BGSG

Volume 61

Research Paper

Correspondence to:
stiros@upatras.gr

DOI number:
http://dx.doi.org/10.12681/bgsg.36598

Keywords:
boulder, cyclone, storm, tsunami, wave, coastal flooding, Samos

Citation:
Stiros, S., 2024. Tsunamis versus extreme meteorological waves: evidence from the 2004 Aegean Sea cyclone in Samos island, Bulletin Geological Society of Greece, 61, 1-9.

Publication History:
Received: 22/01/2024
Accepted: 01/03/2024
Accepted article online: 18/07/2024

The Editor wishes to thank Dr. Gerassimos Papadopoulos for his work with the scientific reviewing of the manuscript and Mr Georgios Goutsos for editorial assistance.

TSUNAMIS VERSUS EXTREME METEOROLOGICAL WAVES: EVIDENCE FROM THE 2004 AEGEAN SEA CYCLONE IN SAMOS ISLAND

Stathis C. Stiros

Dept of Civil Engineering, Patras University Patras, 26500, Greece

stiros@upatras.gr

ORCID: 0000-0002-6451-5375

Abstract

In January 2004 a Mediterranean cyclone in the Aegean Sea seriously affected the north coast of Samos Island, damaged the harbour mole of a coastal village, and catapulted its building material along with heavy boulders to the inner harbour basin. This area was also affected by a 2020, magnitude 7.0 earthquake which produced localized tsunamis. The evidence from the 2004 cyclone, with boulders shifted from known positions and with known trajectories, can contribute to the debate for the causes of mobilization of coastal boulders because of storms, tsunamis, or their combination.

Keywords: *boulder, cyclone, storm, tsunami, wave, coastal flooding, Samos*

ΠΕΡΙΛΗΨΗ

Τον Ιανουάριο 2004 ένας Μεσογειακός κυκλώνας προκάλεσε μία καταιγίδα που πλημμύρισε ένα παράκτιο χωριό στη βόρεια ακτή της Σάμου, προκάλεσε καταστροφές στο μόλο του λιμανιού και εκτόξευσε τμήματα του μόλου και ογκώδεις προστατευτικούς ογκόλιθους στη λεκάνη του λιμανιού. Η ίδια περιοχή επηρεάστηκε το 2020 και από σεισμό μεγέθους 7.0 που προκάλεσε και μικρά, τοπικά τσουνάμι. Τα δεδομένα του κυκλώνα του 2004, και ιδιαίτερα οι εκτοξεύσεις ογκολίθων από γνωστές θέσεις και γνωστές διαδρομές, μπορούν να συμβάλουν στη συζήτηση για τις αιτίες μετακίνησης παράκτιων ογκολίθων από τσουνάμι, καταιγίδες ή και το συνδυασμό τους.

Λέξεις - Κλειδιά: *ογκόλιθοι, κυκλώνας, καταιγίδα, τσουνάμι, παράκτια πλημμύρα, Σάμος*

1. Introduction

In January 2004 a spectacular drop of the atmospheric pressure by 24 mbars in less than 24 hours led to the formation of a cyclone in the Aegean Sea and the broader region. This event was associated with intense snowfall and strong winds with recorded velocities of up to 45 m/s and caused much damage, first in Greece, and then in Türkiye. Details for the formation, evolution, and modeling of this event, unique in a period of 40 years covered by detailed instrumental data, are summarized in Lagouvardos et al (2007) and Brikas et al (2013).

The January 2004 cyclone caused flooding (surges) in various coastal areas in the Aegean, but its impact on the small harbour of Agios Konstantinos (Agios Constantinos; Fig. 1), on the northern coast of Samos Island in the East Aegean are comparable to those of a tsunami. This event, so far ignored, is the focus of this article, based on personal observations. The particularity of the 2004 storm at Agios Konstantinos, Samos, is that large boulders were tossed into the harbour basin, and this event can contribute to the debate for the origin of boulders brought to the coast either by storms or by tsunamis; a debate which has been very intense in the last decades (for a review see, Shiki et al, eds. 2008; Browne, 2011). The Samos case is quite promising in this perspective because in 2020 a magnitude 7 earthquake occurred offshore this island, and produced small, localized tsunamis (Triantafyllou et al, 2021; Aksoy, 2021), especially to the Bay of Vathy, capital of Samos, to the east of Agios Konstantinos village (for location see Fig 1). Hence evidence of both a meteorological and a common tsunami is available for a small area and for a short period.

