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Constraining Source Properties of the 1894 Istanbul Earthquake

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07.05.2020

I. Introduction

On 10 July 1894 at 12.24 p.m., a large earthquake hit Istanbul.

At least 22,000 houses were damaged which corresponds to 1/7 of the total dwellings of the city at that time.

According to the official reports, the 1894 earthquake resulted in 474 losses of life and 482 injuries. These numbers reflect information only in Istanbul and its villages. Because of the censorship and limited information about the neighboring cities, the exact number remained unknown.

Demetrius Eginitis, the director of the Greek National Observatory, came to Istanbul to investigate the earthquake by accepting an invitation of Sultan Abdulhamid II. Eginitis visited the damaged areas by his assigned ferry and prepared the first scientific report on this earthquake to present to the Sultan on 20 August 1894.

Based on site examinations and information received with telegrams from the governorates, he was able to determine the isoseismal map of the earthquake (Figure 1).

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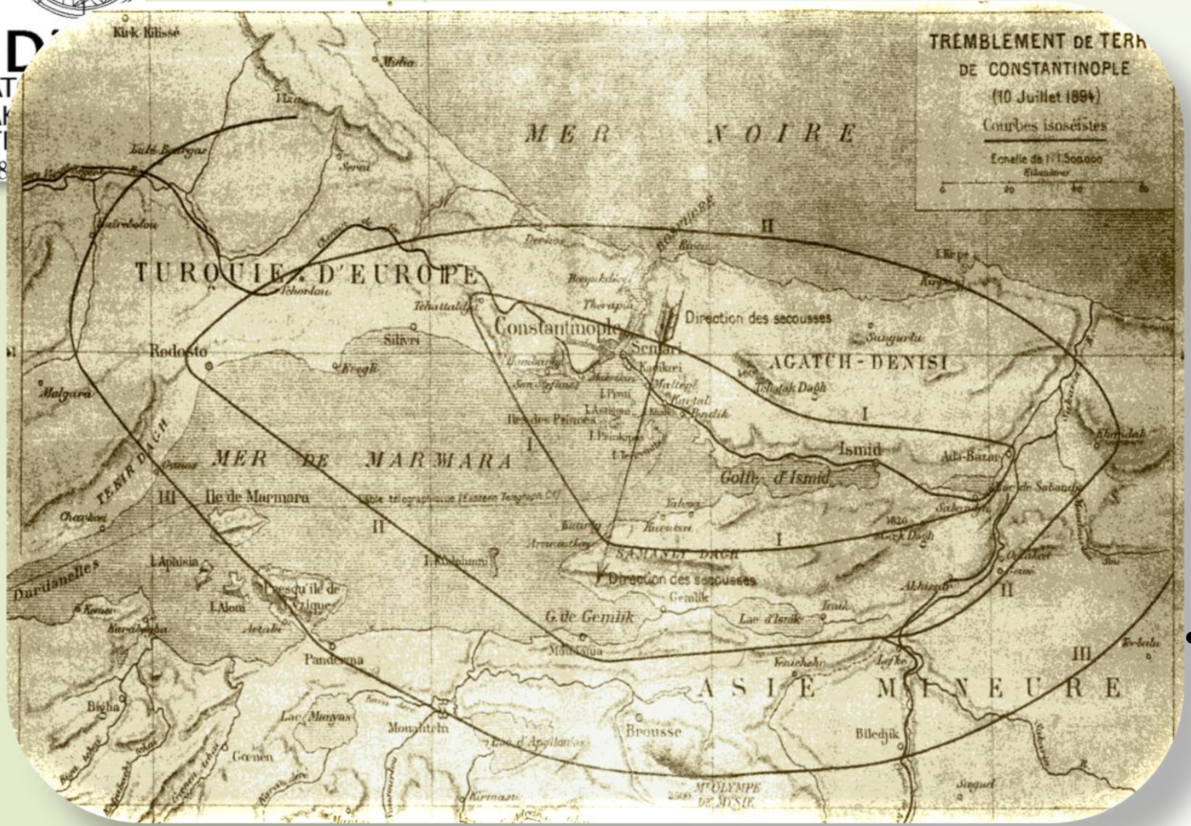

Figure 1: Isoseismal map prepared by Eginitis in 1894 (Eginitis, 1895).

- The first elliptical zone includes the epicenter and covers the most damaged areas. Well-built structures in this region have been destroyed. The major axis of the ellipse is from Çatalca to Adapazarı, which continues along the Gulf of Izmit with a length of 175 km. The small axis covers the land between the villages of Katırlı (Esenköy) near the Gulf of Izmit and Maltepe as 39 km long. The direction of the shakes is approximately parallel to the small axis and vertical to the large axis.
- The second region contains the badly built houses; few of them collapsed and most of with slightly damaged. This elliptical region includes Çorlu, Rodosto (Tekirdağ), Mudanya, Akhisar, Üsküdar, Ortaköy, Terkos as 248 km long axis and 74 km small axis.
- In the third region, the earthquake did not cause any structural damage but only small items displaced or overturned.
- The fourth region, which is not shown on the map, involves Yanya (Ioannina), Crete, Bucharest, Greece, Konya, and Anatolia which are undamaged but where the shaking is felt by people.
- The last region corresponds to an immensely extent area including Europe, Asia, and part of Africa where the shake is very slight and only recognizable with seismic devices (Eginitis, 1894).

I. Introduction

The damage was severe in the historical peninsula. Especially, the Grand Bazaar has been ruined and many people have died inside it. Eginitis saw the maximum damage on Prince Islands, Heybeliada, and Kınalıada.

In Yeşilköy, Ambarlı, Kınalıada, Büyükada, and Katırlı (Esenköy), many houses have been totally destroyed, numerous mosques and churches either collapsed or seriously cracked, and most of the minarets fell down.

In the report, it is also stated that having mostly wooden houses decreased the casualties, otherwise the shake could result in higher loss. Even the old wooden buildings with poor quality have survived, while the well-built, new masonry buildings even which are constructed using iron ties, have been demolished.

The damaged structures in Suriçi district using the inventory shared by Oztin, 1994 are illustrated in Figure 2. Having the old and poorly maintained structures increased the devastation of the earthquake in Suriçi. Many monumental structures damaged. Fatih, Edirnekapı, Balat, Eminönü, Gedikpaşa, Samatya, Kumkapı, Kadırga had the worst damage. Many houses, mosques, churches collapsed. Chimneys, water gauges, minarets fell down.

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Figure 2: Damaged structures in Suriçi district after the 1894 earthquake, using the inventory given by Oztin, 1994.

II. Discrepancies

There are also discrepancies between researchers about the intensity, epicenter, magnitude, rupture length and associated fault segment of the event . Even though we have respectively more knowledge about the 1894 event, researchers have split in opinion as it can be seen in the table below and Figures 3 and 4.

N	E	Intensity	Mag	Fault Type	L (km)	R (m)	Reference
40.943	29.039	8	Mw=6.70				***Stucchi et al. (2013)*** (SHEEC)
40.750	29.200	9	Mw=7.20				***Papazachos & P., 2003***
40.6	28.7	IX	M=6.94				***Ergin&Guclu,1967, Tezcan 1991.***
40.75	29.55		Ms=7.3	S.S.	90	4,4	***Ambraseys, 2001***
40.75	29.55		M=7.3	S.S.	80		***Ambraseys&Jackson, 2000***
40.9	28.8						***Sezer, 1997***
40.6	28.7	X					***Soysal&Sipahioğlu, 1981***
			M=7.0	N.F.	50	2,0	***King&Ferrari, 2001***
			M= 7.0	N.F. & S.S.			***Parsons, 2004***
				N.F.			***Le Pichon, 2003***
40.6	28.7	X					***KOERI***

II. Discrepancies

Figure 3 illustrates epicenters assigned by different researchers to the 1894 event.

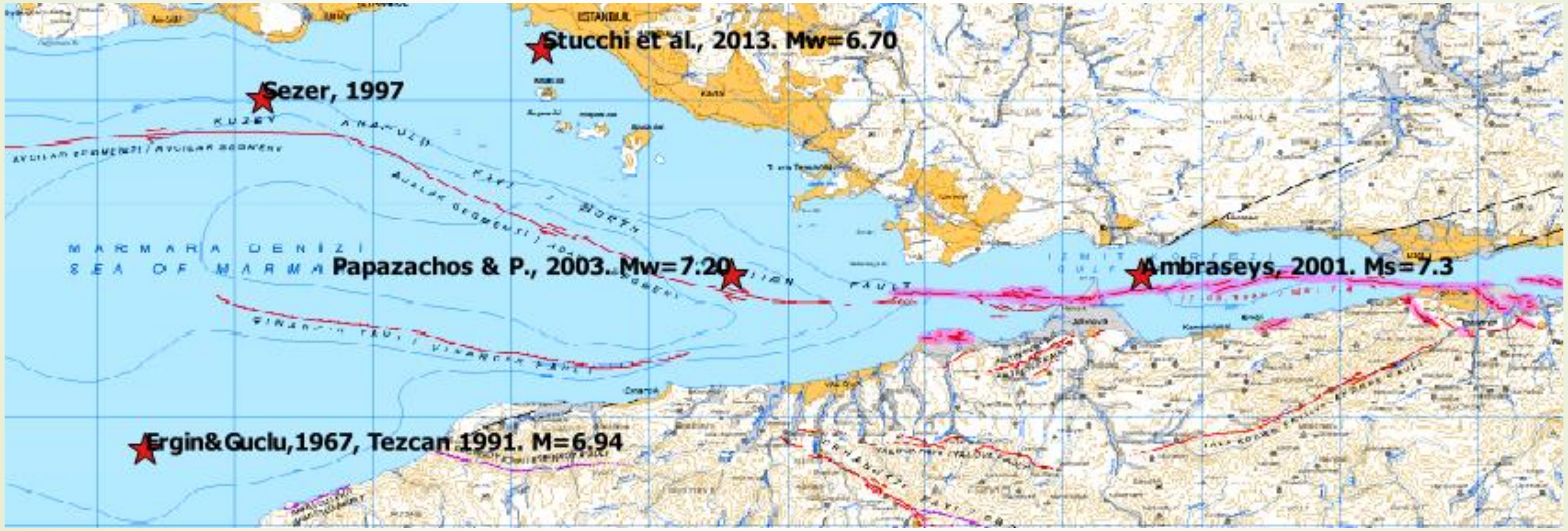

Figure 3: Red stars correspond to the epicenters of the 1894 event by different researchers.

