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Three Days before the Earthquake in Skopje there was a Compression of the Earth's Crust

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ABSTRACT. In this paper are analysed daily changes of all distances between four MAKPOS GNSS referent stations (Skopje, Tetovo, Kumanovo and Veles). In that way are defined the deformations of the Earth's crust in wide area of Skopje from 20th of August 2016 till 20th of September 2016. It was noticed that three days before the earthquake from 11th of September 2016, there was decreasing of the site distances between MAKPOS GNSS stations in Skopje surrounding, practically there was compression of the Earth's crust around Skopje. On 11th of September 2016 there were several smaller earthquakes, all of them were with epicentres nearby Skopje. The most powerful earthquake was with magnitude 5.2 degrees per Richter and its hypocentre was at a depth of 4 km. We decide to analyse in more detail whether was any decreasing of the site distances between MAKPOS GNSS stations before 20th of August 2016 and for that was analysed time period from the beginning of 2016 till 30th October same year. We found that prior to all earthquakes, even those smaller before and after the main earthquake there was always decreasing of the site distances between GNSS referent stations and that the earthquake appeared two to nine days after the compression. With analyse of the earthquake in Kraljevo (Serbia) from 2010, also we get that tree days before earthquake there was decreasing of the site distances between GNSS referent stations. With analyse of the earthquake in Drežnica (Croatia) from 2013 was obtained such a result. Drežnica earthquake was on reversal fault, and Kraljevo and Skopje earthquakes were on normal faults.

Keywords: MAKPOS, GNSS reference station, Leica Geosystems, earthquake.

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1. Introduction

Nowadays the deformations of the Earth's crust cèan be determined with the help of GNSS navigation satellites and established satellite positioning systems on the Earth's surface. With that purpose, a system of permanent stations called MAKPOS (English acronym of Macedonian Positional System) was set up in Macedonia to determine the position of points on the ground. Such ground-based positioning systems were also developed in Croatia (CROPOS), Slovenia (SIGNAL), Serbia (AGROS), Montenegro (MONTEPOS) and Bosnia and Herzegovina (BHPOS and RSPOS).

The purpose of these systems is to enable surveyors to determine the position of points where an antenna is placed with only one GNSS receiver in real time. With other words, to allow geodetic experts on the entire territory of the above mentioned countries to virtually instantly determine horizontal positions directly on the ground with up to 2 cm horizontal accuracy and around 4 cm vertical accuracy. For this purpose, 14 GNSS reference stations were set up in Macedonia (Figure 1,

Figure 1. *GNSS reference stations of the MAKPOS network and the net for determination shifts of the Earth's crust before and after the earthquake in Skopje in 2016.*

Table 1). Distances between reference stations are in range from 50 to 70 km and each station is equipped with GNSS antenna and GNSS receiver from the manufacturer Leica Geosystems. At the reference stations, GNSS receivers continuously receive outgoing signals from the GNSS satellites passing through the sky above the GNSS antenna horizon for 24 hours per day all year round. Then they transmit the received radio signals from the satellite to the control (computer) centre in Macedonia (Dimeski et al. 2012, Trpeski et al. 2013).

In the computer center these data are processed and corrections are calculated and then that corrections are sent to the users of the positioning system.

A geodetic expert on the field with his GNSS antenna and receiver receives signals from the GNSS satellite and immediately sends them to the control (computer) center via mobile internet radio and receives the corrections from the computer center via mobile internet. In this way, the geodetic expert is able to determine the position coordinates of a certain point with up to 2 cm horizontal accuracy and up to 4 cm vertical accuracy in real time using one GNSS device. At the same time, the surveyor is no necessary to have at least 2 GNSS receivers to determine the position coordinates of the point in a differential mode. In the postprocessing it is possible for measured points enables accuracy up to 1 cm. But by use of the Bernese 5.2 scientific software at the GNSS reference stations enables accuracy of coordinates up to millimeter for measurement data of 24 houres (Solarić, M. et al. 2017).

Table 1 *The coordinates of the MAKPOS GNSS stations in datum ITRF 2008 at epoch 1.1.2011 are given below.*

Point	**E**	**N**	**h**
KUMANOVO	559 297.065	4 665 165.601	391.496
TETOVO	497 541.327	4 650 824.906	527.319
SKOPJE	533 742.784	4 649 821.225	311.132
VELES	564 093.893	4 618 774.657	246.170

(where E – eastern coordinate, i.e. the distance in meters from 21° meridian to which is added 500 000 m, N – northern coordinate, i.e. the distance in meters from the Equator and h – the ellipsoidal height in meters)

The MAKPOS positioning system, as well as other established positioning systems in the immediate surroundings, can be applied in the field of geodynamics, apart from being used only for purely geodetic needs. This way, the positioning system which uses the Bernese 5.2 software to determine coordinates for GNSS reference stations with up to millimeter accuracy for 24 houres measurement can help surveyors, but also to seismologists (and seismotectonics experts) to determine the movements and presse in the Earth´s crust.

So geophysics obtained new method (instrument) for better reseaching Earth´s crust.

2. The earthquake in Skopje in 2016

A few smaller earthquakes occurred in Macedonia in the vicinity of Skopje on 11.9.2016. The biggest one, which was third in occurrence, happened at 15:10 (local time) and was with moderate strength of 5.2 degrees on the Richter scale. The earthquake's epicenter was locateat geographic latitude φ = 41.98° and geographic longitude λ=21.50° and its hypocenter was at a depth of 4 km (Figure 2). It was felt in Kosovska Mitrovica, Niš, Vranje and Belgrade (URL 1).

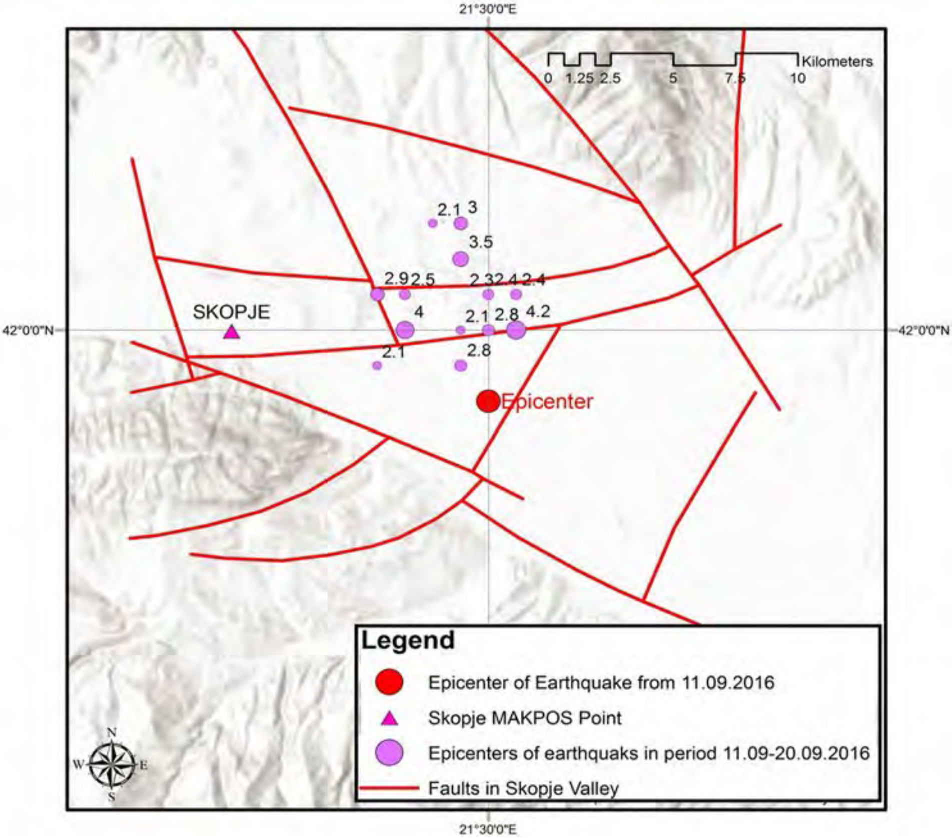

Figure 2. *Display of the epicenters of the earthquakes in Skopje region in period 11–20.9.2016, regarding to MAKPOS GNSS permanent station Skopje and major faults in the same region (Z. Bogdanovski).*

