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RAPID DETERMINATION OF EARTHQUAKE SOURCE PARAMETERS FOR TSUNAMI EARLY WARNING SYSTEM FOR EGYPT

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ABSTRACT

Early warning systems in countries depend on how fast they can determine source parameters, especially magnitude. This study used SeisComP3 (SC3) to determine different magnitudes for 32 significant earthquakes in the Mediterranean Sea. Different magnitudes (i.e., mb, Mwp, and mB) under different computational times are compared with the Mww determined by the United States Geological Survey (USGS) for evaluation. Tsunami Travel Time (TTT) Software Package by ITIC was used to calculate the tsunami wave arrival times on Egypt's coasts. The results obtained for mb confirmed the magnitude saturation, especially for large earthquakes. We determined the relationship between Mww and Mwp and between Mww and mB. We obtained Mw estimates from Mwp using the formula implemented in SC3 and those using the relation of this study. Then, we evaluated the tsunami messages following the Standard Operational Procedures at different times and compared those for Mww from USGS. The messages did not change much for the estimates from SC3 and those from the formula of this study. At 11 minutes after the origin times, for 28 events, the messages are accurate, and for 4 events, they are under-estimates for both cases. For mB results at 11 minutes after the origin times, for 22 events, the messages are accurate, and for 10 events, they are false when the estimates from SC3 were used. The number of false messages decreased to 6 when we applied the formula obtained by this study. These results suggest that Mwp is more stable and accurate than mB. It takes more than 65 minutes for tsunamis from the Hellenic and Cyprian arcs to reach the Egyptian coasts. Therefore, tsunami warnings around 11 minutes after the origin times are expected to be effective for tsunami countermeasures in Egypt.

Keywords: Tsunami Early Warning System (TEWS), Magnitude estimation, Mwp, mB, SeisComP3.

1. INTRODUCTION

The annual tsunami threat worldwide risks individuals and assets because violent and potent tsunamis exact a heavy toll on humanity and infrastructure, devastating coastal areas. Egypt is in northern, eastern Africa, boarded by the Red Sea from the east and the Mediterranean Sea from the north. The tsunamis from the Mediterranean and Red Seas were recorded; the tsunami from the Red Sea is considered smaller than that from the Mediterranean Sea. The Eastern Mediterranean (EM) is divided into the west and east Hellenic arc, forming the Hellenic and the Cyprian arcs arranged from west to east (Tinti et al., 2005). After the significant Ocean tsunami in India on December 26, 2004, and the World Conference on Disaster Reduction in Kobe in 2005, the associated consequences were comprehensively analyzed and reviewed. Five national monitoring centers act as TSPs supporting the North-Eastern Atlantic and

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Mediterranean Tsunami Warning System (NEAMTWS) in cooperation with several task teams and technical working groups. By subscription, the focal points can receive tsunami alerts and warning information. Egypt is one of the service recipients. This study investigates how to quickly and precisely determine the earthquake source parameters (e.g., magnitude) as the first step in accomplishing a tsunami early warning system for Egypt. We also compare different magnitude types that the NRIAG might rely on to produce the first alert.

2. DATA

Many significant earthquakes in the Mediterranean Sea region produced tsunamis through the Mediterranean coast. 32 significant earthquakes above 5.5 occurred in this region between 2012 and 2022. The study area between 30° N and 38° N latitude and between 21° E and 36° E longitude was selected for the automatic computation of the source parameters. These selected earthquakes were used to check the SeisComP3 configuration and the magnitudes' computational time. The earthquake that occurred on January 17, 2013, at 21:17:00 UTC with ~ Mb 4.9 magnitude was selected to test the supposed travel time of the tsunami wave because it was the nearest earthquake to the Egyptian forecast points at the Alexandria Station and Rashid town. With the SeisComP3 software, various configurations were tested using different data sets. Initially, the data for this event list were archived through the Federation of Digital Seismograph Networks (FDSN) to be an SDS archive for many of the global networks served by both the Incorporated Research Institutions for Seismology (IRIS) and the German Research Centre for Geosciences (GFZ). Figure 1 depicts the globally configured stations used in SeisComP3 (SC3, Olivieri & Clinton, 2012) for the automatic solution and source parameter computation.

