Field survey of the 30 October 2020 Samos (Aegean Sea) tsunami in the Greek islands

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Abstract

On October 30th, 2020, a magnitude 7.0 earthquake offshore off the northern coast of Samos, Greece, generated a tsunami that impacted the nearshore Greek islands and the Aegean coastline of Turkey. Here, we describe detailed results from several post-event field surveys, and report first wave arrival timing and polarity information as well as tsunami height/runup measurements, from five islands. In Chios, wave runup reached 1.38 m, in Samos ~ 3 m, in Fourni 1.57 m, in Thimena 1.46 m, and in Ikaria 1.18 m. This event marks two milestones. One, the General Secretariat for Civil Protection of Greece, disseminated a message through Greece’s 1–1-2 Emergency Communications Service to all cell phones in the eastern Aegean geographical region, warning recipients to stay away from coastal areas. According to eyewitnesses, the message was received ~ 3–5 min prior to the second and largest flood in Vathi, as the first flood had not sufficiently alarmed the local authorities to evacuate residents. Two, we were able to infer complete tsunami hydrographs from measurements for the first two floods in Vathi, which suggests that the water level rose to about one meter overland flow depth in one minute.

Keywords October 2020 · Tsunami · Samos earthquake · Aegean · Field survey · Coastal impact

1 Introduction

On October 30th, 2020, at 11:51:27 UTC a magnitude 7.0 (USGS) earthquake was triggered in the Aegean Sea ~ 10 km offshore off the northern coast of Samos (Fig. 1) generating a tsunami that impacted the nearshore Greek islands and the Aegean coastline of Turkey. In the Greek islands, the 30 October 2020 Samos (Aegean Sea) tsunami mainly impacted the low-topography areas (below 2 m elevation) along the waterfront of Vathi,
Samos, and caused minor damages in other ports and harbours in the wider region. There were no casualties from the tsunami in Greece (Triantafyllou et al. 2021), while one person’s life was lost in Turkey (Aksoy 2021). Along the Aegean Turkish coast, damage from the tsunami was more extensive, with runup values as high as 3.8 m being measured in Akarca and inundation distance reaching ~760 m in Zeytineli (Dogan et al. 2021). A maximum runup of 5.3 ± 0.3 m was inferred for the town of Sigacik through satellite and topographic maps (Aksoy 2021). The earthquake shaking caused widespread damage to buildings, particularly in the Turkish city of Izmir where ~4% of the buildings sustained damage and 115 people lost their lives (Erdik et al. 2020).

The Samos (Aegean Sea) earthquake ruptured the cross-border region of the eastern Aegean microplate and western Anatolia (Fig. 1). The tectonic regime of the area is highly complex, and it is deforming due to both extensive and transtensive shear
(Tur et al. 2015; Kiratzi et al. 2020). At the plate boundary, England et al. (2015) have argued that most of the relative motion is aseismic, hence the modern record of seismicity provides little or no information about the faults that are likely to generate such earthquakes. Active faulting patterns change gradually from transtensional in the north to extensional in the south, as the distance from the North Anatolian Fault Zone (NAFZ) and its splays increases (Chatzipetros et al. 2013). The Samos earthquake is attributed to north–south extensional stress along a moderately dipping normal east–west striking fault north of Samos, as a result of the upper crust being pulled apart due to slab rollback, where the African plate is subducting northwards below the Aegean Sea and Eurasia, while the slab is sinking by gravitational forces, causing it to retreat southwards (Meng et al. 2021). A 40 km × 15 km fault rupture area located offshore Samos with an average co-seismic slip of 1.7 m and a moderate dip-angle (37°) have been suggested by the source-inversion model of Ganas et al. (2021) that is based on Global Navigation Satellite System (GNSS) and Interferometric Synthetic Aperture Radar (InSAR) data. Lentas et al. (2021), using kinematic slip inversion, suggested a non-uniform bilateral rupture of 2.5 m maximum slip on a fault area of 60 km × 20 km, with dip angle 34° and the main rupture propagating to the west.

The earthquake occurrence prompted the Tsunami Service Providers (TSPs) operating in the eastern Mediterranean in the framework of the North-Eastern Atlantic, Mediterranean and connected seas Tsunami Warning System (NEAMTSWS) of IOC/UNESCO, namely CAT-INGV-TSP, HLNTWC-NOA-TSP and KOERI-TSP to issue tsunami warning messages. The initial tsunami warning messages that set the near-field coastal areas (distance < 100 km from the earthquake epicentre) in Watch threat level were all issued within 12 min from the earthquake. While reports of tsunami sightings had already circulated in social and news media within the first hour after the earthquake, the official confirmation of tsunami generation came through tsunami records at the nearest tide gauges in the islands of Syros, Lesvos and Kos (available through the Sea Level Monitoring Facility website of IOC/UNESCO, https://www.ioc-sealevelmonitoring.org), which were used by TSPs to issue Watch Ongoing tsunami warning messages (Dogan et al. 2020). The tsunami signature remained prominent in tide gauge records in the Aegean and Cretan Seas for several hours after first wave arrival (Dogan et al. 2020).

Following the broadcast of the initial tsunami warning message by HLNTWC-NOA-TSP, the Hellenic Hydrographic Service issued a NAVTEX (NAVigational TEleX) message for tsunami waves in the Aegean Sea based on the area of responsibility of the Greek Navy (Tuncag et al. 2020). Additionally, the General Secretariat for Civil Protection of Greece disseminated a message through Greece’s 1–1-2 Emergency Communications Service to all cell phones in the eastern Aegean geographical area, warning recipients to stay away from coastal areas. To the authors’ knowledge, this was the first use of the Emergency Communications Service for tsunami warning and had a positive impact in the evacuation of the population in Vathi, Samos, where the message according to eyewitnesses was received prior to the second and largest flood. The warning time window gave the opportunity to emergency services to be actively involved in the evacuation, while at the same time, the message dissemination to all cell phones directly warned the population to self-evacuate in an area with limited prior (generational) knowledge of tsunamis.

While tsunami awareness and generational tsunami wisdom (Fritz and Kalligeris 2008; Esteban et al. 2015) are faint in the region, the Aegean has a long history of documented tsunamis in the past two millennia (Ambraseys and Synolakis 2010). The Samos tsunami is arguably the most significant event in the Aegean since the 09 July 1956 Amorgos earthquake and tsunami that produced wave runup values as high as 20 m on the south coast of Amorgos.
It follows four other smaller events that have impacted the Greek coasts since 2017, namely Lesvos on 12 June 2017, Kos on 20 July 2017 (Heidarzadeh et al. 2017; Dogan et al. 2019), Zakynthos on 25 October 2018 (Cirella et al. 2020; Ganas et al. 2020), and south Crete on 02 May 2020 (Heidarzadeh and Gusman 2021). It is also worth noting that a small tsunami was observed along the north coast of Chios island and Cesme, Turkey, following the 23 July 1949 Chios earthquake (Melis et al. 2020). The 30 October 2020 Samos (Aegean Sea) event is yet another reminder of the hazard posed by tsunamis in the region and highlighted once again the tsunami warning challenges posed by near-field tsunamis.

Here, we discuss eyewitness observations and present quantitative runup and overland flow depth measurements and infer a tsunami hydrograph, i.e., a figure which shows the change of the overland flow depth of the tsunami at a particular location. Our field work and our analysis indicate that normal earthquakes with magnitudes not typically associated with perilous tsunamis can cause havoc on waterfronts and may even kill people, who—while nearshore—don’t heed the earthquake shaking as a harbinger message to move immediately away from the shoreline.

2 Methodology and instrumentation

We interviewed eyewitnesses of the tsunami and collected quantitative measurements of tsunami impact, per established methods (Synolakis and Okal 2005; UNESCO 2014). Quantitative measurements are useful in characterising the intensity of the generated tsunami, in better understanding the dynamics of impact, and finally as benchmark for hydrodynamic models; a visual description of the quantitative measures of tsunami intensity collected during the field surveys is provided in Fig. 2. From the eyewitness interviews and collected photos/videos—particularly timestamped footage—information can be extracted regarding the arrival time of the first wave, its polarity, as well as the time sequence of the floods. Audio in the videos can be helpful in understanding people’s reactions.

