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COMPARISON BETWEEN TSUNAMI MODELING SCENARIOS FOR SHABLA AREA (BLACK SEA) USING TWO DIFFERENT SOFTWARE

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ABSTRACT. There are evidences of 22 past tsunamis generated in the Black Sea area. Shabla area is the most dangerous for the Romanian shoreline and triggered past high magnitude earthquakes and tsunamis. According to National Oceanic and Atmospheric Administration (NOAA) data base, 3 important events occurred in Shabla: the most recent, on 31st of March 1901, an earthquake of magnitude 7.2 triggered waves of 5 m, other sources estimating 2.5 - 3 m; the oldest documented event, in the1st Century BC, in Bisone area, and the third one, year 543 AC, when a 7.5 magnitude earthquake generated tsunami waves of 2 - 4 m.

Tsunami modeling was accomplished for Shabla area using two software, Tsunami Analysis Tool (TAT) and TRIDEC Cloud, and past earthquake parameters (location, depth, focal mechanism). A comparison between the results of the two software was accomplished, for the same input parameters: magnitudes of 7, 7.2, 7.5 and 8, depths of 5, 10 and 30 km and 5 fault plane solutions. The worst case scenario with TRIDEC software displays waves of maximum 2.62 m in Varna, for a magnitude 8 and a depth of 5 km, with 0.32 m in Constanta; the worst case using TAT software shows maximum waves of 4.3 m in Kamen Bryag, with 4Romanian locations affected (2 m waves in Costinesti). Moderate waves are given by scenarios using magnitude 7.5, with 0.6 - 0.8 m heights. For lower magnitudes (7 - 7.2), the modeling estimates very low waves, 0.2 - 0.4 m.

Key words: *tsunami modeling, Shabla area, Black Sea, earthquakes.*

INTRODUCTION

Documents show the evidence of 22 tsunamis generated in the past, in the Black Sea area (Altinok, 1999). All the countries surrounding the area have faced tsunamis in the past, but the most dangerous seismogenic/tsunamigenic zone for the Romanian shore is Shabla. There are scientific papers describing 3 past events in the area, triggered by earthquakes (according to National Oceanic and Atmospheric Administration - NOAA data base), as follows: 31st of March 1901, an 7.2 M earthquake generated waves of 5 m (Papadopoulos et al., 2011), other sources estimating 2.5 - 3 m height (Ranguelov and Gospodinov, 1995); the oldest documented event, in the 1st Century BC, in Bisone area (Nikonov, 1997); year 543 AC, an earthquake of 7.5 M generated tsunami waves of 2 - 4 m (Ranguelov, 1998), displayed in table 1 and figure 1.

Table 1. *Tsunami past events generated in Shabla area (NOAA database)*

Number	Date	Magnitude	Lat.	Long.	Max. wave (m)
1	1st Century BC	-	43.01	28.2	-
2	Year 544	7.5	43.2	28.3	2 - 4
3	31st of March 1901	7.2	43.3	28.7	5

Fig. 1. *Map with the locations of past tsunamis from Shabla area, extracted from the total number of 22 events. Numbers 1, 2 and 3 correspond to seismic tsunamis (table 1). Number 4 represents a submarine landslide source*

Tsunami modeling was performed based on past earthquakes parameters and the bathymetry of the Black Sea, using two different software, Tsunami Analysis Tool (TAT) and TRIDEC Cloud. The modeling results display maximum wave heights, affected locations, tsunami arrival times and propagation, etc. In order to better estimate the effects of a future tsunami in the area, the results were compared and some conclusions are drawn regarding maximum waves that might be generated.

METHOD AND RESULTS

Two software were used for modeling: Tsunami Analysis Tool (figure 2), provided and developed by the Joint Research Center (JRC), Ispra, Italy (Annunziato, 2007) and TRIDEC Cloud (figure 3), provided by German Research