3. Analysis of the deformations of the Earth's crust before and after the earthquake in Skopje in September 2016

For the analysis of the horizontal deformation of the Earth's crust, were analyzed changes in the distance between 4 neighboring MAKPOS GNSS reference stations: Skopje, Kumanovo, Veles and Tetovo (Figure 1) from 20.8.2016 until

20.9.2016. Coordinates of reference stations near Skopje were obtained from the Agency for Real Estate Cadastre, and in Excel we calculated the site distances between the reference stations, their daily changes and graphically presented them.

We have selected GNSS referent stations near Skopje, which make the triangle and a reference station in the center of triangle in Skopje. Such a form of referent stations scheduling usually makes it easier to analyze the strength of field compression than if it is an elongate quadrangle shape with diagonal lines. Such a quadrangle with diagonals was used in analysis earthquakes in Kraljevo (Solarić, N. and Solarić, M. 2012) and Drežnica (Solarić, N. et al. 2017). This choice dictated the distribution of reference stations.

If the changes in the reference stations coordinates are only analyzed, it is not possible to see what kind of deformations and what presse occurred on the surface of the Earth's crust. That is why the changes in the distance between the reference stations had to be determined using the reference stations coordinates. Namely, only the changes in the distance between object points on the Earth's crust indicate the size of the deformation and presse in the Earth's crust. In addition, it is important to emphasize that by computing distances between the GNSS stations a part of system errors is eliminated and greater accuracy in the analysis of the changes in distances between the GNSS stations is achieved. It should be emphasized that errors caused by the atmosphere and errors in the satellite ephemerides have an approximately equal effect on neighboring points when determining station coordinates. In this way, the distances between the MAKPOS GNSS stations are relatively well determined. Shortening the length between GNSS stations will indicate compression of the terrain. Furthermore, the vertical changes of the deformation of the Earth's crust around Skopje are examined by analyzing the changes in their ellipsoid heights for the same time period.

The side distances between the 4 MAKPOS GNSS stations were calculated from coordinates determined from signals which were received from the GNSS satellite and calculated by scientific software Bernese 5.2.

The coordinates are determined for time period from 20th of August till 20th of September and they are calculated with an average standard deviation of 1.5 mm for latitudes, and with an average standard deviation of 1.8 mm for longitudes. The ellipsoidal heights were determinate with an average standard deviation of 4.7 mm. It should be emphasized that these standard deviations also include the shifts of the terrain area.

In order to get an overview of changes for all site distances between 4 MAKPOS GNSS stations, in Figure 3 are shown graphically all daily changes of distances between stations. In that way we determined the deformations of the Earth's crust on the surface as well as the pressure in it. The criterion for definition when compression in Earth's crus for our network type (Figure 1) may be that all pages between GNSS stations are shortened. However, a site may appear that does not have a shortcut, if it was later earthqake on big distant from that site (see Figure 9). After the analysis on the next earthquakes, the compression of the terrain will be better defined.

According to the measurements registered on the seismographs in the time period from 20th of August till 20th of September 2016 at EMSC

(European-Mediterranean Seismological Centre) in Skopje area were detected several smaller earthquakes on 11th of September and one earthquake with magnitude 5.2 (see Table 2).

Table 2. *Earthquakes magnitudes higher than 1.6 degrees on Richter in the area of Skopje registered in EMSC (European-Mediterranean Seismic Centre) from January 1, 2016 up to the November 7, 2016.*

Date	**Time** (UTC)	**Latitude** (degrees N)	**Longitude** (degrees E)	**Depth** (km)	**Magnitude**
22. 1. 2016	22:06:03.7	41.92°	20.74°	5	2.0
6. 4. 2016	09:05:17.6	42.38°	21.49°	5	2.4
19. 4. 2016	02:51:06.3	41.61°	20.68°	10	2.5
19. 5. 2016	00:33:20.1	41.91°	20.99°	5	3.1
19. 5. 2016	01:06:21.5	41.93°	21.04°	2	2.4
2. 7. 2016	05:54:35.4	41.94°	20.98°	10	3.2
13. 7. 2016	17:12:59.1	42.01°	21.46°	3	2.0
26. 8. 2016	22:42:10.2	42.05°	21.50°	5	2.1
27. 8. 2016	16:26:32.6	42.10°	21.55°	7	2.4
11. 9. 2016	04:58:01.1	42.00°	21.51°	4	4.2
11. 9. 2016	05:00:05.4	41.99°	21.50°	3	2.8
11. 9. 2016	**13:10:07.4**	**41.98°**	**21.50°**	**4**	**5.2**
11. 9. 2016	13:14:27.2	42.01°	21.46°	2	2.9
11. 9. 2016	13:19:11.4	42.00°	21.50°	2	2.8
11. 9. 2016	13:30:25.3	42.00°	21.49°	1	2.1
11. 9. 2016	14:07:21.0	42.01°	21.51°	1	2.4
11. 9. 2016	14:45:58.5	42.01°	21.47°	3	2.5
11. 9. 2016	18:57:17.6	41.99°	21.46°	9	2.1
12. 9. 2016	09:50:30.6	42.01°	21.50°	1	2.3
12. 9. 2016	12:19:05.0	42.02°	21.49°	2	3.5
13. 9. 2016	23:32:29.3	42.03°	21.49°	3	3.0
15. 9. 2016	21:40:52.5	42.03°	21.48°	1	2.1
20. 9. 2016	13:56:46.4	42.01°	21.50°	1	2.4
4. 10. 2016	10:52:16.2	42.00°	21.51°	1	3.1
6. 10. 2016	23:06:22.0	42.02°	21.48°	1	1.6
9. 10. 2016	21:00:42.8	41.85°	22.10°	2	2.4
11. 10. 2016	16:14:40.2	42.15°	21.31°	1	2.1
12. 10. 2016	09:39:02.4	42.01°	21.48°	6	2.5
18. 10. 2016	20:13:54.5	42.04°	21.41°	1	1.8
7. 11. 2016	03:11:26.4	42.01°	21.47°	2	2.0