2. Boulders transported by storms and tsunamis

Boulders transported from the sea to the supralittoral zone and farther inland have been among the features that are considered as indicative of tsunamis. However, opinions are diverted, and some regard them as signs of tsunamis (e.g. Kelletat et al, 2007; Scheffers et al, 2008), while others as results of storms (e.g. Morton et al, 2006). Nott (2003) presented some equations to calculate the minimum wave height capable of mobilization of boulders as a function of their characteristics (geometry, density) and of their pre-transport location, for both storms and tsunamis. A basic conclusion is that in the case of an atmospheric effect, the wave height necessary to mobilize boulders is much larger than in a tsunami. On these grounds, a tsunami can be inferred if the boulder mobilized is very heavy (say about 80-100 tons), larger than the maximum value of a boulder expected to be mobilized by a storm in a certain area. However, for smaller boulders there exists no clear diagnostic criteria for the causes of transport of boulders from the infralittoral or the midlittoral zone upwards. For this reason, Shah-Hosseini et al (2016) argued that boulders in the coast of Egypt which correlate with the 1303 East Mediterranean tsunami are likely of tsunamigenic origin, while all others should be assigned to storminess.

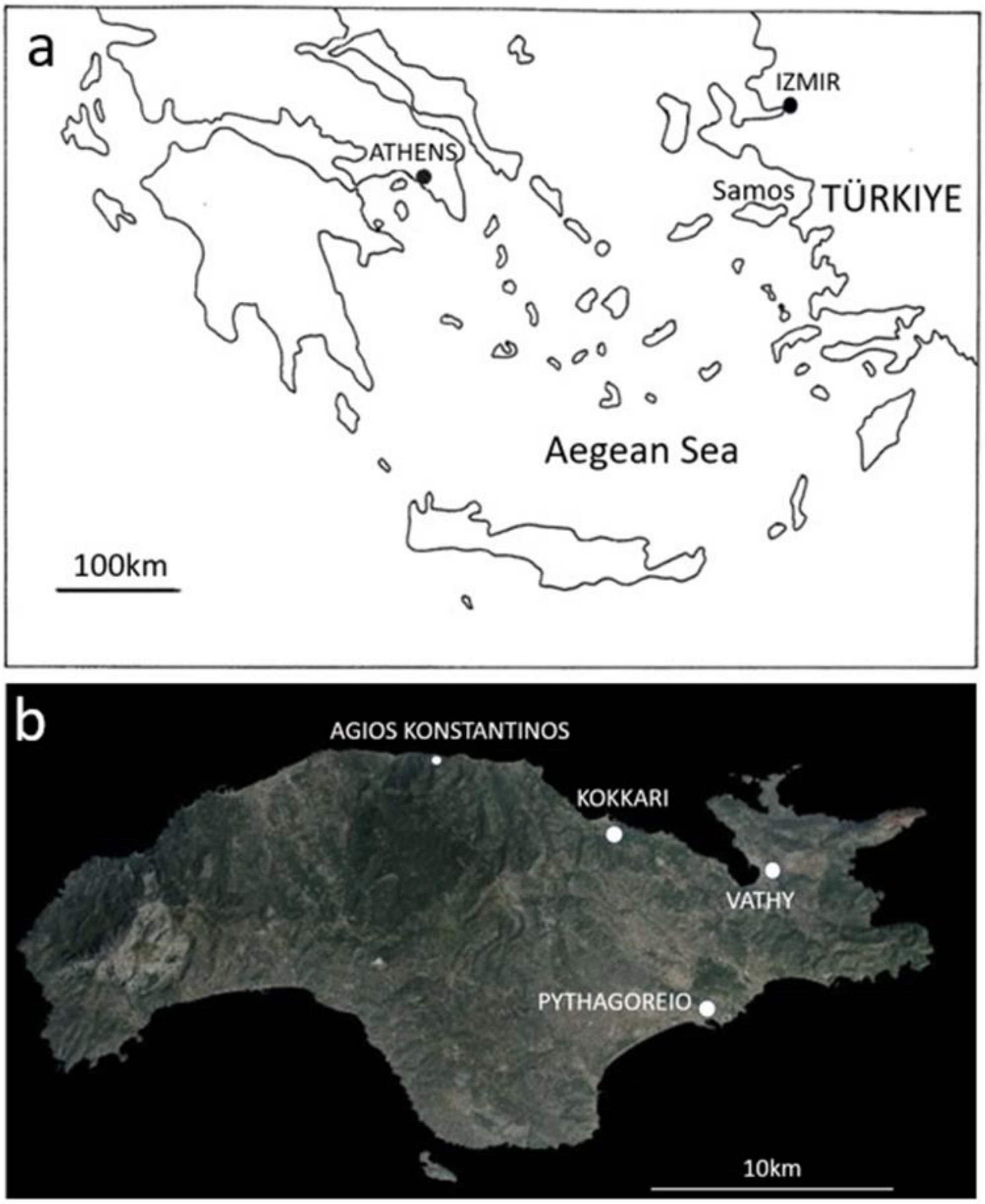

Fig. 1. Location map

3. The effect of the 2004 cyclone in Samos

During the night of 22/23 January 2004, the north coast of Samos Island was among the coasts of the Aegean battered by this unusual Mediterranean cyclone. Wind gusts with velocity of at least 45 m/s were recorded (Lagouvardos et al 2007), producing waves of 15 m (H. Kalogerakis, Head of Civil Protection, interview to daily newspaper TA NEA, no 17847, 23 Jan 2004). As a result, damage was caused to roads, houses, and harbors, for instance at the Kokkari village in Samos (for location see Fig. 1), while marine sediments and destruction debris covered coastal zones and the mole of the harbour of this village was slightly damaged.

