

Tsunami Hazard Assessment in İstanbul

İstanbul'da Tsunami Tehlikesinin Değerlendirmesi

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Abstract

Historical tsunami events have impacted the İstanbul coasts along the Sea of Marmara. Offshore seismic sources may trigger these tsunamis directly or through coseismic underwater failure. The 1999 İzmit Bay tsunami led to more comprehensive analyses of these events which are generally caused by underwater failures close to the target coastline. Waves so generated can arrive at nearby coastlines in minutes, causing extensive damage and loss of life. Here this paper propose, on the basis of tsunami models in the Sea of Marmara and methodology used internationally, first generation tsunami inundation maps for the areas along the southern coast of İstanbul. Such maps for selected areas help to understand the possible effects on those regions and should only be used for evacuation planning and reducing possible hazard.

Keywords: Tsunami, Hazard, inundation, Sea of Marmara, İstanbul, underwater failures

Introduction

Tsunamis are caused by any large-scale disturbance of the sea floor; e.g. faulting, landslide or volcanic eruption. A tsunami can propagate in any direction and thus, dependent on the location of the source, path of propagation and nearshore morphology form a risk to any vulnerable coastline. The nearshore seabed morphology determines both the wavepath towards shore as well as the wave runup characteristics (Figure 1).

Throughout history, the Sea of Marmara has been beset by small-scale tsunami waves (Altınok et al., 2001a). Its coasts are subjected to a near-field hazard – a tsunami generated in something under 2 hours tsunami travel time to the locality. Different from far-field tsunamis, it may be difficult to generalise the effects of near-field tsunamis, because there is a large variability over short distances of the height of tsunamis and their destructiveness. Coseismic underwater failures accompanying earthquakes on the North Anatolian fault (Figure 2) in the Sea of Marmara (Alpar et al., 2001), which shape and move vast quantities of sediment down on the continental slopes, are mostly responsible for the generation of these tsunamis (Alpar et al., 2001; Yalçiner et al., 2002).

The sediment movement is transmitted to the overlying sea surface, forming the initial tsunami wave which propagate rapidly. Since underwater failures on the continental slopes are close to shore, the generated waves arrive to the target shoreline in a short time with a low dispersion and cause extreme run-up (Synolakis et. al., 2002).

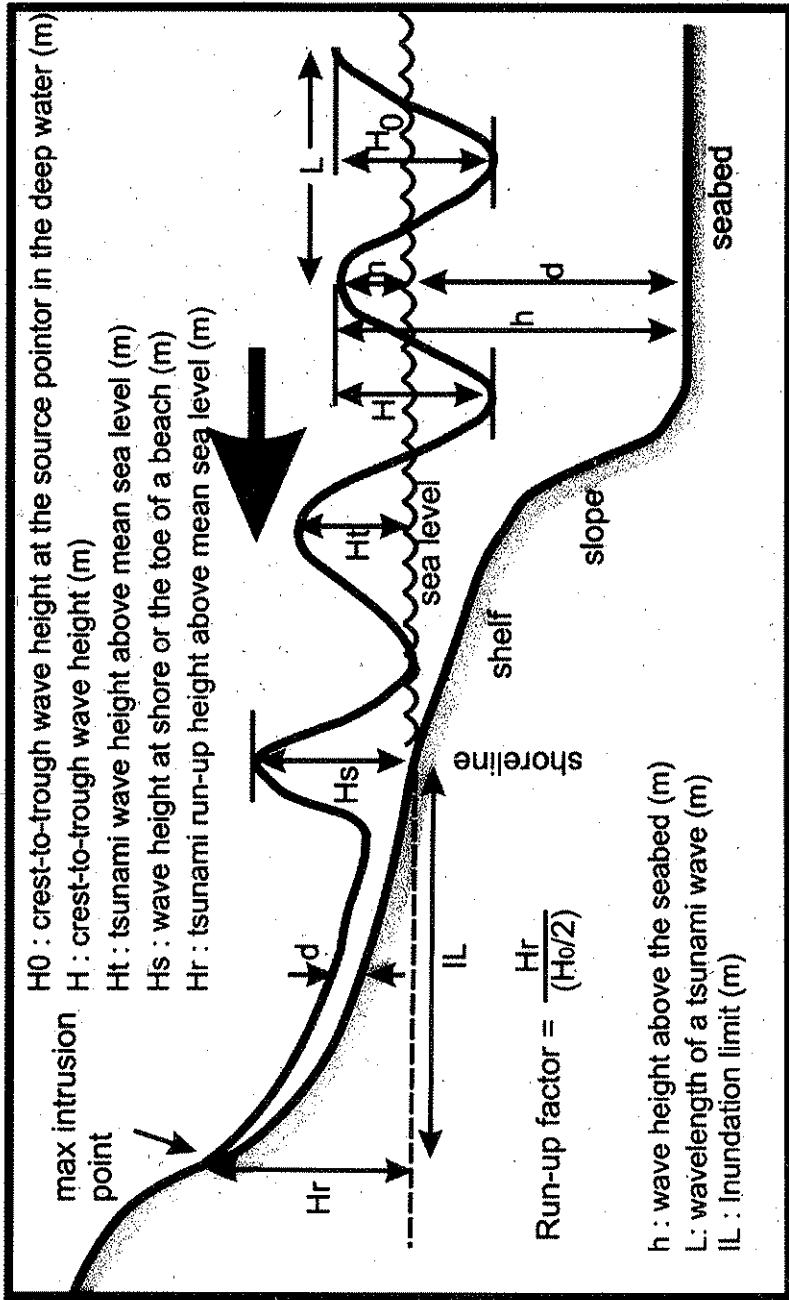


Figure 1. Graph explains terms used to express the wave height of a tsunami.

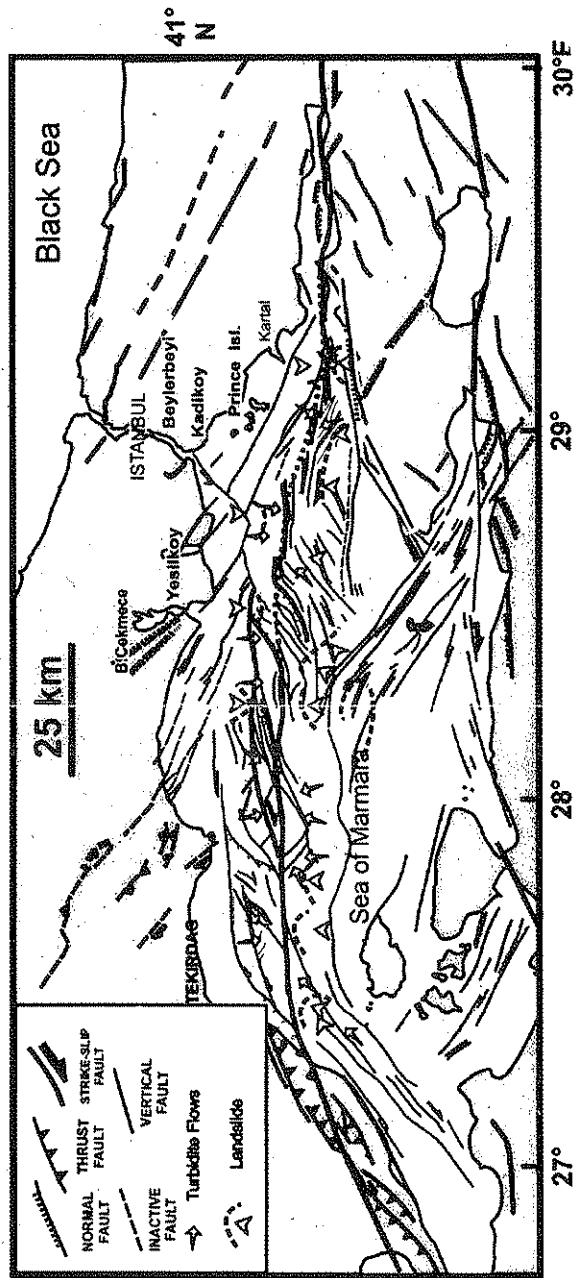


Figure 2. Potential underwater failures superimposed on the tectonic setting of the Sea of Marmara region (modified from Yaltrak, 2002; Altmok et al., 2003). All focal depths are shallow either on the North Anatolian Fault and other accompanying faults in the Sea of Marmara. Turbidite flows and landslides are lined up along the main fault segments.