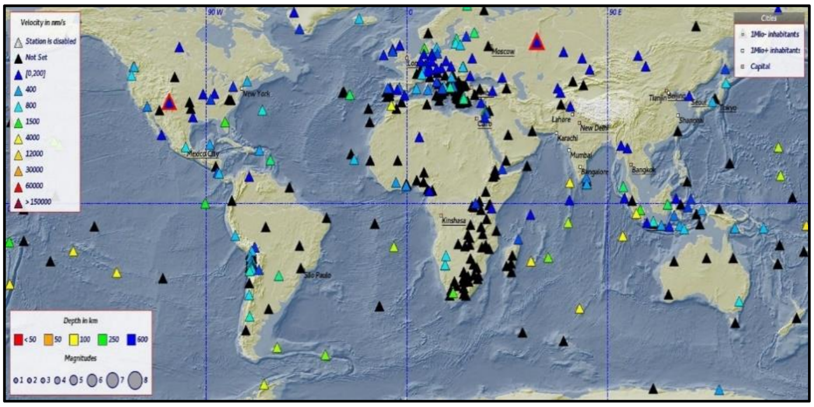

Figure 1. Distribution of seismic stations configured in SeisComP3.

3. METHODOLOGY

3.1. SeisComP3 Software

SC3 is an automatic earthquake solution tool developed for the German–Indonesian Tsunami Early Warning System (GITEWS) project in the aftermath of the catastrophic 2004 Sumatra Tsunami framework (Necmioğlu et al., 2021). SC3 exhibits a markedly modular architecture with developed modules tailored for automated and interactive data processing. It integrates various essential components, including versatile data acquisition capabilities, robust data quality control procedures, and efficient data archival systems. It also supports real-time data transfer protocols, automated algorithms for precisely determining seismic event characteristics (e.g., location, depth, magnitudes, and rupture parameters), advanced alerting mechanisms, and sophisticated visualization tools (Hanka et al., 2010). This comprehensive integration facilitates comprehensive seismic data analysis and interpretation within the scientific context of this work. SC3 can compute various magnitude types (i.e., ML, mb, mB, Mw(mB), Mwp, Mw(Mwp), MLv, and Ms_20).

3.2. SeisComP3 Magnitude Determination

SC3 is used to detect earthquakes and determine hypocenters and magnitudes. The magnitudes analyzed in this study are Mwp (Tsuboi et al., 1995), mB (Bormann & Saul., 2008), and mb (Gutenberg & Richter, 1956). Mw(mB) is an estimate of moment magnitude from mB. The following conversion formula is implemented in SC3. (SeisComP3, Modules, SCMAG, https://docs.gempa.de/seiscomp3/current/apps/scmag.html):

$$\mathrm{Mw(mB)} = 1.30\ \mathrm{mB} - 2.18 \tag{1}$$

SC3 rapidly estimates the broadband moment magnitude (Mwp) from the first-arrival P waves. The Mw(Mwp) is an estimate of moment magnitude from Mwp. The following conversion formula is implemented in SC3.

$$\mathrm{Mw(Mwp)} = 1.31\ \mathrm{Mwp} - 1.91 \tag{2}$$

We used SC3 herein to estimate the different magnitude types and determine their computational time and accuracy in detecting the most suitable magnitude type for our configuration. The efficiency of an early warning system relies on both time and accuracy. Analyzing the previous historical earthquakes in the Mediterranean Sea required SC3 playback. Accordingly, online and offline playback ways were tested in SC3 under various trials.

3.3. Standard Operational Procedure and Decision Matrix

The earthquake source parameters (i.e., magnitude and epicentral distance) that could easily and automatically be determined with SC3 control the alert level for the forecast points in coasts. The earthquake magnitude is an essential source parameter for the first tsunami alert computational time. The determined source parameters go through the standard operating procedures (SOP) for early warning. In the Mediterranean Sea region, issuing tsunami alerts follows a decision matrix (DM) that the NRIAG also looks forward to considering similar procedures in further steps for establishing the early warning system. The DMs employed by the TSPs generally exhibit a shared underlying major structure, although some minor variations exist. Table 1 shows the SOP by KOERI-TSP and the procedures that mainly involve three different source parameters with three alert levels (Necmioğlu et al., 2021).

Table 1. KOERI-TSP decision matrix.

Depth	Epicenter Location	magnitude	Tsunami Message		
			Local	Regional	Basin- Wide
			< 100 km	≥ 100 and ≤ 400 km	> 400 km
< 100 km	Offshore or ≤ 40 km inland	$5.5 \leq M \leq 5.9$	Information	Information	Information
		$6 \leq M \leq 6.4$	Advisory	Information	Information
	Offshore or ≤ 100 km inland	$6.5 \leq M \leq 6.9$	Watch	Advisory	Information
		$7 \leq M \leq 7.4$	Watch	Watch	Advisory
		$M \geq 7.5$	Watch	Watch	Watch
	> 40 km and < 100 km inland	$6 \leq M \leq 6.4$	Information	Information	Information
≥ 100 km	≤ 100 km inland	$M \geq 6$	Information	Information	Information

4. RESULTS AND DISCUSSION

4.1. mb Magnitude Saturation

Figure 2 shows the comparison between mb and Mww. The mb is underestimated for the larger earthquakes (Mww ≥ 6.2). The saturation of mb was confirmed. Hence, we excluded mb from the following early warning system procedures because it is inefficient and shows low accuracy for large earthquakes.

