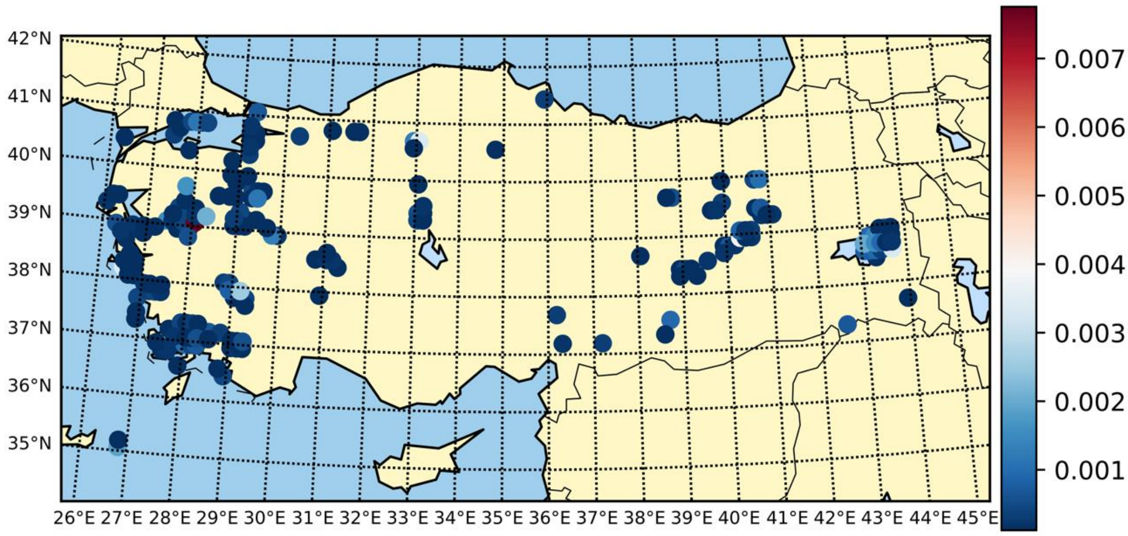

Figure 3. Degree centrality for $Mth = 2.5$, $\tau = 10$ days, $L = 0.125^{\circ}$ and $Q = 0.9$.

Other prominent regions are the Aegean coasts and the southern Marmara region. The lineaments from İstanbul to Bursa, from Bursa to Balıkesir and Kütahya are trace to Northwest Anatolia Transition Zone. Notably, faults on Manyas-Bursa Bend and Simav Fault are very active, at least for small earthquakes ($M \geq 2.5$). Two different patterns at Aegean cost can be seen in Figure 3. One of them started from Lesbos Island and ended in Kuşadası/Aydın. If one focus on this lineament can see formations perpendicular to Aegean costs. These formations reveal the fault structure of the region. The second lineament can be seen at Gökova Bay. It starts from Kos Island, and it reaches approximately 50 km inside the land. This lineament is a result of frequently occurred earthquakes in that region. It should not be forgotten the effects of the earthquake storm at Gökova Bay. Earthquake storms increase these regions event synchronization levels and help them to be part of the network. It is notable that there are two parallel and long lineaments. On the other hand, there are a few relatively short faults known and drawn in the fault maps. There may be a different fault structure that starts from the inner part of the Aegean Sea and continues on land. These structures show that conducting seismic surveys in the Aegean Sea is essential for understanding the seismicity of the region. These researches should be considered to continue on the land, especially between Köyceğiz and Fethiye.

Apart from these, relatively small clusters or single cells can be seen as a part of the network in degree centrality figure (Figure 3). These active regions are Denizli Graben System (GBS), Afyon-Akşehir Graben System (AAGS), the region at the north to the Tuz Lake, some cells eastern part of the NAFZ close to Erzincan and Erzurum, the western strand of the NAFZ, southern and northern strands of EAFZ and some single cells.