İstanbul, which is the most populated historical city of Turkey, have had many experiences for different-size tsunamis. In the case of tsunami hazard, the southern coastal area of Istanbul is subjected to a near-field hazard – a tsunami generated in something under 2 hours tsunami travel time to the locality. Different from far-field tsunamis, it may be difficult to generalise the effects of near-field tsunamis, because there is a large variability over short distances of the height of tsunamis and their destructiveness. The long interval between events in a specific position makes the problem more complicated.

Hoping it limits construction of new essential facilities and special occupancy structures in tsunami flooding zones for public safety, we attempt to assess tsunami hazard focused along the southern coasts. It may be important for particular areas where the inland distance of inundation is greater.

Tsunamis observed in İstanbul

Even the historical records of near-field tsunamis is often incomplete due in large part to inadequate data and data of questionable quality, especially in the case of older events, there are many events well documented for our case. During last 1600 years, at least 21 historic tsunamis are known to be felt in İstanbul, nearly half of them impacted its coasts. Most of these tsunamis are well documented (e.g. Çesmi-zade, 1766-1768; Eginitis, 1894; Sadi, 1912; Mihailovic, 1927; Orgun, 1941; Heck, 1947; Ambraseys, 1960; Antonopoulos, 1978; Soysal et al., 1981; Papadopoulos and Chalkis, 1984; Soysal, 1985; Papazachos et al., 1986; Ambraseys and Finkel, 1991, 1995; Öztin and Bayülke, 1991; Batur, 1994, 1999; Guidoboni et al., 1994; Selimoglu, 1999; Papadopoulos, 2000; Altınok et al, 2003). The I and M values stands for intensity (in MM) and surface wave magnitude, respectively, are given by Papadopoulos (2000). Tsunami intensity (TS) scale is defined by Ambraseys (1962).

- 368** : Sea waves in Bithynia (40°30'N 29°36'E). I=VIII, M=6.4.
- 01.04.407** : Ships damaged in İstanbul (41°00'N 29°00'E). I=VIII, M=6.6.
- 26.01.447** : Large sea inundation in Bithynia (İzmit) (40°54'N 28°30'E). I=VIII, M=7.3.
- 24/25/26.09.477/478/480** : An earthquake affected almost all of the Sea of Marmara region. Damaging waves were observed at the coastal areas of İstanbul. (40°48'N 29°12'E). I=IX, M=7.2.
- 14.12.557** : The earthquake affected İstanbul and İzmit Bay area. The sea inundated 3000 m to the land. (40°54'N 27°36'E). I=IX, M=7.0.
- 26.10.740** : Sea receding and inundation was observed at some places as a result of the earthquake affecting northern and eastern parts of the Marmara region. (41°00'N 28°47'E). I=IX, M=7.4.
- 25-26.10.989** : The earthquake, which caused great damage in the eastern Marmara and eastern Trace, set up waves along the southern coasts of İstanbul. (40°48'N 29°12'E). I=IX, M=7.5.
- 11.03.1231** : Large sea inundation in the Sea of Marmara. (41°00'N 28°36'E). I=VIII, M=6.9.
- 10.08.1265 (night)** : Sea inundation in the Sea of Marmara. (40°42'N 27°24'E). I=-, M=6.6.
- 12.02.1332** : Sea inundation in the Sea of Marmara.
- 18.10.1343** : Sea surged up, and flowed out far into the flat coastal plains in İstanbul. The sea invaded for a distance of 2.2 km inland and ships were cast ashore. (41°06'N 28°48'E). I=X, M=7.4, TI=5.
- 14.10.1344** : An earthquake affected all of the northern region of the Sea of Marmara, including İstanbul. An inland inundation is reported to be 2000 m.

25.05.1419 : Sea inundation in İstanbul. (40°54'N 28°54'E). I=VI, M=6.6.

10.09.1509 : The magnitude of this İstanbul earthquake was close to 8.0. The tsunami wave height was most probably more than 6 m above mean sea level along the İstanbul coasts. Sea inundated the area behind the city walls of İstanbul, and invaded the streets. The locality of this observation is difficult to specify precisely because the city towers extend more than 7 km along the coast.

17.07.1571 : Sea swell over galleys.

05.04.1646 : With the earthquake in İstanbul, tsunami has been observed. The date of this earthquake may be 05.04/1641 and 136 ships have been damaged by the tsunami waves. (41°00'N 29°00'E). TI = 3.

22.05.1766 : Earthquake was destructive mostly around eastern Marmara and its associated tsunami caused considerable damage in Gemlik Bay. The waves were also recognised in Beşiktaş and the inner parts of the Strait of İstanbul. (40°48'N 29°06'E). I =IX, M=7.3, TI=4.

19.04.1878 : Damaging waves in Nikomedia. (40°42'N 29°42'E). I=VIII, M=6.6, TI=3.

10.07.1894 : The tsunami induced by the earthquake was effective in İstanbul when the sea receded up to 50 m and then returned. The residence of the sea and consequently sea water inundation to its original level was also confirmed around the Prince Islands and on the northern coast from Büyükçekmece to Kartal. There was no permanent change to the coastline. The sea rose up and inundated 200 m. The tsunami wave height was less than 6 m and the earthquake magnitude was less than 7.0. The Karaköy and Azapkapı Bridges crossing the estuary Golden Horn were under the water. Approximately 10 minutes before the earthquake, the sea receded at Yeşilköy and not long after, huge waves attacked the coast and inundated up to the 3 rows of houses and even swept off the first row. (41°00'N 29°00'E). I=VIII, M=6.6, TI=3.

09.08.1912 : An earthquake occurred on the Ganos fault segment, at western end of the North Anatolian fault in the Sea of Marmara. An underwater failure observed on the multibeam bathymetry is associated with this earthquake. Recent studies by Altınok et al. (2003) contributed many new findings to this tsunami. Related waves were observed along the İstanbul coasts and in the Strait of İstanbul. At Yeşilköy, the sea lifted a rowing-boat up to a height of 2.7 m. During this event, the sea receded about 10 minutes before the earthquake and huge waves caused by the earthquake swept off the first row of houses ashore in Yeşilköy. Similar observations are valid along the coastline from Kartal to Büyükçekmece. The waves inundated into the Golden Horn and flooded the Karaköy (4.0 m) and Azapkapı (4.5 m) bridges. In the middle of the Strait of İstanbul, the waves demolished an anchored yacht.