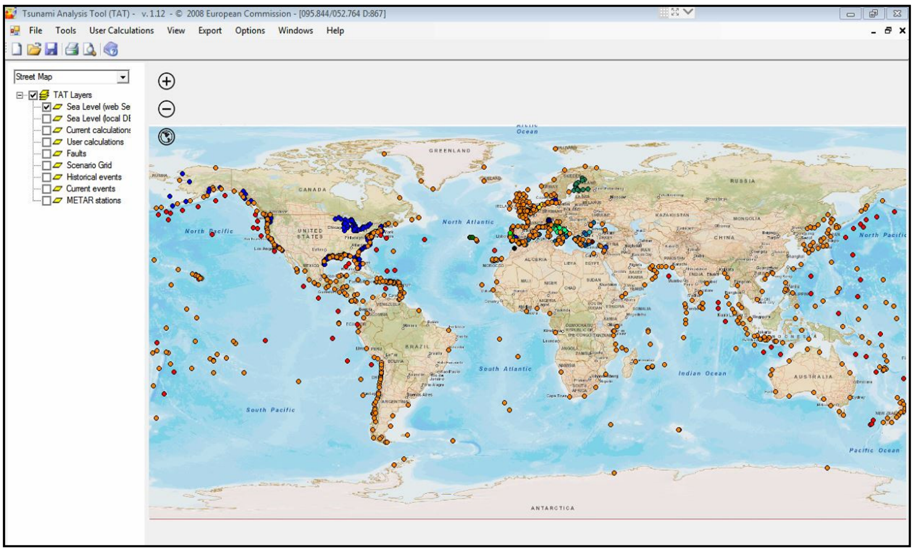

Fig. 2. *Display of the TAT software interface (http://webcritech.jrc.ec.europa.eu/TATNew_web/)*

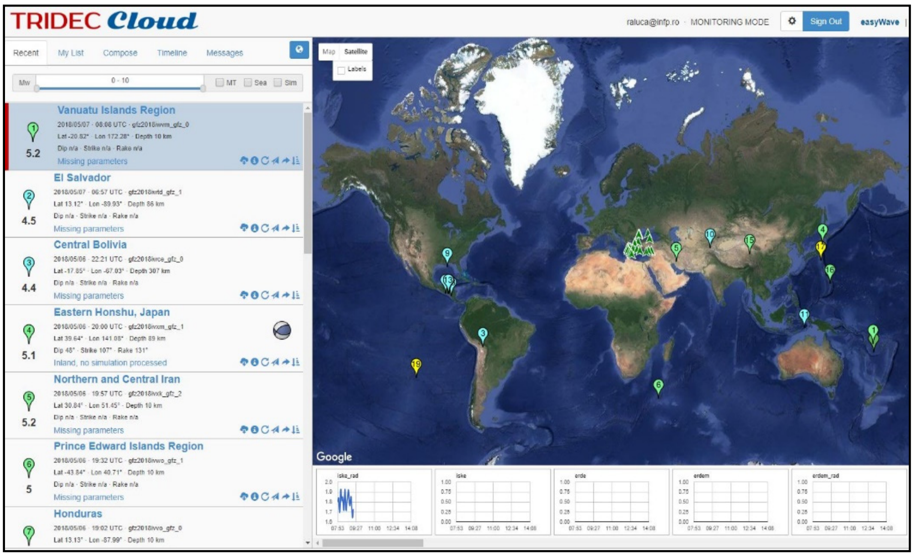

Fig. 3. *Display of the TRIDEC Cloud software interface (https://trideccloud.gfz-potsdam.de/)*

Center for Geosciences (GFZ), Potsdam, Germany (Hammitzsch et al., 2016). A comparison between some of the results accomplished with the two software is presented in table 2, for the same input earthquake parameters, varying magnitudes between 7, 7.2, 7.5 and 8, maximum possible for Shabla area (Solakov et al., 2014), also depths of 5, 10 and 30 km and 5 different fault plane solutions. The worst case scenarios are presented for each software, for a magnitude 8 potential earthquake and a depth of 5 km. Decreasing the magnitude leads to lower waves generation.

Table 2. *Comparison between the modeling results with TAT software vs. those with TRIDEC, for the same earthquake parameters*

SOFTWARE	LAT.	LONG.	MAG.	DEPTH (km)	MAX WAVE (m)
TAT	43.45	28.69	7	5	Varna 0.1, Techirghiol / Costinesti 0.1
TRIDEC					Varna 0.25
TAT	43.45	28.69	7.2	10	Varna 0.2, Constanta / Techirghiol 0.1
TRIDEC					Varna 0.41
TAT	43.45	28.69	7.5	10	Varna 0.6, Costinesti / Mangalia / Constanta 0.3
TRIDEC					Varna 0.8, Constanta 0.11
TAT	43.45	28.69	7.5	30	Bliznak 0.2, Varna 0.2, Mangalia 0.1
TRIDEC					Varna 0.87, Constanta 0.13
TAT	43.45	28.69	8	10	Kraveno 0.8, Varna 0.5, Costinesti / Mangalia / Techirghiol 0.6
TRIDEC					Burgas 1.07, Varna 0.55, Constanta 0.65
TAT	43.45	28.69	8	5	Kamen Bryag 4.3, Varna 2.1, Costinesti 2.0
TRIDEC					Varna 2.62, Burgas 0.7, Constanta 0.32

Parts of the results are displayed in table 2, with the input earthquake's parameters and the maximum resulted waves for different locations from Romania and Bulgaria.