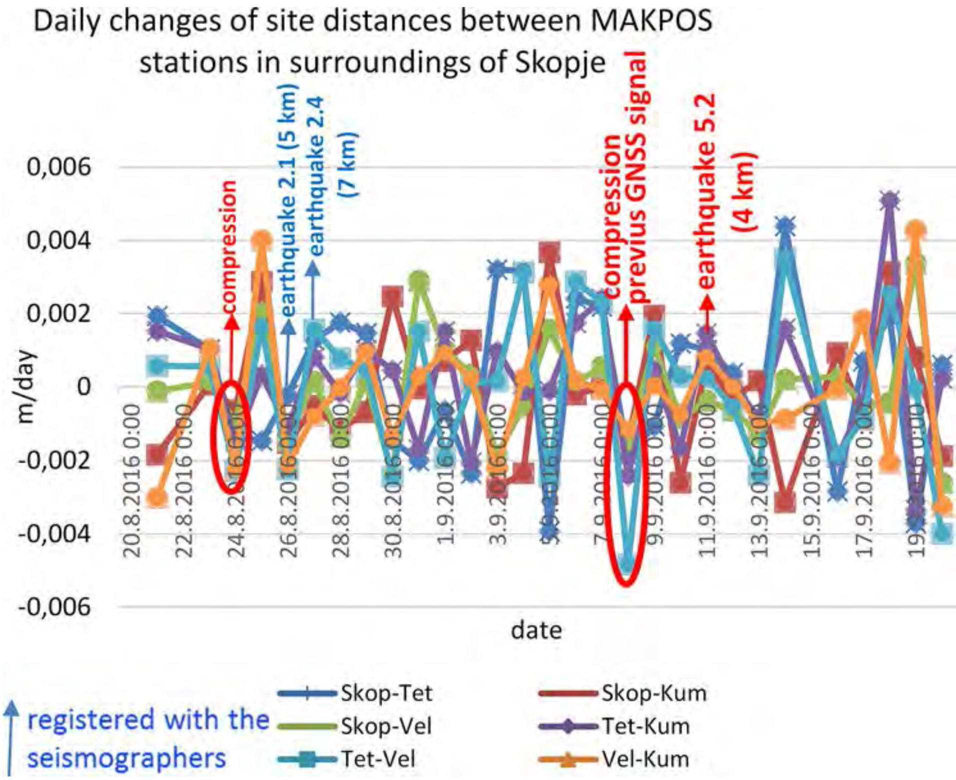

Figure 3. *Daily changes of side distances between the observed MAKPOS GNSS stations around Skopje. The decrease in all the distances (terrain "compression") occurred on 8.9.2016 and three days later the strongest earthquake in this area occurred. Earthquakes greater than 5.0 in Europe are marked in red colours.*

It is interesting to mention, as it can be seen from Figure 3, that on 8.9.2016 all the side distances between the observed MAKPOS GNSS stations decreased. We shall call the decrease in side distances between the MAKPOS stations as "compression". This means that three days before the earthquake in Skopje there was a "compression" (i.e. decrease in the side distances between points on the Earth's crust) around Skopje (Figure 4).

We have also made a graphic illustration of the total horizontal changes in distances between the MAKPOS GNSS stations from 20.8.2016 to 12.9.2016 (Figure 5). In this graph it can be seen that in this time period of about 23 days the most stretched was the Skopje–Tetovo side and that it was extended by approximately 6 mm, Tetovo–Kumanovo 4 mm and Tetovo–Veles 2 mm. The other three sides had a much smaller decrease. This means that the west Earth's crust (west from Skopje) pushed the east Earth's crust towards to east and south of Skopje.

The Figure 3 according to EMSC registered earthquakes in Table 2 also shows that there were two smaller earthquakes in Skopje area on August 2016 with magnitude 2.1 and 2.4. The compression of these two smaller earthquakes was

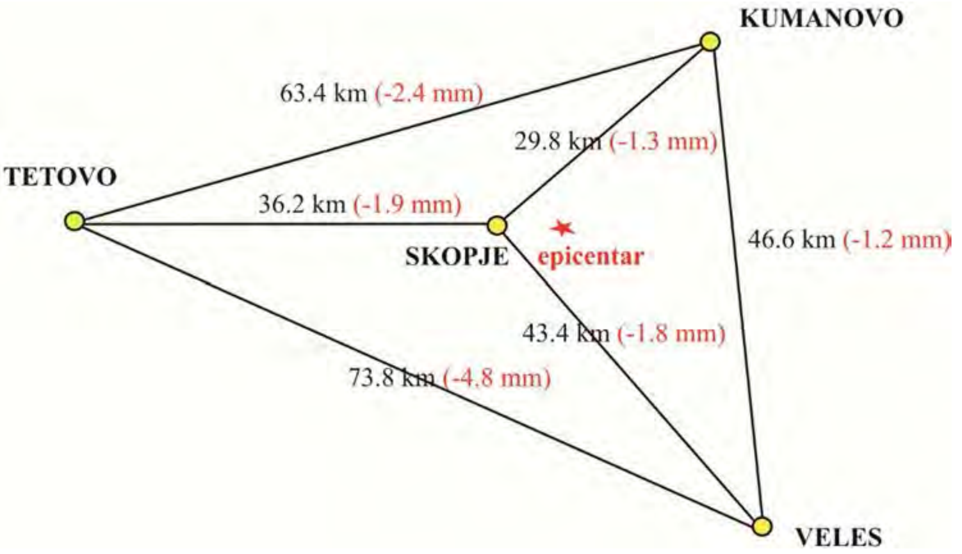

Figure 4. *The side distances between the observed GNSS stations in the MAKPOS network near Skopje, the red colour in the brackets indicates how much those distances were decreased on 8.9.2016 compared to 20.8.2016.*

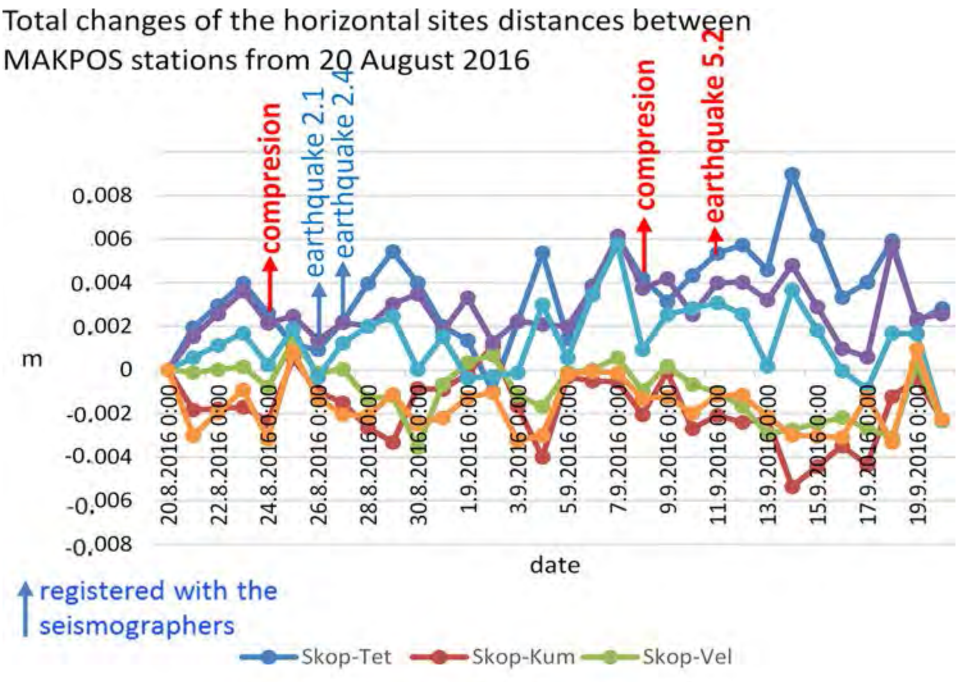

Figure 5. *Chart for total changes of horizontal distances between the MAKPOS GNSS stations near Skopje from 20.8.2016 to 20.9.2016.*

smaller than the compression on 8th of September 2016, i.e. three days before the main earthquake with magnitude 5.2. It means that according to the compression size, and if there is some layers are broken, which can be seen from the chart with daily changes of site distances between MAKPOS stations, thus it will be possible only to estimate the magnitude of the future earthquake, because the size of the deformation on the surface of the Earth's crust before the earthquake depends also on the depth of the hypocentre. Beside that the shape of the chart for compression depends from the shape (geometry) network of referent stations with which is analysing the earthquake. For that it will be need for further exploring with future earthquakes.