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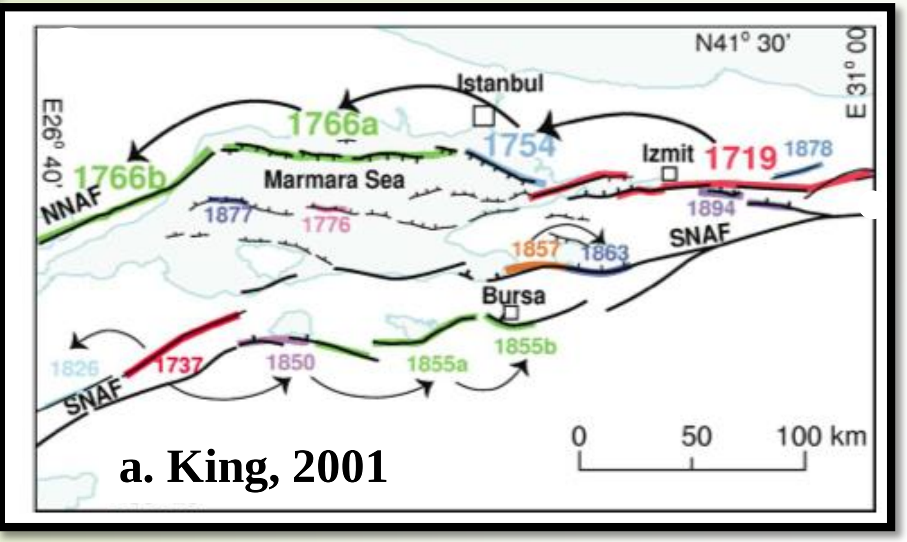
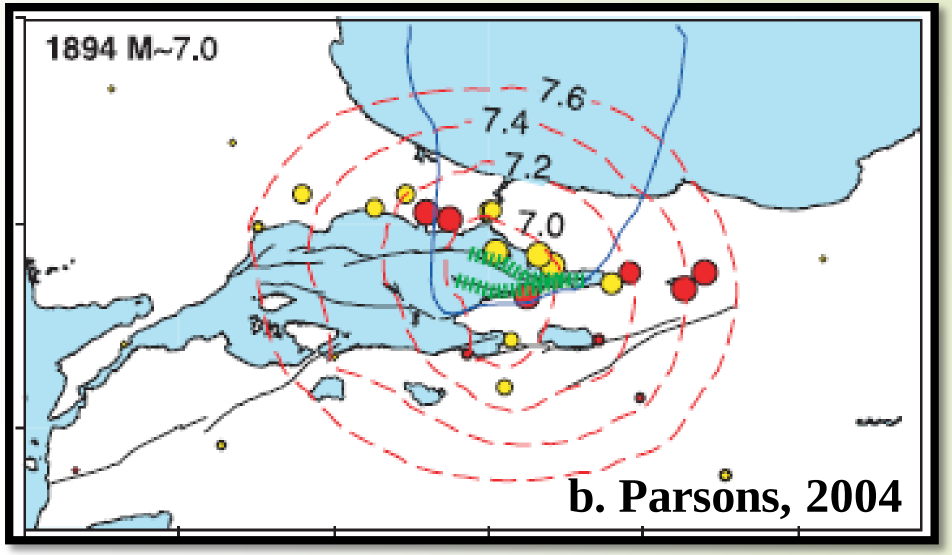
II. Discrepancies

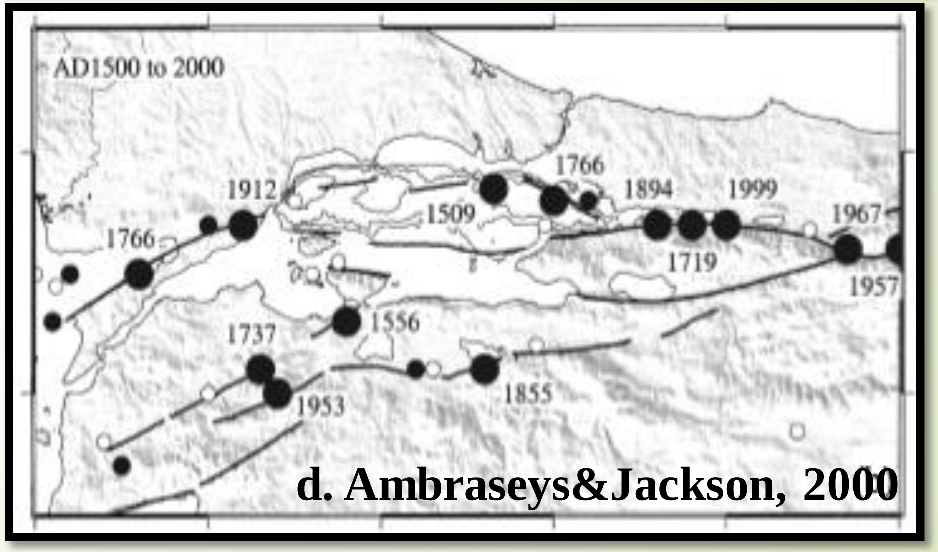


a. King, 2001



b. Parsons, 2004

c. Boğaziçi University Department of Earthquake Eng. Report, 2003.



d. Ambraseys&Jackson, 2000

Figure 4: NAF segments associated with the 1894 event by different researchers.

II. Number of Dwellings and Population

- The most affected structures by the earthquake were dwellings and they were not included in damage reports. According to the list showing the amount of aid to the earthquake victims, the number of households destroyed/damaged in the 1894 earthquake was 20,959 in only Istanbul.

- In 1893-1894, the number of dwellings in Istanbul was 162,950. Of these, 158,000 were in Istanbul (including Pera, Eyüp, and the suburbs in the European and the Asian coasts of the Bosporus), 4,950 of them are the dwellings in the Prince Islands (1,810 were mansions and 3,140 were ordinary dwellings, Cervati, 1894).

- If the number of households repaired with their own means is neglected, damaged dwellings will be approximately 1/7 of the number of households in Istanbul at that time (Ozkilic, 2015, page:68).

- The highest damage seems to have occurred in Suriçi, with 12,762 damaged structures.

- According to the first census records, the population of Istanbul was 873,575 in 1885. In 1906 it increased to 864,576 (Shaw, 1976). The population was concentrated especially in Galata and Suriçi districts.

III. Structure Type in Istanbul at the end of 19th Century

Even though financial support was provided to the locals to build their houses and shops in concrete and the law in 1882 that attempted to change the type of structure from wood to masonry, it was never fully implemented (Çelik, 1993). Stone-masonry construction was used mostly in public buildings. Wood was still preferred material of the residential buildings , but gradually masonry buildings were also built. (Kuban, 1998; Kuban, 2010).

IV. Damage Inventory

Ottoman Empire archive records, prepared scientific reports, newspapers, government correspondence, letters, notes of voyagers and diaries are the major sources for damage information.

Ottoman Empire had vast archive records, which are mostly available in the Ottoman Archives of the Prime Minister's Office (Başbakanlık Osmanlı Arşivi). Unfortunately, at that time Ottoman Empire mostly focused on old city part called Suriçi in Turkish, which contains Eminönü, Fatih and Aksaray districts. There are limited records about the rest. For example, there is no any information about the loss of life in Yalova, despite its close distance to Istanbul (Sezer, 1997).

Damages to ordinary dwellings after natural calamities were rarely recorded in the Ottoman Empire archives except if they were not damaged due to collapse of a structure that was under the responsibility of the government (Mazlum, 2011).

In the following, compiled damage inventories, which will be used to estimate damage distribution and the intensity maps, for the 1894 earthquake is explained.

IV. Damage Inventory

Based on the detailed inventories compiled with great efforts by Eginitis (1894, 1895), Oztin (1994), Finkel & Ambsareys (1997), and Ozkılıç (2015) using official archival records, daily press, and other documentations, a new damage inventory of the 1894 earthquake has been created.

In the inventory there are approximately 2150 damage entries with their coordinates and structure types. In addition, there are 600 structures about which their spatial neighborhood information is known, but their exact coordinates could not be found. Apart from this, around 75 records have not been evaluated because their location information is not available.

