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DETAILED TSUNAMI MODELING IN THE REGION OF NE COAST OF BULGARIA

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Люба Димова, Ренета Райкова, Алберто Армилято, Джанлука Паньони, Стефано Тинти. ДЕТАЙЛНО МОДЕЛИРАНЕ НА ЦУНАМИ ЗА СЕВЕРОИЗТОЧНОТО КРАЙБРЕЖИЕ НА БЪЛГАРИЯ

В това изследване е оценена опасността от цунами за североизточното крайбрежие на България чрез числени симулации. Разгледани са четири хипотетични сеизмични източници и са използвани вградени една в друга мрежи с различна резолюция. Изчислени са съответните показатели на цунами и са приложени при построяването на полето на максимални и минимални отклонения на морското ниво, максимална скорост на частиците и максимален воден стълб на сушата. Симулациите показват височина на водния стълб на сушата за района на Варна не по-голям от 0,63 m, а за района на Балчик достига до 0,91 m.

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In this study we examined the tsunami impact on the north-eastern Bulgarian Black Sea coast by running numerical simulations. We considered four hypothetical seismic sources using two nested grids with different resolution. Corresponding tsunami settings are computed for each scenario and applied to build fields of maximum and minimum water elevation, maximum particle velocity and maximum water column on land. Simulations indicate the water column on land in the region of Varna not greater than 0.63 m and for the region of Balchik it reaches values of 0.91 m.

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1. INTRODUCTION

Tsunamis are long gravitational waves spreading across the oceans and seas. The wavelength is much longer then the tidal or wind waves. The speed is about 700–800 km h^{-1} in the deep water but closer to the shore in shallow waters the velocity slows down up to 50 km h^{-1}. This is the reason for increasing height of the tsunamis close to the coast. Most of the tsunamis occur in Pacific and Indian oceans nevertheless these anomalous waves take place in small basins like Mediterranean or Black Seas. Historically known or recorded tsunamis in the region of the Eastern Mediterranean are more then 130, for the Black Sea events do not exceed 25 but still the hazard in some regions is moderate to high [1–3].

We summarized seven potentially tsunamigenic areas in the region of Black Sea according to the geographical position of the hypocenters for all recognized events [4]. The geological structure in the region is reviewed and the main faults are considered. We made simulations for the generation and propagation of tsunami waves by the numerical code UBO-TSUFD, developed in the University of Bologna [5], for every tsunamigenic source in the Black Sea. The results of these simulations are described and discussed in Dimova et al. [6].

In this study we presented detailed modeling for the north-east Bulgarian coast of Black Sea. This part of Bulgarian coast is one of the potentially vulnerable due to local inundations. This study is focused on earthquake-induced tsunamis near the Shabla Seismic Zone. We present results of simulations of tsunamis generated by four different seismic sources and the effects on the Bulgarian coast from Varna bay to Balchik town.

2. OVERVIEW OF THE THEORY AND THE METHODS

To study local effects from tsunamis on a specific place we need a very detailed bathymetry. Previously [6] we used bathymetry data, provided by GEBCO [7]. This data is 30 arc seconds, which means about 500 m resolution. The geographical position of the grid spaced over the whole Black Sea is located between 27°–42° E and 40°–48° N with cell size of 500 m. Universal Transverse Mercator (UTM) coordinate system was used in calculations. Figure 1 shows the Western Black Sea and focal source mechanism solutions of the tsunamigenic sources considered in this study: three of them near Shabla seismic zone and one near north-western part of Turkey, located in Black Sea. The parameters of these sources are given in Dimova et al. [6].

The numerical code UBO-TSUFD is able to manage several nested grids with different steps. In this study we used second grid, with more comprehensive data – for the NE coast of Bulgaria nested in the first grid for the Western Black Sea. The detailed data is provided by Shuttle Radar Topographic Mission

(SRTM) [8]. The resolution of the data is about 90 m (Fig. 2) and thus the second nested grid has a step of 100 m. Position of several virtual tide gauge stations (black points and white triangles) are shown in Fig. 2. We selected the position of these virtual stations close to the big cities, resorts, or in shore zone.

