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# On the source of the 6 February 2023 tsunami in the Eastern Mediterranean

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**Summary.** — On 6 February 2023 the region between southern Türkiye and northern Syria was hit by a devastating earthquake sequence, starting with a $M_w = 7.8$ event at 01:17:34 UTC on the Eastern Anatolian Fault, followed by a $M_w = 7.5$ at 10:24:29 UTC and a large number of aftershocks. Both events were accompanied by many different coseismic and secondary effects, including a modest tsunami following the first mainshock recorded by a few Tide Gauges (TGs) in the eastern Mediterranean. In this work, we aim to constrain the nature and location of the tsunami source through numerical simulations. Submarine landslide sources are investigated, using a combination of two Gaussian functions with opposite polarity as the analytical initial condition. Several hypotheses regarding the source are tested using the numerical code JAGURS. The results of the simulations are compared to the available TGs, allowing for the identification of a source area capable of reproducing some key features of the observed TG records during the first minutes following the tsunami's arrival. The hypothesis suggests that a complex generating mechanism is involved, combining the action of a submarine landslide with sources of different nature.

## 1. – Introduction

The 6 February 2023 $M_w = 7.8$ earthquake is the largest earthquake that occurred on the East Anatolian fault (EAF) during the instrumental period. In about 9 hours it was followed by a $M_w = 7.5$ earthquake along the Sürgü Fault (SF), forming a "doublet" due to their comparable magnitudes and proximity. Aftershocks with magnitude up to 6 were recorded for weeks [1], along the EAF and SF faults up to the coastline. Türkiye's accelerometer networks (the Turkish Civil Defence network (AFAD) and the Kandilli Observatory and Earthquake Research Institute) registered very high peak ground acceleration (PGA) values which were responsible for numerous liquefaction and landslide phenomena extending to the coast [2, 3]. Within one hour after the initial mainshock on 6 February 2023 a modest tsunami was observed by tide gauges in Iskenderun Bay, the Cilicia Adana Basin, and eastern Cyprus. Historical earthquakes in the Eastern

Mediterranean region often accompanied by seismically triggered landslides, generated tsunamis of various intensities [4]. To investigate the potential origin of the 6 February 2023 tsunami, simulations were carried out assuming a submarine landslide as the source. A trial-and-error approach was utilized and each result was compared with tide gauge observation in order to find the best fit in the first hour after the tsunami arrival time.

## 2. – Data and methods

The tide gauge signals taken into account are those recorded by the stations of Erdemli (Türkiye), Arsuz (Türkiye) and Famagosta (Turkish Republic of Northern Cyprus, TRNC), with sampling frequency of 30 seconds. The Erdemli and Arsuz raw signals have been retrieved from the Intergovernmental Oceanographic Commission (IOC) sea level monitoring facility, while the already de-tided record of Famagosta has been digitized from [5]. In the recordings of Erdemli and Arsuz the tsunami signal was obtained by removing the instrumental spikes and applying the Fast Iterative Filtering (FIF) method [6]. The bathymetry data were downloaded from the EMODnet database at a resolution of about 115 m. To achieve maximum detail, in the coastal areas hosting the instruments shallow bathymetry contours with steps of 1 m and coastlines were manually digitized from nautical chart avaiable online. Bathymetry, coastline and topography data was assembled to build a set of nested bathymetric grids in Cartesian coordinates, consisting in a parent grid with a resolution of 150 m and in three couples of 50 m and 10 m children grids, one for each tide gauge station location. The JAGURS software [7] was used to simulate the tsunami in the shallow-water approximation, with linear and nonlinear equations adopted in the parent and in the children grids, respectively. Dispersion is not accounted for, relying on the fact that for most past submarine landslides it was found to play only a minor role [8]. The simulations were performed for 2 hours starting from the origin time of the first mainshock of the 6 February 2023 seismic sequence with a time step of 0.2 s. Following earlier studies such as [9, 10], an asymmetric dipolar, Gaussian shaped source has been employed to model the initial sea surface displacement (eq. (1))

$$H_z(x,y) = Ae^{-\frac{1}{2}\left[\frac{(x-x_{01})^2}{\sigma_{x1}^2}+\frac{(y-y_{01})^2}{\sigma_{y1}^2}\right]} + Be^{-\frac{1}{2}\left[\frac{(x-x_{02})^2}{\sigma_{x2}^2}+\frac{(y-y_{02})^2}{\sigma_{y2}^2}\right]}. \tag{1}$$