The worst-case scenario for TRIDEC Cloud shows waves of maximum 2.62 m in Varna (Bulgaria), for a possible earthquake of M 8, located at a depth of 5 km, with 0.32 m waves in Constanta. The worst case scenario for TAT displays maximum waves of 4.3 m in Kamen Bryag (Bulgaria), with more than 1 m wave heights on 3 locations from the

Romanian shore, at Costinesti (2 m), Constanta (1.5 m), and Mangalia (1.4 m). Moderate tsunami waves are given by scenarios using magnitude 7.5, with 0.6 - 0.8 m maximum heights. For lower magnitudes (7 - 7.2), the modeling estimates very low waves, of 0.2 - 0.4 m (Varna).

The results using TRIDEC Cloud show the following: maximum waves of 2.62 m in Varna, for a possible earthquake of M 8, located at a depth of 5 km, with 0.32 m waves in Constanta, 0.7 m in Burgas (Bulgaria), and 0.34 in Kirklareli Igneada (Turkey) and 0.25 m at Kocaeli Kefken (Turkey) - see figures 4, 5 and table 3; waves of 1.07 m at Burgas (Bulgaria) for a M 8, depth 10 km, with 0.55 m at Varna and 0.65 at Constanta (Romania); values of maximum 0.87 m at Varna for an earthquake of M 7.5 generated at 30 km depth, with 0.13 m at Constanta; moderate heights of 0.8 m at Varna for a magnitude 7.5 and a depth of 10 km, with 0.11 m at Constanta; low waves of 0.41 m in Varna for a M 7.2 and a depth of 10 km; and the lowest waves of 0.25 m (Varna) are generated by an M 7 earthquake at a depth of 5 km.

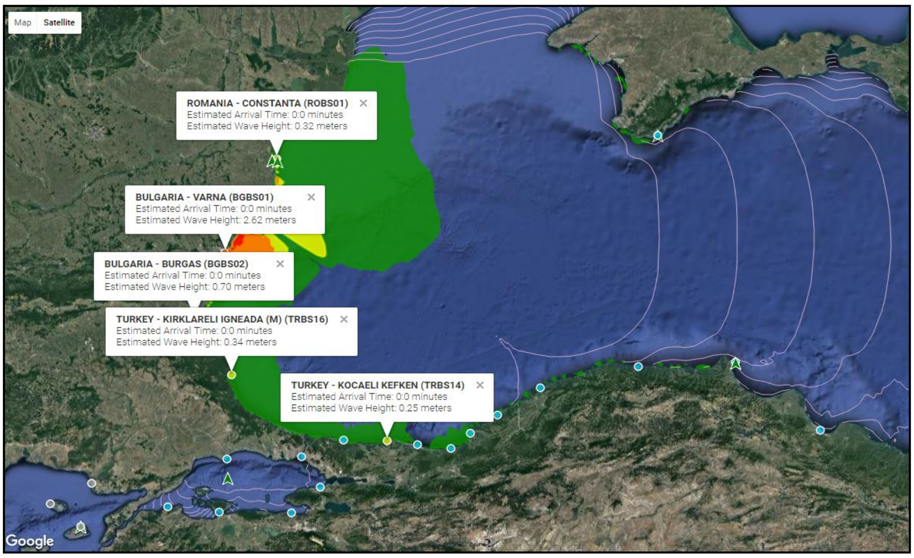

Fig. 4. *Map with the estimated wave heights for certain locations for the worst case scenario (M 8, depth 5 km) using TRIDEC software*