17.08.1999: An $M_w=7.4$ earthquake struck İzmit Bay. Co-seismic subsidence is a matter of fact along the southern coasts of the bay. Even the accompanying small amplitude (2.6 m) tsunami waves was only effective in the central part of İzmit Bay (Imamura et al., 1999; Yalçiner et al., 2001a; Altınok et al., 2001b), some abnormal events were observed around the Prince islands and in the Strait of İstanbul. The sea receded at the Heybeliada wharf a short time before the earthquake. After the earthquake, the walls of a Military School located at the midway of the strait and separated from coast by 10-m wide asphalt road, were poured with splashed sea water about 2 m above the modern sea level (Altınok et al., 2003). ($40^{\circ}45'N$ $29^{\circ}58'E$). $I=XI$, $M=7.4$, $TI=4$.

Modeling for Underwater Failures

Numerical simulation are useful tools for analysing tsunami propagation and coastal amplification. The tsunami waves generated by earthquakes depends on the size and the impact of the source mechanism on the displaced water. On the other hand, those generated by underwater landslides are governed by the landslide geometry and its kinematics (Grilli and Watts, 1999).

By estimating different underwater landslide and earthquake scenarios in the Sea of Marmara, Yalçiner et al (2001b; 2002) have

modelled tsunamis. Their tsunami simulation model considers a two-layer flow which makes this computation tool to be more realistic. The layers are the water column and the moving mass at the sea bottom. This model, known as Two_Layer, solves the non-linear long wave equations simultaneously by using the finite difference technique and following the Leap-Frog solution procedure within two interfacing layers with appropriate kinematic and dynamic boundary conditions at the sea bed, interface and water surface (Imamura and Imteaz, 1995; Özbay, 2000).

Yalçiner et al. (2002) proposed 3 different hypothetical tsunami scenarios; an underwater failure at offshore Yenikapı, another one offshore Tuzla, and an earthquake on the Armutlu Fault and two accompanying landslides located along this fault (Figure 3). These scenarios showed that the tsunami waves can reach the nearest coastal area within 5-10 minutes (see Figs. 7-10 in Yalçiner, et.al., 2002). The numerically simulated run-up elevations showed that the maximum positive tsunami amplitudes near the shore can exceed the 3-m level on some parts of the coast, even reaching the 5-m level at some localities (Figure 3) depending on the source and the coastal topography. Temporal histories, i.e. sequence and relative height of tsunami waves, showed similar appearances.

Such kind of models need accurate bathymetry data, since the canyons cause funneling wave energy while the shallows and banks refract the waves in complex ways. The Prince islands may cause the waves to refract, constructively interfering at eastern coasts (Tuzla) where runup is more than high (Figure 3c).

These numerical models predicted lesser tsunami run-ups in some areas, however, one should not underestimate possible flooding which may occur from subsidence. Therefore, all these effects should be considered as important risks for the shores of the Sea of Marmara where the coastline is densely populated and widely used for many purposes.

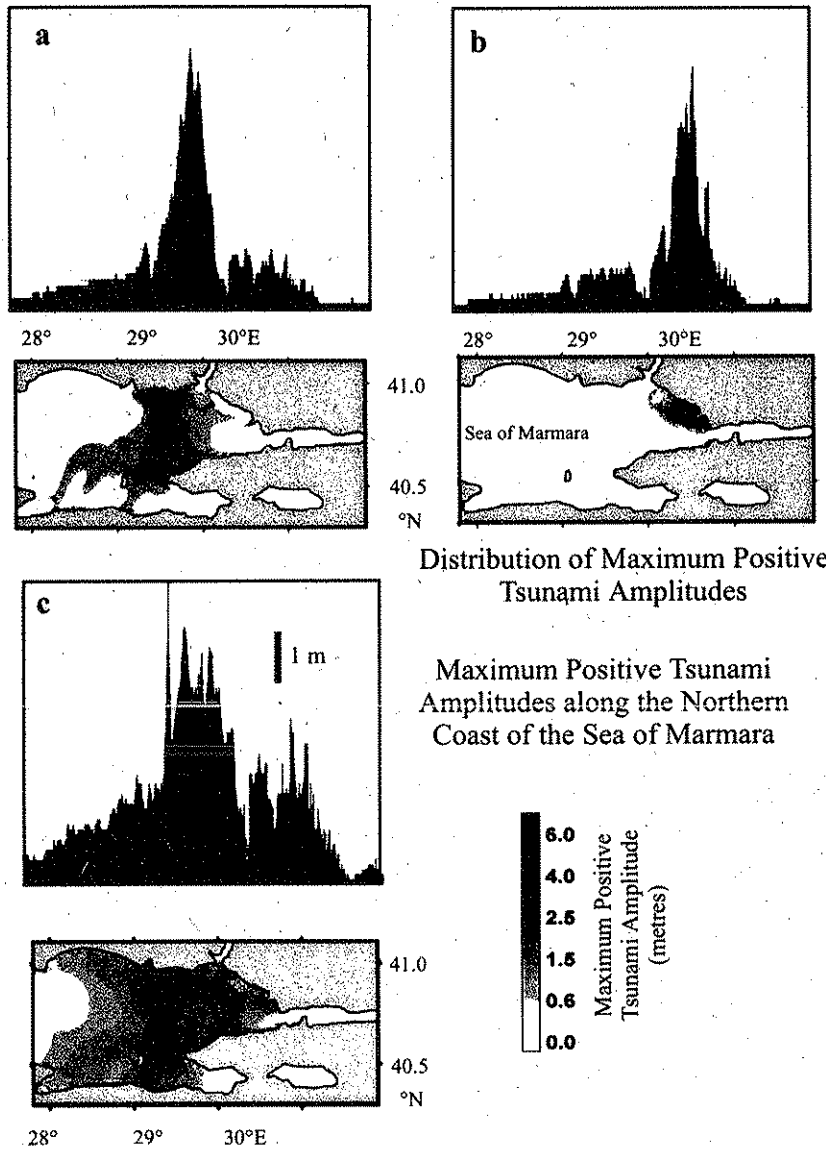


Figure 3. The distributions of maximum run-up elevations at each longitude along the southern coast of Istanbul due to the scenario underwater landslides at offshore (a) Yenikapi (b) Tuzla Cape and (c) Armutlu Peninsula (modified from Yalçiner et al., 2002).

Mapping Method and Inland Penetration

The inundation map was produced by numerically simulating the resulting tsunami waves due to scenario underwater failures, and mapping the maximum inland flooding limit. The first part was done by computer methods. The last step was accomplished chiefly by prior conclusions about inland penetration depending on the circumstantial characteristics of the inundation area and available topographic data (Priest, 1995).

Tsunami flooding or the volume of water carried onshore is directly related with the size of tsunami and its wave period. On the other hand, the cross-sectional area of coastline flooded by a tsunami is almost equal to that of water under the tsunami wave crest close to shore (Hills and Mader, 1997). The limit of landward incursion is the maximum distance that run-up can penetrate inland and can be given the following formula;

$$x_{\max} = (H_s)^{1.33} n^{-2} k$$

where k is a constant and taken as 0.06 for many tsunamis. The term n is another constant and depends on the characteristics of the inundation area. It is 0.015 for smooth terrains such as grasslands or tidal plains, 0.03 for areas covered in buildings and 0.07 for landscapes densely covered with forest (Figure 4).