It would have been better if we had half-day (12-hour) coordinates of the MAKPOS stations. However, in that case the accuracy of the position coordinates of the 12-hour coordinates of the MAKPOS GNSS stations would have been slightly reduced because a smaller amount of measurements for the determination of the stations position would have been collected. Therefore, it would not be advisable to reduce the time for data collection from the GNSS satellites, but, on the other hand, it could lead to an earthquake possibly being predicted earlier and more accurately.

4. Examination of the terrain deformations using daily distance changes in the MAKPOS network in surroundings of Skopje before and after main earthquake, i. e. from 1.1.2016 till 30.10.2016

To explore is there any previous compression of the terrain before the main earthquake from 11th of September, we made analyse on daily changes of site distances between GNSS stations in surroundings of Skopje since the beginning of the year.

We have determined daily changes of site distances between GNSS stations in surroundings of Skopje for January 2016. The chart of daily changes for mount January is shown in Figure 9. From this chart can be seen that on 12.1.2016 there was a relatively large extends of the site distances Skopje–Tetovo, Tetovo–Kumanovo and Tetovo–Veles, and then the next day these site distances were significantly reduced. Those shifts were about 3.5 cm, which could have suggested that in next time period when will be the next compression of the terrain the shifts will be smaller. Nine days after the compression smaller earthquake occurred with magnitude 2.0 per Richter (Figure 6).

We also calculated daily changes of site distances between MAKPOS referent stations in surrounding of Skopje for mounts: February, March, April, May, June, July, August, September and October 2016. They are graphicaly shown in Figures from 7 to 15.

Conclusion: From this analyse can be seen that before every earthquake was present a compression of the terrain. Two to nine days after the compression the earthquake occurred. Only one time after compression of the terrain on 29th of July 2016 (Figure 12) there was no earthquake, because the earth layers were not break. This can be seen from daily changes of site distances between GNSS stations from 30th and 31st of July when all changes of site distances of GNSS stations

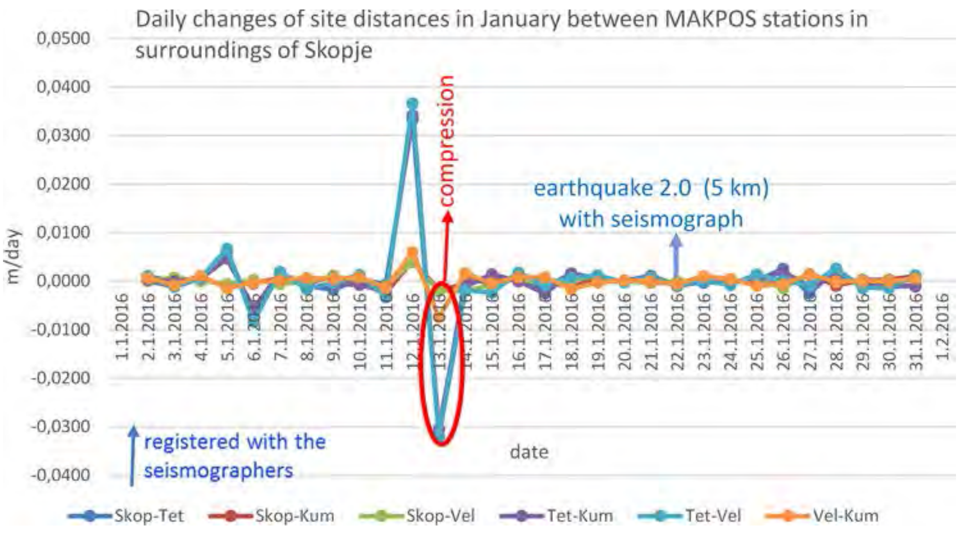

Figure 6. *Chart of daily changes of site distances between MAKPOS GNSS stations in surroundings of Skopje for January. The terrain compression was on 13th of January and after 9 days it was smaller earthquake with magnitude of 2.0 per Richter.*

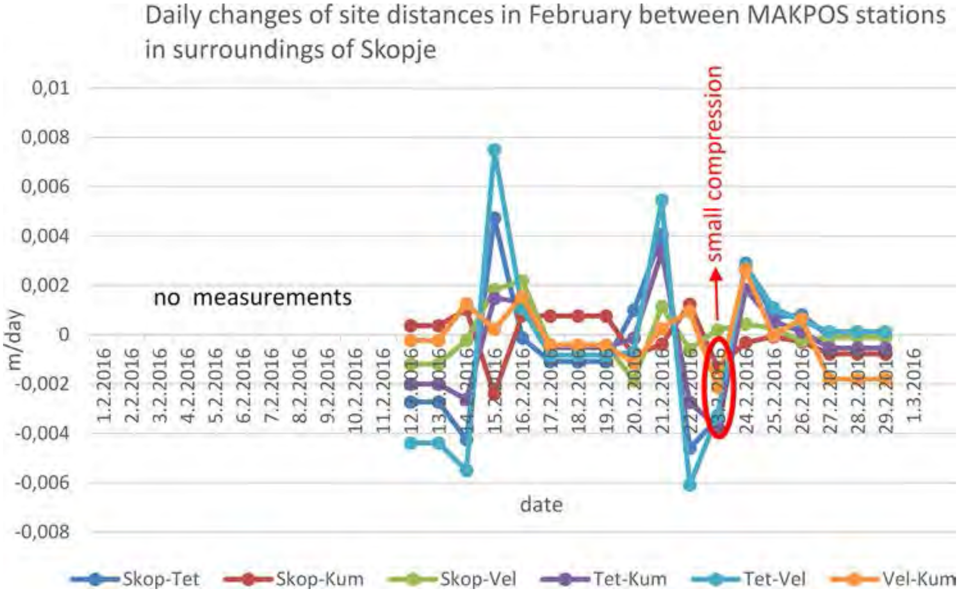

Figure 7. *Chart of daily changes of site distances between MAKPOS stations for February. In February, there was smaller compression, so all site distances were not decreased, and after which there was no earthquake registered in the EMSC.*

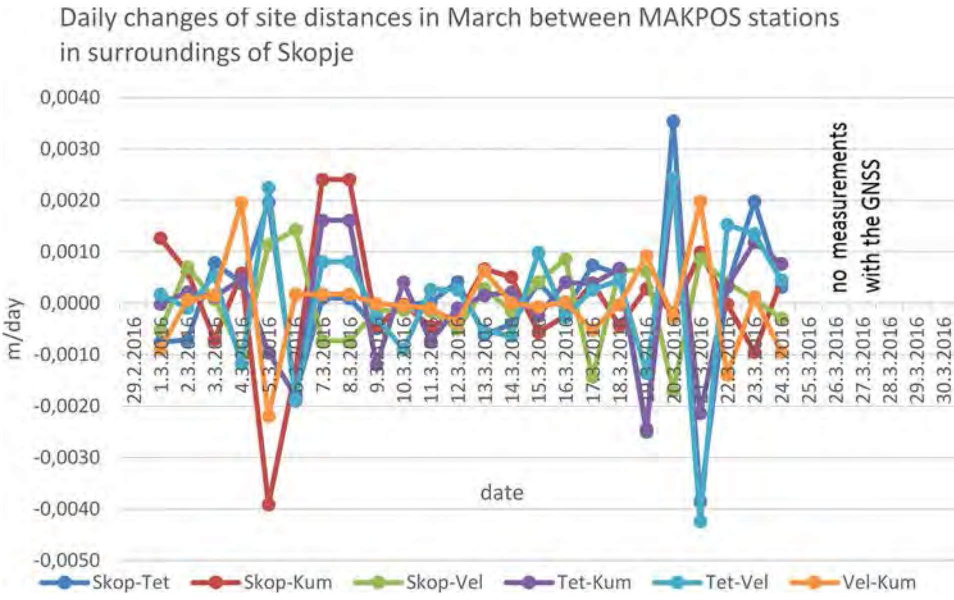

Figure 8. *Chart of daily changes of site distances between MAKPOS stations for March, when there was no earthquake in surroundings of Skopje registered in EMSC.*