There is information about various structures in this inventory such as: religious buildings (mosques, masjids, monasteries and churches, synagogues), tombs, dervish lodges, hospitals, police stations, other public buildings, inns, commercial centers, factories, Turkish baths (hammams), schools, madrasahs, some mansions and pavilions, palaces, city walls, castles and bastions, bridges, hotels, some cylindrical structures like minarets, bell towers, historical water gages, towers and so on.

V. Locations and Structural Type of the Damaged Buidings

Locations of damaged buildings due to the 1894 earthquake were found using old city maps. Brief information about the maps can be found below:

Positions of the damaged buildings were mostly obtained using Map of İstanbul in 19th Century by Ekrem Hakkı Ayverdi. Ayverdi Maps in black and white represent settlements in Istanbul between 1875 and 1882 (Ayverdi, 1958).

As the first fire insurance map for the city of Istanbul, Goad maps clearly show footprints, heights, usages and locations for each building with their roof and construction materials between 1904 and 1906. Construction materials were presented using different colors as red for brick or stone buildings and yellow for wooden buildings.

The German Blues were prepared for the purpose of city planning between 1913 and 1914. German Blues mostly focused on the public and monumental structures of Istanbul, dwelling houses were excluded.

As another precious fire insurance map in extended time period between 1922-1945, Pervititch Maps include name, street number, material type of the construction and its roof, height, number of floors, and some other detailed information about the buildings. In Pervititch Maps, construction material types of buildings were represented using different colors as pink for masonry and yellow for wooden. By looking the sheets, it is clearly seen that pink colors are concentrated in city center, and yellow marked buildings are getting denser in exurban areas.

a

b

Ekrem Hakkı Ayverdi

German Blue

c

d

Goad

Pervititch

Figure 5: Examples of maps a) Ayverdi Maps, b) German Blue, c) Goad Maps, d) Pervititch Maps.

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VI. Vulnerability Class

After compiling inventories and finding the type of construction material of the buildings, the next step is classifying buildings in terms of their strength.

The European Macroseismic Scale categorized building strength taking both building type and other factors into account to estimate how they respond to ground shaking. Based on the vulnerability table given in EMS-98, the buildings in the inventory were classified into three main vulnerability classes considered by the EMS98 scale as A, B or D.

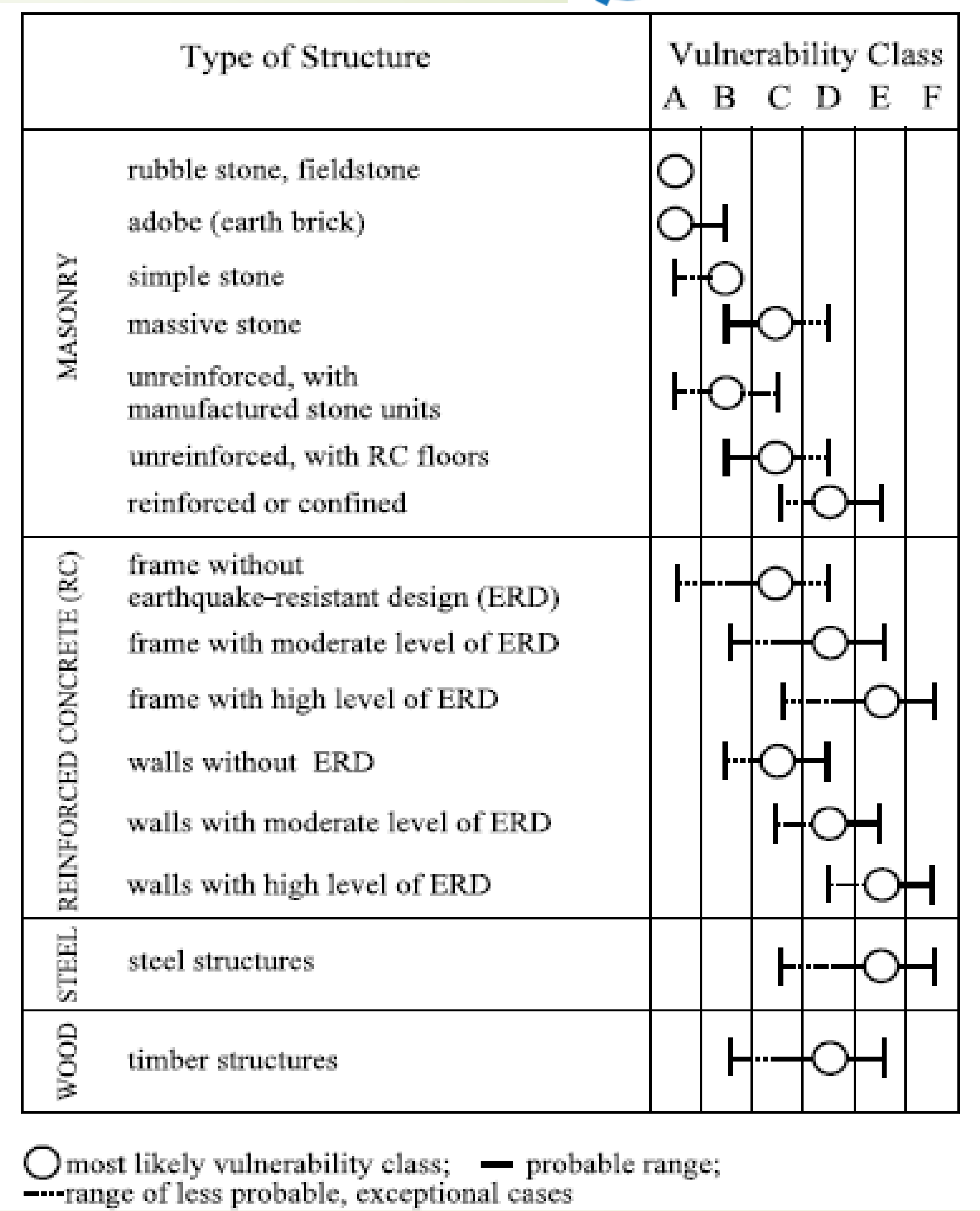


Table1 : Classifications used in the European Macroseismic Scale (EMS).

VII. Damage Grades

Damage grades from 1 to 5 by looking different types of building responds for both masonry and reinforced concrete buildings in EMS-98.

In the inventory documents, since the main goal is to determine the benefit of allowance caused by the earthquake, the damage is often defined roughly and damage levels are mostly phrased with using stereotyped phrases. These expressions are sometimes may overestimate or underestimate the level of damage and be erroneous. These unclear statements cause hardness to define damage accurately.

To reduce the error caused from these formulaic expressions, it is important to collect information from various sources especially from the contemporary ones, and differentiating structural and nonstructural damages. Besides, by looking pictures those were taken after the 1894 event, it is possible to understand what was meant by a source. These pictures are accessible as 3 albums in Atatürk Library, under Muallim Cevdet Catalog photography collection, with the name of Istanbul-1894. In addition, Istanbul University, Rare Works Library shares 19 frames of the 1894 event.

One example of the pictures taken after the 1894 earthquake:

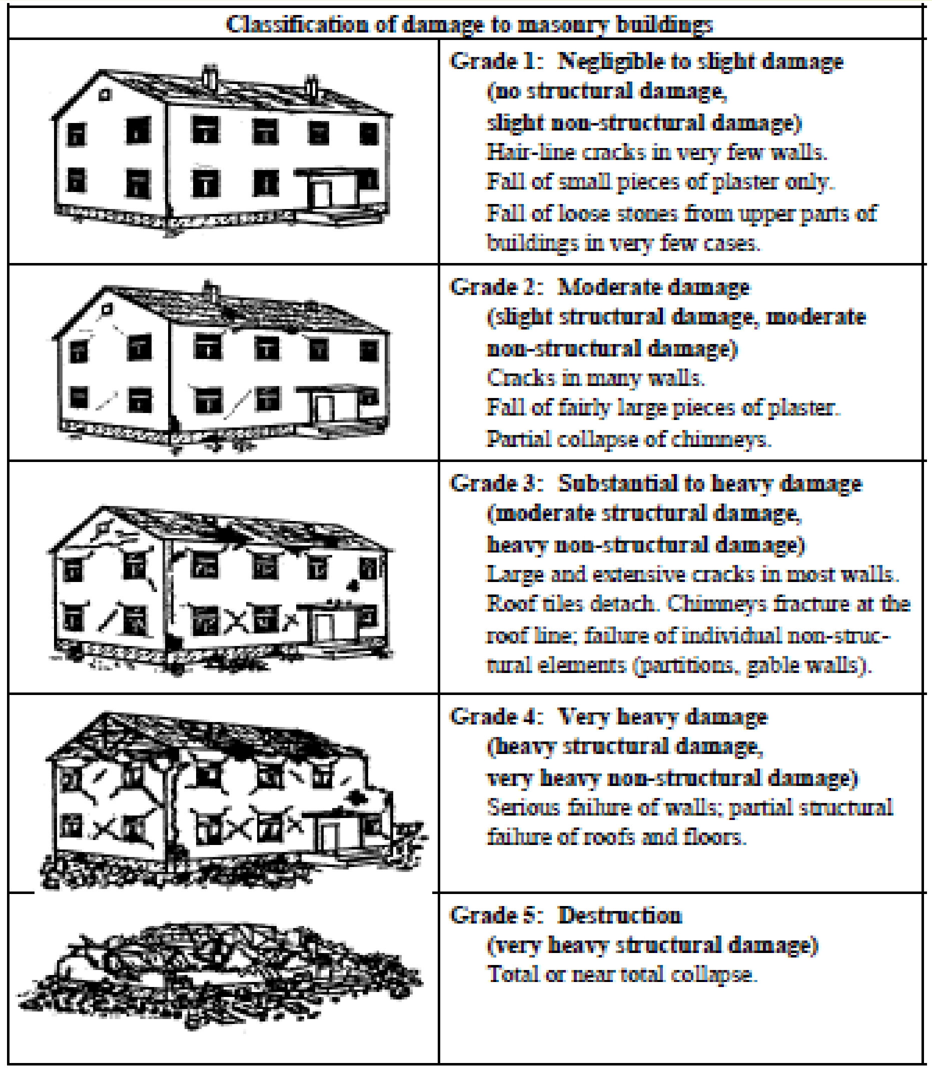
Figure 6: Damage Level of Ecole de Theologie, Heybeliada, different views.