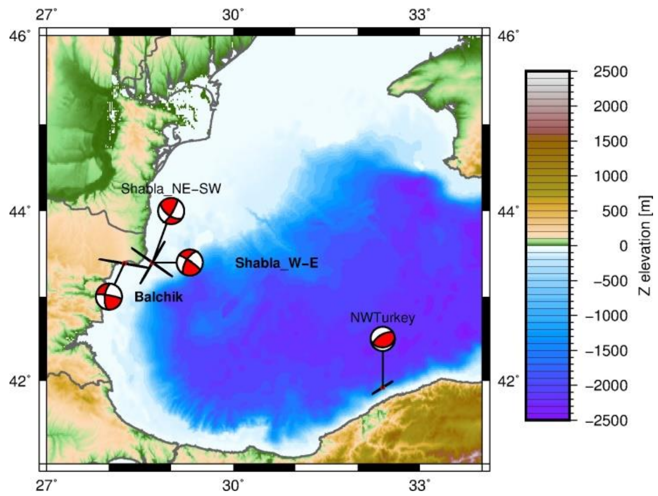

Fig. 1. Topography and bathymetry data for the Black Sea region – 30 arc seconds – data from GEBCO. Focal mechanisms for the selected seismic sources are presented

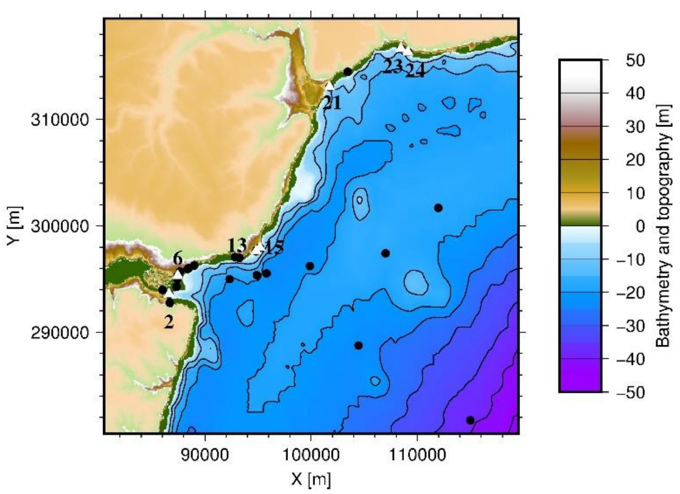

Fig. 2. Bathymetry and topography data for the region from Varna to Balchik town – 3 arc seconds (data from SRTM). The black points and white triangles show virtual tide gauge stations The data is in UTM coordinate system. Mareograms in white triangles are shown in Fig. 7

They provide information about the water elevation at a specific point before, during and after the tsunami waves pass over this point. The simulations were made for 5 astronomical hours which includes the reflected waves from the shores.

We calculated the theoretical velocity of tsunami waves according to equation $c = \frac{\lambda}{T} = \sqrt{g.h}$, where h is the depth in [m], and g – gravity acceleration in [m s^{-2}]. The speed is bigger than 150 m s^{-1} far from the shore while approaching the coasts the velocity decreases considerably (Fig. 3). An increase in wave amplitude results in „shoaling” when tsunamis, run from deep to shallow water. This slows down the wave: the shallower the water, the slower the wave. As a consequence, the leading edge of the tsunami slows dramatically due to the shallower water, but the trailing part of the wave is still moving rapidly in the deeper water. This effect easily can be seen close to the shelf zone i.e. north-western part of Black Sea.