Dry-land inundation distance across relatively flat ground was inferred by extrapolating the run-up elevation at the shoreline inland until a barrier was encountered or until a lateral distance was reached that conforms approximately to the above equation.

On the basis of this graph, a tsunami 2.6 m high can penetrate 950 m inland for smooth plains. However, since the study area is a developed land on flat coastal plains, such a tsunami can only penetrate 250 m inland.

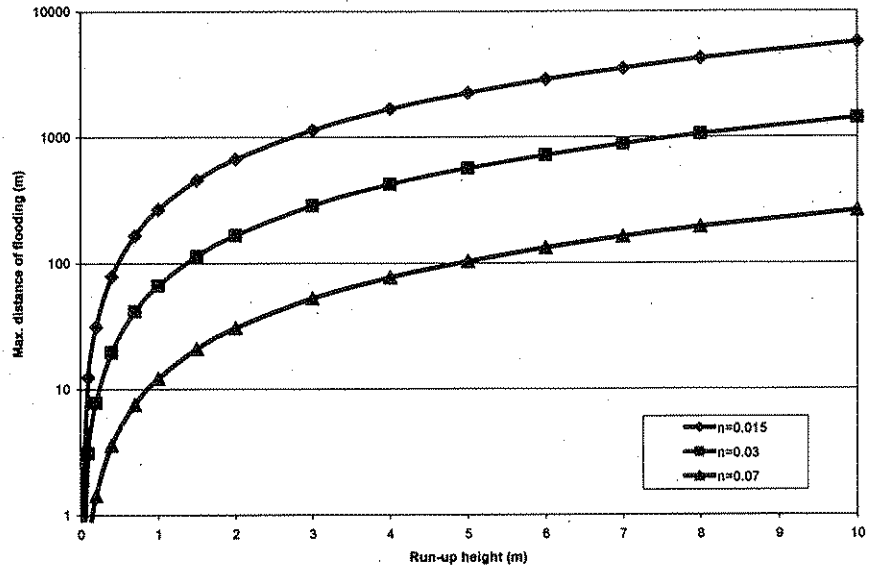


Figure 4. Maximum distance of flooding against run-up height for different n values which is 0.015 for smooth terrains such as grasslands or tidal plains, 0.03 for areas covered in buildings and 0.07 for landscapes densely covered with forest.

Mapping Tsunami Inundation

For definition of the inundation limit, a Digital Terrain Model (DTM) with a vertical resolution of ± 1.2 m was used. On the basis of elevation data of the surface, a DTM creates topography by geometric surfaces in a computer environment. This method provides best approach to a 3D terrain surface using elevation points which were defined on a horizontal plane, from various data sources such as measured data, topographic maps, bathymetric data and images. Our DTM was produced from 1:25,000-scale topographic maps and has a cell size of 50 m. In order to define the environmental condition of the inundation area (smooth terrain, areas covered in buildings or forest), we have merged the DTM with respective Panchromatic satellite images with 5 m resolution. Finally, calculated inundation limits based on some assumptions were drawn on these maps (Figure 5 a-f).

Precision and Accuracy of the Inundation Lines

One of the largest sources of error is uncertainty in the absolute run-up elevation at the open coast. Therefore, it is assumed to be 2, 2.5 and 3 m in our calculations (Figure 5 a-f).

The numerical grids were refined enough to simulate the details of the land topography (pixel size ± 50 m). Therefore uncertainty in the inundation distance (horizontal accuracy) is small.

Due to the inherent uncertainties in tsunami models, the parameters we used in calculations (models, topography etc) and our judgement to infer inundation, the resulting error is difficult to quantify. Vertical precision, for example, depended on the spacing of the elevation contours and the proximity of the contours to the inferred run-up elevation. The maximum uncertainty between contours is 100 percent of the contour interval. Where the inundation distance fell by chance at or very close to an elevation contour, the precision is better. In addition, the precision may be large at inlets, lagoons, river mouths and estuaries and smaller at steep shorelines. In all cases the precision of the inundation lines is limited by the resolution of the images to no better than ± 5.8 m horizontal and ± 1.2 m vertical.

Figure 5a-f. Inundation maps for the Marmara coasts of Istanbul. Each line shows how far inland and uphill a tsunami caused by an underwater failure is expected to go. Taking into consideration the simulated tsunami waves due to scenario underwater failures, topographic elevations, settlement conditions and geographic characteristics of the inundation area, the maximum inland flooding limits were developed for the wave heights of 2, 2.5 and 3.0 m at shore, respectively. The inundation distance was calculated on the basis of circumstantial characteristics of the inundation area along the coastal zone which was classified for smooth terrains and areas covered in buildings. There is no any landscapes densely covered with forest. Occasional steep coastal terrain at some localities limits inundation. These maps may be useful to restrict construction of certain types of essential facilities and special occupancy structures within the tsunami inundation zone. These lines are subject to changes on the basis of prehistoric tsunami deposits found along the coast, further computer tsunami modelings, and scientific studies of other tsunamis that occurred in the Sea of Marmara.

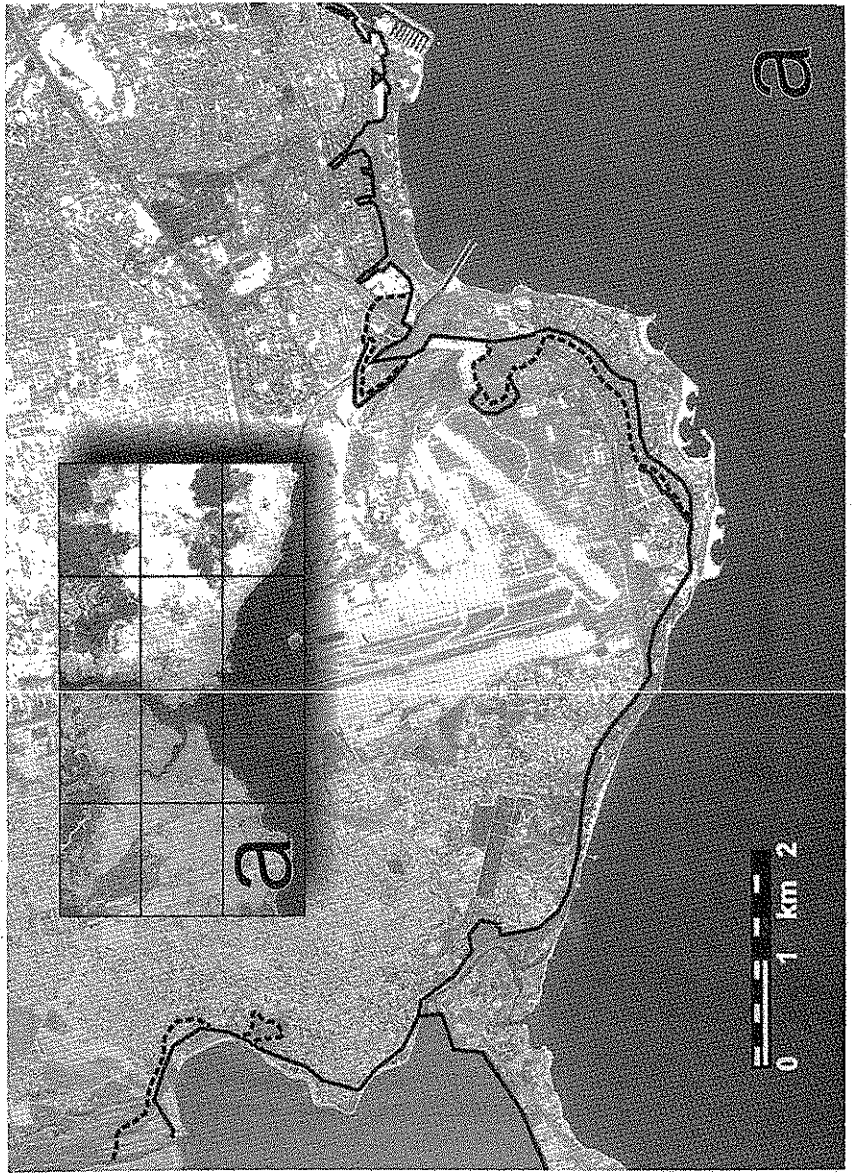


Figure 5a.