Heybeliada, Ecole de Theologie

Damage Definition: dislodged and uninhabitable

Damage Level: **D4**

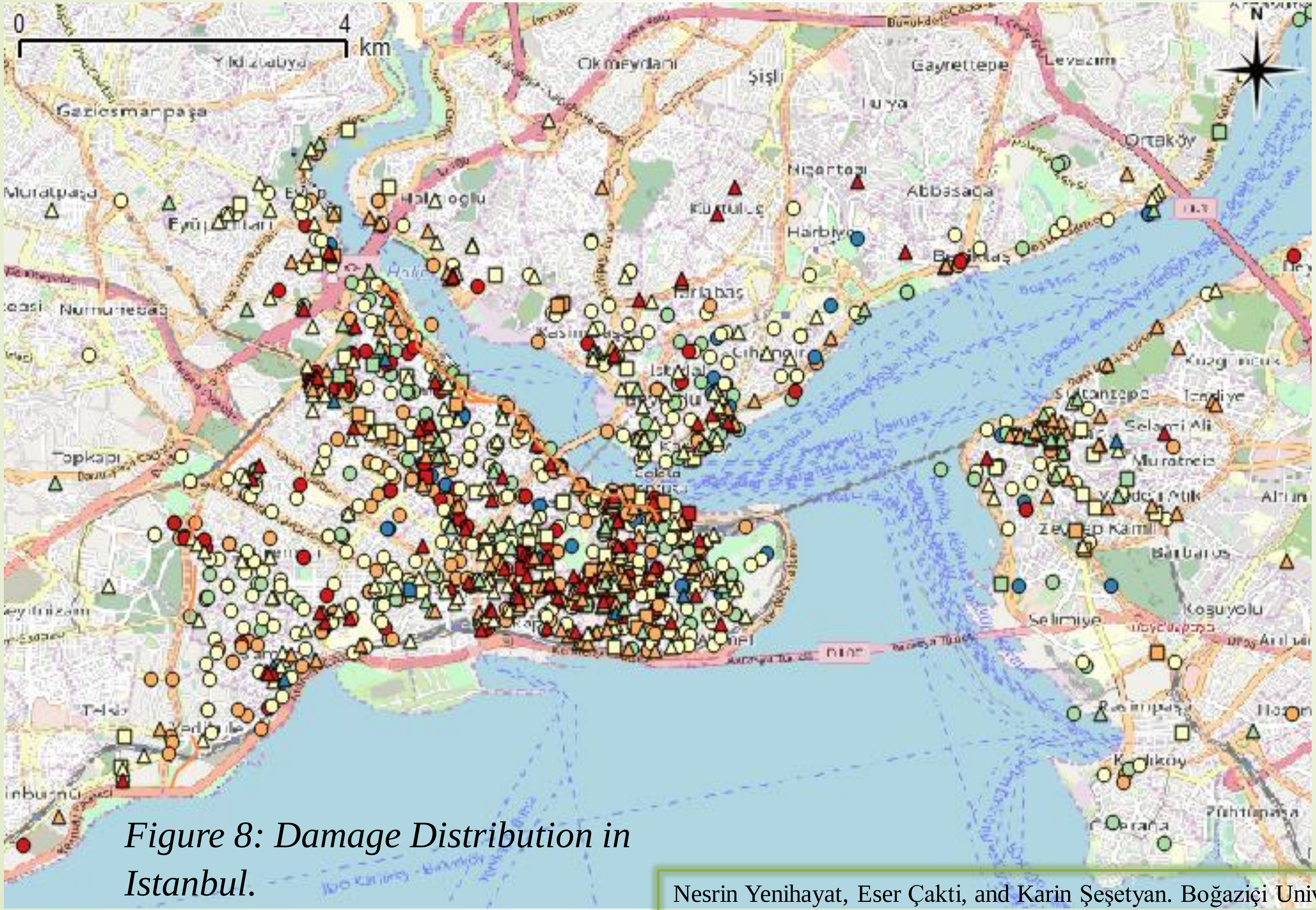
Ref: İBB Ataturk Kitaplığı



Classification of damage to masonry buildings	
	Grade 1: Negligible to slight damage (no structural damage, slight non-structural damage) Hair-line cracks in very few walls. Fall of small pieces of plaster only. Fall of loose stones from upper parts of buildings in very few cases.
	Grade 2: Moderate damage (slight structural damage, moderate non-structural damage) Cracks in many walls. Fall of fairly large pieces of plaster. Partial collapse of chimneys.
	Grade 3: Substantial to heavy damage (moderate structural damage, heavy non-structural damage) Large and extensive cracks in most walls. Roof tiles detach. Chimneys fracture at the roof line; failure of individual non-structural elements (partitions, gable walls).
	Grade 4: Very heavy damage (heavy structural damage, very heavy non-structural damage) Serious failure of walls; partial structural failure of roofs and floors.
	Grade 5: Destruction (very heavy structural damage) Total or near total collapse.

Figure 7: Damage Grades as given in EMS-98.

VIII. Damage Distribution



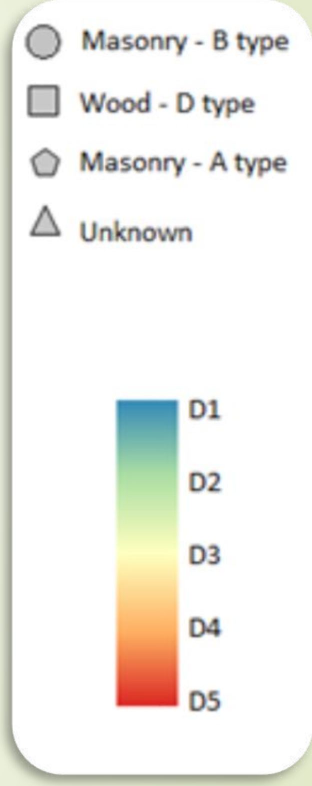


Figure 8: Damage Distribution in Istanbul.

IX. Damage Distribution

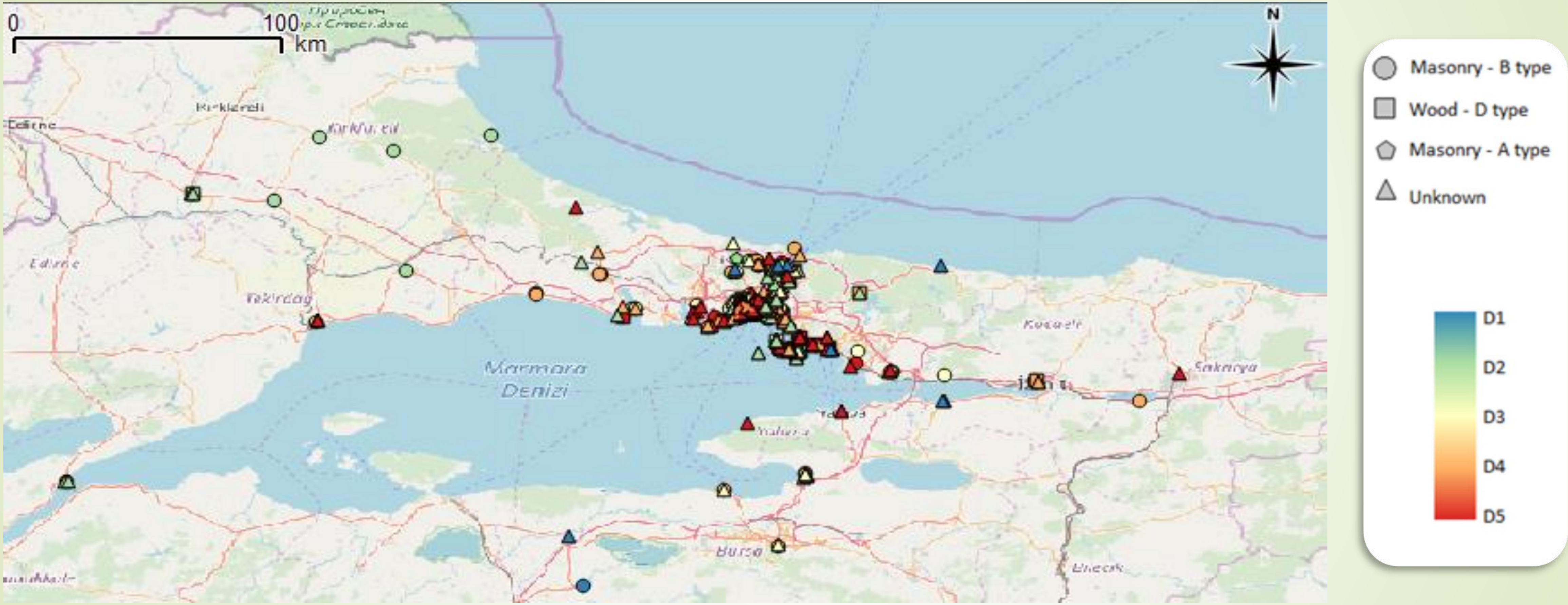


Figure 9: Regional Damage Distribution.