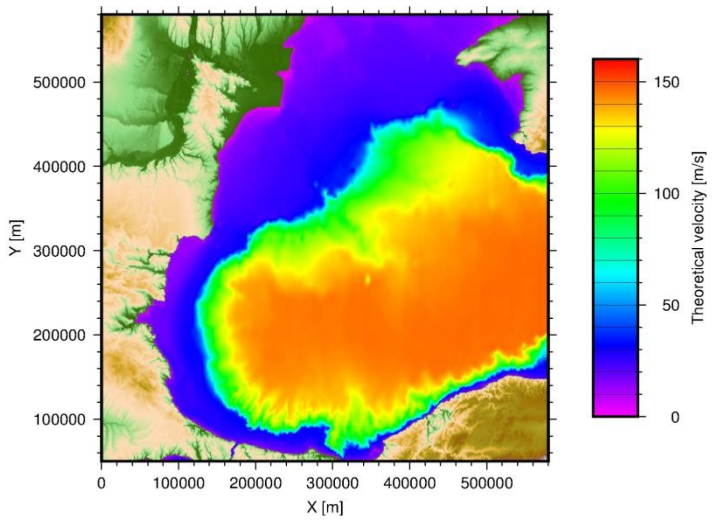

Fig. 3. Theoretical velocity of tsunami waves spreading in western Black Sea

3. RESULTS

We present results of several detailed simulations affecting the NE Bulgarian coastline. Moment magnitude for three of the hypothetical seismic sources near Cape Kaliakra is 7.5 and 7.0 for the hypothetical seismic source near the Turkish coast [6]. Figure 4 shows extreme water elevation fields computed for the selected sources for the second nested grid for the region of NE Bulgarian coast. The modeled maximum water elevation from four sources is shown in the left panels and modeled minimal water elevation – in the right panels. From top to bottom are represented simulations from ShablaNE-SW, ShablaW-E, Balchik source and NW Turkey.

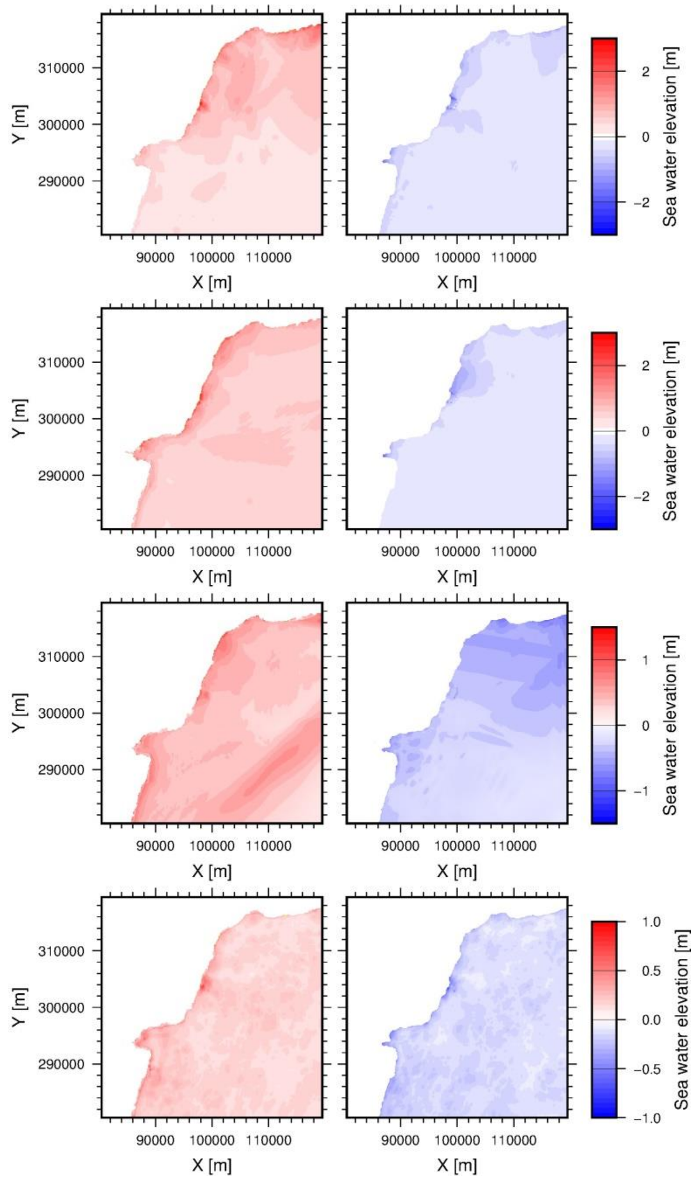

Fig. 4. Computed maximum (left) and minimum (right) sea water elevation.
From top to bottom: ShablaNE-SW, ShablaW-E, Balchik source, NW Turkey scenarios

The estimated negative and positive wave heights of hypothetical source ShablaW-E are –2.14 m and +3.42 m and of ShablaNE-SW are –2.35 m and +3.3 m.