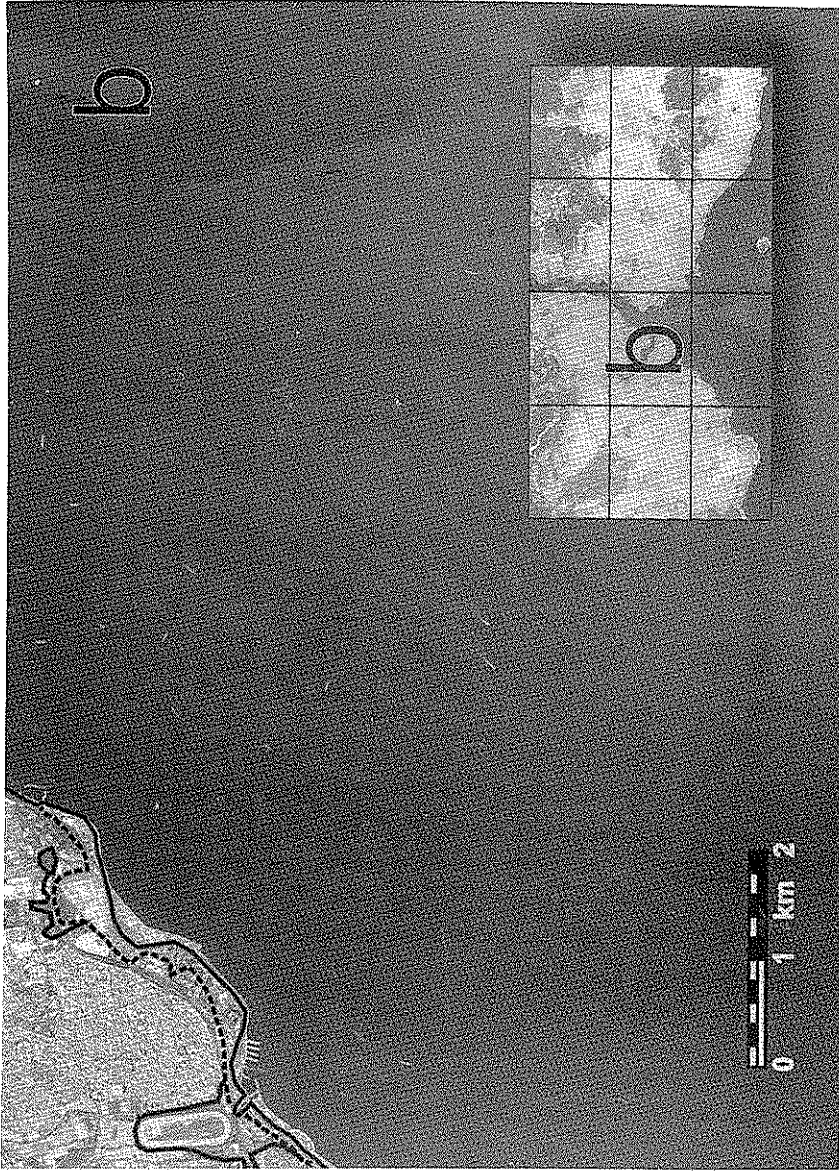


Figure 5b.

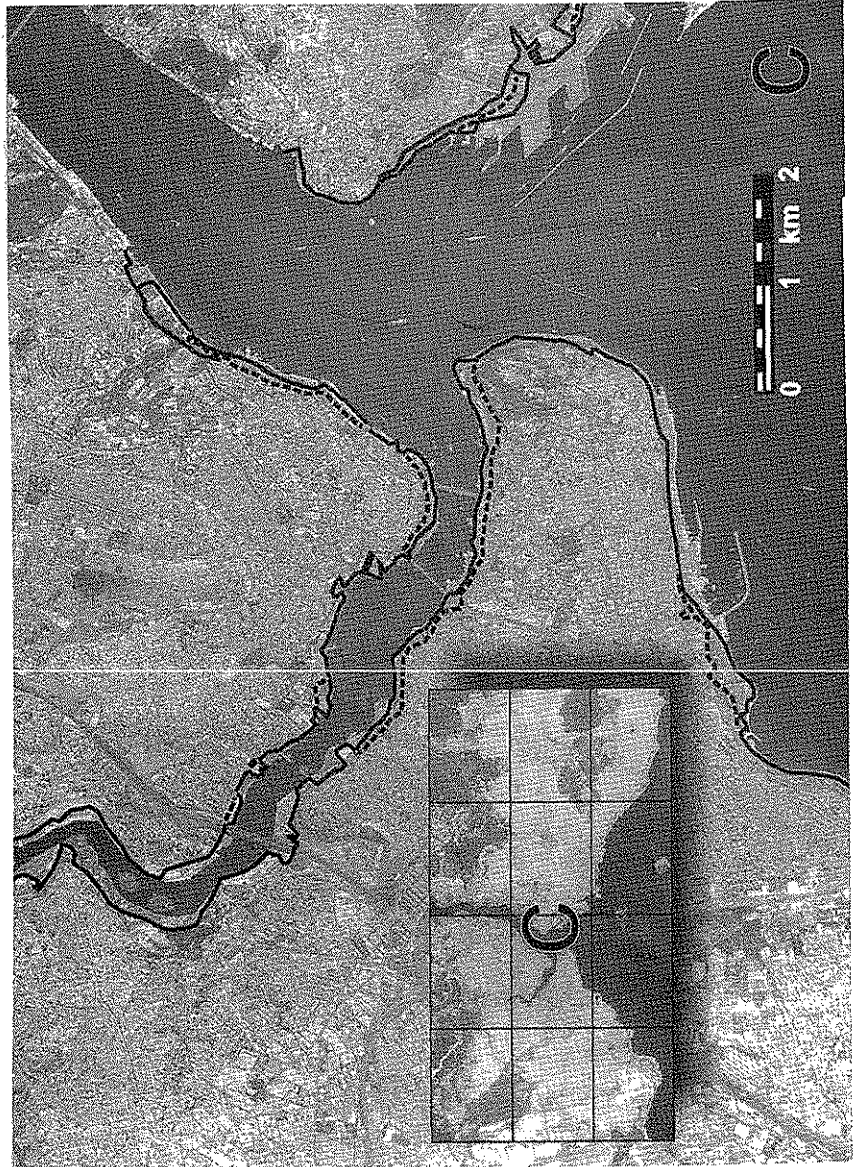


Figure 5c.