The instrumentation used to collect quantitative measurements consisted of a Topcon Hiper Pro Real Time Kinematics (RTK) GNSS system, a 40 m long water level and a levelling rod. The GNSS system was operated in network RTK mode using the nearest available reference station of the URANUS network in Greece (URANUS 2021); the largest baseline distances of ~26 km correspond to the data points collected in Fourni and the NW coast of Samos (Karlovasi and Ag.
Nikolaos). According to the errors provided by the GNSS system, the accuracy of the GNSS-recorded measurements was within ±3 cm and ±5 cm in the horizontal and vertical directions, respectively. For the data points collected in the narrow streets of Vathi where the satellite coverage was low, a water-level was used to collect vertical measurements near buildings. The water level is simply a clear plastic tube filled with water through which a horizontal plane of reference can be defined. On one side of the tube, the water level inside the tube matched the height of interest (e.g., a flow depth mark), and on the other side, the reading on a levelling rod (positioned on top of a GNSS-measured point) that matched the water level was recorded. The precision of the vertical difference measurements using the water level is approximately ±1 cm.

The GNSS system measured orthometric heights using the URANUS geoid model. In each location visited, all elevations measured with the GNSS system were subsequently corrected according to the orthometric height corresponding to the still water level (SWL) at the time of measurement; the date and time the SWL was measured in each location are provided in Table 1 of the Appendix. Since there are no tide gauge data available near the measurement locations, measured elevations were not adjusted to the water level at the time of tsunami impact. In order to assess the influence of the astronomical tide to the water level measurements, the time series of the tidal elevation from the closest grid point of the OSU TPXO9.v4a tidal model (Egbert and Erofeeva 2002) to each measurement location were extracted for the period between 30 October 2020 and 5 February 2021. Due to the absence of detailed offshore and nearshore bathymetry data, the local amplification and dissipation of the tidal wave at the shallow zone and in engulfed areas could not be inferred. Therefore, the tidal range provided in Table 1 of the Appendix for each of the measurement locations is only a qualitative indication of the microtidal regime (Andrew and Cooper 2005) and the associated error in the elevation measurements.

In the town of Vathi, where more detailed tsunami measurements were collected, a drone was used to create a high-resolution orthophoto and a Digital Surface Model (DSM) of the town’s waterfront. The drone, a DJI Phantom 4 Pro, was flown at 55 m elevation above ground, capturing images of 5472 × 3748 pixel resolution. Another, more detailed, drone flight was scheduled at an altitude of 19 m focusing on the building housing the Library of Samos to create a DSM which was used with the tsunami footage frame-by-frame analysis presented in Sect. 4.1. The drone data were post-processed using the Agisoft

![Fig. 3 The orthophoto (a), DSM (b) and bare earth DEM (c) of Vathi created using drone aerial images](image-url)
Photoscan software to produce high-resolution point clouds, and the data were georeferenced using well-distributed ground control points (GCPs, in the form of targets on the ground) of known world coordinates. The final products were a 5.3 cm resolution orthophoto and DSM of the waterfront of Vathi (Fig. 3), and a 1.7 cm resolution DSM of the Samos Library and its surroundings (Fig. 4). The mean total (xyz) errors of the two DSMs are 3 and 3.7 cm, respectively. The DSM of the waterfront of Vathi was post-processed using ArcGIS Pro tools to create a (bare earth) Digital Elevation Model (DEM) (Fig. 3).

3 Field observations

A post-tsunami reconnaissance team was deployed to the island Samos one day after the earthquake for an initial tsunami impact assessment. Three post-tsunami field survey missions between January and February 2021 followed to collect quantitative measurements of the tsunami impact and interview tsunami eyewitnesses in the Greek islands around the earthquake epicentre, namely the islands of Samos, Chios, Ikaria, Thimena and Fourni. For the surveys, special permits were obtained from the General Secretariat for Civil Protection of Greece, given that the country was on travel restrictions due to the ongoing COVID-19 pandemic. We present an overview of the maximum tsunami runup or tsunami elevation values measured in the field surveys in Fig. 5, while the full list of data points is provided in Table 2 of the Appendix. A description of the findings in each location visited follows below.

3.1 Chios

The E-W orientation of the fault rupture translates to a predominantly N-S tsunami directivity. The island of Chios is located northwest of the fault rupture area, however, the southeast coastline of Chios did receive considerable tsunami energy. Tsunami impact in Chios did not make the mainstream Greek news, as most articles focused on Vathi (Samos), but local news websites (e.g., Astraparis 2020) reported tsunami-induced damage in the harbour of Komi (location C2 in Fig. 5 and Fig. 6a). According to eyewitnesses and local officials, the first wave arrived as a leading depression (Tadepalli and Synolakis 1994), and fishing boats touched the sea floor as the water level dropped. In the flood that followed, which according
Fig. 5 Overview of the maximum runup and/or tsunami elevation measured in all locations visited in the post-tsunami reconnaissance missions to the Greek islands. Values including the > (greater than) symbol correspond to elevation measurements of structures that were flooded. Since the flow depth on those structures is unknown, the tsunami elevation value corresponds to at least the elevation of the structure. The text balloons are colour-coded according to their respective runup/tsunami elevation value using the “jet” colour map (ranging from 0 to 3 m, 0 being blue and 3 being red). The coloured background shows the GEBCO bathymetric relief (GEBCO 2020) and the red star corresponds to the USGS earthquake epicentre.

Fig. 6 a Google Earth satellite picture of Komi and the location of the runup/inundation measurement. b A picture from the field showing the maximum runup/inundation point measured north of the harbour slip. c A picture from a news article showing the fishing boats that were dragged by the tsunami-induced currents to the side of the breakwater (source: Astraparis 2020)
to eyewitnesses was the largest observed, the water overtopped the harbour dock and reached the coastal road at ~1.46 m of elevation (Fig. 6b). The mooring lines of some of the fishing boats broke or came off and the tsunami-induced currents dragged and deposited them on the harbour side of the breakwater (Fig. 6c). While the tsunami impacted the harbour, the waves didn’t reach any of the houses sitting on the beach adjacent to the harbour.

In the small bay and town of Emporios (location C1), located ~2 km SW of Komi, three significant tsunami-induced floods were observed by an eyewitness. The first and largest flood was described as having “momentum” and inundated the coastal road of the town, reaching 1.4 m of elevation, penetrating ~60 m inland. Tsunami amplitude gradually decayed moving north of Komi, along the coast. Tsunami observation locations are limited to small harbours where tsunami amplitude was amplified, but the water level fluctuations did not cause any damage. The waves overtopped the dock only in the harbour of Katarraktis (location C4), with an additional ~5 cm of flow depth, but the water level rise was described as “gradual” and didn’t cause any damage. In the port of Chios (location C7), where the northernmost data point was collected, only people observing the sea were able to identify any tsunami effects and pointed us to a maximum tsunami elevation reaching ~0.3 m (data point C7). The authors were not able to collect any timestamped pictures or video of first wave arrival in any of the locations visited in Chios.

### 3.2 Ikaria

Eyewitness accounts and CCTV footage show that the tsunami arrived in both the northern and southern coast of Ikaria as a leading depression wave. From the map in Fig. 5, it is evident that the maximum tsunami elevation/runup data points recorded in the field survey were generally higher on the north coast compared to the south. Reports of tsunami sightings have mainly focused on the two main ports of the island, namely Evdilos (location I2) on the north coast, and Ag. Kirikos (location I7) on the south coast, which is also the administrative capital of Ikaria. CCTV videos from cameras overlooking the two ports (YouTube, 2020a, 2020b) show the water level dropping first at ~11:57 and ~12:02 UTC at Evdilos and Ag. Kirikos, respectively (after correcting the clock time based on the earthquake shaking initiation). The first, third and fifth floods appear to be the largest in Evdilos, whereas the second and fourth floods appear to be the largest in Ag. Kirikos. In both locations, the maximum floods are seen just overtopping certain harbour docks that were measured in the field survey, but no major damage was reported. The periodicity of the fluctuations deduced by the CCTV videos is on average ~6 and ~3 min in Evdilos and Ag. Kirikos, respectively.