The computed wave heights from hypothetical source Balchik vary between –1.0 m and +1.5 m and reached the coast of Balchik town in less than 5 minutes. Tsunami radiation pattern from seismic source NW Turkey spreads mainly along the western part of Black Sea [6]. The impact of this hypothetical source on the coast of NE Bulgarian coast is quite insignificant compared with the other three sources but computed maximum amplitudes of +0.5 m can cause damages.

Maximum values of the speed of the material fluid particles [9] were also modeled. Speed values are of interest close to the shore because increase in the shallow water regions and it is negligible offshore where the water is deeper. Fig. 5 shows the fields of maximum particle velocity.

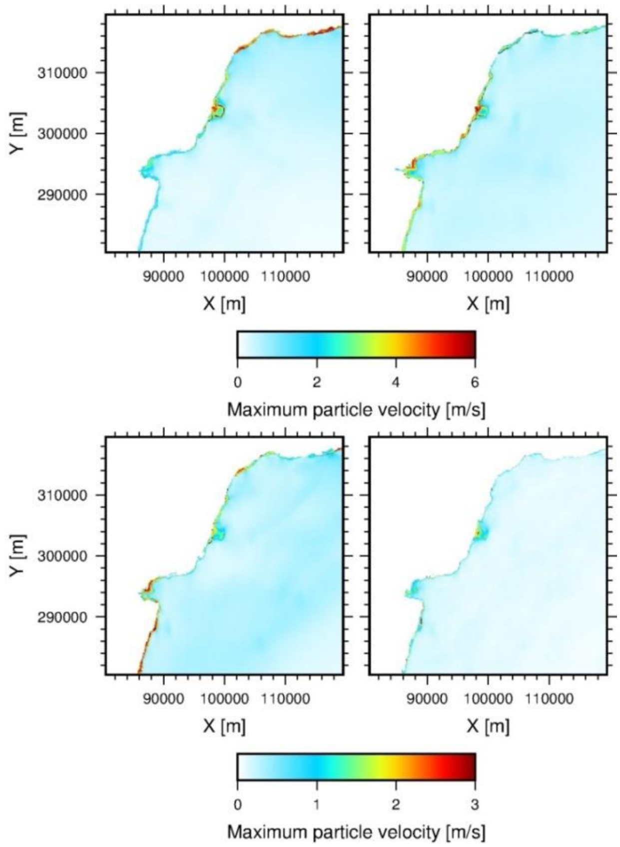

Fig. 5. Computed field of maximum particle velocity: ShablaNE-SW (upper left), ShablaW-E (upper right), Balchik (bottom left), NW Turkey (bottom right) scenarios

The speeds from sources ShablaNE-SW and ShablaW-E reach the values of 6 m s^{-1} (top left and top right panels). Seismic source Balchik caused a speed up to 3 m s^{-1}, south of the city of Varna (bottom left panel). All four cases caused a specific field near the area of Golden Sands resort, north of Varna due to the peculiarity of the shallow bathymetry in front of the resort (Fig. 6).