Figure 5d.

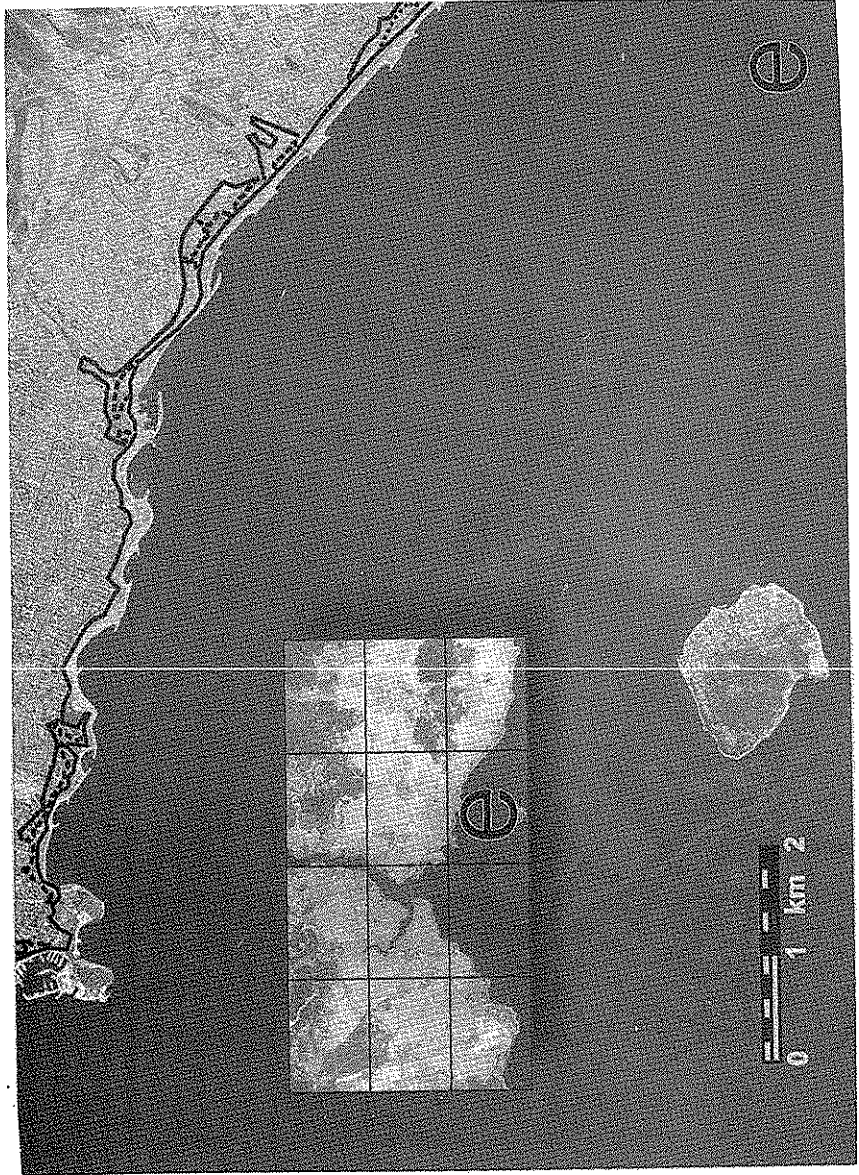


Figure 5c.

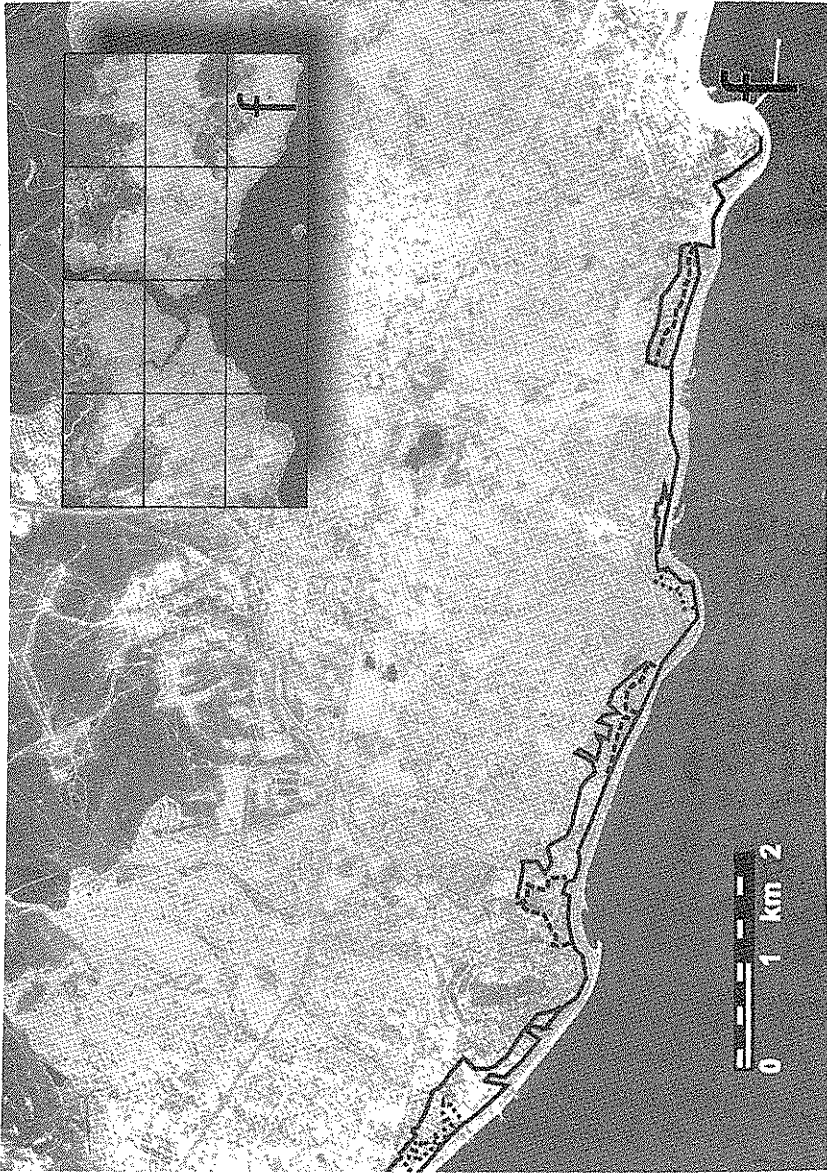


Figure 5f.

In normal conditions, sea level changes should be considered and possible coseismic subsidence should be added to results of inundation limit as an additional run-up. Even the tidal amplitudes are small in the Sea of Marmara with a mean spring range of 3-5 cm, seasonal sea level changes are in the order of 10-20 cm. Maximum effective wave height in the Sea of Marmara is as much as 2.4 and 3.3 m in fall and winter, respectively. Wind stress on the water surface can result in a pushing or piling up of water in the downwind direction. During persistent southerly winds, mostly effective during winter, there may be a substantial rise in the sea level as high as 1 m along the northern coasts of the Sea of Marmara, called as surge caused by wind setup, wave setup, and air pressure drop (Alpar et al., 1999). Therefore it may be assumed that the sea level may be 1.25 m above the mean sea level. On the other hand, coseismic subsidence may be effective in some areas such as wetlands or marsh, as observed in case of 1999 event in İzmit Bay (Altınok et al., 2001b). Especially some alluvial flats along the European coasts of İstanbul may be opposed to coseismic subsidence which should be estimated from study of wetland soils buried during prehistoric subsidence events. Subsidence inferred from the prehistoric geologic record may increase in large estuaries. Therefore, an additional run-up (e.g. < 1 m) can be added for such potential localities (e.g. mouth of the Ayamama River, Golden Horn etc.). In fact, estimates of prehistoric tsunami run-up require extensive and expensive field studies. Tsunami run-up estimates are generally within the uncertainty of the run-up elevations estimated from the prehistoric data. Therefore such adjustments may make only minor differences in the mapped inundation, and in our calculations, neither uplift nor subsidence was assumed.