Elsewhere in Ikaria, the maximum runup did not reach any of the buildings located near the shoreline and the tsunami effects were mostly noticeable in harbours, where no significant damage was reported. The only additional timestamped footage collected, apart from the publicly accessible CCTV videos for the two main ports, were provided by an eyewitness in the harbour of Ag. Kiriaki (location I4), which is located on the north coast, right west of the airport runway. The video in Ag. Kiriaki shows a flood peaking at ~12:25 UTC, which according to the eyewitness corresponds either to the third or fourth wave in this location.

### 3.3 Fourni

Eyewitnesses in the main town of Fourni (location F1) reported the first wave as a leading depression. The shoreline withdrawal at the beach next to the harbour and water level depression along the harbour docks were quickly noticed by locals. Upon associating the
depression with the earthquake, and realising the imminent threat of a flood, the local coast guards quickly gave orders to evacuate people from the waterfront. The first flood peaked around 12:03 UTC, which was inferred from an eyewitness timestamped picture (Fig. 7b) and video. The maximum sea level reached in Fourni overtopped an older low-lying dock (southernmost dock in Fig. 7a), partially flooded another, but did not overtop the higher-elevation newer dock (Fig. 7a). The water penetrated inland through the beach, but also through wall openings, drains, and coastal features of lower level topography.

Maximum runup was measured along the main commercial town street (data point F1-5), which at the time of writing did not appear to have a name. An additional runup and three tsunami elevation points were collected in the town of Fourni as indicated by eyewitnesses. The residents mentioned at least two additional floods in Fourni, but that the first was the largest. A timestamped video captured at 12:14 UTC shows that the water level was rising and had already flooded the coastal road, while a picture taken at 12:31 UTC shows another flood event. There was no substantial damage due to the tsunami in the town of Fourni, which was described as a fast-rising tide with no significant overland flow velocity. The data points collected in other locations along the northern part of the island of Fourni (data points F2-F4) show consistent runup/tsunami elevation values above 1 m, but no flooding of any coastal buildings was reported.

3.4 Thimena

The town of Thimena (location T1) on the namesake island features a small harbour (Fig. 8a) and is located ~2.3 km to the west of the town of Fourni. According to several eyewitnesses, the tsunami arrived as a leading depression wave, and during the drawdown phase some fishing boats touched the sea floor. The (first) flood that followed was described as being the largest. An eyewitness video shared with us that was filmed at 12:07 UTC,
shows an eddy forming at the eastern corner of the harbour dock (Borrero et al. 2015; Kalligeris et al. 2016, 2021), presumably during the second drawdown phase, and the harbour docks appear to have been previously flooded (Fig. 8c). The overtopping of the docks during the first (and largest) flood was also confirmed by eyewitnesses, who described a flow depth over the dock between 15—20 cm; the harbour docks were not overtopped during any of the subsequent floods. Eyewitnesses pointed to a staircase that connects the harbour with the town and described how the maximum water level reached the first step, which was the data point recorded in this location (Fig. 8b). According to a local eyewitness, the tsunami had a much smaller amplitude in the small town of Keramidou.

### 3.5 Samos

Being the most heavily impacted island from the earthquake and tsunami, Samos became the main focus of the field survey. Data points were collected from fifteen coastal locations on the north, east and south sides of the island. On the southern coast, moving from east to west, we visited Pythagorion (location S13), Ireo (location S14) and Marathokampos (location S15), with measured runup/tsunami elevation values being below 0.65 m. In Ireo and Marathokampos, eyewitnesses described a leading depression wave, while in Pythagorion eyewitnesses were not able to provide wave polarity information. Timestamped eyewitness pictures taken in Marathokampos show that at 12:12 UTC the shoreline on a beach inside the local harbour had already receded. No damage due to the tsunami has been reported on the south side of Samos.

On the east and northeast side of Samos, we visited Charavgi (location S12) and Ag. Paraskevi (location S11). In Ag. Paraskevi, the eyewitness we interviewed described the first wave arriving ~30 min after the earthquake as a leading elevation, whereas in
Charavgi the eyewitnesses described a leading depression first wave arrival. The maximum tsunami elevation reached in Charavgi was indicated by eyewitnesses on a wooden jetty, whereas in Ag. Paraskevi at a staircase on the local harbour dock (Fig. 9d). Moving north of Ag. Paraskevi, the bay and beach of Livadaki (location S10) are sitting at the northeastern tip of Samos. The owner of the local business in Livadaki drove to the beach about an hour after the earthquake and recognised the wrack line left by the wave runup next to a beach shack (Fig. 9a–b). The measured wave runup of 0.68 m is significantly lower than the data point collected in Asprochorti (location S9), sitting at the end of a northwest-facing narrow bay, ~1.7 km south of the beach of Livadaki. In Asprochorti, a local resident witnessed a leading depression wave and three “significant” floods, each being larger than the previous one. Wave runup from the third flood reached 1.74 m (Fig. 9c), which is comparable to the wave runup measured in Vathi, both places being located at the end of narrow bays on the north-eastern side of Samos.

On the north-western side of Samos, we visited the port and town of Karlovasi (location S1), and the coastal town of Ag. Nikolaos (location S2). In Karlovasi, two times-tamped pictures were shared by an eyewitness in the boat maintenance area of the port taken during the initial drawdown phase (data point S1-2) and shortly after maximum runup of the first flood (Fig. 10b–c). We found another picture taken at 11:58 UTC shortly after the first flood peaked in front of the Hellenic Coast Guard building and when the water level was dropping, with the water level being at 1.66 m with respect to the SWL; all three were key in identifying the timing of tsunami impact. The four runup points measured as indicated by eyewitnesses are consistent with a > 1.8 m wave runup in Karlovasi, which is comparable to the maximum runup recorded in Vathi. However, flooding was limited in Karlovasi, primarily due to the high elevation of the port docks, which also resulted in a smaller flow depth compared to Vathi. In Karlovasi, only the
first-row buildings facing the waterfront on the western side of the port were flooded by the tsunami and no major damage was reported. A mobile structure of the Hellenic Rescue Team resting on top of a supporting wooden frame, right next to the dock of the marina was most likely uplifted by the overland flow and displaced, leading to some small damage to the wooden frame (Fig. 10d).

In Ag. Nikolaos (location S2), the authors were provided with the CCTV footage shared in social media that shows a coastal residence being impacted by the tsunami (YouTube, 2020c). Figure 11 depicts four frames extracted from the video that contain important
information for the timing of impact: the shoreline withdraws (Fig. 11b), the sea level rises and peaks (Fig. 11c), and the last frame (Fig. 11d) shows the impact of a subsequent flood. The steep wave front that impacts the coastal residence appears more violent compared to any other coastal location for which video footage is available for the Samos (Aegean Sea) tsunami, and is seen arriving from the east, propagating westward along the coast. Upon visiting this location and measuring the elevation of the distinct features on the house’s facade (Fig. 11a), it can be safely said—excluding the water splash—that the tsunami elevation in this location reached at least 2.22 m above SWL (windowsill), and was below ~3.0 m (the lower side of the “Beach” sign).

The first harbour ~6.5 km east from Ag. Nikolaos on the north coast of Samos is Ag. Konstantinos (location S3). A local eyewitness described first noticing the sea level rising and pointed to a certain step on the dock reached by the maximum tsunami elevation which measures at 0.63 m above SWL (data point S3), which was confirmed by another eyewitness. Further east, at Avalakia (location S4), an eyewitness described that the third wave was the largest and ran up to a point we measured at 0.62 m above SWL (data point S4). In Kokkari (location S5), the eyewitness we interviewed first noticed the water level rising ~15 min after the earthquake and pointed to the maximum runup point at the end of a small beach inside the local harbour, which measures at 0.73 m above SWL (data point S5). Thus, all coastal locations along the coastal stretch between Ag. Konstantinos and Kokkari received significantly less tsunami energy compared to Ag. Nikolaos.