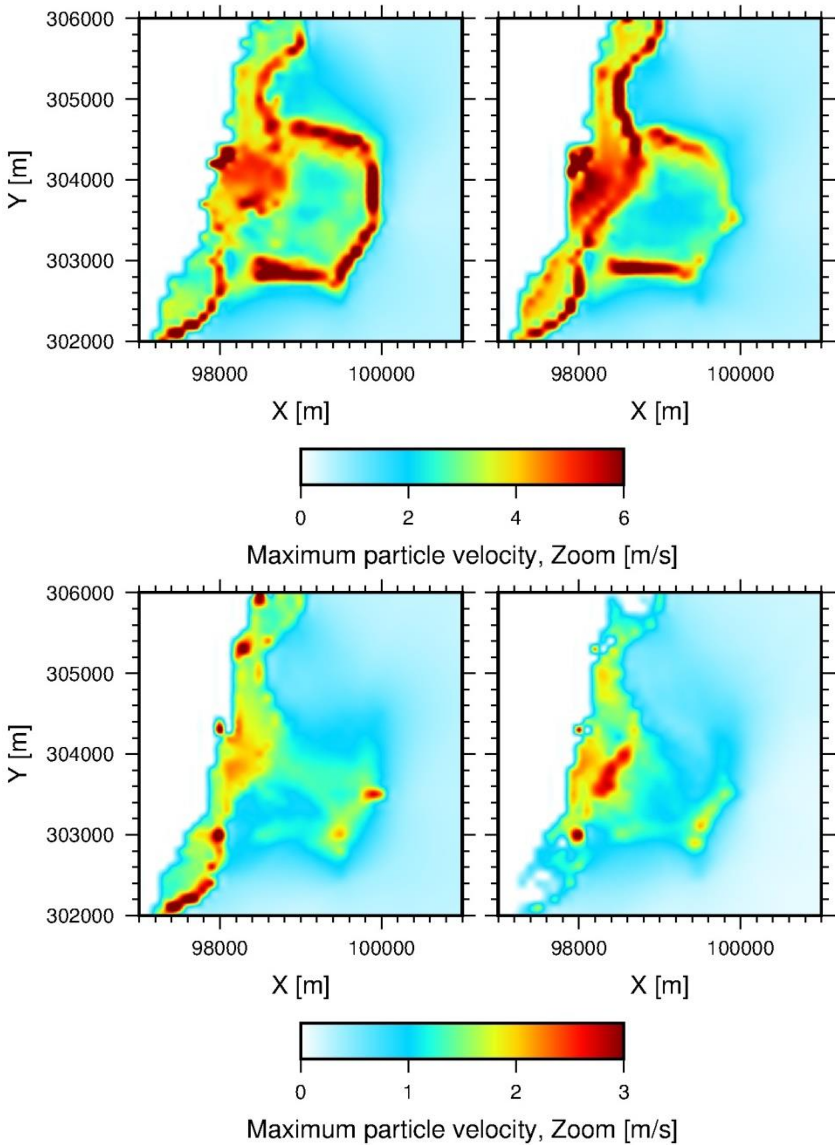

Fig. 6. Field of maximum particle velocity, zoom in on the area in front of Golden Sands resort, for all scenarios – see Fig. 5 caption

Entitled synthetic mareograms (virtual tide gauge stations) are obtained for a number of points close to the coastline and some points offshore (locations are shown in Fig. 2). These mareograms show the water elevations in certain point before, during and after the modeled tsunami waves. Thus we track out the sea water changes in each node due to the simulated earthquake-induced tsunami. Fig. 7 shows time series at seven grid nodes from all four sources. Four points are on land (number 2, 6, 13 and 24) and the computed water elevations are only positive.

Virtual tide gauge n. 2 and n. 6 are placed very close to the shore – the first one close to the port of Varna, the second one near the central beach of Varna. In less than 50 minutes the waves from hypothetical seismic source ShablaNE-SW and seismic source Balchik reached the port of the city of Varna with amplitudes of +0.55 m. The maximum positive wave is computed for ShablaW-E source – about +1.0 m. The waves from NW Turkey seismic source reach the port in about 80 minutes after the origin time with estimated range of 0.5 m. Gauge n. 6 show larger water elevation, 1.7 m above sea level, again from ShablaW-E source. Most of the oscillations end 240 minutes after the origin time, with the exception of the ShablaNE-SW in which last about 300 minutes with amplitudes of +0.5 m due to the numerous reflections.