$A$ and $B$ represent the maximum (positive and negative, respectively) water displacements at the source; $(x_{01}, y_{01})$ and $(x_{02}, y_{02})$ are the positions of the peaks; $\sigma_{x1}$, $\sigma_{y1}$, $\sigma_{x2}$, and $\sigma_{y2}$ denote the width of the Gaussian surfaces in the $x$ and $y$ directions. Eleven different scenarios (see next section) of this type were developed. For each scenario, a comparison is performed at each station between the actual observation and the calculated tide gauge record in order to tune the abovementioned initial condition parameters. The misfit between the two signals is evaluated through visual inspection and the tsunami wave characteristics targeted for reproduction include tsunami arrival time, the first polarity and the amplitude of the first polarity. These features are expected to be observable within one hour of the tsunami's arrival during this event.

## 3. – Discussion on the submarine landslide simulations

Based on the distribution of PGAs reported by the AFAD network combined with a qualitative analysis of the bathymetric gradients, a set of eleven submarine landslide sources were hypothesized and positioned in the NE sector of the Levantine Basin, offshore the bay of Iskenderun. The initial conditions provided to JAGURS for each scenario were computed by means of eq. (1). It is noted that the landslide model used does not consider the dynamic evolution of the landslide, and it is assumed that at time zero (the origin time of the first mainshock), a positive wavefront in the propagation direction has already been created. In the following, four out of the eleven tests' results are reported, referred to as T98, T81, T404 and T46, respectively (fig. 1).

The tests are able to reproduce quite well the arrival times at all stations simultaneously and two out of three polarities of the first peaks. T98 is here considered the favoured test, reproducing fairly well the first period of the wave (with corresponding amplitudes of the negative-positive-negative oscillation sequence) recorded at Arsuz, noting that it fails at Erdemli and Famagosta. In no scenario could the polarity of the first peak at Erdemli be reproduced. It is argued that a landslide with a negative peak in shallower waters and a leading positive one offshore cannot create a negative first arrival at this station. The test results are better as regards Famagosta.

## 4. – Conclusions

The origin of the modest tsunami following the $M_w$ 7.8 mainshock on 6 February, 2023, was investigated using numerical simulations considering a submarine landslide