One should note that the magnitude threshold is $M \geq 2.5$ in Figure 3. So the term of activity is related to "How often that cell generates an earthquake which magnitude is greater than 2.5". It is not directly related to "How big an earthquake occurred in that cell". Of course, bigger earthquakes affect their surrounding regions, and its aftershock sequence dominates the catalogue for a certain period at that region and increases the event synchronization level of these cells. We can clearly see effects of $M > 6.0$ earthquakes at its surrounding region such as Van ($M = 7.2$, 2011), Orta ($M = 6.1$, 2000), Çay-Sultandağı ($M = 6.4$, 2002), Pülümür ($M = 6.2$, 2003), Bingöl ($M = 6.4$, 2003), Simav ($M = 5.9$, 2011) earthquakes. On the other hand, if there are frequently occurring $M > 2.5$ earthquakes in any cell, they also increase the event synchronization level of that cell. This means that a cell that regularly generates earthquakes does not need a major earthquake or earthquake storm, to be represented on the network.

If the magnitude threshold increases as $M \geq 3.0$, many cells cannot be part of the network. Only a few of them survive. They are represented as a single cell and small clusters. These small clusters are located at Sığacık Bay, Gökova Bay, Simav, Izmit Bay, Denizli, close to Bala/Ankara, Van, Karlıova/Bitlis and its surrounding region, and a single cell is at the Çorum. It is notable that there are $M > 5.5$ earthquakes in these regions. It can be concluded that many cells in Figure 3 generally generates earthquakes between $2.5 < M < 3.0$. These cells cannot stay to be part of the network for $M \geq 3.0$.

Degree centrality values increase when τ increases. As expected both, new cells join the network, and existing cells make extra connections. Almost all new cells are located aforementioned active regions and, they create more coward clusters step by step as τ increase up to 365 days (10,30,180,365). Especially lineament at Gökova Bay is notable. This lineament is about 200 km long.

The total number of cell degrees for larger cell sizes (0.125°, 0.25°, 0.50°, 1.0°). On the other hand, the number of earthquakes in each cell increase. Is a result of this, degree centrality values increase for these cells. Since we represent the same area with fewer cells, the fault traces appear coarser. This masks the active regions. It is like looking at a photograph with a lower resolution. It seems that ($0.125^{\circ} \times 0.125^{\circ}$) cell size is the better option for creating a network with the possible highest resolution. Hereafter, other cell sizes will not be mentioned unless they are necessary.

Another parameter is the event synchronization threshold. Decreasing the event synchronization threshold has the same effect as increasing τ. One can think that using a higher τ and lower event synchronization threshold is an ideal option in order to create a network with higher magnitude thresholds. Although it seems a good option, the number of earthquakes with $M > 3.0$ not enough to realize this opinion. On the other hand, we do not want to decrease the event synchronization threshold so lower values since to avoid the effects of possible random event pairs.

3.2. Betweenness centrality

Betweenness centrality is another measure of the importance of a node. It is based on if a node is on the connection path of any two nodes, this node is important for the communications of these two nodes. From the point of information flow view on a network, these nodes with high betweenness values are important. Due to this advantage, they can receive all information between nodes whose shortest path passes through these nodes. A node with a high betweenness value may have a very low degree centrality or any other centralities. However, it can be still so important for the network, especially if it is only one node between two parts of the network. Betweenness centrality can be informative in terms of stress propagation paths for an earthquake network. This measurement is given as,

$$C_k^B = \sum_{k \neq i \neq j} \frac{\sigma_k\,(i,j)}{\sigma\,(i,j)}, \qquad (6)$$

where $\sigma_k(i,j)$ is the number of shortest paths between i and j passing through k and $\sigma(i,j)$ is the number of all shortest paths between i and j.