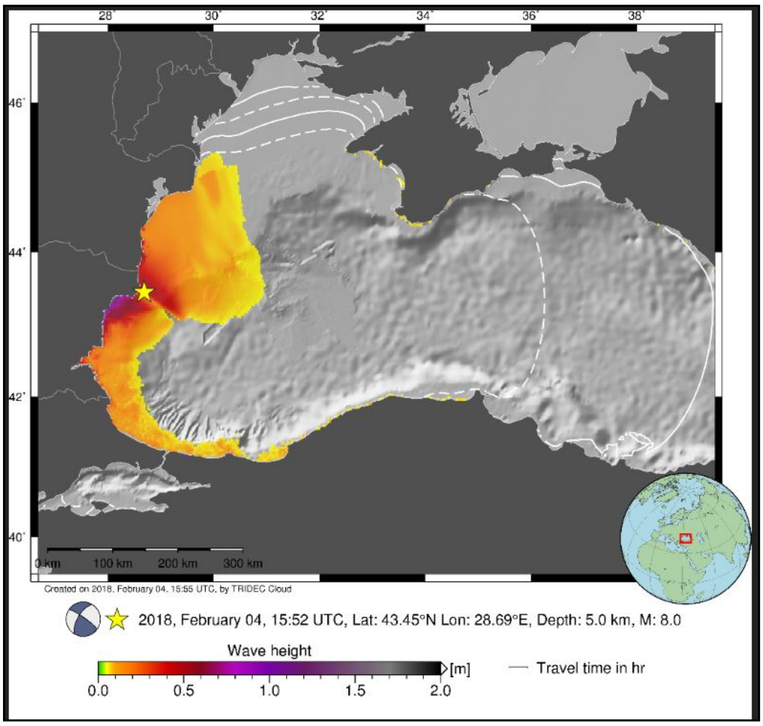

Fig. 5. *Maximum wave heights and travel times for the worst case scenario (M 8, depth 5 km) using TRIDEC software*

Table 3. *Table with the estimated wave heights for certain locations, for the worst case scenario (M 8, depth 5 km) using TRIDEC software*

Location	**Max wave height (m)**
Varna	2.62
Burgas	0.7
Kirklareli Igneada	0.34
Constanta	**0.32**
Kocaeli Kefken	0.25

The results using the TAT software displays maximum waves of 4.3 m in Kamen Bryag (Bulgaria), 2.9 m at Bulgarevo (Bulgaria), 2.1 m in Varna, 1.8 m in Bliznak (Bulgaria), 1.7 m at Kranevo and Balchik (Bulgaria), 1.6 m in Krapets (Bulgaria), with 4 locations from the Romanian shore affected, Costinesti (2 m), Constanta (1.5 m), Mangalia (1.4 m) and Techirghiol (0.9 m) - see figure 6 and table 4; waves of 0.8 m at Kraveno (Bulgaria) for a M 8, depth 10 km, with 0.5 m at Varna and 0.6 m at Mangalia, Costinesti and Techirghiol; values of maximum 0.2 m at Bliznak (Bulgaria) for an earthquake of M 7.5 generated at 30 km depth, with 0.2 m at Varna and 0.1 m at Mangalia; moderate wave heights of 0.6 m at Varna for a magnitude 7.5 and a depth of 10 km, with 0.3 m at Constanta, Costinesti and Mangalia; low waves of 0.2 m in Varna for a M 7.2 and a depth of 10 km, with 0.1 m at Techirghiol and Constanta; and the lowest waves of 0.1 m (Varna) are generated by an M 7 earthquake at a depth of 5 km, with 0.1 m at Costinesti and Techirghiol.