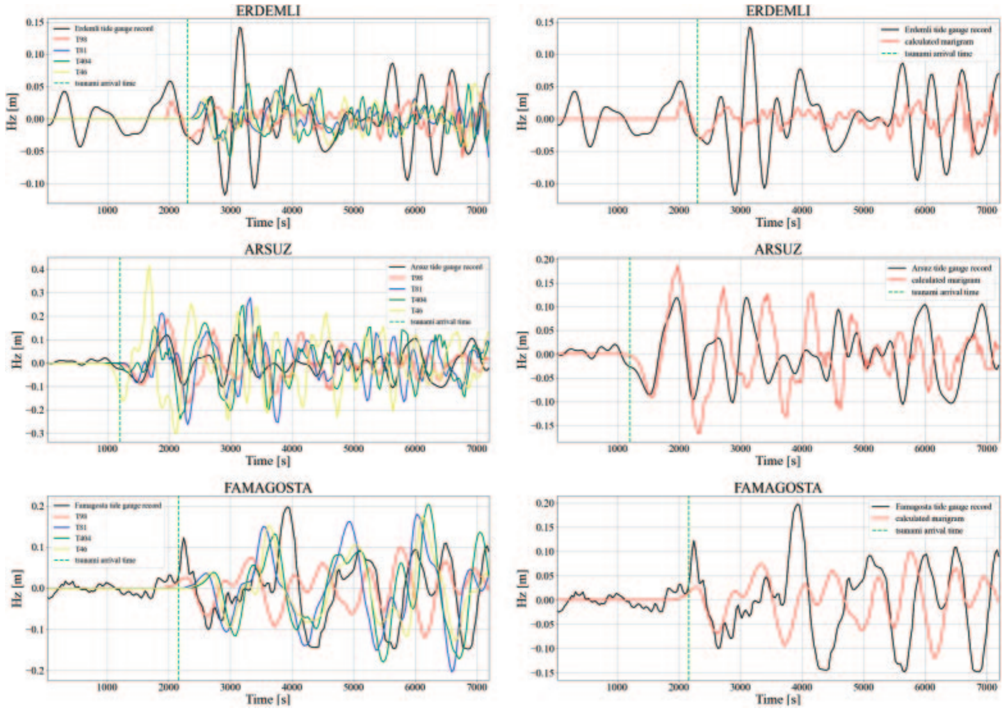

Fig. 1. – Left: comparison at each station between the theoretical signals (colour lines) and the experimental one (black line). Right: fit at each station of test T98 only, judged here to provide the best results. The $\sigma_x$ parameters (considering both the Gaussian peaks) range in 3000–7200 m, while $\sigma_y$ in 1700–3000 m. Taking the displaced water volume as the volume subtended by eq. (1), the displaced water volumes range 90–120 $\times 10^6 \mathrm{m}^3$.

triggered by ground shaking as the source. Unfortunately, tide gauge recordings are completely absent on the eastern side of the Levant Basin. It was possible to reproduce fairly accurately the initial period of the signal observed at Arsuz. Furthermore, a source area has been located where landslide tsunami simulations produce arrival times comparable to those observed, and with appropriate polarities at two out of three stations, often including the first wave period. This area is situated near the coast of the Hatay region, primarily affected by liquefaction and landslides during the seismic sequence. It is noted that other studies, such as [9, 10], have explored hypotheses of tsunamigenic submarine landslides within the Levant Basin, using different approaches compared to those employed here (referring to landslide model, linear/nonlinear wave propagation equations, bathymetric resolution, etc.). Our final conclusion is that the observed tsunami had a complex source mechanism, likely dominated by one or more moderate volume landslides, and possibly involving a minor contribution from other sources such as coseismic seafloor displacement.

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Erdemli and Arsuz tide gauge records have been retrieved from the Intergovernmental Oceanographic Commission (IOC) sea level monitoring facility (`https://www.ioc-sealevelmonitoring.org/org/`), while the already de-tided record of Famagosta has been digitized from [6]. The bathymetry data was acquired from the EMODnet database (`https://emodnet.ec.europa.eu/en/bathymetry`) and from the nautical charts available online (`https://maps.garmin.com/it-IT/marine/?key=sy3qz3fkfs9d&maps=another-brand`). The coastline and topographic information are retrieved from the European Environment Agency dataset (`https://www.eea.europa.eu/data-and-maps/data/eea-coastline-for-analysis-2`) and from the "ALOS World 3D-30 m (AW3D30)" database (`https://www.eorc.jaxa.jp/ALOS/en/dataset/aw3d30/aw3d30_e.htm`). The seismic sequence details are available from the Disaster and Emergency Management Presidency (`https://tadas.afad.gov.tr/event-detail/17966`).

## REFERENCES

[1] Över S. *et al.*, *Tectonophysics.*, **866** (2023) 230058.
[2] Görüm T. *et al.*, *Eng. Geol.*, **327** (2023) 107315.
[3] Taftsoglou M. *et al.*, *Remote Sens.*, **15** (2023) 4190.
[4] Maramai A. *et al.*, *Front. Earth Sci.*, **9** (2021) 596044.
[5] Yalciner A. *et al.*, METU/EERC Report No. 2023-01 (2023) 58.
[6] Angeli C. *et al.*, *Nat. Hazards Earth Syst. Sci. Discuss.*, **25** (2025) 1169.
[7] Baba T. *et al.*, *Pure Appl. Geophys.*, **172** (2015) 3455.
[8] Harbitz C. *et al.*, *Nat. Hazards*, **72** (2014) 1341.
[9] Heidarzadeh M. *et al.*, *Geosci. Lett.*, **10** (2023) 50.
[10] Hu G. *et al.*, *Geophys. Res. Lett.*, **50** (2023) e2023GL103997.