Conclusion and Suggestions

Tsunamis are unpredictable events and increasing the uncertainty of preventive action, contribute to a very low social memory on these phenomena that is inversely related with a high demand for decision criteria based on scientific knowledge. On the basis of this contextual situation which shows us the urgent necessity to develop integrated actions research, tsunami risk maps in a microzonation sense along the Sea of Marmara coasts of İstanbul were produced.

The absolute run-up elevation at the coast is assumed to be 2, 2.5 and 3 m in our calculations (Figure 5 a-f). For particular areas, the inland distance of inundation is apparently greater. Küçükçekmece lagoon is separated from the coast by barriers with present elevations on the order of a few metres. The inferred inundation is high enough, within the uncertainties of the run-up estimates, to inundate this lagoon.

We have produced 3 different case scenarios for absolute run-up elevations of 2, 2.5 and 3 m at the coast. In fact, in normal conditions, a single line representing a worst case scenario was preferable, for it simplified the preparedness response of city officials and it better informed the general public (Synolakis et al., 2001). However, a comparison of low and high risk lines on a same map indicates most vulnerable localities and help us to rank the relative risk from different scenarios. These resulting maps (Figure 5 a-f) should be used for the tsunami impact in relations to the natural environment, land use/land cover types and road network.

One should not forget that a local tsunami generally produces run-up significantly higher than that of a distant generated tsunami, provided that the source earthquakes were of similar magnitude. Therefore, the tsunami waves may be destructive along the Marmara coasts of İstanbul and for shallower areas (<20 m). The effect of tsunami can be minimised on flat coastal plains (e.g. Çekmece lagoons, Ayamama, Bakırköy, and Zeytinburnu) by planting tree belts between shorelines and areas needing protection. At Büyükçekmece lagoon and in small harbours or marinas, very strong currents and extensive damage to property may occur if the tsunami amplitude is more than 2m. It may also be expected loss of life in addition to general loss of property, if the runup exceeds 2.5 m. Constructing breakwaters at harbours entrances, avoidance of potential areas for settlement and having streets aligned perpendicular to the wave advance may solve such problems.

Our inundation mapping efforts depend upon the numerical tsunami modes based on the landslide and slump hazards in the Sea of Marmara. Such kind of models developed for tsunami generation, propagation and coastal amplification are not enough to

know the maximum run-up with any certainty. On the basis of new marine surveys, shallow water models should be developed and upgraded to a better convenient faster accurate level. Simulation of historical events is important. Comparisons between simulated results and other observations allow the first estimation of the source energy.

A monitoring system for acquisition of seismic signal and water level displacement simultaneously must be installed to favouring the study of the tsunami generation in a selected area. At least two digital mareographic stations based upon a submerged pressure gauge and a microbarograph must be installed; one in the İmralı island.

The rises in sea level from storms at the time of an actual tsunami could change the run-up elevation by $\pm 1-1.5$ m from the mean sea level assumed in the simulation. This would also make significant changes in the horizontal position of the inundation lines.

Narrow estuaries and straits may maintain or amplify the wave height of open coastal tsunamis. Wave propagation modelling studies are suggested for the Strait of İstanbul and the Golden Horn estuary. The coastal run-up is assumed to decrease inland in barrier-protected bays and estuaries. Experiments showed that a run-up is locally higher if the tsunami partially or completely overtops the barrier, strikes a shoreline directly behind the entrance to an estuary, or enters a constriction in the estuary. Such errors should be added to the average run-up value to obtain the final run-up elevation.

In future, if any area is found to be underlain by deposits inferred to be from historic or prehistoric tsunamis, these areas should be included in the inundation boundaries we have defined. Since tsunamis can inundate without leaving behind a sediment deposit, presence of deposits was considered a good indication of minimum inundation.

Özet

İstanbul'un Marmara kıyıları tarih boyunca özellikle Marmara depremlerine bağlı olarak gelişen sualtı heyelanlarının yarattığı tsunami

dalgalarının etkisinde kalmıştır. Son 1999 depreminin İzmit Körfezinde yarattığı tsunaminin ardından yapılan daha ayrıntılı araştırmalar bu şekilde oluşan dalgaların kıyılara birkaç dakika içinde ulaşabileceğini ve önemli maddi hasarlara neden olabileceğini göstermiştir. Bu modeller baz alınarak ve uluslararası kabul gören ve kıyı yerleşimine göre değişen metodolojiler kullanılarak, İstanbul güney kıyıları boyunca tsunami basmasının kıyılardaki dağılımının ilk jenerasyon haritaları üretilmiştir. Bu haritalar kıyı alanları üzerindeki olası tsunami zararlarının azaltılmasında, bu alanlardaki geleceğe yönelik endüstriyel planlamalarda ve tahliye planlarının hazırlanmasında kullanılabilir.

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References

- Alpar, B., Doğan, E., Yüce, H., Altıok, H., Kurter, A., Kara, K. and Burak, S. (1999). Symptoms of a prominent Mediterranean layer blockage in the Strait of Istanbul (March 26-28, 1998) on the interactions of the Golden Horn Estuary, Turkish J. Mar. Sci., 5: 87-104.
- Alpar, B., Yalçiner, A.C., Imamura, F. and Synolakis, C.E. (2001). Determination of probable underwater failures and modeling of tsunami propagation in the Sea of Marmara. Proceedings of the International Tsunami Symposium 2001, August 7-10, 2001, Seattle, Washington, USA, pp. 535-544.
- Altınok, Y., Ersoy, Ş., Yalçiner, A.C., Alpar, B. and Kuran, U. (2001a). Historical tsunamis in the Sea of Marmara, International Tsunami Symposium 2001 Proceedings, NOAA, Pacific Marine Environmental Lab., Editor(s) : Eddie Bernard and Frank Gonzales.; U.S.A., Session 4, Number 4-2: 527 - 534.
- Altınok, Y., Tinti, S., Alpar, B., Yalçiner, A.C., Ersoy, Ş., Bortolucci, E. and Armigliato, A., (2001b). The tsunami of August 17, 1999 in İzmit Bay. Natural Hazards, 24: 133-146.

Altınok, Y., Alpar, B. and Yaltırak, C. (2003). Şarköy-Mürefte 1912 Earthquake's Tsunami, Extension of the Associated Faulting in the Marmara Sea, Turkey. *Journal of Seismology*, 7(3): (in press).

Ambraseys, N.N. (1960). The seismic sea wave on July 9, 1956, in the Greek Archipelago. *J. Geoph. Res.* 65: 1257-1265.