IX. Intensity

Intensity represents the combined effects of ground shaking to buildings with different vulnerabilities, reactions of living things and effects on the natural environment. In this study to assign intensity, the description given in EM-98 intensity scale has been followed.

Intensity	Vulnerability	D1	D2	D3	D4	D5
XI	A					
	B					Most
	C				Most	Many
	D				Many	Few
	E			Many	Few	
	F		Many	Few		

Intensity	Vulnerability	D1	D2	D3	D4	D5
X	A					Most
	B					Many
	C				Many	Few
	D			Many	Few	
	E		Many	Few		
	F		Few			

Intensity	Vulnerability	D1	D2	D3	D4	D5
IX	A					Many
	B				Many	Few
	C			Many	Few	
	D		Many	Few		
	E		Few			
	F					

Intensity	Vulnerability	D1	D2	D3	D4	D5
VIII	A				Many	Few
	B			Many	Few	
	C		Many	Few		
	D		Few			
	E					
	F					

Intensity	Vulnerability	D1	D2	D3	D4	D5
VII	A			Many	Few	
	B		Many	Few		
	C		Few			
	D	Few				
	E					
	F					

Intensity	Vulnerability	D1	D2	D3	D4	D5
VI	A	Many	Few			
	B	Many	Few			
	C	Few				
	D					
	E					
	F					

Few: 0 - 20%

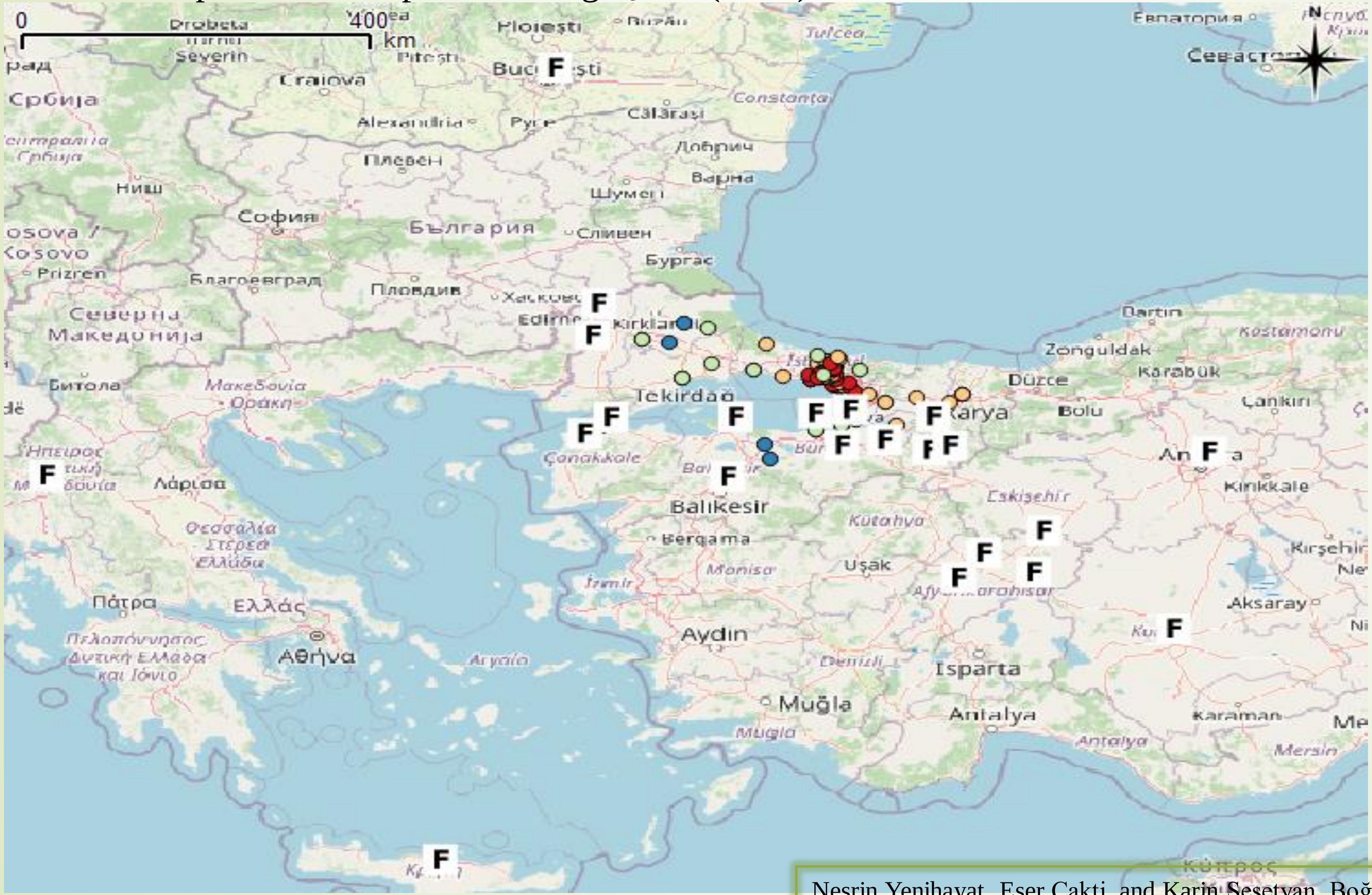
Many: 10 - 60%

Most: 50 - 100%

IX. Intensity

Figures 10-12 show intensity maps for the 1894 event, the highest intensity was assigned as 9.

Maps have been plotted using QGIS (2018).



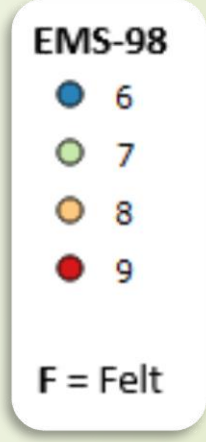


Figure 10: Regional Intensity Distribution.

IX. Intensity

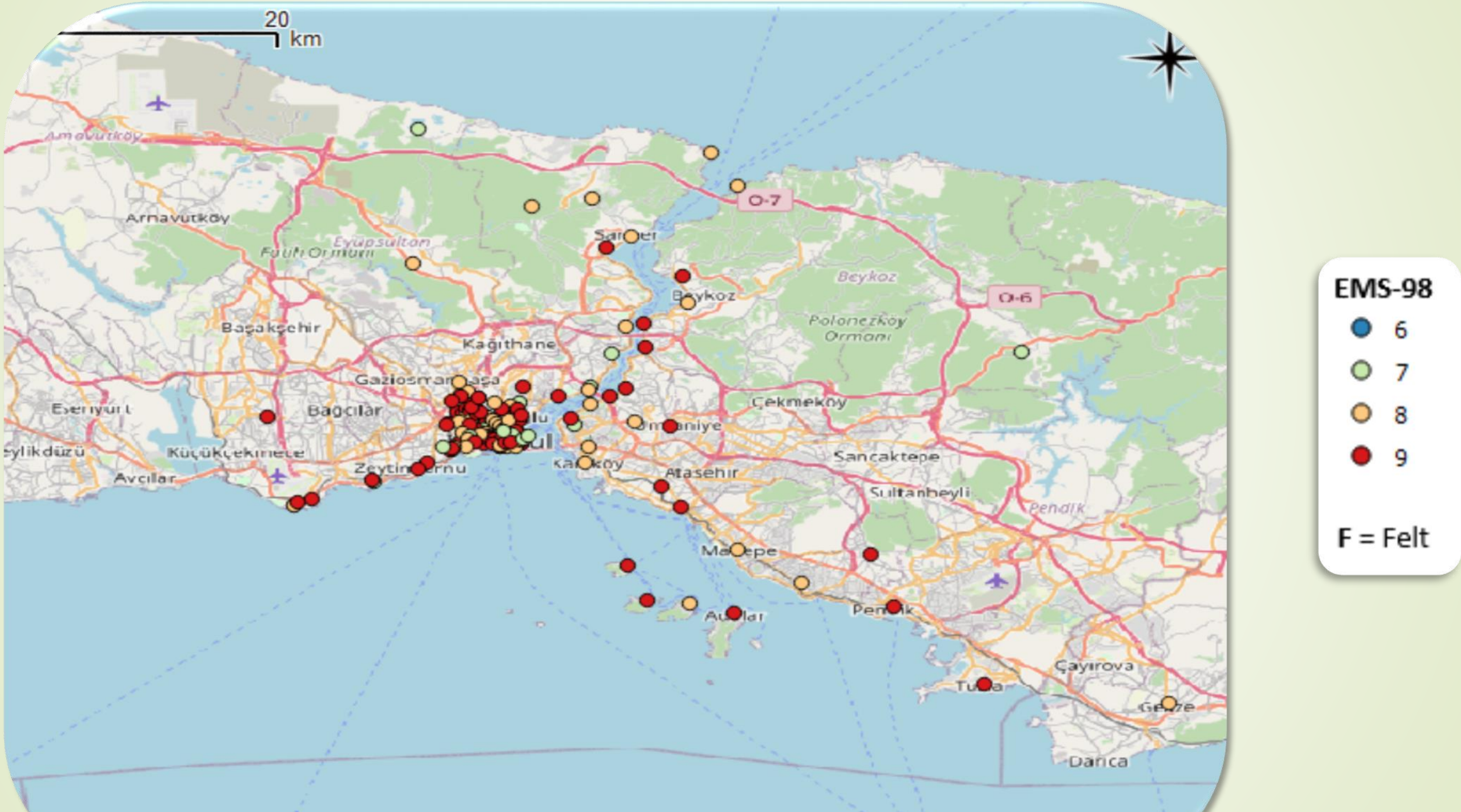


Figure 11: Damage Distribution in Istanbul.