In the bay of Vathi, three locations were surveyed, namely Gaggos beach (location S8) on the northeast side of the bay, Malagari on the west (location S6), and the town of Vathi (location S7) located at the end of the bay. In Gaggos beach, two eyewitnesses described that the shoreline started receding about 10 min after the earthquake and the flooding was repeated every ~10 min. A wrack line with small debris was still recognisable on the beach on the day of our visit (data point S8), while another runup/inundation point indicated by an eyewitness matched the runup height corresponding to the wrack line. In Malagari, we interviewed several eyewitnesses along the coast. A runup/inundation point was collected on the north side, as indicated by an eyewitness/local resident, who following the earthquake rode his motorbike along the dirt road that connects his business to the coastal road and saw the sea advancing. Further south, around the boat parking/maintenance area, we collected two data points. The first was based on the interview with a local resident who indicated that the maximum water level reached the first step at the entrance to her residence. A runup/inundation point was indicated by another eyewitness in the parking lot area of his business. At the same location, CCTV footage was shared with us from a camera overlooking the boat parking area. The video shows that the water level started rising at 12:23 UTC (after correcting the clock time based on the earthquake shaking initiation) and reached its maximum level at ~12:27 UTC (Fig. 12a–b). The southernmost data point collected in Malagari was indicated by an eyewitness who went to higher ground after the earthquake and identified the maximum inundation point when he came back to his business soon after.

The town of Vathi, the largest town in the island of Samos, was the hardest-hit location in the Greek archipelago. The tsunami reached the first two–three building blocks along the waterfront of Vathi and flooded basements and ground floors of businesses and residential buildings (Fig. 13). The overland flow depth exceeded 1 m in certain locations of lower elevation, causing extensive property damage to the local retail sector. Being located at the end of Vathi bay, and also further away from the fault rupture area, tsunami arrival was delayed compared to Karlovasi. The tsunami arrived as a leading depression wave and the first flood started at ~12:04 UTC. Following the first flood, the message from the Secretariat for Civil
Protection of Greece through Greece’s 1–1-2 Emergency Communications Service was received on cell phones in Samos. The message warned people to stay away from the coast following the earthquake and, importantly, was received prior to the second and largest flood. It is worth noting that emergency response authorities reported soon after the event that the 1–1-2 emergency message was received prior to the first flood; this implies that due to its smaller amplitude compared to the second flood, the first flood was either unnoticed in areas of higher elevation or was not perceived as of any significance.

The following section presents extensive field measurements and video analysis in Vathi to shed light on the local sequencing and impact of the tsunami.

4 Detailed field observations in Vathi, Samos

In Vathi, we undertook a detailed survey and collected 33 data points. The majority was identified through eyewitness interviews, while a small number of points were either visible flow depth marks or were inferred through eyewitness videos. Figure 14a presents an overview of
the locations and types of data points collected in Vathi; the data point elevations can be identified through the top and side plots. Figure 14c–i show selected topography cross profiles normal to the shoreline, extracted from the DSM, with the maximum water level inferred from the nearest field data, as well as from eyewitness and CCTV footage.

Moving from NW to SE along the shoreline until reaching the marina, the elevation of the harbour quay decreases from 0.68 m to 0.4 m above SWL (transects T1-T4). The vulnerable sections of the waterfront in Vathi between T2 and T4, were impacted by both the first and second waves. Pythagoras square was partially flooded by the first wave and was completely flooded by the second and largest wave. During the second flood, the water travelled through the square and also along section T3 to reach Ag. Nikolaos square from two sides, where we measured a wave runup of 1.91 m and the largest inundation distance of 108 m (data point S7-20). On the SE side of Pythagoras square, the water climbed on commercial Ag. Nikolaoos St., where the water ran up to 1.98 m, the highest runup measurement in Vathi (data point S7-17). The second flood also significantly impacted the commercial Cpt. Stamatis St, where flow depth was as high as 0.7 m on the southern end, while on the northern end the wave ran up to 1.77 m (data point S7-15). Interestingly, maximum wave runup along Kyrillou St. was measured at 1.59 m (data point S7-16) – runup data points S7-15 and S7-16 along the two intersecting streets indicated by eyewitnesses were 13 m apart.

South of the marina, a rip-rap breakwater apparently reduced the impact of the tsunami. From its northernmost extent until cross profile T6, the elevation of the breakwater was below the maximum water level reached in the second flood. Albeit briefly, that section of the breakwater was overtopped, and wave overtopping contributed to the flooding mostly in the lower-topography areas near the breakwater (see cross profiles T5-T6).

The furthest south business to be flooded by the tsunami was a storage room along cross profile T6 (southernmost data point S7-1). The source of flooding in that area, which approximately constitutes the south limit of the alongshore tsunami inundation in Vathi, was very complex. Figure 14b, h, i show how wave inundation propagated southwards through the lower topography along the shore-parallel street and the breakwater was overtopped when the offshore water level peaked (the waves did not overtop the breakwater south of cross profile T6). Sea water was also flowing out of the storm drains through hydrostatic pressure while the offshore water level was higher than the elevation of the storm drains.

The discharge of water through the storm drains depended not only on the elevation of the storm drains, but also on the size of the storm drain pipes and their outlets in the sea. Cross profile T5 (Fig. 14g) runs along one of the storm drain pipes and outlets. The back flow through the storm drainpipe due to hydrostatic pressure was such that the pavement next to the storm drain collapsed (local depression in T5 captured by the DSM), leading to higher discharge rates. This effect likely caused a local increase in the tsunami elevation—refer to side plot of Fig. 14a.

4.1 Video analysis

The sequencing, timing, water elevation and surface velocities of flood events in Vathi were interpreted through CCTV footage shared with us from two buildings along the waterfront: Samos Library and the Rhenia Tours travel office; video analysis has been done for other past tsunamis to extract water levels and current velocities (Fritz et al. 2006, 2012, 2018; Kalligeris et al. 2016). The travel office CCTV footage overlooking the business entrance on the waterfront covers 2 h and 37 min. after the earthquake and captures five flood events. Figure 15 shows the frames from the travel office footage at
the time each flood event reached its maximum elevation. The maximum water elevation reached in each flood displayed in Fig. 15 was inferred through objects seen in the image whose elevations were surveyed, in combination with the high-resolution DSM of Vathi created using the drone images. It is important to stress that in this location only the second and fourth waves overtopped the concrete structure located between the harbour quay and the street, while in the other events the water flooded the street and pavement through areas of lower topography and the storm drains (located at ~0.44 m above SWL). As a result, for the flood events that didn’t overtop the concrete structure, flooding was delayed, and the maximum water level was deficient compared to other locations impacted directly through wave overtopping.

Samos Library has several security cameras mounted on the perimeter of the building. The two cameras that are of particular interest to this study are the one overlooking the library entrance on the waterfront, and the camera that overlooks the lane on the side of the building leading to the parking area in the back, labelled cam1 and cam2 in Fig. 16a, respectively. The library videos, covering the first two floods, were used to extract overland tsunami height and free surface velocity time series.

Tsunami elevation time series were extracted from the cam1 videos of the first two floods simply by placing a levelling rod at a corner of the Samos Library facade next to the entrance (Fig. 16b). At each video frame, the water level reached on this corner of the building as seen in the video was translated to tsunami elevation by reading the corresponding levelling rod values and adding the ground elevation with respect to the still water level (SWL) at the time of measurements. The resulting tsunami elevation time series extracted from the videos are shown in Fig. 17a–b. The first and second floods peaked at just over 1 and 1.5 m above SWL, respectively. In comparison with the timing and maximum elevations extracted from the travel office CCTV footage, the maximum water level of the first flood was reached earlier at the library (~12:05:50 UTC at the library versus ~12:08:03 at the travel office) and had a higher elevation compared to the travel office (~1.05 m at the library versus ~0.6 m at the travel office). The elevation of the cross section between the shoreline and the street is lower at the library compared to the travel office (compared cross profiles in Fig. 14c–d) and as a result, it was overtopped by the first wave only at the library and not at the travel office.