Ambraseys, N.N. (1962). Data for the investigation of the seismic sea-waves in the Eastern Mediterranean. *Bull. Seism. Soc. Am.* 52: 895-913.

Ambraseys, N.N. and Finkel, C.F. (1991). Long term seismicity of İstanbul and of the Marmara Sea region. *Terra Nova*, 3, 527-539.

Ambraseys, N.N. and Finkel, C.F. (1995). The Seismicity of Turkey and Adjacent Areas. A Historical Review, 1500-1800. Eren Yayıncılık, İstanbul.

Antonopoulos, A. (1978). Contribution to the knowledge of tsunamis in the Eastern Mediterranean from ancient times until the recent. *Ann. Geol. Des. Pays. Helleniques, Le serie TXXXIX/2*: 740-757.

Batur, A. (1994). Bir depremin yüzyıl dönümü. *İstanbul Dergisi* 10: 24-33.

Batur, A. (1999). Muharrem ayında bir salı günü. *Cogito, Deprem Özel Sayısı, Yapı ve Kredi Yayınları, İstanbul*, 20: 42-59.

Çesmi-zade, M.R. (1766-1768). *Cesmi-zade Tarihi (1766)*. Ed. B.S. Kütükoglu, İstanbul Fetih Cemiyeti Yayınları 1993.

Eginitis, D. (1894). "1310 Zelzelesi Hakkında Rapor", Translated by Bogos, İstanbul, 21 August 1310 Başbakanlık Arşivi Genel Müdürlüğü, Yıldız Esas Evrakı Sıra No. 674, Dosya No. 11, Gömlek No. 24, Varak 29 (handwritten manuscript, 1894).

Guidoboni, E., Comastri, A. and Traina, G. (1994). *Catalogue of Ancient Earthquakes in the Mediterranean Area up to 10th Century*. Istituto Nazionale di Geofisica, Rome.

Grilli S.T. and Watts, P. (1999). Modeling of waves generated by a moving submerged body; applications to underwater landslides. *Engineering Analysis with Boundary Elements* 23: 645-656.

Heck, N.H. (1947). List of seismic sea waves. Bull. Seism. Soc. Am. 37: 269-286.

Hills, S.G. and Mader, C.L. (1997). Tsunami produced by the impacts of small asteroids, Annals of the Sciences, 822: 381-394.

Imamura, F. and Imteaz, M.A. (1995). Long waves in two layer, governing equations and numerical model. Journal of Science of Tsunami Hazards, 13(1): 3-24.

Imamura, F., Koshimura, S. and Yağcıner, A.C. (1999). Field survey and numerical modeling of tsunami generated by Turkish Earthquake of August 17, 1999. Proceedings of Coastal Engineering in Japan 47: pp. 331-335 (in Japanese).

Mihailovic, J. (1927). Memoir-Sur les Grands Tremlement de Terre de la Mer de Marmara, Beograd, 215-222.

Orgun, Z. (1941). 1509 (Hicri 915) senesinde İstanbul'u baştan başa harap eden zelzele ve şehri tamir için alınan tedbirler. Arkitekt Neşriyatı, İstanbul.

Özbay I. (2000). Two Layer Model for Tsunami Generation, M.Sc. Thesis, Middle East Technical University, Civil Engineering Department, Ocean Engineering Research Center.

Öztiin, F. and Bayülke, N. (1991). Historical earthquakes of İstanbul, Kayseri, Elazığ. Proceedings of the Workshop on Historical Seismicity and Seismotectonics of the Mediterranean Region, 10-12 Oct. 1990, Turkish Atomic Energy Authority, Ankara, pp.150-173.

Papadopoulos, G.A. and Chalkis, B.J. (1984). Tsunamis observed in Greece and the surrounding area from antiquity to the present times. Mar. Geol. 56: 309-317.

Papadopoulos, G.A. (2000). Tsunamis in the East Mediterranean: a catalogue for the area of Greece and adjacent seas, In : Tsunami Risk Assessment Beyond 2000: Theory, Practice and Plans, Tsunami Risk Workshop, Moscow, Russia, June 2000, Proceedings, V.K. Gusiakov, B.W. Levin, O.I. Yakovenko (eds.), pp. 34-43.

Papazachos, B.C., Koutitas, Ch., Hatzidimitriou, P.M., Karacostas, B.G. and Papaioannou, Ch.A. (1986). Tsunami hazard in Greece and the surrounding area. *Annales Geophysicae* 4B,1: 79-90.

Priest, G.R. (1995). Explanation of Mapping Methods and Use of the Tsunami Hazard Maps of the Oregon Coast, State of Oregon Department of Geology and Mineral Industries, Suite 965, 800 NE Oregon St., #28 Portland, Oregon 97232, Open-File Report O-95-67.

Sadi (1912). Marmara Havzasının 26-27 Temmuz Hareket-i Arzi 15 Eylül 1328, İstanbul, Resimli Kitap Matbaası, 45p (Ottoman Language).

Selimoğlu, Z. (1999). Deprem, bir yaratık olarak. Pen'in Deprem Kitabı, Ay Sallanıyor, Cumhuriyet Kitap Klübü, İstanbul, 296-300.

Soysal, H. (1985). Tsunami (deniz taşması) ve Türkiye kıyılarını etkileyen tsunamiler, İstanbul University, Bulletin of Marine Sciences and Geography, 2: 59-67.

Soysal, H., Sipahioğlu, S., Kolçak, D. and Altınok, Y. (1981). Türkiye ve Çevresinin Tarihsel Deprem Kataloğu (MO 2100-MS 1900), TÜBİTAK project Tbag 341, İstanbul.

Synolakis, C.E., Borrero, J., and Yalçiner, A.C. (2001). Developing inundation maps for the state of California. In : A.C., Yalçiner, (Ed.), NATO Advanced Research Workshop, Underwater Ground Failures on Tsunami Generation, Modeling, Risk and Mitigation, Book of Abstracts, May 23-26, 2001, İstanbul, pp. 188-192.

Synolakis, C.E., Bardet, J.P., Borrero, J., Davies, H., Okal, E., Silver, E., Sweet, S. and Tappin D. (2002). Slump origin of the 1998 Papua New Guinea Tsunami. Proceedings of the Royal Society, Series A.

Yalçiner, A.C., Synolakis, C.E., Alpar, B., Borrero, J., Altınok, Y., Imamura, F., Tinti, S., Ersoy, Ş., Kuran, U., Pamukçu, S. and Kanoğlu, U. (2001a). Field surveys and modeling of the 1999 İzmit Tsunami. Proceedings of the International Tsunami Symposium 2001, August 7-10, 2001, Seattle, Washington, USA, pp. 557-564.

Yalçiner, A.C., Alpar, B., Özbay, İ., Altınok, Y. and Imamura, F. (2001b). Tsunami generation and coastal amplification in the Sea of Marmara, NATO Advanced Research Workshop, Underwater Ground

Failures On Tsunami Generation, Modeling, Risk and Mitigation, Book of Abstracts, 23-26 Mayıs 2001, Istanbul, pp. 138-146.

Yalçiner, A.C., Alpar, B., Altınok, Y., Özbay, İ. and Imamura, F. (2002). Tsunamis in the Sea of Marmara: Historical documents for the past, models for the future, Marine Geology, 190(1-2): 445-463.

Yaltrak, C. (2002). Tectonic evolution of the Marmara Sea and its surroundings, Marine Geology, 190(1-2): 493-529.

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