At the nearby village of Agios Konstantinos (for location see Fig. 1), in particular, damage was more serious. The extreme wave attack lasted for about 15 min, and the coastal zone of the village, at a depth of up to 100 m was flooded. Waves damaged road sidewalks, crushed doors and flooded coastal houses; in one case an elderly couple survived flooding on top of a table. When the water gradually withdrew, a layer of sand, pebbles, marine biological remains and destruction debris, reminiscent of a typical tsunami layer, was left. Fortunately, nobody perished because in winter very few people were living in the coastal houses. The mole of the harbour of Agios Konstantinos, about 60 m long, made of reinforced concrete, 4 m wide, was seriously damaged (Figs 2, 3). Along a distance of a few tens of meters concrete slabs 1.2 m high, 0.8 m wide and about 2 m long protecting the mole from the open sea and cemented on it, were toppled down and were thrown into the harbour basin.

In addition, boulders protecting the mole, some over 10 tons in weight, were lifted, passed over the mole, about 1 m above mean sea-level, and were catapulted into the harbour basin, at the distance of >10 m, beyond the anchors area. One of these boulders, along with a concrete slab cemented to it, remained on the mole (Fig. 2). The majority of the boulders protecting the mole, however, retreated in the open sea. The harbour was repaired two years later.

Fig. 2: The Agios Konstantinos (Samos) harbour mole, striking nearly E-W, after the 2004 cyclone, view from the east. Damage caused is clearly visible. After the storm (cyclone) a part of the concrete wall protecting the mole from northern winds was found displaced, along with a boulder protecting the mole to the north. Missing parts of the concrete wall and other boulders from the seaside part of the mole were catapulted to the harbour basin. Photo taken by the author a few months after the event.

Fig. 3. The harbour mole of Agios Konstantinos (Samos) view from the west. Damage in the protective wall and missing boulders from the seaside part of the mole can be

clearly noticed. During the storm, some of the missing boulders had fallen into the harbour basin. Photo taken by the author a few months after the event.

4. Effects of the 2020, M7.0 Samos earthquake

In October 2020 a magnitude M7.0 earthquake hit Samos and the adjacent coast of Minor Asia, causing serious damage in Samos and hundreds of victims in Izmir, in Türkiye. This earthquake was associated with a normal fault, with its upper tip very close to the northernmost coast of Samos Island. Numerous studies cover this event, including papers in Special Volumes in the Turkish Journal of Earth Sciences (vol. 30, 2021), in Acta Geophysica (vol. 69, 2021), and in the Bulletin of Earthquake Engineering (vol. 20, issue 14, 2022). This earthquake produced serious damage to the harbour of Kokkari, and smaller scale damage to the harbour of Agios Konstantinos (Fig. 4). In addition, it produced a small tsunami in the Bay of Vathi, where is located the capital of the island, while small scale, localized incursions of water were noticed in various parts of its coast (Triantafyllou et al, 2021), as well as in the opposite Turkish coast (Aksoy, 2021).

5. Discussion and Conclusions

The evidence from Agios Konstantinos is important for several reasons. *First*, it presents evidence of boulders which were catapulted to the inner basin of the harbour during an extreme storm. In contrast to most other cases, in the case of Samos, it is known the pre-event location of these boulders, and especially their elevation relative to the mean sea level in an area essentially free of a significant tide (mean tide < 12 cm, Zoi-Morou, 1981). Furthermore, it was not an isolated boulder, but a cluster of boulders which were mobilized during this single storm. This clear evidence can be used to validate or even refine mathematical models for boulder mobilization during extreme storms. *Second*, while the cyclone front was tens or hundreds of kilometres long, a peak event occurred in a specific site, along a distance of a few tens of metres only, in a part of the mole of Agios Konstantinos. This may indicate that during a strong meteorological event, localized peaks of a certain of its parameters may occur. *Third*, apart from the unusual occurrence of a cyclone, the Mediterranean and other coastal regions are occasionally affected also by spouts and waterspouts with intensity up to T6 in the TORRO 12-grade tornado intensity scale, which are sometimes catastrophic (Sioutas, 2003). Interestingly, the impacts of the 1955, July 16, magnitude 6.9 earthquake (epicentre between Samos Island and the Turkish coast; Papazachos and

Papazachou, 1997) on the coastal town of Pythagorion in SE Samos were aggravated by a spout which occurred some weeks later (pers. comm. with local people).