The cam2 footage was used to extract free surface velocities for the second and largest flood in Vathi using the same methodology as described in Kalligeris et al. (2016). Optical tracing requires to determine the camera intrinsic (camera and lens properties) and extrinsic (camera location and orientation) parameters. For the camera intrinsic parameters, only radial and decentering lens distortion parameters were recovered through straight line objects appearing curved in the image using the methodology outlined by Swaminathan and Nayar (2000). The camera extrinsic parameters were defined through the Direct Linear Transformation (DLT) coefficients \( L_i, i = 1, 2, 3, \ldots, 11 \) (Holland et al. 1997). The best-fitting DLT coefficients were recovered by rewriting the relationship between image and world coordinates as a system of linear equations of the
form $\mathbf{A} \cdot \mathbf{x} = \mathbf{b}$ and using the seven non-coplanar ground control points (GCPs) shown in Fig. 16c whose world coordinates were obtained from the Library high-resolution DSM (Fig. 4). Reconstructing the world coordinates of the GCPs from their (undistorted) image coordinates using the best-fitting DLT coefficients yields a mean horizontal error of 1 cm.

After optically tracing various floating objects identified in the video, the tracer paths in image coordinates $(u, v)$ were translated to world coordinates $(x, y)$ using the DLT coefficients as (Kalligeris et al. 2016):

$$
\begin{bmatrix}
    x \\
    y 
\end{bmatrix}
= 
\begin{bmatrix}
    L_1 - L_9u & L_2 - L_{10}u \\
    L_5 - L_9v & L_6 - L_{10}v
\end{bmatrix}^{-1}
\begin{bmatrix}
    u - L_4 + z_t(L_{11}u - L_3) \\
    v - L_8 + z_t(L_{11}v - L_7)
\end{bmatrix}
$$

where $z_t$ is the tracer elevation, which was independently estimated. After the flood peaked, the tracer level $z_t$ was set equal to the water level at the building facade extracted from the cam1 video analysis. Due to the narrow width of the entrance through which the water was rushing from the waterfront to the lane on the side of the building, the water level on the side of the building was not equal to the water level on the waterfront before the flood peaked. The water level for two optically tracked objects, appearing in the footage before
the flood peaked, was inferred through features of known dimensions that were partially flooded. For the world coordinates \((x, y)\), a local coordinate system was defined where the \(x\) and \(y\) axes are parallel and normal to the shoreline, respectively (Fig. 16a).

The tracer paths in world coordinates extracted with the 25 Hz sampling frequency were first filtered using a low-pass Butterworth filter with 2.5 Hz cut off frequency to remove high frequency fluctuations due to optical tracing errors and local water level fluctuations. The filtered paths (Fig. 17e) were then translated to velocities using the first order central difference scheme. The resulting shore-normal velocities and corresponding velocity magnitudes are shown in Fig. 17c–d. Each tracer, plotted using a different colour, experienced high acceleration/deceleration as it moved through the camera field of view in regions of varying velocity as is evident from the steep individual velocity curves. Free surface velocities as high as 2.5 m/s were measured as the flow depth reached ~0.83 m, which corresponds to a subcritical flow according to the Froude number \((Fr < 1)\) using the mean ground elevation in the optical field of view \(h = 0.68\) m. The video frames shown in Fig. 17f–g indicate supercritical flow conditions before the second flood peaked.

5 Discussion and conclusions

We described our results from several post-event field surveys we undertook. In Chios, the SE shoreline between Emporios and Komi received most of the tsunami energy, with 1.44 m of wave runup measured in Komi, while the wave amplitude faded moving north.
along the shoreline towards the port of Chios. In Chios and Ikaria, the tsunami was mostly noticeable in ports and harbours justifying the Japanese term. Along the north coast of Ikaria, runup ranged between 0.9 m and 1.2 m, while along its southern coastline maximum measured runup was below 1 m. Provided the timing correction of the published CCTV footage for the tsunami in Evdilos (YouTube, 2020b) is accurate, the tsunami arrived to the north coast of Ikaria as a leading depression wave within 10 min after the earthquake.

In the islands of Fourni and Thimena, the measured maximum runup values of 1.57 and 1.46 m, respectively, were perhaps surprisingly high given the location of the islands with respect

Fig. 17  a–b Tsunami elevation time series of the first two floods in Vathi extracted from the cam1 Samos Library CCTV video. c Shore-normal free surface velocities for the second flood in Vathi extracted from the cam2 Samos Library CCTV video through particle tracking; each colour corresponds to a different particle. d Same as (c), but showing the velocity magnitude; the black curve corresponds to the shallow water speed $\sqrt{gd}$, where $d$ is the flow depth computed by subtracting the mean ground elevation in the optical field of view ($h = 0.68$ m) from the water level $d$ extracted from (b) after the flood peaked. e The paths of the objects optically tracked, projected on top of an orthophoto. f–g Two frames of the cam2 footage for the second flood showing the flow conditions during the flood rise stage.
to Samos and the fault rupture area. The relatively early arrival time of the first flood in both towns of Fourni and Thimena (12:03 UTC in Fourni and before 12:07 UTC in Thimena) is another factor that puts a question mark on the origin of the first and largest wave in these locations.

In Samos, the southern and eastern coastlines received significantly less wave energy than the north side and the tsunami was mostly noticed in harbours. Maximum measured runup/elevation values ranged between 0.34 and 0.63 m, while the arrival of the leading depression wave at 12:12 UTC inferred from eyewitness pictures in Marathokampos is noteworthy.

In the NW coast of Samos, located very close to the outcrop of the fault rupture area, the first wave arrived as a leading depression within a few minutes after the earthquake in Karlovasi and Ag. Nikolaos. Wave runup in Karlovasi was consistently measured close to ~2 m, and the town was spared from significant flooding because of the relatively higher topography compared to Vathi. In Ag. Nikolaos, a CCTV footage shared in news and social media shows a steep wave propagating from east to west and impacting a coastal residence, with tsunami elevation reaching values above 2.22 m (~3 m when considering the splash on the wall). In Ag. Konstantinos, located ~6.5 km east of Ag. Nikolaos, tsunami runup/elevation drops to 0.63 m. Such a steep alongshore runup decay is characteristic for landslide tsunamis (Okal and Synolakis 2004). If that is indeed the case, the origin of the submarine landslide may possibly lie just east of Ag. Nikolaos, in an area that features steep bathymetric inclines (Nomikou et al. 2021).

In Vathi bay, recorded maximum wave runup increased from 0.91 m in Gaggos beach to 1.98 m in the town of Vathi located at the end of the bay—comparable maximum runup (1.78 m) was measured in Asprochorti which is located ~2.5 km NNE of Vathi, at the end of another, smaller and narrower bay. Vathi is the capital of the municipality of East Samos and the largest town of the island. Due to its location at the end of the bay, its low elevation and vulnerable waterfront, it was the hardest hit coastal location in the Greek islands. CCTV footage at the waterfront shared by a local travel office showed that at least five waves impacted Vathi, the second being the largest. We presented detailed measurements of tsunami elevation and wave runup along the impacted region, accompanied by drone-extracted topographic cross profiles that showcase the vulnerability of the waterfront of Vathi and the complexity of flooding through multiple routes. Analysis of CCTV footage from the Library of Samos revealed the tsunami hydrographs of the first two floods, i.e. time series of overland flow depth of the tsunami at the particular location, as well as overland flow velocities through particle tracking velocimetry. The hydrograph of the second flood shows that the overland flow depth rose by one meter within one minute.

The message disseminated by the General Secretariat for Civil Protection of Greece through the national 1–1-2 Emergency Communications Service, warning recipients to stay away from coastal areas, was the biggest take away from this event. It was received in Vathi prior to the second and largest flood and according to local officials had a positive effect in the evacuation of the population. Given this promising outcome, future use of this technology for tsunami warning shall be examined. However, raising tsunami awareness of the population to self-evacuate remains the main priority, given that the earthquake itself provides the clearest natural warning in the near-field and it can save lives.