As seen from Figure 4 previously mentioned regions draw the attention. If we start from the east, the first pattern can be seen close to the Van Lake and this pattern is probably highly dominated by the 2011 Van Earthquake. Aftershocks of this earthquake increased the possibility of nearby nodes becoming a part of the network. It seems that each node has a role for stress transfer for that region. As same with degree centrality, lineament on EAFZ, clusters at Southern Marmara, Bala, Simav, Sığacık Bay, Denizli, Gökova Bay are other active regions. Cells at these regions may have a role in stress transfer. We think that these patterns are the results of $M > 5.5$ earthquakes in these regions. Aftershock sequences of these earthquakes dominate their surrounding regions. It is thought that the accumulated stress is transferred to others through these cells. Thus, each cell acts as both a new resource and a bridge to stress transfer to its surrounding regions. One red coloured cell close to Gökova Bay has the highest betweenness centrality. However, this cell cannot continue its importance with different parameter combinations. In addition to this, most of the cells have approximately the same betweenness centrality value. It seems that these cells have the same importance for possible stress propagation. Although the energy can separate all directions after an earthquake, stress prefers to transfer along to the fault direction. As a result, almost all cells on this fault are between others and have approximately the same importance for stress propagation. Similar results have been observed in [13].

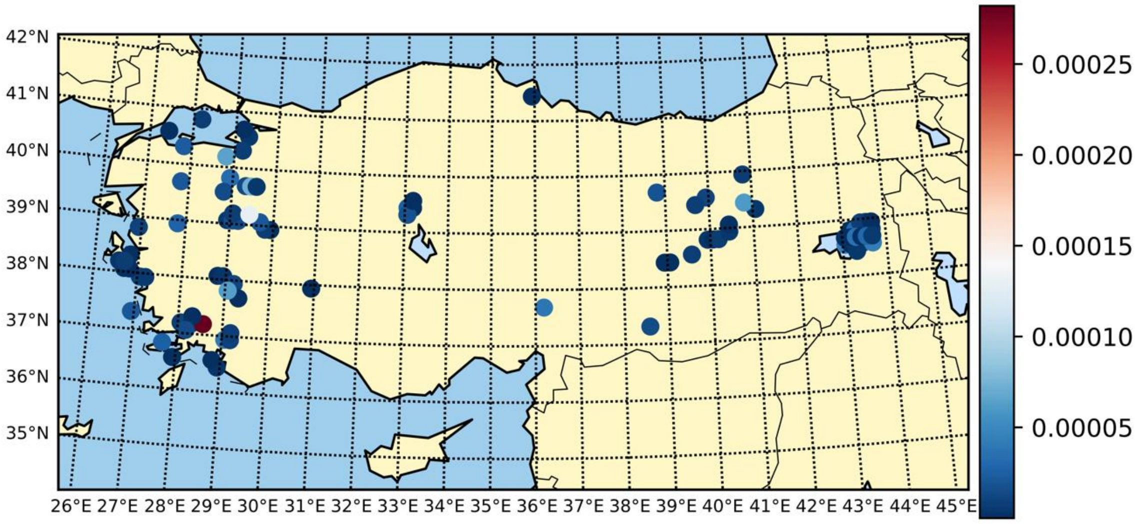

Figure 4. Betweenness centrality for $M_{th} = 2.5$, $\tau = 10$ days, $L = 0.125^{\circ}$ and $Q = 0.9$

On the other hand, the number of cells in active regions increases with increasing τ. Especially when it increase 10 days to 30 days, the number of cells in active region clusters is close to the number of cells for 180 days and 365 days. However, it is seen that betweenness values decrease with increasing τ. Of course, as the τ increases, the possibility of occurrence an earthquake at that period of time in each cell increases, so more cells make connections with each other. Thus, many alternative shortest paths can be appeared between any two cells and betweenness values decrease. Besides a lineament along the Marmara Sea draws attention with increasing τ. A network structure goes south perpendicularly to this lineament and then connects to Izmir via Manisa. This structure seems to consist of a lineament from İzmit to Kütahya, a cluster at Manisa and Balıkesir and another lineament from Lesbos Island to Kuşadası. There are many faults and fault zones in the region Southern Marmara, Simav, and Manisa. Although they are considered independent zones, the network structure gives the impression that the NAFZ's effect is carried over the Aegean coast via these faults. It can be interpreted that the stress caused by the NAFZ can be carried to the Aegean shores on a long time scale. Also, Gökova Bay is another important region. The structure in this region become more evident with increasing τ. As mentioned before, it is known that there are many faults in the region, most of which are short. These faults have caused earthquake storms in the recent past. On the other hand, as mentioned before, the long lineament structure, which we consider to be stress continuity, may indicate a different fault mechanism in the region. Another structure on the EAFZ between Bingöl and Hatay emerged more clearly with increasing τ. In other words, it is thought that there may be a stress transfer along this line. Other prominent regions where cells behaviour as a bridge for possible stress transfer are Denizli, Afyon, north to Tuz Lake and Van Lake. More prominent clusters arise with increasing τ in these regions. Decreasing event synchronization level almost the same effect with increasing τ.