Fourth, should the two marine invasion events in Samos, the 2004 meteorological tsunami and the 2020 earthquake-generated tsunami had occurred earlier, in a period not covered by detailed observations, a mixture of two, nearly co-eval events would have been observed. The only possibility to study them would have been through geomorphological observations and sedimentological and radiocarbon analyses. From such a study, it is likely that the mixture of the two distinct nearly co-eval events (earthquake and storm) would appear as a single, larger scale event, a tsunami, or an even more extreme storm. This implies that in various other cases, a combination of different events should be examined as a possibility for mobilization of coastal boulders.

Fig. 4. Some of the damage to the harbour mole of Kokkari (top) and of Agios Konstantinos (bottom) because of the 2020 earthquake (view to the north). The east part of the Kokkari mole was seriously damaged, while most boulders protecting the east edge of the Agios Konstantinos mole were thrown into the water. Photos taken by the author in June 2021.

6. Data Availability

The data used to support the findings of this study come from the author's observations and are available upon reasonable request.

7. Conflicts of Interest

The author declares no conflict of interest regarding this publication.

8. Funding Statement

The author received no financial support for the research, authorship and/or publication of this article.

9. References

Aksoy, M.E. 2021. Post-event field observations in the İzmir–Sığacık village for the tsunami of the 30 October 2020 Samos (Greece) Mw 6.9 earthquake. *Acta Geophysica*, 69 (3), 113-1125.

Brikas, D., Karacostas, T., Pytharoulis, I. 2013. Synoptic Aspects of the Eastern Mediterranean Explosive Cyclogenesis of 22 January 2004. In: Helmis, C., Nastos, P. (eds) Advances in Meteorology, Climatology and Atmospheric Physics. Springer Atmospheric Sciences. Springer, Berlin, Heidelberg. doi: 10.1007/978-3-642-29172-2_6

Browne, A. 2011. Coarse coastal deposits as palaeo-environmental archives for storms and tsunamis. PhD thesis, Southern Cross University, Lismore, Australia, 276 pp.

Kelletat, D., Scheffers, S.R., Scheffers, A. 2007. Field Signatures of the SE-Asian megatsunami along the West Coast of Thailand Compared to Holocene Palaeo-tsunami from the Atlantic Region. *Pure Applied Geoph.*, 164: 413-431.

Lagouvardos, K., Kotroni, V., Defer, E. 2007. The 21–22 January 2004 explosive cyclogenesis over the Aegean Sea: Observations and model analysis, *Q. J. R. Meteorol. Soc.*, 133, 1519–1531.

Morton, R.A., Richmond, B.M., Jaffe, B.E. & Gelfenbaum, G. 2006. Reconnaissance investigation of Caribbean extreme wave deposits-preliminary observations, interpretations, and research directions. – Open-file report 1293, USGS, 46 pp.

Nott, J. 2003. Waves, coastal boulders and the importance of the pre-transport setting. *Earth Planet. Sci. Lett*. 210, 269-276.

Papazachos, V., Papazachou, C., 1997. Earthquakes in Greece, Zitis, Thessaloniki.

Scheffers, A., Kelletat, D., Scheffers, S.R., Bryant, E.A. 2008. The Holocene Palaeo-Tsunami History of West Australia. – Earth and Planetary Science Letters, 270: 137-146.

Shah-Hosseini, M., Saleem, A., Mahmoud, A.M.A. et al. 2016. Coastal boulder deposits attesting to large wave impacts on the Mediterranean coast of Egypt. *Nat Hazards* 83, 849–865.

Shiki, T., Tsuji, Y., Yamazaki, T. & Minoura, K. (eds). 2008. *Tsunamiites. Features and Implications*. Elsevier, 411 pp.

Sioutas, M. 2003. Tornadoes and waterspouts in Greece, *Atmosph. Res.* 67– 68, 645–656.

Triantafyllou, I., Gogou, M., Mavroulis, S., Lekkas, E., Papadopoulos, G.A., Thravalos, M. 2021. The Tsunami Caused by the 30 October 2020 Samos (Aegean Sea) Mw7.0 Earthquake: Hydrodynamic Features, Source Properties and Impact Assessment from Post-Event Field Survey and Video Records. *J. Mar. Sci. Eng*., 9, 68. https://doi.org/10.3390/jmse9010068

Zoi-Morou, A., 1981. Data on the tides of Hellenic harbours. Oceanographic Study No. 13, Hydrographic Survey, Athens (in Greek).