**Appendix**

See Tables 1 and 2.
Table 1  Water level (WL) measurements collected and tidal model predictions (statistics for the time period between 30 October 2020 and 5 February 2021) for all locations visited

| Island | Location            | Date       | Time (UTC) | Lon (deg) | Lat (deg) | Nearest cell depth (m) | Min. amp. (cm) | Max amp (cm) |
|--------|---------------------|------------|------------|-----------|-----------|------------------------|----------------|--------------|
| Chios  | Komi                | 14/1/21    | 9:03       | 26.048974 | 38.20196  | 54                     | −10.1          | 8.7          |
| Chios  | Emporios            | 14/1/21    | 9:57       | 26.028846 | 38.18812  | 66                     | −10.3          | 8.9          |
| Chios  | Vokaria             | 14/1/21    | 11:17      | 26.106569 | 38.24169  | 73                     | −10.1          | 8.7          |
| Chios  | Katarraktis         | 14/1/21    | 11:37      | 26.10324  | 38.26552  | 49                     | −10.3          | 8.9          |
| Chios  | Ag. Ioannis         | 14/1/21    | 13:05      | 26.11825  | 38.28363  | 58                     | −10.6          | 9.1          |
| Chios  | Farkena             | 14/1/21    | 15:25      | 26.14346  | 38.35705  | 9                      | −13.0          | 11.4         |
| Chios  | Chios Port          | 14/1/21    | 17:10      | 26.13747  | 38.37173  | 9                      | −13.0          | 11.4         |
| Ikaria | Magganitis          | 18/1/21    | 12:18      | 26.117641 | 37.55696  | 473                    | −6.9           | 6.2          |
| Ikaria | Fanari              | 18/1/21    | 14:49      | 26.35177  | 37.67302  | 55                     | −7.5           | 6.2          |
| Ikaria | Ag. Kiraki          | 18/1/21    | 15:01      | 26.34335  | 37.6864   | 76                     | −9.1           | 7.6          |
| Ikaria | Thera (also applied to Ag. Kirikos) | 19/1/21 | 14:18 | 26.305627 | 37.62312 | 94 | −6.9 | 6.0 |
| Ikaria | Karavostomo         | 19/1/21    | 10:55      | 26.218245 | 37.63424  | 42                     | −9.2           | 7.8          |
| Ikaria | Gialiskari          | 19/1/21    | 11:52      | 26.102734 | 37.63237  | 50                     | −9.2           | 7.9          |
| Ikaria | Evdilos             | 19/1/21    | 12:35      | 26.180024 | 37.63101  | 32                     | −9.2           | 7.8          |
| Fourni | Fourni              | 20/1/21    | 9:25       | 26.479776 | 37.57789  | 147                    | −7.5           | 6.5          |
| Fourni | Bali                | 20/1/21    | 10:53      | 26.505687 | 37.5918   | 114                    | −7.8           | 6.6          |
| Fourni | Kamari              | 20/1/21    | 11:21      | 26.532789 | 37.59866  | 106                    | −7.8           | 6.7          |
| Fourni | Chrisomillia        | 20/1/21    | 12:05      | 26.507986 | 37.6269   | 96                     | −8.0           | 6.7          |
| Thimena| Thimena             | 20/1/21    | 13:15      | 26.454445 | 37.58275  | 147                    | −7.5           | 6.5          |
| Samos  | Gaggos beach        | 11/1/21    | 8:08       | 26.964569 | 37.76557  | 31                     | −9.1           | 7.4          |
| Samos  | Ag. Paraskevi       | 11/1/21    | 10:01      | 26.993232 | 37.78102  | 31                     | −9.1           | 7.4          |
| Samos  | Asprochorti         | 5/2/21     | 13:41      | 26.981603 | 37.78284  | 31                     | −9.1           | 7.4          |
| Samos  | Livadaki            | 5/2/21     | 12:29      | 26.984829 | 37.79435  | 31                     | −9.1           | 7.4          |
Table 1 (continued)

| Island | Location         | Date   | Time (UTC) | Lon (deg) | Lat (deg) | Nearest cell depth (m) | Min. amp. (cm) | Max amp (cm) |
|--------|------------------|--------|------------|-----------|-----------|------------------------|----------------|--------------|
| Samos  | Charavgi         | 5/2/21 | 15:35      | 27.035123 | 37.73     | 30                     | −7.8           | 7.3          |
| Samos  | Kokkari          | 11/1/21| 13:08      | 26.89314  | 37.78028  | 74                     | −9.1           | 7.5          |
| Samos  | Avlakia          | 11/1/21| 13:41      | 26.857284 | 37.7986   | 111                    | −9.1           | 7.5          |
| Samos  | Ag. Konstantinos | 11/1/21| 14:12      | 26.816526 | 37.80816  | 129                    | −9.1           | 7.5          |
| Samos  | Ag. Nikolaos     | 11/1/21| 15:33      | 26.742111 | 37.81287  | 80                     | −9.1           | 7.6          |
| Samos  | Karlovasi        | 13/1/21| 7:25       | 26.678726 | 37.79614  | 235                    | −9.1           | 7.6          |
| Samos  | Marathokampos    | 13/1/21| 9:25       | 26.699904 | 37.70981  | 86                     | −8.6           | 7.5          |
| Samos  | Ireo             | 13/1/21| 10:59      | 26.883216 | 37.66014  | 45                     | −7.8           | 7.3          |
| Samos  | Pythagorion      | 31/10/20| 8:35      | 26.94289  | 37.68866  | 26                     | −7.8           | 7.3          |
| Samos  | Malagari         | 11/1/21| 11:01      | 26.960658 | 37.75115  | 31                     | −9.1           | 7.4          |
| Samos  | Vathi            | 4/2/21 | 12:15      | 26.975827 | 37.75581  | 31                     | −9.1           | 7.4          |
| Point ID | Lat (deg) | Lon (deg) | Data type | Value (m) | Location | Notes |
|----------|-----------|-----------|------------|-----------|----------|-------|
| C1-1     | 38.188008 | 26.028245 | TE         | 1.38      | Emporios | Stairs leading to taverna “Porto Emborios” where the maximum water level reached according to the owner |
| C1-2     | 38.188183 | 26.027884 | IN         | 70        | Emporios | Inundation point |
| C2       | 38.202046 | 26.049063 | RU         | 1.44      | Komi     | Runup point just inland of Komi harbour. Indicated by an eyewitness |
| C2       | 38.202046 | 26.049063 | IN         | 12        | Komi     | Inundation for the same point |
| C3       | 38.241741 | 26.106489 | TE         | 0.82      | Vokaria  | Maximum tsunami elevation point measured at the side of the harbour dock. Indicated by a local resident |
| C4       | 38.265574 | 26.103296 | TE         | 0.75      | Katarraktis | Maximum tsunami elevation point measured at the top of the harbour dock. Indicated by eyewitnesses. FD = 5 cm from dock level |
| C5       | 38.283665 | 26.11824  | RU         | 0.65      | Ag. Ioannis | Runup point measured at the slip of the harbour. Indicated by eyewitness and confirmed through eyewitness pictures |
| C6       | 38.357033 | 26.14352  | TE         | 0.52      | Farkena  | Maximum tsunami elevation point indicated by an eyewitness on an armour rock inside the harbour basin. Confirmed by another fisherman/eyewitness |
| C7       | 38.372222 | 26.137751 | TE         | 0.32      | Chios Port | Elevation of a rubber tire/fender hanging on the side of the dock. Indicated by the owner of the kiosk next to the customs building |