3.3. Local clustering coefficient

The local clustering coefficient is another measurement on a network that has the potential to provide useful information about the regions mentioned above. This measurement has been used to understand spatial continuity of rainfall events for monsoon rainfalls in India [16] and spatial continuity of earthquakes for the Southern California Earthquake region [13]. If two connected nodes are also connected with a third one, it is called a triad. The ratio of the total triads to the possible triads of a node gives its clustering coefficient value. This is a measure of how neighbours of this node are close to a clique. Suppose that there are k_j neighbours of node j. The number of total possible links between neighbours of this node is $k_j(k_j - 1)/2$. On the other hand, this is the maximum value and generally real number of total links between neighbours less than this maximum. If there are ε_j links between neighbours, the local clustering coefficient can be given as,

$$C_j^{LCC} = \frac{2\varepsilon_j}{k_j(k_j-1)}. \quad (7)$$

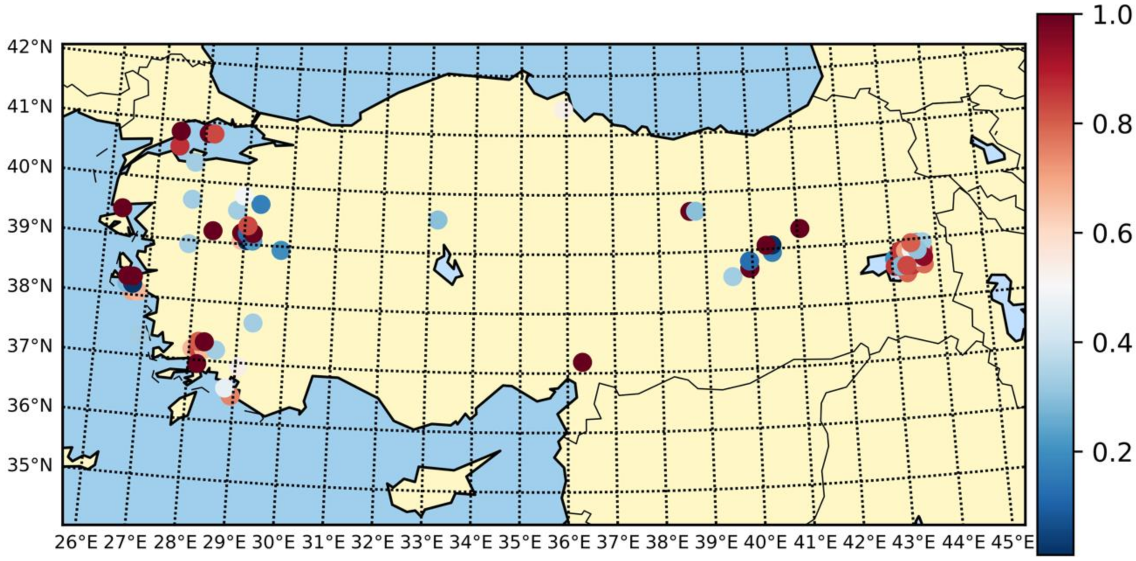

Figure 5. Local clustering coefficient for $M_{th} = 2.5, \tau = 10$ days, $L = 0.125^{\circ}$ and $Q = 0.9$

As seen from Figure 5, almost the same previously mentioned regions have a kind of earthquake continuity. They are KTJ, Van, Kütahya- Manisa, İzmir, Gökova Bay and the Marmara Sea. We think that after an earthquake happens in these regions, another earthquake frequently occurs in their surrounding regions. Hence, it can be interpreted as a stress continuity in the surrounding region of the main earthquake.