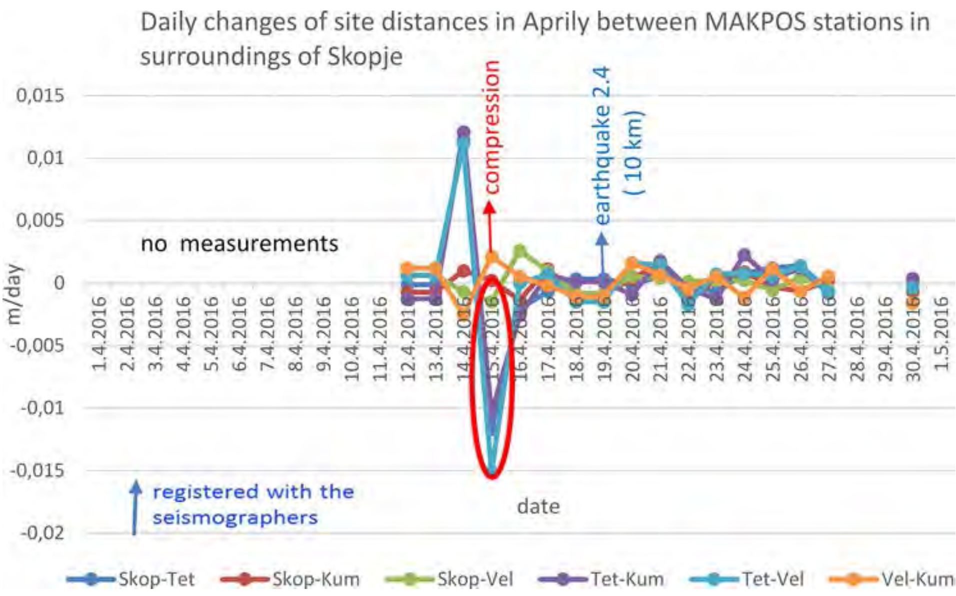

Figure 9. *Chart of daily changes of site distances between MAKPOS stations for April. The compression of the terrain occurred on 15th of April, and some terrain layers slammed, indicating that the compression was strong enough, and the earthquake occurred 4 days later. The side Veles–Kumanovo was not shorted because the earthquake was west 0.30° and south 0.39° from Skopje.*

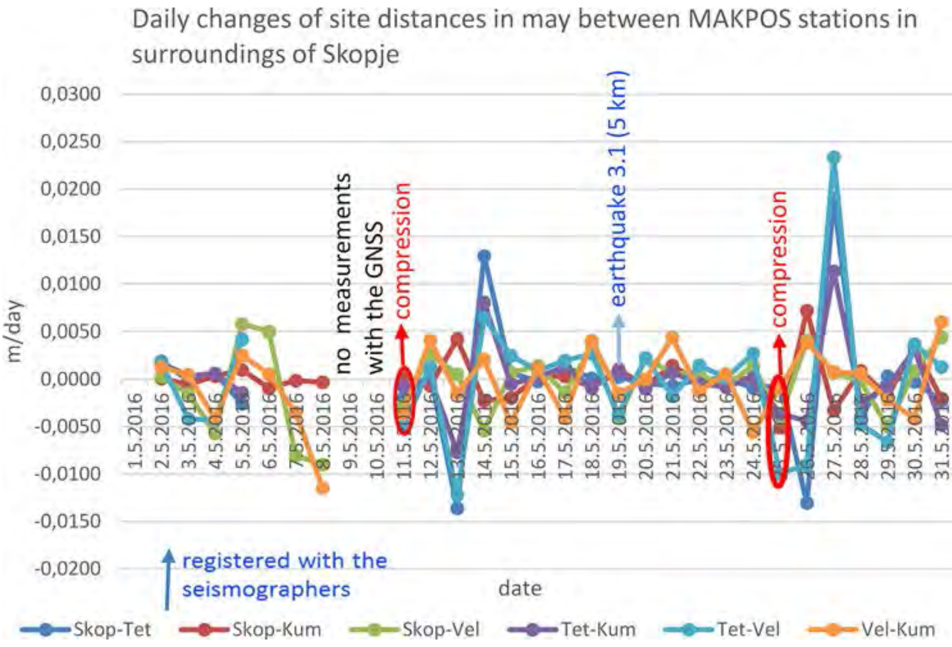

Figure 10. *Chart of daily changes of site distances between MAKPOS stations in surroundings of Skopje for May 2016. From this chart we can see that the compression occurred on 11[th] of May and after 8 days it was earthquake on 19.5.2016. There was also a compression on 25.5.2016, after which there was no earthquake, registred in EMSC, but there was big shifts.*

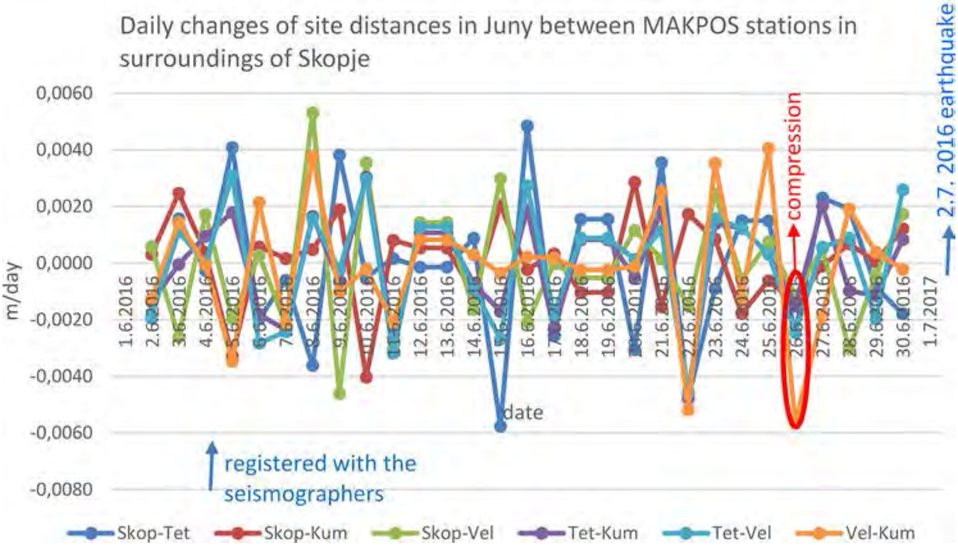

Figure 11. *Chart of daily changes of site distances between MAKPOS stations in surroundings of Skopje for June 2016. The compression of the terrain occurred on 26.6.2016 and on 2.7.2016 (after 6 days) earthquake occurred.*