IX. Intensity

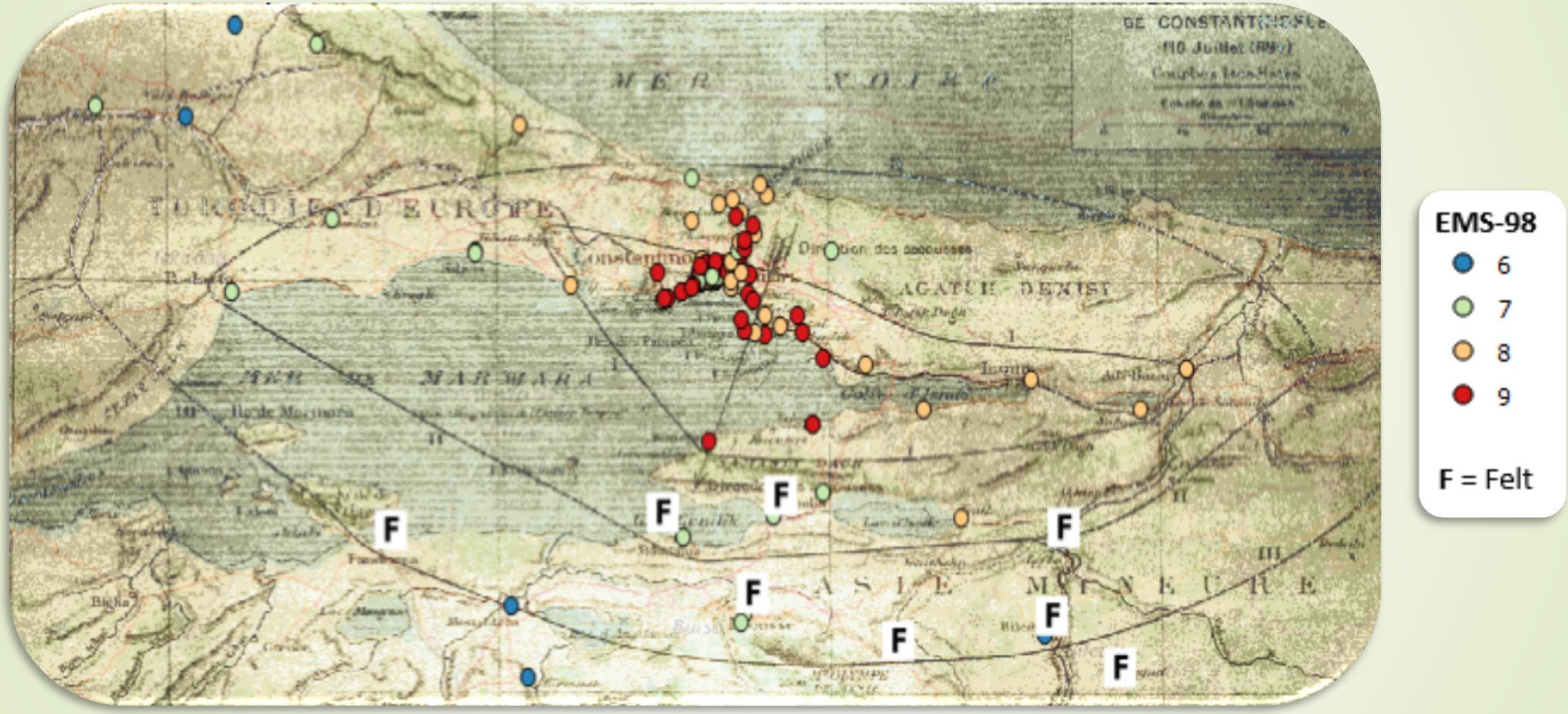
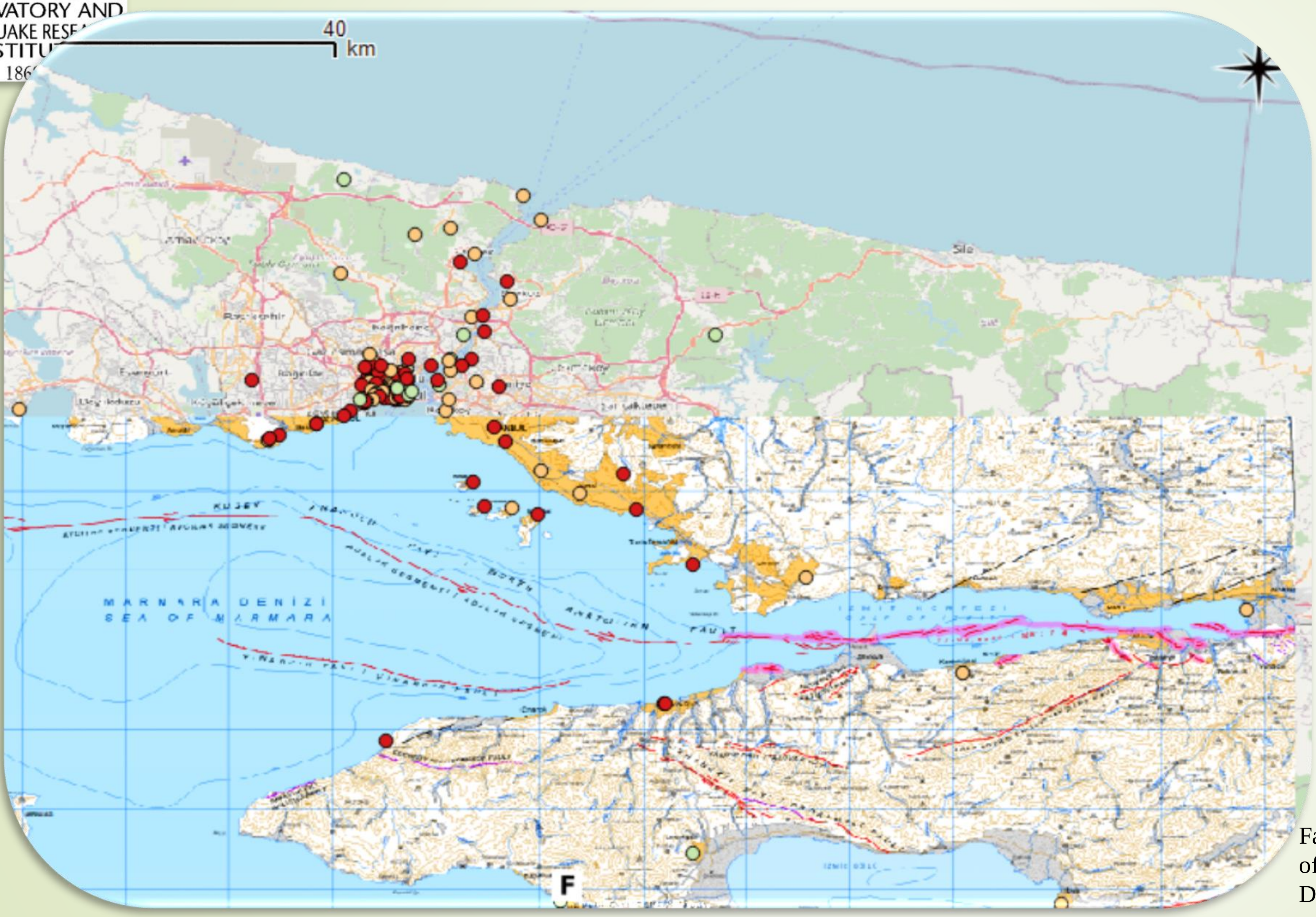


Figure 12: Comparison of the intensity map with the isoseismals of Eginitis, 1895.