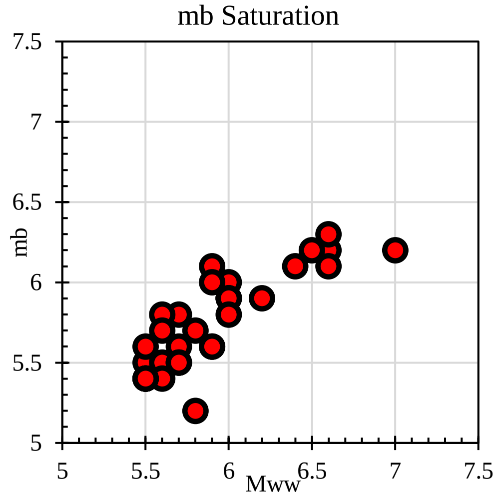

Figure 2. Comparison between Mww and mb.

4.2. Comparison of Mwp and Mww

Figure 3 shows the comparison between the Mwp computed by SC3 and the Mww by the USGS for the 32 earthquakes in the Mediterranean Sea. The relationship between them is presented in Eq. (3).

$$Mwp = 0.714\ Mww(USGS) + 1.803 \quad (3)$$

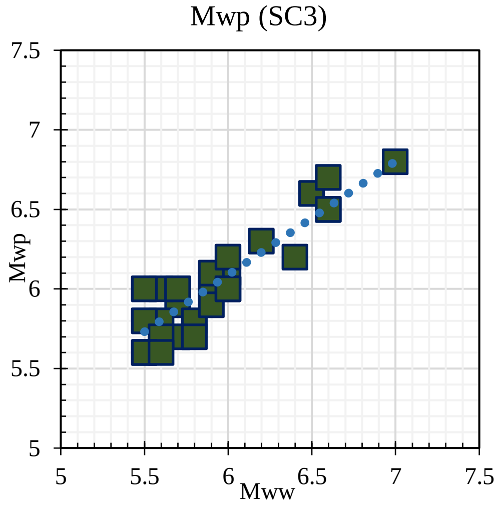

Figure 3. Comparison between Mwp and Mww.

4.3. Comparison of mB and Mww

Figure 4 compares the mB and the Mww by the USGS. The relationship between them is presented in Eq. (4).

$$mB = 0.868\ Mww(USGS) + 1.035 \quad (4)$$

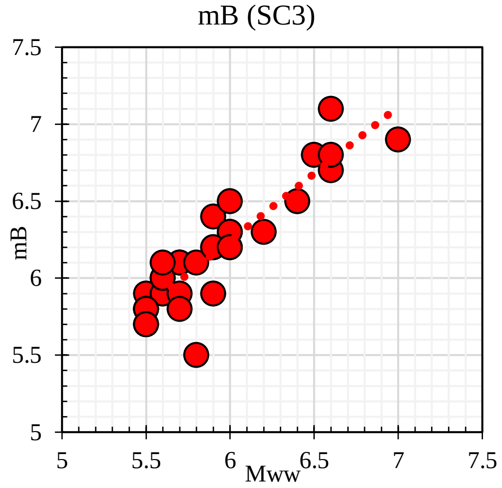

Figure 4. Comparison between mB and Mww.

4.4. Decision Matrix Performance

The magnitudes values obtained by SC3 are used in the SOP for the DM to produce tsunami messages. Watch, Information, and Advisory are the three messages used in the early warning SOP. Only two alerts, Information and Advisory, are produced for the analyzed earthquakes on Egypt's coasts. The watch alert message was not produced for the earthquakes analyzed in this study for Egypt. We used the USGS magnitude as a reference magnitude to produce the actual alert level. Tables 2 and 3 summarize the total number of accurate and false alerts for the magnitude values estimated by SC3 and this study, respectively. The used magnitude values are the final estimates and those obtained around 6 and 11 minutes after the origin times.

Table 2. Accurate and false alerts are estimated by SC3 results at different times for Mw(Mwp) and Mw(mB).

SC3 Alerts	6 Minutes		11 Minutes		Final Estimate	
	Mw(Mwp)	Mw(mB)	Mw(Mwp)	Mw(mB)	Mw(Mwp)	Mw(mB)
Over-estimate False Alerts	1	1	0	1	0	1
Under-estimate False Alerts	4	9	4	9	3	9
Total False Alerts	5	10	4	10	3	10
Accurate Alerts	27	22	28	22	29	22

Table 3. Accurate and false alerts for Mw(Mwp) and Mw(mB) are calculated by the respective relationships estimated in this study.