Virtual tide gauge n. 13 and n. 15 are placed close to “Sts. Constantine and Helen” resort, north of city of Varna. Gauge n. 13 show positive sea level elevations of +1.6 m and +0.9 m for ShablaW-E and ShablaNE-SW sources respectively. The oscillations subside very quickly in comparison with the other synthetic mareograms – 100 minutes after the origin time. Practically insignificant variations in sea level due to seismic sources Balchik and NW Turkey. Virtual tide gauge n. 15 displays initial negative waves from three of the seismic sources. The maximum wave height does not happen at the leading but the secondary waves. Computed extreme water elevations vary between –0.6 m and +1.3 m as a result of ShablaW-E seismic source. 110 minutes after the origin time the oscillations shift in the interval ±0.4 m for all four sources.

Virtual tide gauge n. 21 is located near the coastline of the central beach of Albena resort. In this node, ShablaW-E source prevails with computed water elevations between –0.9 m +1.6 m. It is interesting that the behavior of ShablaNE-SW and ShablaW-E is almost the same at this point, initial negative oscillations and later positive waves with period of 17–20 minutes. The initial waves due to Balchik seismic source are negative with estimated water displacements of –0.6 m.

Virtual tide gauge n. 23 and n. 24 are placed very close to the port of Balchik. Although these gauges are near the hypothetical source of Balchik, maximum positive elevations are coming from seismic source ShablaNE-SW while the negative displacements of –0.73 m are induced by seismic source

Balchik only 7 minutes after the origin time. Maximum sea water elevation is caused by ShablaNE-SW and ShablaW-E, around +1.0 m.

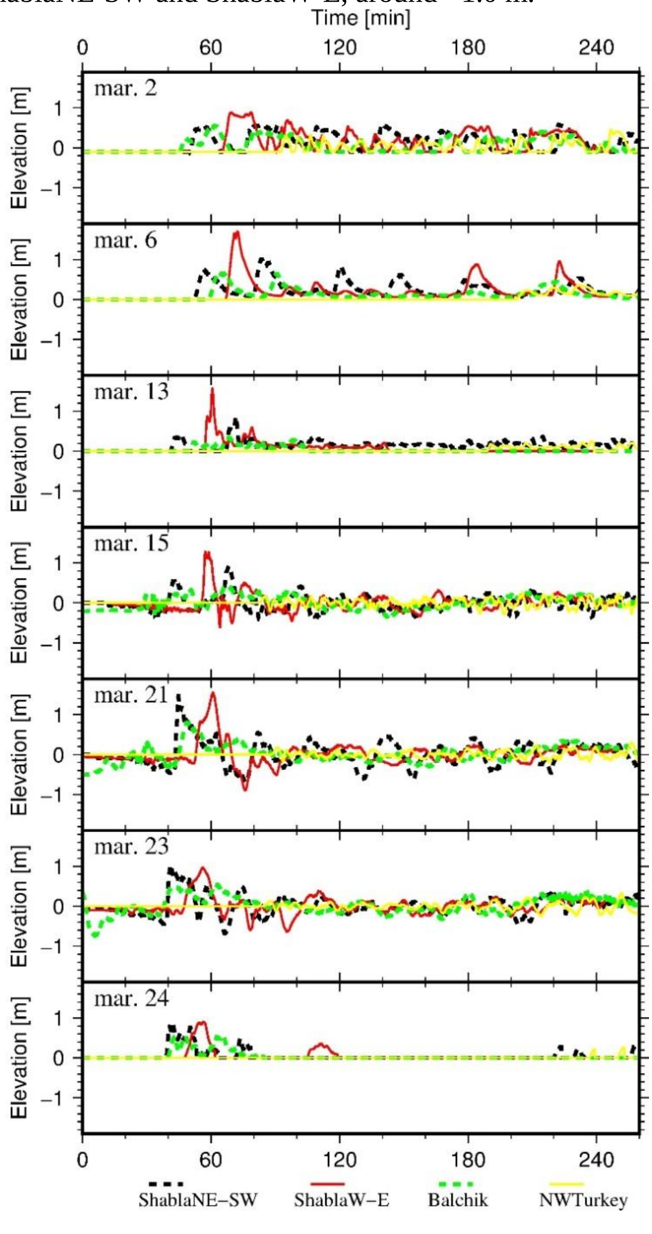

Fig. 7. Computed time series for all four scenarios for the first 260 min of tsunami propagation

