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Historical tsunamis of Taiwan in the 18th century: the 1781 Jiateng Harbor flooding and 1782 tsunami event

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Abstract. This research aims to study two historical tsunamis that occurred in Taiwan during the 18th century and to reconstruct the incidents. The 1781 Jiateng Harbor flooding, recorded by the Chinese historical document entitled "Taiwan Interview Catalogue" took place on the southwest coast of Taiwan. In contrast, the 1782 tsunami was documented in foreign languages, with uncertainties about the actual time. These two events seem to be close enough in time and location that, to some researchers, they are considered as the same event. Reasoning these historical events requires carefully examining the literature records and performing the scenarios that match the descriptions. The impact intensity analysis (IIA) is employed to locate possible regions of tsunami sources in order to reproduce the events. Numerical simulations based on the Cornell Multi-grid Coupled Tsunami Model (COMCOT) analyze the influence of different types of tsunamis generated by both submarine mass failures and seismic activities. Numerical results indicate that the source of the 1781 Jiateng Harbor flooding is located very possibly on the south-southwestern side of Taiwan. However, simulation results and historical records put the existence of the 1782 tsunami in doubt, and the possibility of storm surges could not be ruled out.

1 Introduction

One of the major hazards in coastal regions is inundation by water waves generated by different mechanisms such as storm surges, tsunamis, or meteotsunamis. Storm surges and meteotsunamis are known to be triggered by weather events associated with pressure changes. On the other hand, tsunamis could be generated by earthquakes below or near the ocean, submarine landslides, volcanic eruptions, meteorite impacts, or off-shore rock falls, causing damage to the infrastructure and large loss of life in the coastal areas (Ghobarah et al., 2006; Mori et al., 2013; Widiyanto et al., 2019). On 15 January 2022, the volcanic eruption of Hunga Tonga–Hunga Ha'apai generated tsunami waves that triggered evacuations in the surrounding countries. The sea-surface fluctuations were widely recorded and raised worldwide attention on the issue of coastal inundations (Carvajal et al.,2022; Manneela and Kumar, 2022; Ramírez-Herrera et al., 2022). To prepare for possible natural disasters in Macau, Li et al. (2018) have assessed the future tsunami hazard evolving with a rising sea level. Potential tsunami hazard assessments in the South China Sea (SCS) have also been extensively studied over recent years (Li et al., 2016; Liu et al., 2009; Megawati et al., 2009; Okal et al., 2011). However, it is still essential to look back and examine the historical events in order to recognize the regions that could be affected again. In fact, although most historical tsunamis were reviewed already (Lau et al., 2010; Terry et al., 2017), some of the events in Taiwan remain unknown.

Located in the typhoon-prone area and the Circum-Pacific Belt, Taiwan suffers from both low-pressure weather systems and seismic activities. As the historical storm surge events have been studied (Huang et al., 2007; Tsai, 2014), historical tsunami events have also been modeled (Ma and Lee, 1997; Okal et al., 2011), particularly for the 1867 Keelung event, which is the only historical tsunami incident officially recognized by the government (Cheng et al., 2016; Chung, 2018; Lee, 2014). The 1781 Jiateng Harbor flooding and 1782 tsunami event have received attention as well (Li et al., 2015; Mak and Chan, 2007; Okal et al., 2011). Nevertheless, these two incidents which seem close in time and location stay mysterious with unfounded tsunami sources (Fig. 1).

Customs and local news of Taiwan during the Qing dynasty were recorded in the "Taiwan Interview Catalogue" (Chen, 1830). The Chinese historical document indicates a destructive flooding event occurred at Jiateng Harbor, submerging the villages located in southwest Taiwan in 1781 (See Text S1 from Li et al., 2015). At that time, the weather was fine. Hence, it is less likely to be storm surges or meteorological tsunamis. However, the phenomena described in the historical report match well with typical features that usually appear in tsunami events (the sea roared like thunder, giant wave appeared, water retreated quickly, leaping fishes and shrimps left on the ground). Therefore, the 1781 Jiateng Harbor flooding has been viewed and formally listed as a historical tsunami in previous research (Hsu, 2007; Lau et al., 2010; Li et al., 2015; Lin, 2006; Mak and Chan, 2007; Yu, 1994).