**Ikaria**

| Point ID | Lat (deg) | Lon (deg) | Data type | Value (m) | Location | Notes |
|----------|-----------|-----------|------------|-----------|----------|-------|
| I1       | 37.632272 | 26.102797 | RU         | 0.92      | Gialiskari | A local resident indicated the maximum wave runup point reached along the harbour slip during the first and largest wave. Not an eyewitness, relayed information from others |
| I1       | 37.632272 | 26.102797 | IN         | 6         | Gialiskari | Inundation for the same point |
| I2       | 37.631363 | 26.180027 | EM         | 1.18      | Evdilos   | Elevation of dock running along the perimeter of the harbour that appears flooded in CCTV video |
| I3       | 37.63415  | 26.216981 | RU         | 0.97      | Karavostamo | Runup point on a broken wall corner. Indicated by a local resident who was relaying the account of eyewitnesses |
| I3       | 37.63415  | 26.216981 | IN         | 25.8      | Karavostamo | Inundation for the same point |
| I4       | 37.686107 | 26.343209 | RU         | 0.91      | Ag. Kiriai | Runup point on the harbour slip. Indicated by an eyewitness |
| I4       | 37.686107 | 26.343209 | IN         | 6.5       | Ag. Kiriai | Inundation for the same point |
| Point ID | Lat (deg)   | Lon (deg)   | Data type | Value (m) | Location          | Notes                                                                 |
|---------|-------------|-------------|-----------|-----------|-------------------|----------------------------------------------------------------------|
| I5      | 37.673002   | 26.351707   | EM        | 0.79      | Fanari            | Elevation of the dock that locals indicated was covered with water    |
| I6      | 37.622663   | 26.305387   | EM        | 0.79      | Therma            | Elevation of dock an eyewitness indicated was covered with water      |
| I7-1    | 37.616014   | 26.298375   | TE        | 0.82      | Ag. Kirikos-marina| Elevation of rubber/fender running along the side of the dock that the maximum water level reached in the marina according to eyewitnesses |
| I7-2    | 37.614348   | 26.295276   | EM        | 0.86      | Ag. Kirikos       | Elevation of the higher of the two docks that appear to be flooded in CCTV video |
| I8      | 37.556635   | 26.117919   | RU        | 0.51      | Magganitis        | Runup corresponding to a sitting area in the harbour that was flooded according to a local resident |
| I8      | 37.556635   | 26.117919   | IN        | 6.2       | Magganitis        | Inundation for the same point                                        |
| Fourni  |             |             |           |           |                   |                                                                      |
| F1-1    | 37.576892   | 26.479918   | TE        | 1.31      | Fourni            | Tsunami elevation point indicated by the carpenter whose business is next to the point |
| F1-2    | 37.577329   | 26.480019   | RU        | 1.28      | Fourni            | Runup point according to eyewitness                                   |
| F1-2    | 37.577329   | 26.480019   | IN        | 24.6      | Fourni            | Inundation for the same point                                        |
| F1-3    | 37.577801   | 26.480088   | TE        | 1.44      | Fourni            | Tsunami elevation point at the last step to the entrance of Antica Chocolateria Bakery according to the owner. FD = 20 cm from pavement, FD = 33 cm from street level |
| F1-4    | 37.577708   | 26.480145   | TE        | 1.42      | Fourni            | Tsunami elevation point inside Proton Supermarket. FD = 20 cm from street level |
| F1-5    | 37.577673   | 26.480318   | RU        | 1.57      | Fourni            | Runup point indicated by eyewitnesses                                |
| F1-5    | 37.577673   | 26.480318   | IN        | 49.1      | Fourni            | Inundation for the same point                                        |
| F2      | 37.591709   | 26.505587   | EM        | 0.96      | Bali              | Highest elevation point of the harbour dock which was covered with water according to eyewitnesses |
| F3      | 37.628163   | 26.506743   | RU        | 1.18      | Chrisomillia      | Runup point according to a local fisherman                            |
| F3      | 37.628163   | 26.506743   | IN        | 19        | Chrisomillia      | Inundation for the same point                                        |
| F4      | 37.598882   | 26.532921   | RU        | 1.25      | Kamari            | Approximate runup point according to the owner of taverna “Almyra”   |
| F4      | 37.598882   | 26.532921   | IN        | 20.7      | Kamari            | Inundation for the same point                                        |
| Thimena |             |             |           |           |                   |                                                                      |
| T1      | 37.582458   | 26.453472   | TE        | 1.46      | Thimena           | Elevation of the first step at the end of the harbour dock where the maximum water elevation reached according to eyewitnesses. FD= 23 cm from dock level |
| Point ID | Lat (deg) | Lon (deg) | Data type | Value (m) | Location   | Notes                                                                 |
|---------|-----------|-----------|------------|-----------|------------|----------------------------------------------------------------------|
| S1-1    | 37.795116 | 26.6782   | RU         | 2.08      | Karlovasi  | Runup point in the boat maintenance area. Indicated by eyewitness and confirmed through pictures |
| S1-1    | 37.795116 | 26.6782   | IN         | 55.7      | Karlovasi  | Inundation for the same point                                         |
| S1-2    | 37.796084 | 26.678651 | DD         | -1.21     | Karlovasi  | Drawdown point identified through an eyewitness photo taken on 30 October 2020 at 11:55 UTC |
| S1-3    | 37.794502 | 26.680252 | RU         | 1.88      | Karlovasi  | Runup point in front of a house. Indicated by eyewitness              |
| S1-4    | 37.794214 | 26.682689 | RU         | 1.96      | Karlovasi  | Runup point next to Relax Café Patisserie. Indicated by eyewitness    |
| S1-5    | 37.796464 | 26.687001 | IN         | 36.1      | Karlovasi  | Tsunami elevation identified on the side of a temporary structure. FD = 5 cm from ground |
| S1-6    | 37.794915 | 26.686501 | RU         | 1.85      | Karlovasi  | Runup point indicated by eyewitness                                   |
| S1-6    | 37.794915 | 26.686501 | IN         | 82.5      | Karlovasi  | Inundation for the same point                                         |
| S2      | 37.81271  | 26.742123 | TE         | 0.63      | Ag. Nikolaos | Elevation of the lower part of the "Beach" sign on the wall (splash on wall, see text for details) |
| S3      | 37.808316 | 26.816561 | TE         | 0.63      | Ag. Konstantinos | Elevation of a step on harbour dock reached by the maximum water level. Indicated by an eyewitness |
| S4-1    | 37.799189 | 26.857104 | RU         | 0.62      | Avlakia     | Runup point on concrete terrace in front of a waterfront house. Indicated by an eyewitness  |
| S4-2    | 37.798596 | 26.857285 | DD         | -0.95     | Avlakia     | Drawdown point. An eyewitness described the shoreline receding to that point |
| S5      | 37.780309 | 26.893043 | RU         | 0.73      | Kokkari     | Runup point on the beach inside the harbour. Indicated by an eyewitness |
| S5      | 37.780309 | 26.893043 | IN         | 9.2       | Kokkari     | Inundation for the same point                                         |
| S6-1    | 37.757543 | 26.955781 | RU         | 1.03      | Malagari    | Runup point indicated by an eyewitness (owner of Moto Service Karydas) |
| S6-1    | 37.757543 | 26.955781 | IN         | 52        | Malagari    | Inundation for the same point                                         |
| S6-2    | 37.755518 | 26.957241 | RU         | 0.97      | Malagari    | Runup point in the parking lot of Roussakis Marine. Indicated by the owner of the business |
| S6-2    | 37.755518 | 26.957241 | IN         | 53.8      | Malagari    | Inundation for the same point                                         |
Table 2 (continued)