X. Fault and Magnitude

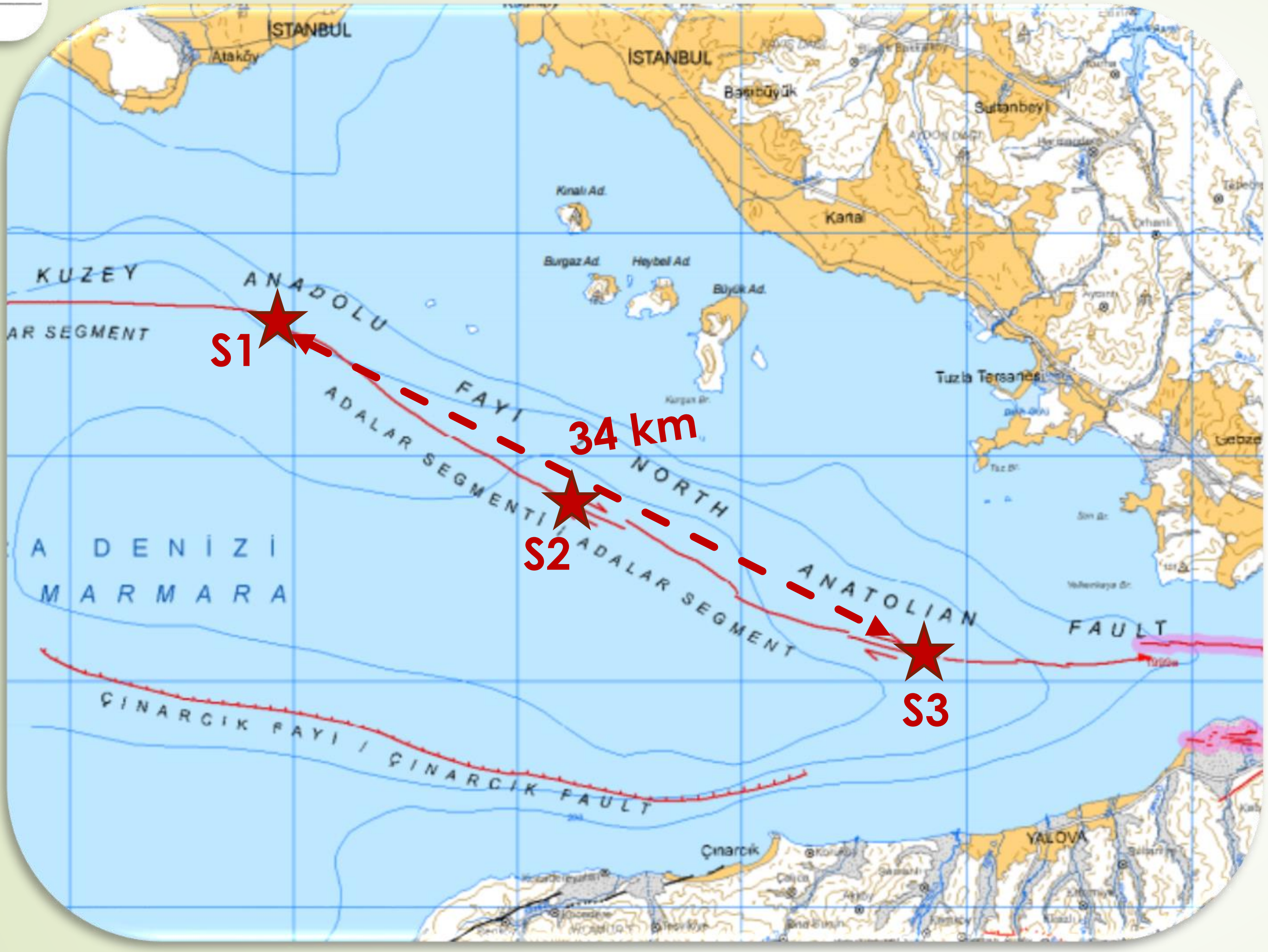


According to the intensity distribution, the 1894 Istanbul earthquake is most likely associated with the NAF, Adalar Segment.

Fault map was compiled from Active Fault Maps of Turkey, MTA (Mineral Research & Exploration General Directorate)

Figure 13: Intensity map with associated faults in the region.

X. Fault and Magnitude



Because ELER does not account for the directivity effect, epicentral location on the same fault will not change the results. Since epiceneral location will be important in simulations in our future studies, it has been visualized at this stage.

Figure 14: Adalar segment and the selected scenarios. Red stars correspond to the epicenters of the scenario earthquakes.

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XI. Scenario Events

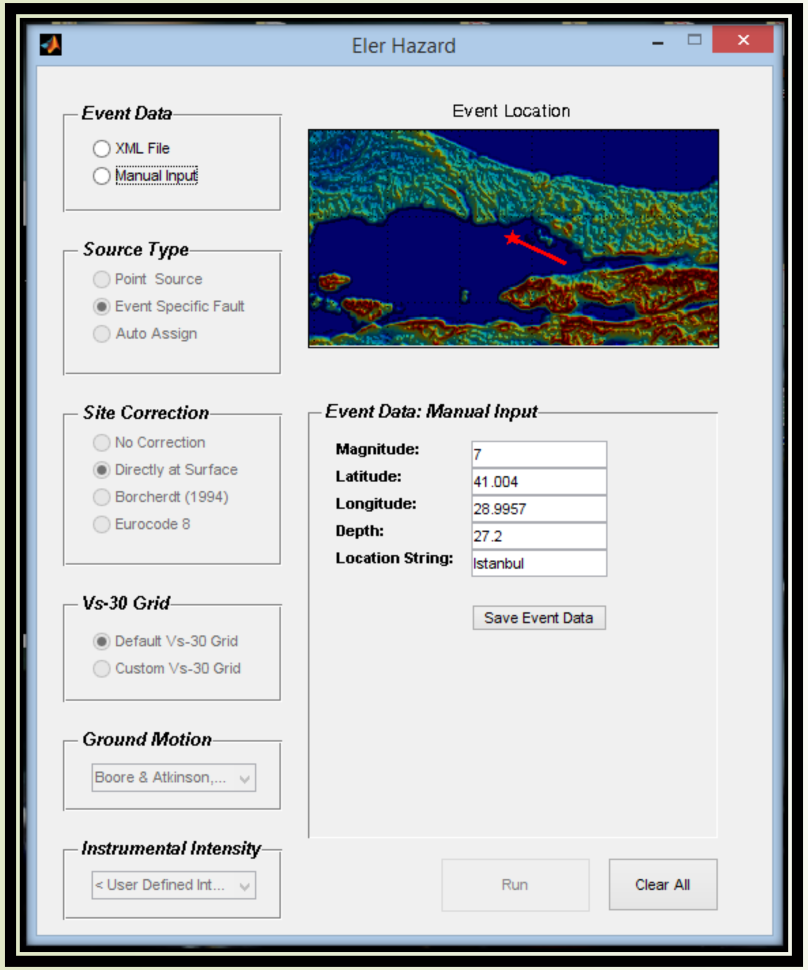
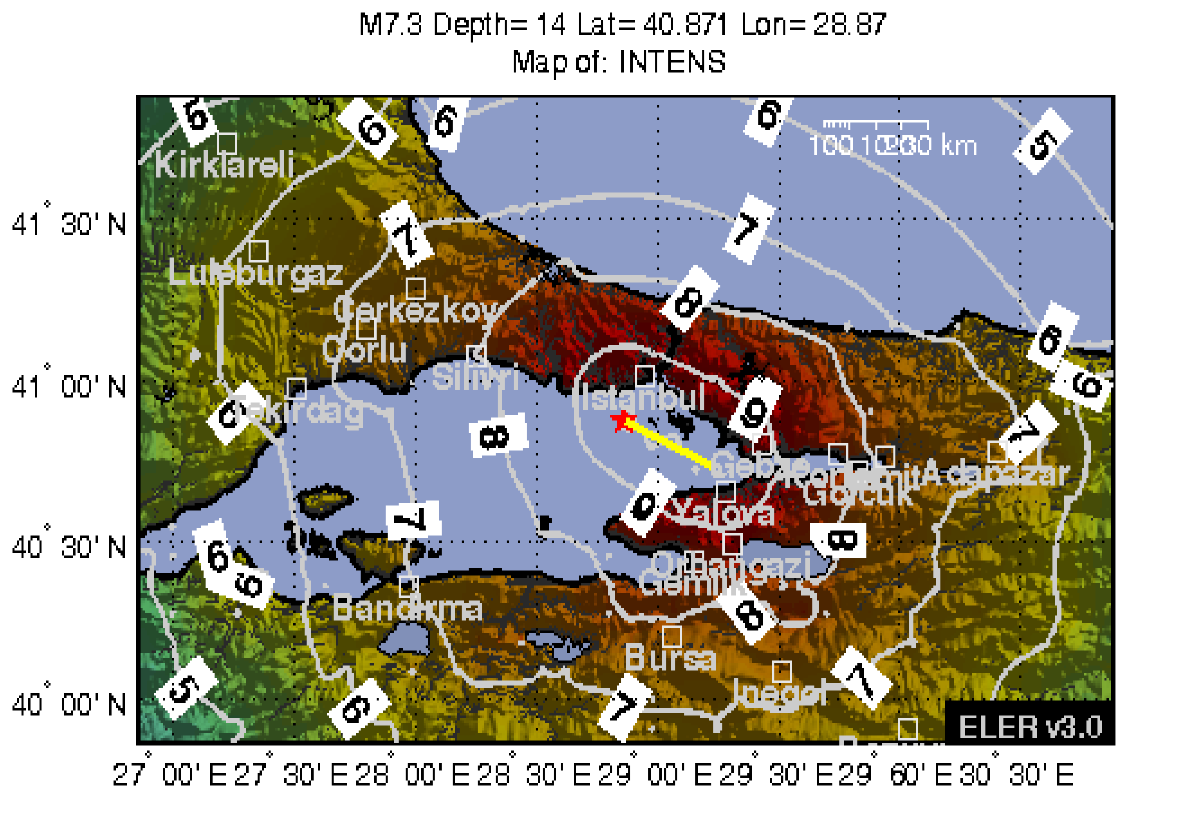