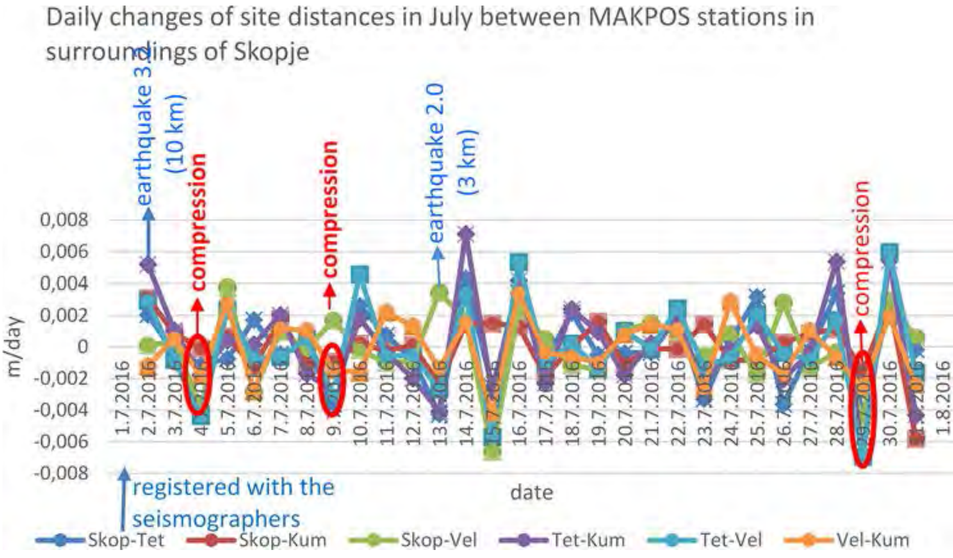

Figure 12. *Chart of daily changes of site distances between MAKPOS stations in surroundings of Skopje for July 2016. The compression of the terrain occurred on 4th and 9th of July and after 4 days earthquake occurred. Compression also occurred on 29.7.2016, but there was no earthquake because of weak strengthens of compression to break some layers. This can be seen from daily changes of site distances from 30th and 31st of July when all changes of site distances of GNSS stations are linearly changed in the same direction.*

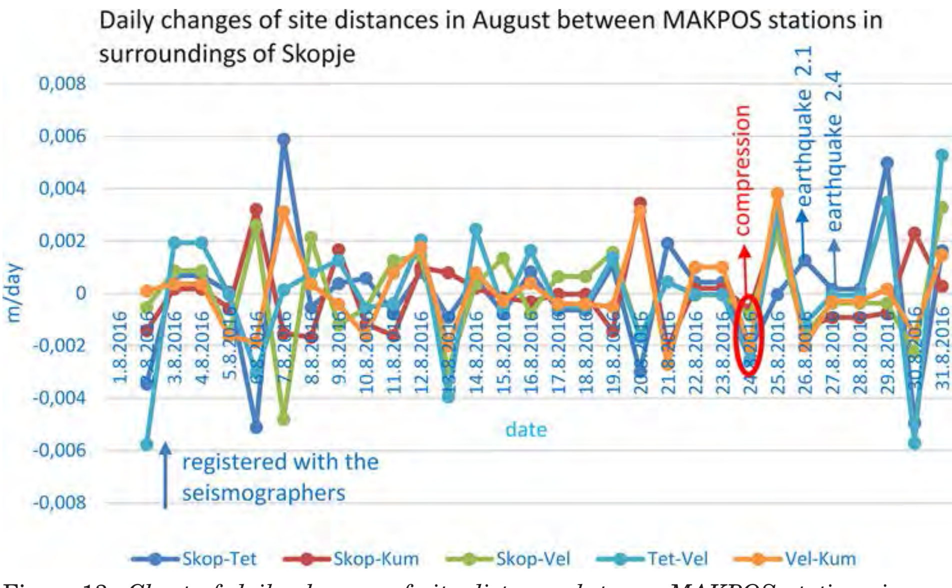

Figure 13. *Chart of daily changes of site distances between MAKPOS stations in surroundings of Skopje for August 2016. The compression of the terrain occurred on 24th of August, and the earthquakes were followed for two or three days later.*

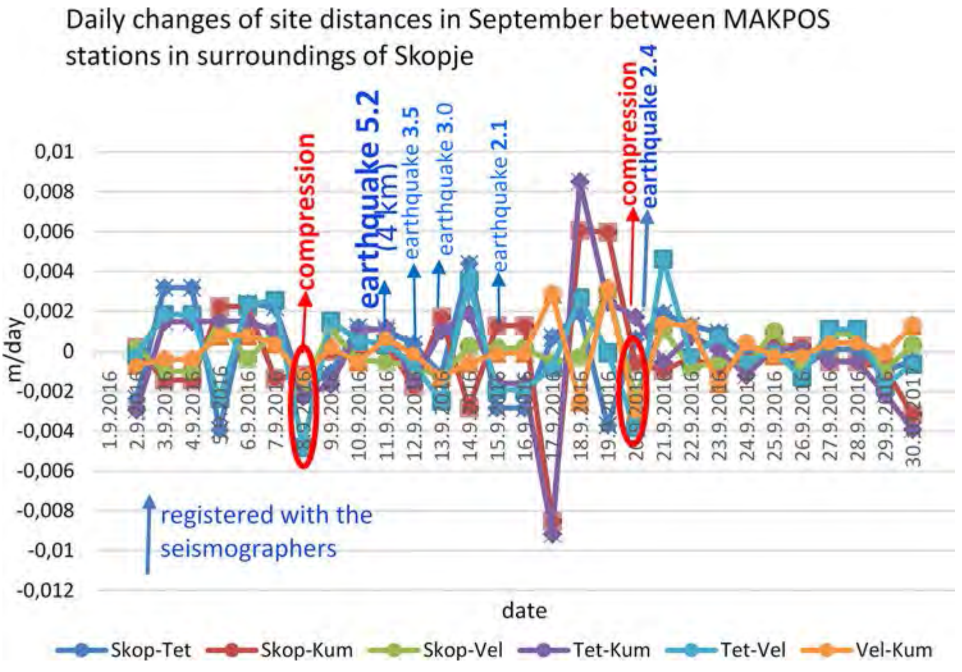

Figure 14. *Chart of daily changes of site distances between MAKPOS stations in surroundings of Skopje for September 2016. From this chart we can see that there was a terrain compression on 8th of September 2016, and three days after the earthquake occurred with 5.2 magnitude per Richter at 4 km depth, as well as smaller earthquakes. After that, on 20.9.2016, there was compression and then earthquake.*

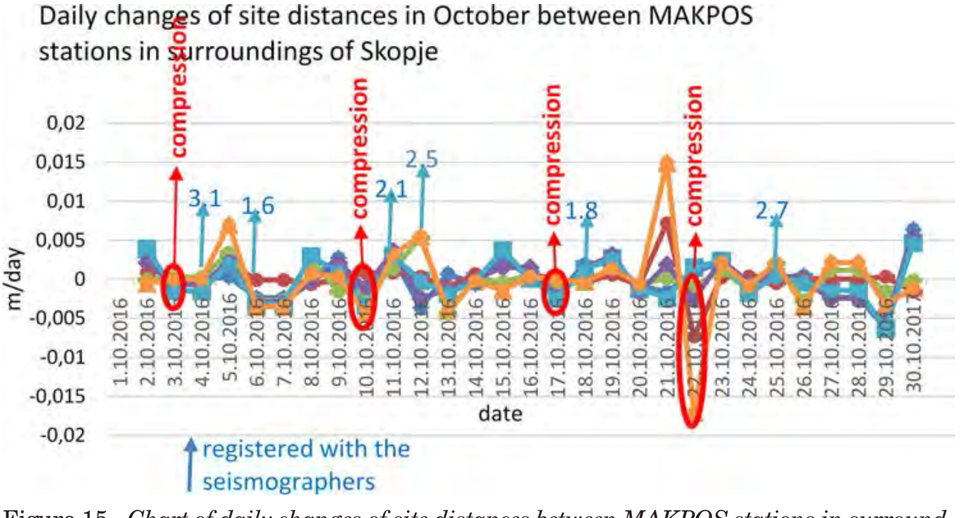

Figure 15. *Chart of daily changes of site distances between MAKPOS stations in surroundings of Skopje for October 2016. After main earthquake in September, in October was a calming period with more compressions and smaller earthquakes.*

are linearly changed in the same direction. If some of the earth layers had break than all site distances in surruinding of Skopje would not be changed equaly and with same direction.