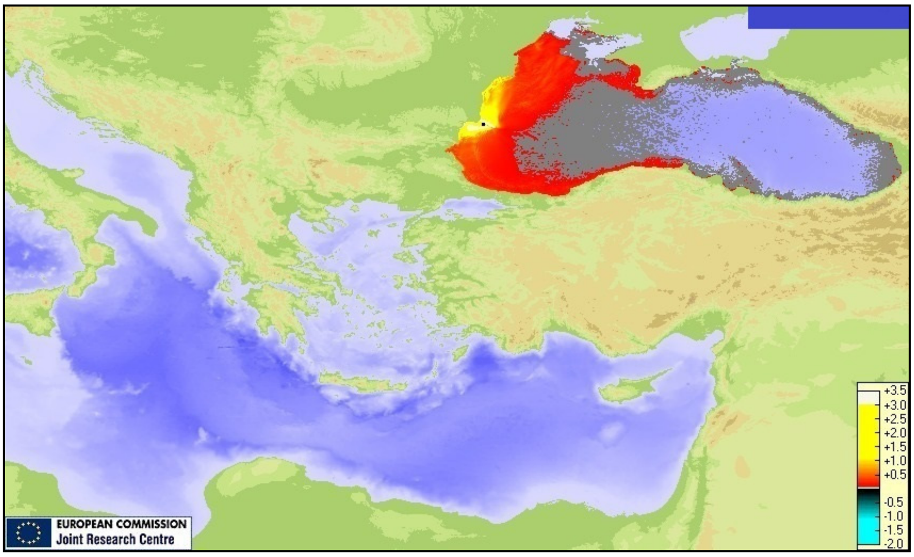

Fig. 6. *Maximum wave heights for the worst case scenario (M 8, depth 5 km) using TAT software*

Table 4. *Affected locations for the worst case scenario (M 8, depth 5 km) using TAT software*

Date of maximum Tsunami wave	Name	Wave height (m)	Delay of tsunami arrival (hours)	Delay of maximum tsunami (hours)	Latitude	Longitude
20 Oct 2014 12:10	Kamen Bryag	4.3	00:02	00:02	43.45	28.55
20 Oct 2014 12:21	Bulgarevo	2.9	00:02	00:12	43.38	28.43
20 Oct 2014 13:07	Varna	2.1	00:10	00:58	43.20	27.93
20 Oct 2014 13:27	**Costinesti**	**2.0**	**00:12**	**01:18**	**43.95**	**28.64**
20 Oct 2014 13:09	Bliznak	1.8	00:10	01:00	43.05	27.90
20 Oct 2014 12:55	Kranevo	1.7	00:04	00:46	43.35	28.07
20 Oct 2014 12:55	Balchik	1.7	00:04	00:46	43.40	28.16
20 Oct 2014 12:19	Krapets	1.6	00:04	00:10	43.64	28.58
20 Oct 2014 13:57	**Constanta**	**1.5**	**00:16**	**01:48**	**44.19**	**28.66**
20 Oct 2014 13:16	**Mangalia**	**1.4**	**00:10**	**01:08**	**43.81**	**28.59**
20 Oct 2014 13:09	Shkorpilovtsi	1.3	00:14	01:00	42.98	27.90
20 Oct 2014 13:09	Byala	1.3	00:16	01:00	42.88	27.90
20 Oct 2014 13:09	Durankulak	1.3	00:06	01:00	43.70	28.57
20 Oct 2014 13:09	Obzor	1.2	00:16	01:00	42.83	27.89
20 Oct 2014 13:58	**Techirghiol**	**0.9**	**00:14**	**01:50**	**44.07**	**28.65**
20 Oct 2014 13:03	Akhtopol	0.7	00:28	00:54	42.10	27.94

Besides the worst cases presented above, for both software, a moderate scenario is displayed bellow, for an earthquake of magnitude 7.5, generated at a depth of 10 km, with the following results: TRIDEC Cloud - maximum waves of 0.8 m in Varna, 0.14 m in Burgas, 0.11 m in Constanta and 0.07 m in 2 locations from Turkey (Kirklareli Igneada, Kocaeli Kefken) - see figures 7 and 8; TAT - maximum 0.6 m in Varna and Kamen Bryag (Bulgaria), 0.4 m and Bliznak, Bulgarevo (Bulgaria), 0.3 m in Kranevo and Shkorpilovtsi (Bulgaria), 0.3 m in Constanta, Mangalia and Costinesti, and 0.2 m at Techirghiol (figure 9, table 5).

Fig. 7. *Map with the estimated wave heights for certain locations for a moderate scenario (M 7.5, depth 10 km) using TRIDEC software*