Figure 15: Earthquake modelling in ELER (Earthquake Loss Assessment Routine)

	Scenario-1		Scenario-2	Scenario-3
Lat., Long.	40.871, 28.870		40.785, 29.046	40.725, 29.228
Magnitude	a) 7.3	b) 7.1	6.8	6.7
Depth(km)	a)12-14	b) 10-20	10-18	8-20
Vs30	USGS		USGS	USGS
GMPE	Boore Atkinson 2008, Strike Slip		Boore Atkinson 2008, Strike Slip	Boore Atkinson 2008, Strike Slip
MMI	Bilal&Askan, 2014		Bilal&Askan, 2014	Bilal&Askan, 2014

XI. Scenario Events

Scenario-1.a



Scenario-1.b

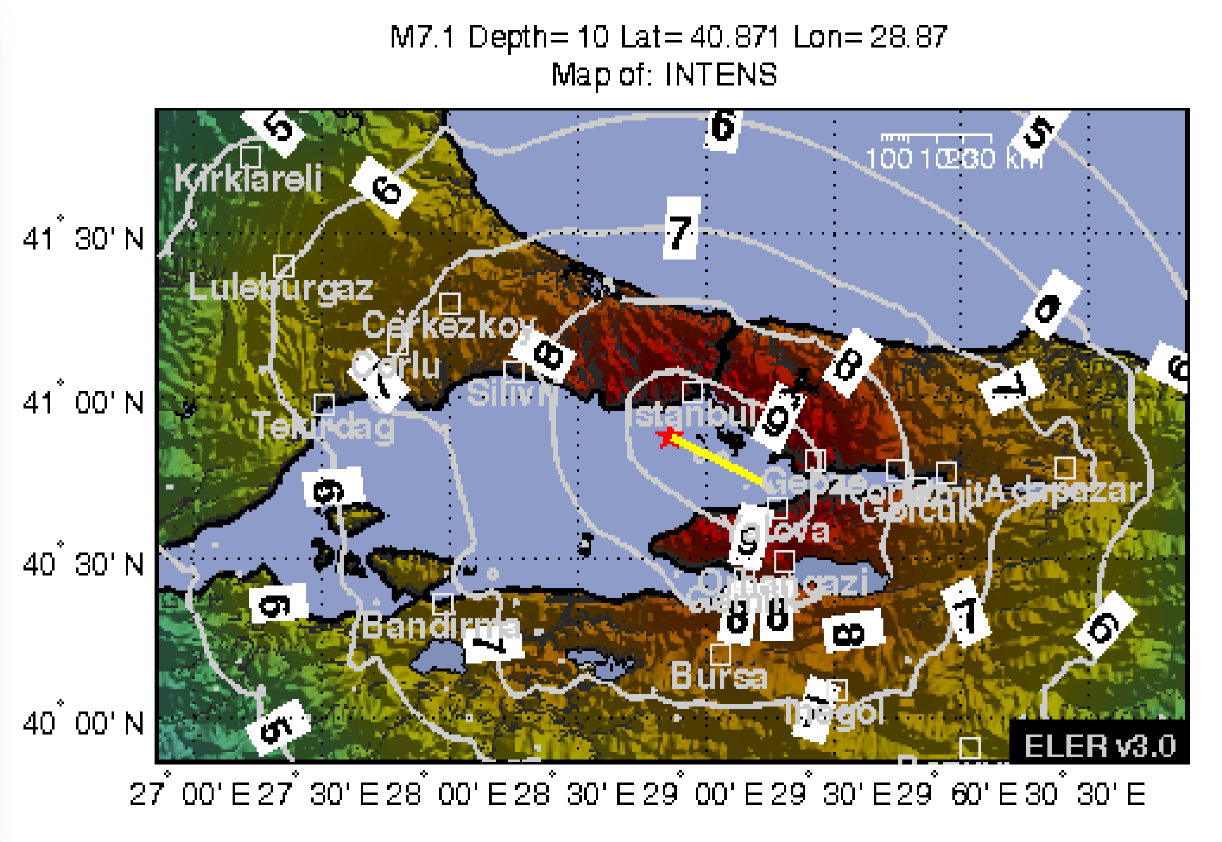


Figure 16: Intensity maps obtained from the Scenario-1, Case-a (left) and Case-b (right).

XI. Scenario Events

Scenario-2 **Scenario-3**

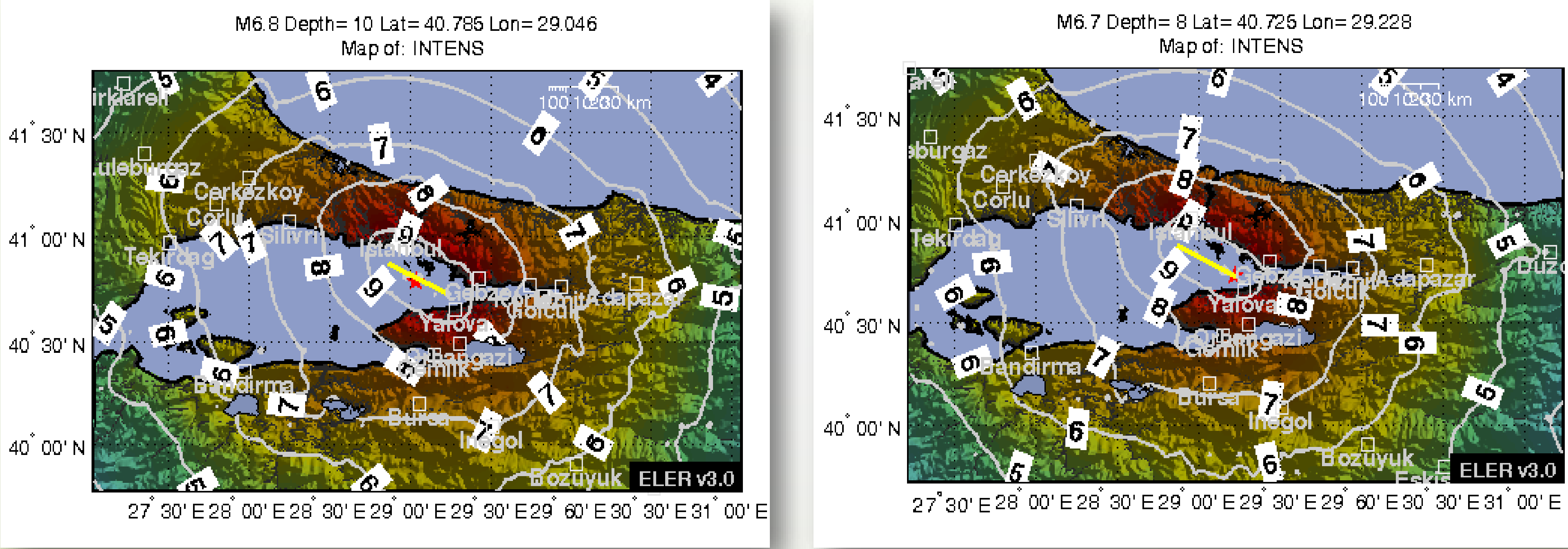


Figure 17: Intensity maps obtained from the Scenario-2 (left) and Scenario-3 (right).

XII. Discussion and Preliminary Results

The aim of this study is reconstructing the locations, magnitudes, intensities, and the related fault segment of the 1894 so-called Istanbul earthquake with the help of comprehensive damage analysis and ground motion modeling.

Damage analysis is based on observations of the extent of damage information reported after the event by different sources. Ottoman Empire archive records, scientific reports, and papers, newspapers, government correspondence, letters, notes of voyagers, and diaries are the major sources to make an evaluation on the type and extent of damage.

Intensity maps are prepared based on macro-seismic information, damage analysis and classification.

Various information types contained in the old thematic city maps and population information have contributed to this assessment. Obtained damage information is presented, evaluated, and interpreted.

Using ELER v.3 tool, several scenarios have been modeled having different input parameters.

XII. Discussion and Preliminary Results

The resulting ground motion distributions are compared with the damage and intensity maps to provide a first-order assessment of the earthquake source parameters of the 1894 earthquake. By analyzing how the scenario earthquake effects overlap with historical damage distribution, we can constrain the depth, epicenter, magnitude, and all other source properties of the historical event.

When the intensity distributions (in Figures 16-17) are compared with the observed damage and the possible intensity maps (Figures 8-12) a good match at many sites can be seen. Because of the shallow characteristics of the earthquake in the Marmara Region (~10km), it seems as the magnitude of the Scenario-1 event is overestimated. To make a more accurate assessment, the analyses will be repeated with the site-specific Vs30 information, instead of using default values.

Scenario events involving the NAF segments in the Kocaeli Bay will also be considered. After achieving a robust constrain on source parameters using ELER, they will be improved by ground motion simulation.

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