It can be emphasized that this method can be used to determine the compression of the terrain at earthquakes even with magnitude less than 2 degrees per Richter. Accordingly, this method achieves satisfactory accuracy.

5. The earthquake in Kraljevo in 2010

Similar analysis was also made after the earthquake in Kraljevo in Serbia on 3.11.2010. This was a moderate earthquake with a magnitude of 5.4 degrees on the Richter scale. The hypocentre of this earthquake was at a depth of 10 km, and it was felt throughout Serbia, Macedonia, Bosnia and Herzegovina and partly in

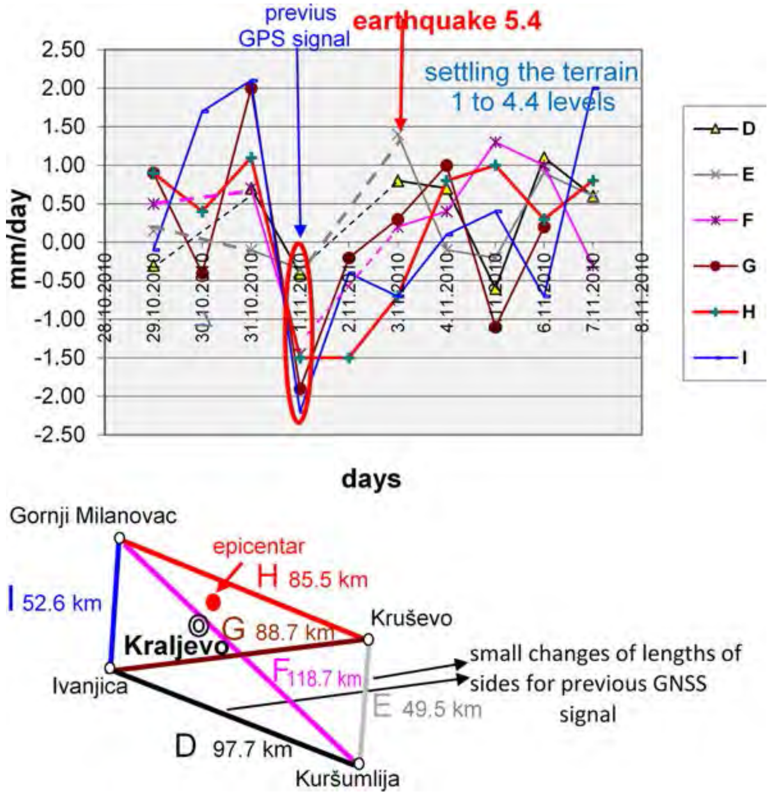

Figure 16. *Daily changes of the side distances between the AGROS permanent stations presented in quadrangle with diagonals around Kraljevo. Almost all the sides were slightly decreased two days before the earthquake, while the sides (E, D and I on the quadrangle) which were further away from what was to be the epicentre of the earthquake show no greater daily changes in distances (Solarić, N. and Solarić, M. 2012).*

Croatia. At that time, the AGROS[3] positioning system was already established in Serbia, so an paper Đalović and Škrnjug (2011) presents the 24-hour coordinates of their GNSS referent stations and the side distances between the AGROS GNSS reference stations around Kraljevo.

In that way we were able to confirm that two days before the earthquake there was a decrease in those side distances (i.e. a compression of the Earth's crust) (Figure 16). The following day some distances stretched, and two days later there was a breaking – an earthquake (Solarić, N. and Solarić, M. 2012).

6. The earthquake in Drežnica in 2013

In Croatia there was a small earthquake on 30.7.2013 at 14:58 with an epicentre in Drežnica, 15 km north-east of Senj (Solarić, N. et al. 2017, URL 2). The earthquake's magnitude was 4.6 on the Richter scale and its hypocentre was at a depth of 20 km. The intensity in the earthquake epicentre was VI-VII on the Mercalli-Cancani-Selberg (MCS) scale.

The earthquake was felt in the areas of Ogulin, Karlovac and Zagreb, as well as in southern and central Slovenia. The 112 information centre in Karlovac received only two reports of damage. Given the small earthquake intensity, only minor material damage was possible in the epicentre area.

After testing the daily changes in side distances between all four CROPOS[4] stations around Drežnica, we have found that the daily changes in side distances between the CROPOS stations were very small (Figure 17). However, two days before the earthquake all the sides were slightly decreased (compressed) (Figure 17). There were virtually no changes at the sides of the quadrangle that were further away from what was to be the earthquake's epicentre, as was the case on the Karlovac–Slunj and Karlovac–Rijeka sides (Figure 17).

Taking into consideration such small changes in side distances and measurements errors in the case of small earthquakes, we cannot predict an earthquake for certain. However, two days before the earthquake there was a decrease in side distances between the GNSS stations (the terrain was compressed), similar to the earthquake in Kraljevo on 3.11.2010.

However, the Kraljevo earthquake was larger (moderate earthquake) with a magnitude of 5.4 on the Richter scale and the changes in side distances were slightly larger. Therefore, it is necessary to investigate whether such a phenomenon occurs in major earthquakes too (Solarić, N. et al. 2017).

Given the small changes in distance between the reference stations and taking into consideration the measurement errors in such small earthquakes, it would not be possible to predict an earthquake with certainty in advance. However, the situation in Drežnica also shows those two days before the earthquake there was a decrease in distance between the reference stations, i.e. a terrain "compression", similar to that of the earthquake in Kraljevo on 3.11.2010 and that in Skopje on

[3] AGROS – acronym of *Aktivna geodetska referentna osnova Srbije* (Active Geodetic Reference Network of Serbia).

[4] CROPOS – Croatian Positional System.