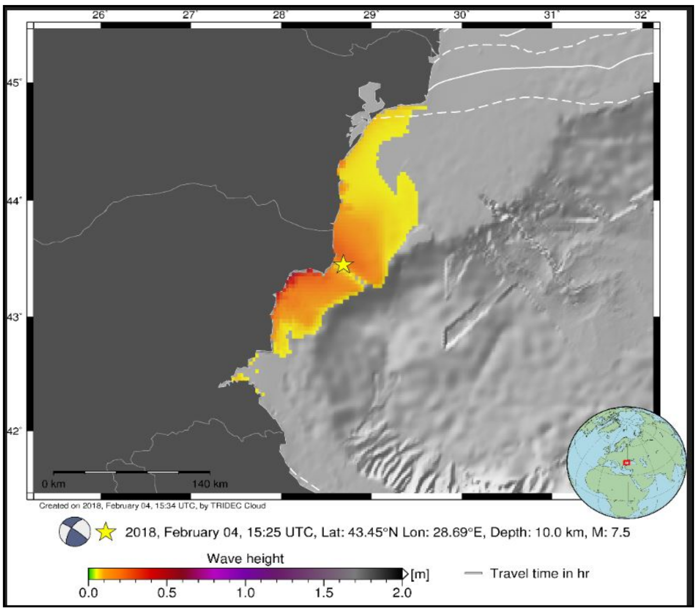

Fig. 8.*Maximum wave heights and travel times for amoderate scenario (M 7.5, depth 10 km) using TRIDEC software*

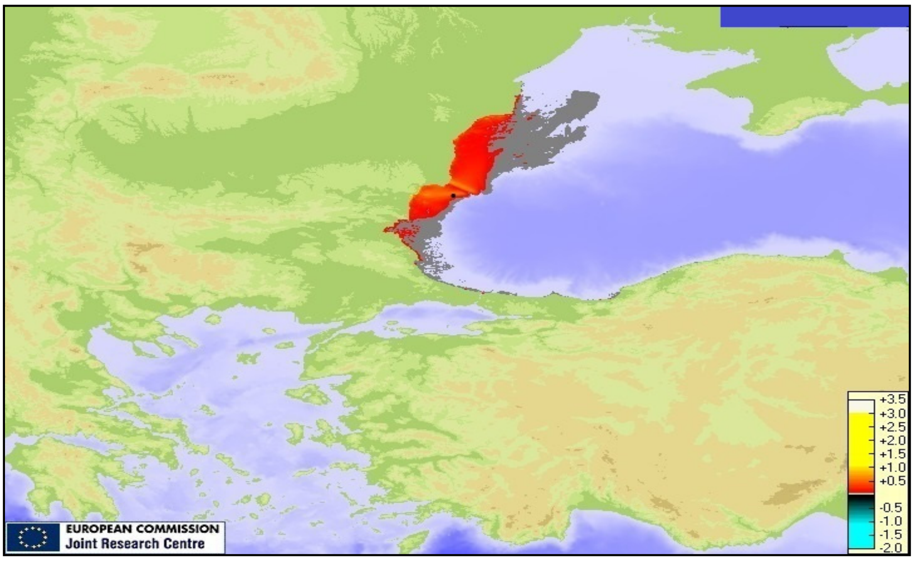

Fig. 9. *Maximum wave heights for the moderate scenario (M 7.5, depth 10 km) using TAT software*

Table 5. *Affected locations for the moderate scenario (M 7.5, depth 10 km) using TAT*software

Date of maximum Tsunami wave	Name	Wave height (m)	Delay of tsunami arrival (hours)	Delay of maximum tsunami (hours)	Latitude	Longitude
05 Aug 2009 08:53	Varna	0.6	00:24	01:04	43.20	27.93
05 Aug 2009 07:50	Kamen_Bryag	0.6	00:02	00:02	43.45	28.55
05 Aug 2009 08:49	Bliznak	0.4	00:30	01:00	43.05	27.90
05 Aug 2009 08:13	Bulgarevo	0.4	00:06	00:24	43.38	28.43
05 Aug 2009 08:38	Kranevo	0.3	00:14	00:50	43.35	28.07
05 Aug 2009 08:50	Shkorpilovtsi	0.3	00:32	01:02	42.98	27.90
05 Aug 2009 09:07	Costinesti	0.3	**00:30**	**01:18**	**43.95**	**28.64**
05 Aug 2009 08:50	Mangalia	0.3	**00:22**	**01:02**	**43.81**	**28.59**
05 Aug 2009 09:32	Constanta	0.3	**00:54**	**01:44**	**44.19**	**28.66**
05 Aug 2009 09:49	Byala	0.2	00:34	02:00	42.88	27.90
05 Aug 2009 08:55	Krapets	0.2	00:08	01:06	43.64	28.58
05 Aug 2009 09:17	Techirghiol	0.2	**00:42**	**01:28**	**44.07**	**28.65**
05 Aug 2009 09:07	Durankulak	0.2	00:18	01:18	43.70	28.57
05 Aug 2009 09:43	Obzor	0.2	00:36	01:54	42.83	27.89
05 Aug 2009 11:32	Rumelifeneri	0.1	00:52	03:44	41.25	29.10
05 Aug 2009 11:32	Iriva	0.1	00:54	03:44	41.22	29.15

The two software display different results, those with TRIDEC are more complex and interactive. On the other hand, the table with the affected locations given by TAT shows more cities, their exact location (Latitude, Longitude) and arrival times. For most of the cases, TRIDEC's results are higher than those given by TAT software, except for M 8, depth 5 km, where the situation is reversed.