| Point ID | Lat (deg)    | Lon (deg)    | Data type | Value (m) | Location       | Notes                                                                 |
|----------|--------------|--------------|-----------|-----------|----------------|----------------------------------------------------------------------|
| S6-3     | 37.75548     | 26.956987    | TE        | 0.98      | Malagari       | Tsunami elevation point on top of a step leading to the entrance to a waterfront house. Indicated by an eyewitness |
| S6-4     | 37.750989    | 26.96035     | RU        | 1.38      | Malagari       | Runup point on the ramp of the Nioti service store. Indicated by the owner/eyewitness |
| S6-4     | 37.750989    | 26.96035     | IN        | 32.7      | Malagari       | Inundation for the same point                                        |
| S7-1     | 37.7525401   | 26.9770241   | TE        | 1.21      | Vathi          | Plaisir coffees store. FD = 23 cm from street level                   |
| S7-2     | 37.7528257   | 26.9771992   | TE        | 0.94      | Vathi          | Inside Fratzeskos Distillery store. FD = 22 cm from store floor       |
| S7-3     | 37.7532461   | 26.9771469   | TE        | 1.13      | Vathi          | Outside store “My Style”. FD = 39 cm from pavement level             |
| S7-4     | 37.7535529   | 26.9772458   | TE        | 1.58      | Vathi          | Entrance to “Coffee Lab”                                            |
| S7-5     | 37.7536998   | 26.9771996   | TE        | 1.45      | Vathi          | Entrance to the “Carousel” store                                    |
| S7-6     | 37.7538739   | 26.9772546   | TE        | 1.18      | Vathi          | Inside Tsoumakis nautical supplies. FD = 5 cm from store floor       |
| S7-7     | 37.7541302   | 26.9776837   | IN        | 82.6      | Vathi          | Approximate inundation point. Indicated by eyewitnesses             |
| S7-8     | 37.754148    | 26.9775439   | TE        | 1.20      | Vathi          | Kiosk. FD = 27 cm from street level                                  |
| S7-9     | 37.7544543   | 26.977239    | TE        | 1.28      | Vathi          | Bazaar Super Market. FD = 5 cm from store floor                      |
| S7-10    | 37.7545137   | 26.9771595   | TE        | 1.25      | Vathi          | Hondos Center entrance. FD = 70 cm from pavement level              |
| S7-11    | 37.7550268   | 26.9770151   | TE        | 1.42      | Vathi          | Bank of Greece steps. FD = 100 cm from street level                  |
| S7-12    | 37.7550948   | 26.9772321   | TE        | 1.43      | Vathi          | In front of a dusty store window along the lane next to the Bank of Greece branch. FD = 95 cm from street level |
| S7-13    | 37.755102    | 26.9773637   | TE        | 1.33      | Vathi          | Water level inside Nova store. FD = 70 cm from street level          |
| S7-14    | 37.755099    | 26.9776471   | TE        | 1.31      | Vathi          | Water level inside di Mario shoe store. FD = 12 cm from store floor  |
| S7-15    | 37.755665    | 26.977428    | RU        | 1.77      | Vathi          | Runup point along Cpt. Stamatis street                              |
| S7-15    | 37.755665    | 26.977428    | IN        | 106       | Vathi          | Inundation for the same point                                       |
| S7-16    | 37.7557168   | 26.9772957   | RU        | 1.59      | Vathi          | Runup point along Kyriillou St                                     |
| S7-16    | 37.7557168   | 26.9772957   | IN        | 98        | Vathi          | Inundation for the same point                                       |
| S7-17    | 37.7562014   | 26.9768673   | RU        | 1.98      | Vathi          | Runup point along Ag. Nikolaou St                                  |
| S7-17    | 37.7562014   | 26.9768673   | IN        | 96        | Vathi          | Inundation for the same point                                       |
| S7-18    | 37.7563249   | 26.9767113   | TE        | 1.72      | Vathi          | Blue Roots Nuts Grocery Store. FD = 22 cm from street level          |
| Point ID | Lat (deg) | Lon (deg) | Data type | Value (m) | Location | Notes |
|----------|-----------|-----------|------------|-----------|----------|-------|
| S7-19    | 37.7566549 | 26.9763639 | TE         | 1.85      | Vathi    | Kanakakis Store. FD = 25 cm from store floor |
| S7-20    | 37.7568643 | 26.975981  | RU         | 1.91      | Vathi    | Runup point in Ag. Nikolaos square |
| S7-20    | 37.7568643 | 26.975981  | IN         | 108       | Vathi    | Inundation for the same point |
| S7-21    | 37.756147  | 26.9762263 | TE         | 1.66      | Vathi    | Armodios Bakery. FD = 88 cm from store floor |
| S7-22    | 37.7564297 | 26.9763809 | TE         | 1.74      | Vathi    | Grigoris store. FD = 70 cm from pavement level |
| S7-23    | 37.7563686 | 26.9759205 | TE         | 1.85      | Vathi    | Charas souvenir store. FD = 100 cm from pavement level, FD = 115 cm from street level |
| S7-24    | 37.756923  | 26.9747185 | TE         | 1.18      | Vathi    | Pharmacy. FD = 60 cm from pavement/street level |
| S7-25    | 37.7570399 | 26.9747659 | TE         | 1.31      | Vathi    | No name store. FD = 47 cm from pavement/street level |
| S7-26    | 37.757196  | 26.9749224 | TE         | 1.56      | Vathi    | Close to runup/inundation point. FD = 20 cm from pavement/street level |
| S7-27    | 37.7570485 | 26.9739481 | TE         | 1.36      | Vathi    | Inside the mini-market. FD = 64 cm from store floor |
| S7-28    | 37.7577578 | 26.9737091 | RU         | 1.78      | Vathi    | Runup point right next to an eyewitness’ house |
| S7-29    | 37.7575183 | 26.9728453 | TE         | 1.52      | Vathi    | Entrance of AutoUnion Car rental store. FD = 80 cm from pavement |
| S7-30    | 37.7576834 | 26.9728608 | TE         | 1.59      | Vathi    | Along Grammou St. FD = 27 cm from street level |
| S7-31    | 37.7576158 | 26.9723026 | EM         | 1.38      | Vathi    | Elevation of tabletop in front of Rhenia tours which the maximum water level exceeded. Vertical distance to pavement = 77 cm |
| S7-32    | 37.7577062 | 26.9722637 | TE         | 1.54      | Vathi    | Inside Pizzeria Appalousa. FD = 72 cm from store floor |
| S7-33    | 37.757806  | 26.971348  | RU         | 1.92      | Vathi    | Runup point on stairs in front of the travel office. Indicated by an eyewitness |
| S7-33    | 37.757806  | 26.971348  | IN         | 22.5      | Vathi    | Inundation for the same point |
| S8      | 37.765361  | 26.964955  | RU         | 0.91      | Gaggos beach | Wrack line identified on beach |
| S8      | 37.765361  | 26.964955  | IN         | 7.6       | Gaggos beach | Inundation for the same point |
| S9-1     | 37.779263  | 26.982792  | RU         | 1.74      | Asprochorti | Runup point along the road leading to the house of the eyewitness |
| S9-1     | 37.779263  | 26.982792  | IN         | 40        | Asprochorti | Inundation for the same point |
| S9-2     | 37.782954  | 26.981743  | RU         | 1.44      | Asprochorti | Runup point in a small beach north of Asprochorti according to an eyewitness in Asprochorti |
| S9-2     | 37.782954  | 26.981743  | IN         | 17.5      | Asprochorti | Inundation for the same point |
| Point ID | Lat (deg) | Lon (deg) | Data type | Value (m) | Location | Notes |
|----------|-----------|-----------|------------|-----------|----------|--------|
| S10      | 37.79462  | 26.985316 | RU         | 0.68      | Livadaki | Runup point according to the owner of the business/eyewitness |
| S10      | 37.79462  | 26.985316 | IN         | 52.5      | Livadaki | Inundation for the same point |
| S11      | 37.781006 | 26.993245 | TE         | 0.59      | Ag. Paraskevi | Tsunami elevation point on steps next to the dock. Indicated by an eyewitness |
| S12      | 37.7296   | 27.035314 | TE         | 0.34      | Charavgi | Tsunami elevation point on a wooden jetty. Indicated by an eyewitness |
| S13-1    | 37.690099 | 26.943089 | DD         | -0.43     | Pythagorion | A drawdown point on the side of the dock according to an eyewitness |
| S13-2    | 37.690104 | 26.943093 | TE         | 0.61      | Pythagorion | A tsunami elevation point on the side of the dock according to an eyewitness |
| S13-3    | 37.688673 | 26.942874 | TE         | 0.53      | Pythagorion | The water just made it to the top of the harbour dock according to an eyewitness |
| S14      | 37.660126 | 26.883229 | TE         | 0.53      | Ireo     | Tsunami elevation point measured at the steps of the harbour dock. Indicated by eyewitnesses |
| S15      | 37.709847 | 26.699884 | RU         | 0.63      | Marathokampos | Runup point on the beach inside the harbour. Indicated by an eyewitness and confirmed through eyewitness pictures. Beach morphology might have changed since the earthquake—use as a proxy |
| S15      | 37.709847 | 26.699884 | IN         | 4.3       | Marathokampos | Inundation for the same point |
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Availability of data and materials  The data points are made available in the Appendix. The tsunami hydrograph and overland flow velocity data inferred through the analysis of the Samos Library CCTV videos can be shared upon reasonable request.

Code availability  Not applicable.

Declarations

Conflict of interest  The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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