This study result Alerts	6 Minutes		11 Minutes		Final Estimate	
	Mw(Mwp)	Mw(mB)	Mw(Mwp)	Mw(mB)	Mw(Mwp)	Mw(mB)
Over-estimate False Alerts	2	1	0	1	0	1
Under-estimate False Alerts	4	5	4	5	3	4
Total False Alerts	6	6	4	6	3	5
Accurate Alerts	26	26	28	26	29	27

By comparing the results, the numbers of false alerts for Mw(Mwp) are smaller than or equal to those for Mw(mB). Therefore, Mwp is considered more accurate than mB. The comparison between 6 and 11 minutes after the origin times is essential to evaluate the time for producing the early warning system for Egypt. By using SC3 estimates, Mw(Mwp) produced 5 false alerts within 6 minutes after the origin time, and the false alerts reduced to be 4 false alerts within 11 minutes. Using this study's estimates, Mw(Mwp) produced 6 false alerts within 6 minutes and 4 false alerts within 11 minutes. Considering that all the false alerts occurred for smaller events (Mww≤5.9), Mw(Mwp) estimates obtained within 11 minutes are effective for tsunami early warning for Egypt's coasts.

4.5. Tsunami Travel Time Evaluation

The tsunami travel times of the analyzed earthquakes shown by the red stars in Figure 5 were compared to those necessary for magnitude estimation. We used the Tsunami Travel Time (TTT) Software Package by ITIC to calculate the tsunami travel times. The bathymetry data for the Mediterranean region were downloaded using (GEBCO Compilation Group, 2023). The tsunami waves will take more than 65 minutes to reach the supposed forecast point (Alexandria Station). We calculated the TTTs for the small event (Mww=4.9) near Egypt (the green star in Figure 5). The tsunami waves will take 45 minutes to reach Alexandria and 35 minutes to reach the nearest town, Rashid.

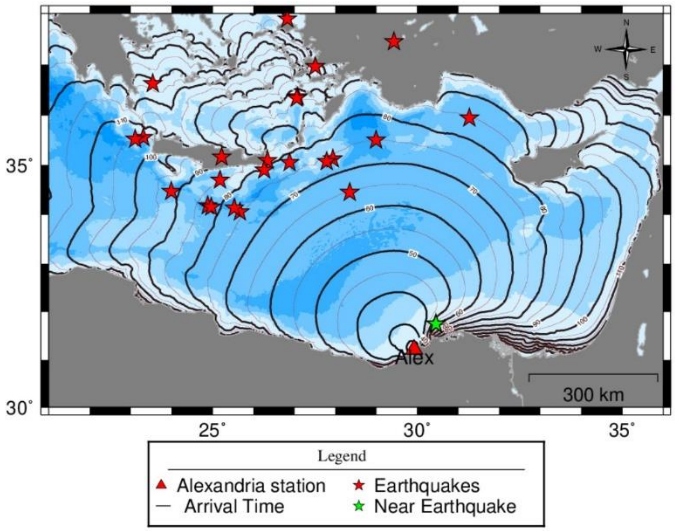

Figure 5. Tsunami travel time for the 32 earthquakes.

5. CONCLUSIONS

In this study, we analyzed the 32 earthquakes (Mww ≥ 5.5) in the Mediterranean Sea between 2012 and 2022 to evaluate how fast we can precisely determine the source parameters, especially the magnitude values. Different magnitude types were automatically computed in SC3. We confirmed that mb is saturated for large earthquakes. The relationships for Mwp and Mw and mB and Mw were obtained using the final magnitude estimates to reduce their systematic differences for the Mediterranean earthquakes.

We used the magnitude estimates and Standard Operational Procedure to obtain the tsunami messages. We used Mww from the USGS as a reference and obtained 1 advisory message and 27 information messages, and no messages for 3 earthquakes.

The number of false alerts for SC3 and the result estimates were computed 6 minutes and 11 minutes after the origin times. The numbers of false alerts for Mw(Mwp) are smaller than or equal to those for Mw(mB) for all the cases, which indicates Mw(Mwp) is more accurate. The estimates within 11 minutes for Mw(Mwp) produced smaller numbers of false alerts than those for 6 minutes.

It takes more than 65 minutes for tsunamis from the Hellenic and Cyprian arcs earthquakes to reach the Egyptian coasts. In conclusion, tsunami messages based on the Mw(Mwp) estimates around 11 minutes after the origin time will effectively reduce tsunami damages for Egypt.

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