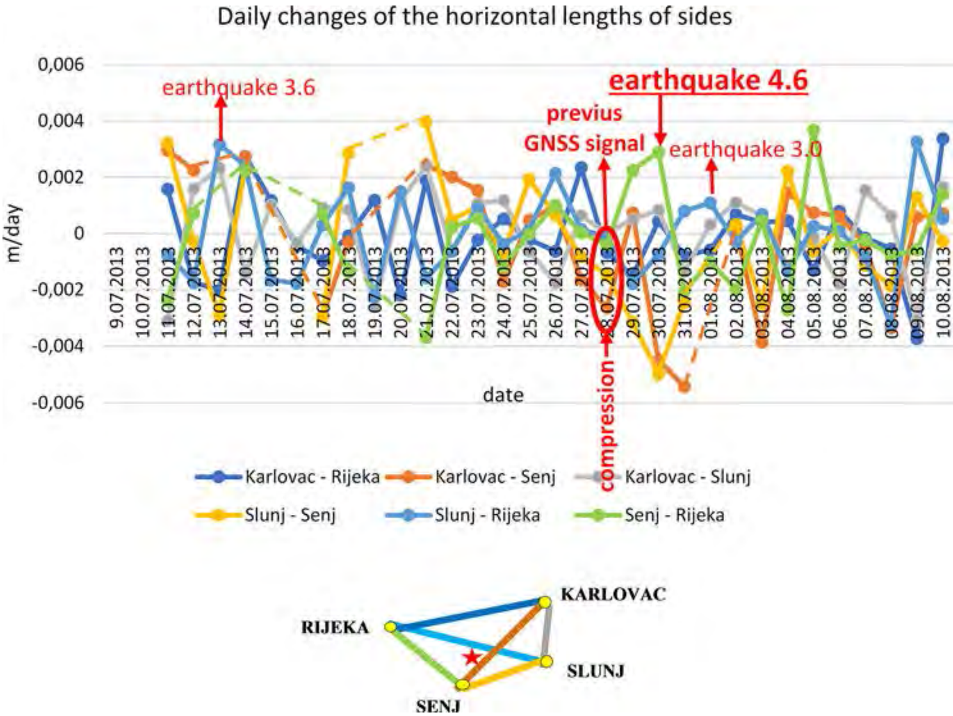

Figure 17. *The daily changes of horizontal side distances between the CROPOS stations near Drežnica on 10.8.2013 were small. However, it can be concluded those two days before the earthquake all the sides near the epicentre were slightly decreased (compressed). (Some parts of the Senj station side are marked with an interrupted line, indicating that measurements between some days are not constant) (Solarić, N. et al. 2017).*

11.9.2016. This time period from "compression" to stretihing, i.e. fracture – earthquake could be as long as two or three days, or even longer than that.

7. Conclusion

The daily changes of site distances between MAKPOS, AGROS and CROPOS referent stations (Figures 3, 16 and 17) are representing that before the earthquake was a small decreasing of site distances i.e. "compression in Earth's crust" nearby the future epicentre. In Japan, they are examining the previous GNSS signal at the earthquakes with magnitudes greater than 6 degrees per Richter with calculating the area of a triangle. In that way we could expect very small changes of the site distances between referent stations, fortunately, in Croatia there were no strong earthquakes, so we were unfortunately unable to perform this examine, just only one earthquake with magnitude of 4.6 degrees per Richter. It is interesting to note that in these three cases, in small earthquakes (light and moderate), there was a lack of terrain, two to three days before the earthquake.

Then there was a small stretch of the terrain, followed by an earthquake. The size of the compression could be utilized after the accumulated experience for the approximate forecast of the earthquake magnitude. It is interesting also to create half day (12-hour) changes of the site distances and based on them with use of GNSS measurement and other geophysical methods to announce an earthquake.

It will be necessary to examine whether this behaviour of the Earth's crust is present for some other types of earthquakes. In Japan the earthquake epicentres are usually about a hundred kilometres in the ocean, so there is no possibility for establishing of quadrangles with diagonals nearby potential future epicentres. The site distances between GNSS stations should be from 30 km to 70 km, if seismotectonics do not suggest a different distance. We have seen published papers in which the distance between the stations was longer, so the previous GNSS signal could not be noticed before the earthquake. In addition, some of them have not calculated the site distances between the GNSS stations, which is contributing to the accuracy, because of calculating of the site distances avoids some of the errors, which are practically equal to the neighbouring GNSS points, and for that they are annulet each other. Therefore, it could be concluded that this GNSS method is useful to monitoring the changes in Earth's crust, and with other geophysical and satellite methods maybe we could possibly provide a more accurate announcement of the earthquake. This is very important in prone earthquake areas where there are many inhabitants, such as Skopje, Zagreb, Nuclear powerplant station Krško, Dubrovnik, Split, Rijeka and other same areas. Therefore, in these areas is more than important to organise some institutions which will continuously monitoring changes of the site distances between GNSS referent stations in prone to earthquake areas. The forecast of the earthquake must be with almost 100% certainty to avoid panic as it was in L'Aquila. Therefore, such examining will must to continue because of better determination of the size and shape of the compression which could be estimated whether will be earthquake with higher magnitude than 5 degrees per Richter. This can help to seismic experts to make proper decision about possibility of earthquake and to officially announce an earthquake. In addition, this analysis will have to be carried out by responsible personnel with great experience. That perso nnel will need also to follows the new geophysical and satellite methods (URL 3, URL 4 and URL 5), with possibility of comparing the results of them with aim to make the forkast of an earthquake.

This measuring method with help of GNSS satellites and positioning systems on the Earth has the potential to increase accuracy with use of the GNSS satellites with higher quality signals, such as satellite navigational system Galileo and similar satellites systems. Also with use of the new optical clocks that are more accurate than atomic clocks (Solarić, N. et al. 2012) and their installation in the satellites will raise the accuracy of time measuring, which means the accuracy of the position of the determined points. Increasing of the quality of data processing will be also one of the next steps forward especially by removing the atmospheric errors. After all, the accuracy of the GPS coordinate determination in 1993 was considerably smaller – perhaps even a few centimeters, and even much more. The measuring accuracy with GNSS satellites till this day was gradual increasing, as well as data processing. Today accuracy of measurements and their processing of 24-hour GNSS measurements from reference stations, result with millimetre positional accuracy.

Special attention should be paid to the stability of the reference stations for the application of GNSS measurement, especially in Geophysics. That there is no shift in the thermal changes and influence of sunshine on the antenna. It should also examine the multipath effect caused by surrounding objects, as well as the existence of disturbing electrical fields.

We will try to continue this research.

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Tri dana prije potresa u Skopju došlo je do kompresije Zemljine kore

SAŽETAK. U radu su analizirane dnevne promjene duljina svih stranica između četiriju MAKPOS-ovih GNSS-referentnih postaja (Skopje, Tetovo, Kumanovo i Veles). Na taj su način određene deformacije Zemljine kore na širem području Skopja od 20.8.2016. do 20.9.2016. Utvrđeno je da je u okolici Skopja tri dana prije potresa, koji se dogodio 11.9.2016. godine, došlo do skraćenja duljina stranica između MAKPOS-ovih GNSS-referentnih postaja, odnosno da je došlo do kompresije terena. Dana 11.9.2016. dogodilo se nekoliko manjih potresa i svi su imali epicentre u neposrednoj blizini Skopja. Najsnažniji potres imao je magnitudu 5.2 stupnja po Richtereovoj skali, a njegov hipocentar bio je na dubini od 4 km. Odlučili smo detaljnije istražiti da li je bilo skraćivanja duljina stranica između MAKPOS-ovih GNSS-postaja i prije 20.8.2016, pa je to istraženo za razdoblje od početka 2016. do 30.10.2016. godine. Utvrdili smo da je prije svih potresa, pa i onih manjih prije i poslije glavnog potresa, uvijek bilo skraćivanja duljina stranica između GNSS-referentnih postaja te da se potres pojavljivao dva do devet dana poslije kompresije. Analizom potresa u Kraljevu (Srbija) 2010. godine, također smo dobili da je tri dana prije potresa došlo do skraćivanje duljina stranica između GNSS-referentnih postaja. Takav je rezultat dobiven i pri istraživanju potresa u Drežnici (Hrvatska) 2013. godine. U Drežnici se potres dogodio na reversnom rasjedu, a u Kraljevu i Skopju na normalnim rasjedima.

Ključne riječi: MAKPOS, GNSS-referentna postaja, Leica Geosystems, potres.

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