The maximum water column on land is computed and plotted in Fig. 8, zooming on Varna and Balchik zones. The figure presents the inundation caused by ShablaNE-SW (left) and ShablaW-E (right) seismic sources for the region of Albena-Balchik (top panels) and Varna – "Sts. Constantine and Helen" resort (bottom panels). We can concluded that hypothetical seismic source ShablaNE-SW affects much more the area of the city of Balchik, while ShablaW-E causes local inundations in the bay of Varna and especially near the port. Both of the sources could generate inundations in Albena resort. The computed water columns on land are between +0.4 m and +0.8 m. Hypothetical seismic source ShablaNE-SW does not affect Varna port according to presented simulations.

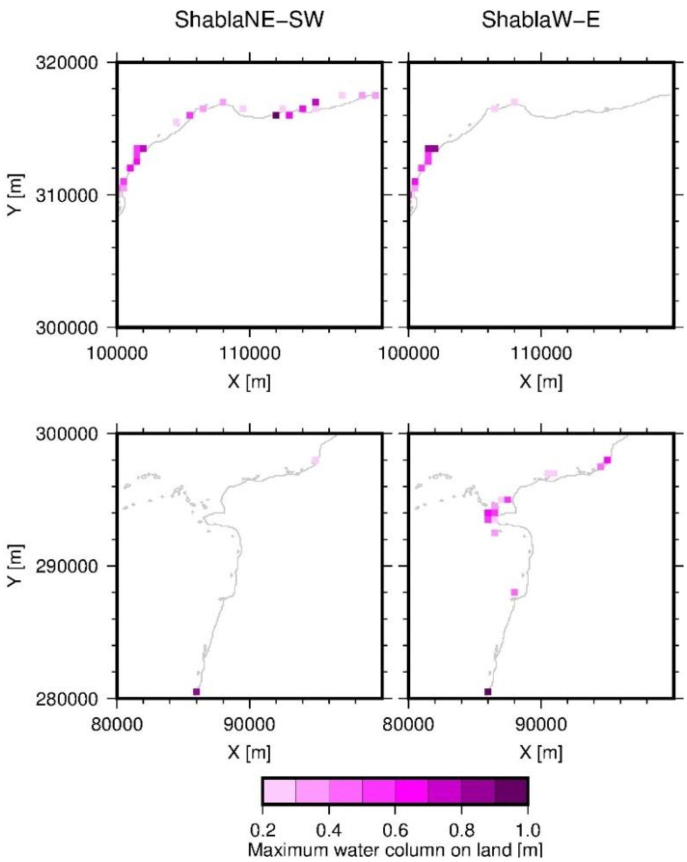

Fig. 8. Water column on land. Zoom in Albena-Balchik (top) and Varna – „Sts. Constantine and Helen" resort (bottom) areas. Hypothetical seismic sources ShablaNE-SW (left) and ShablaW-E (right)

4. CONCLUSIONS

In this study we examined the tsunami impact on the north-eastern part of Bulgarian Black Sea coast by using simulations performed by means of the numerical code UBO-TSUFD. We considered earthquake-induced tsunamis related to four seismic sources – three of them near Shabla seismic zone and one situated near the north-western part of the Turkish Black Sea coastline. We built two nested grids with different resolution. The propagation and time travel series in certain nodes are discussed in detail. We built the field of maximum particle velocity in the finest grid and we pointed out places with maximum water column on land. Simulations show that the region of Varna is affected moderately by inundations up to 0.63 m, while the water column in Balchik area can reach 0.91 m.

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