CONCLUSIONS

In order to help estimating the effects of a tsunami triggered in Shabla coastal area, series of numerical simulations of the tsunami wave's height in different locations were accomplished. Using past earthquakes parameters and information about the bathymetry of the Black Sea, different tsunami modeling simulations were obtained for possible strong earthquakes generated in this area.

Past studies have shown that the tsunami hazard is a real threat for the Romanian and Bulgarian shores, with evidences of maximum 5 m tsunami waves generated by a 7.2 magnitude earthquake (event number 3). However, the simulation results give lower estimates for waves heights for 7.2 magnitude, with both software. This may be due to the fact that in the historical times there were no dedicated equipment for water level measurements, and all information was provided by local witnesses.

Tsunami modeling was accomplished using also the following two software, Tsunami Analysis Tool and TRIDEC Cloud, by varying magnitudes between 7, 7.2, 7.5 and 8, also depths of 5, 10 and 30 km and 5 different fault plane solutions

Only four examples are given in this paper, for a possible earthquake of magnitude 8 and depth of 5 km, and for a magnitude of 7.5 and a depth of 10 km.

The results show worst case scenarios with TRIDEC Cloud of maximum 2.62 m waves in Varna, for an earthquake of M 8, depth 5 km, with 0.32 m waves in Constanta. For the same earthquake's parameters, TAT displays maximum waves of 4.3 m in Kamen Bryag, with 2 m in Costinesti, 1.5 m in Constanta and 1.4 m at Mangalia. Moderate tsunami waves are given by magnitude 7.5 (0.6 - 0.8 m), and for low magnitudes (7 - 7.2) the modeling estimates waves of only 0.2-0.4 m in Varna.

Furthermore, the tsunami modelling data could be useful for a comparison with real sea level measuring data, in case of a tsunami triggered in the future by a high magnitude earthquake. Although these are only modelling scenarios, at some point they could be improved and used by the local authorities in order to evacuate possible affected areas and also for warning and prevention measures.

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REFERENCES

Altinok Y., 1999, Tsunamis along the coasts of the Black Sea, Second Balkan Geophysical Congress and Exhibition. *Proceedings of the Conference*, Istanbul, pp. 46 - 47.

Annunziato A., 2007, The Tsunami Assessment Modelling System by the Joint Research Centre. *Science of Tsunami Hazards*, **26** (2), pp. 70 - 92.

Hammitzsch M., Spazier J., Reißland S., 2016, Advances in the TRIDEC Cloud, *Geophysical Research Abstracts*, General Assembly European Geosciences Union, Vienna, EGU2016-12426, **18**.

Nikonov A. A., 1997, Tsunamis occurrence on the coasts of the Black Sea and the Sea of Azov, Izvestiya. *Physics of the Solid Earth*, **33**, pp. 77–87.

Papadopoulos G.A., Diakogianni G., Fokaefs A., Ranguelov B., 2011, Tsunami hazard in the Black Sea and the Azov Sea: a new tsunami catalogue. *Nat. Hazards Earth Syst. Sci.*, **11**, pp. 945–963.

Ranguelov B., Gospodinov D., 1995, Tsunami Vulnerability Modelling for the Bulgarian Black Sea Coast. *War. Sci. Tech.*, **32** (7), pp. 47-53.

Ranguelov B., 1998, Tsunami investigations in the Black Sea - new data from discovered tsunami deposits. *Abst. Intl. Symp HAZARDS'98*, Chania, Crete, May 17 - 22, 125 p.

Solakov D. E., Simeonova S., Ardeleanu L., Alexandrova I., Trifonova P., Cioflan C.O., 2014, Compte rendus de l'Academie bulgare des Sciences: sciences mathenatique et naturelles, Tome, *Geophysique, Sismologie*, **67** (6), pp. 835-842.