The network becomes more crowded with increasing τ . The patterns on to EAFZ and at the Van Lake are noticeable formations at the east. On the other hand, more contribution to the network comes from Marmara and Aegean regions. A lineament starts from Bolu and reaches the west coast of the Maramara Sea. This lineament is the trace of NAFZ in that region. It shows that there is an earthquake continuity at fault direction. Another pattern in the Marmara region starts from the İstanbul-Adapazarı region and reaches Kütahya in the Aegean region. Pattern touches cluster on to Balıkesir-Manisa region. This cluster bounded another lineament which starts from Lesbos Island, passing through Izmir and reaches Kuşadası. These patterns can be interpreted as earthquake continuity and stress continuity in this region. This continuity is an effect of the NAFZ to the western part of this fault at the Marmara Sea and the western part of the Aegean region. Similar to previous findings pattern along to the Gökova Bay, Denizli, Afyon, and the region north to the Tuz Lake draw attention. In light of all these, it can be said that there are earthquake continuity and possible stress continuity in the mentioned regions in long time intervals, which is not clearly seen in a short period.

3.4. Discussion

As previously mentioned, this manuscript focus on local network measurements to understand earthquake network dynamics of the Anatolian region. It is shown that the western part of Anatolia is more active and has earthquake and possible stress continuity. Although it seems to be the result of medium and large-scale earthquakes, small earthquakes that frequently occur in the region have also been effective in the analysis. It is known that there are many faults and fault zones in the western part of Anatolia. These faults and faults zones create independent tectonic structures. There are different patterns as a result of local measurements. The first one is a lineament Bolu to the west coast of the Marmara Sea. The second pattern perpendicular to the first one stars from the east coast of the Marmara Sea and reaches Kütahya. The third one is another lineament that starts from Lesbos Island and reaches Kuşadası/Aydın. Between them, a cluster shows itself at Manisa and Balıkesir. The last one appears at Gökova Bay. These patterns show that there are earthquake activities. Many cells at these regions may serve as a bridge for possible stress transfer to surrounding cells, and there are spatial earthquake continuities. These patterns appear more clear for higher values of τ. These results led us to think that the NAFZ somehow affected the central and western Aegean regions.

Other prominent patterns appear at Van Lake and region between Karlıova/Bingöl and Pötürge/Malatya. Pattern at Van Lake is dominated by Van Earthquake. A cluster appears as a result of aftershocks in the region. Many surrounding cells are part of this cluster, and there is an earthquake continuity in this region.

These cells also serve as bridges. Also, the pattern appears as a lineament on the EAFZ. It seems there are many activities on the Karlıova-Pötürge part of this fault. These activities show that an earthquake continuity appears in this region. It seems that there is possible stress transfer and, many cells serve as bridges on the lineament. It should be noted that activity on the fault after Pötürge is weaker than the Karlıova-Pötürge part. As a result, the west-south part of the fault does not or weakly represented for different parameter combinations. Although the analyzed period (1999−2017) is not so long, that kind of weak activity may not be meaningful for this region. We would like to point out that there may be an accumulation of stress in this part and, there may be possible belated earthquakes.

Other little clusters appear at Denizli, Afyon, Ankara. It seems that clusters at Denizli and Afyon are results of activities on the DGS and AAGS. The cluster that appears at Bala/Ankara is a result of the Bala Earthquakes (2005, 2007, 2008). These earthquakes occurred north end of the Tuzgölü Fault Zone. It should be noted that this project covers the period 1999-2017. It is known that few earthquakes happened in regions mentioned above after January 2017. Their magnitudes are between 5.5 to 6.9. Especially Sığacık Bay is an active region in all three measurements. Also, this region remains part of the network with different parameter combinations. It is one of the two active cells all Anatolia with high parameter combinations. Other cell is in the Van. Contrary to Van there is no major earthquake in the analyzed period. Samos-Izmir earthquake (M=6.9, October 2020) occurred after the analyzed period just close to that cell. We conclude that it may be evidence of other mentioned regions are also at risk.

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Conflicts of interest

The author state that did not have conflict of interests

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