Since there were no local earthquake movements recorded in the historical report of the 1781 Jiateng Harbor flooding, Yu (1994) considered a long-distance earthquake as a possible source of the tsunami. Nevertheless, none of the historical earthquakes (Ganse and Nelson, 1982) could be found to fit the location and the time of the 1781 Jiateng Harbor flooding. Note that tsunamis might be generated by other far-field activities, such as submarine volcanic eruptions. Omori (1916) recorded a tsunami caused by the eruption of Sakurajima on the afternoon of 11 April 1781, and during this event, three boats were overturned, and 15 people drowned. However, due to the spatial distance and topographic barrier, the tsunami waves should have first arrived at Okinawa and the northeast part of Taiwan and therefore would have less influence on Taiwan's southwest coast.

The records of the 1782 tsunami event could only be found in foreign documents (Gazette de France, 1783; Jäger, 1784; Mallet, 1854; Perrey, 1862; Soloviev and Go, 1984). Based on the descriptions of Gazette de France (1783), Okal et al. (2011) performed an earthquake-induced tsunami scenario in the Taiwan Strait and found that the tsunami waves would mainly be confined to the strait. Nevertheless, because the occurrence time is close to the 1781 Jiateng Harbor flooding, the 1782 tsunami event has been considered as the same event in some of the previous studies (Li et al., 2015; Lin, 2006). Lin (2006) suspected the 1781 flooding event as a typographical error of the 1721 tsunami event, which also occurred on the southwest coast of Taiwan and affected Tainan. Meanwhile, Lin (2006) regarded the 1782 tsunami documented in Russian as another typographical error of the 1867 Keelung tsunami by evaluating the credibility of the historical records. Li et al. (2015), on the other hand, eliminated the seismic movements for the lack of historical reports in the neighboring countries and concluded that the severe tsunami of 1781/1782 was most likely generated by submarine mass failures (SMFs). However, assuming that the 1781 Jiateng Harbor flooding and the 1782 tsunami were independent incidents, we found that Gazette de France (1783) and the German report of Jäger (1784) should also be listed as the first and important sources of information about the 1782 tsunami event (see Sect. A1 and A2). First of all, the publication date of Gazette de France (1783) is the closest to the event's year. Second, from the words "Voici ce que je lis dans J. L. Ab Indagine L. M." (i.e., "Here's what I read from J. L. Ab Indagine L. M.") in Perrey (1862), it is reasonable to believe that most of the content in the document is quoted from the German report "Philosophisch und physikalische Abhandlungen" (Jäger, 1784). After examining these two documents, it is also suspected that the date of a second letter sent from Beijing to Versailles was reported with a typographical error about the year. Indeed, the date "En décembre 1682" is found in Perrey's (1862) record, while the phrase is "Im Decemb. Des 1782" in Jäger's (1784) report, making the former less reliable.

Severe coastal impacts caused by storm surges have been recorded and studied. The Bay of Bengal was struck by Bhola cyclone in 1970, and more than 250 000 human lives were taken away as a result of the storm surge and the flooding it triggered (Hossain et al., 2008). In 2005, the storm surge associated with Hurricane Katrina damaged tremendously the Gulf of Mexico, peaking at over 7 m along the Mississippi coastline (Fritz et al., 2007; Robertson et al., 2007). The high-water marks of Cyclone Nargis surpassed the 2004 Indian Ocean tsunami run-up height at corresponding locations in May 2008 (Fritz et al., 2009), causing over 100 000 deaths in Myanmar. In southwest Taiwan, a unique local ritual (i.e. *Quianshuizang*) is still being practiced today to pacify the victims of the 1845 Yunlin Kouhu storm surge event (Chang, 2019). The storm surge, induced by a super-typhoon, was responsible for over 2000 fatalities (Tsai, 2014; Yin, 2013) and was followed by famine and plague (Chang, 2019). In the year 1782, Taiwan was hit by a violent storm that led to coastal damage and missing vessels. Historical records written in both Chinese and foreign languages were found for this incident (Davidson, 1903; Griffiths, 1785; Grosier, 1785; Hsu, 2007; Rees, 1820; Yin, 2013). According to the records of Griffiths (1785) and Grosier (1785), a typhoon struck Taiwan on 22 May, which is the same date documented in the 1782 tsunami reports (Gazette de France, 1783; Jäger, 1784; Mallet, 1854; Perrey, 1862; Soloviev and

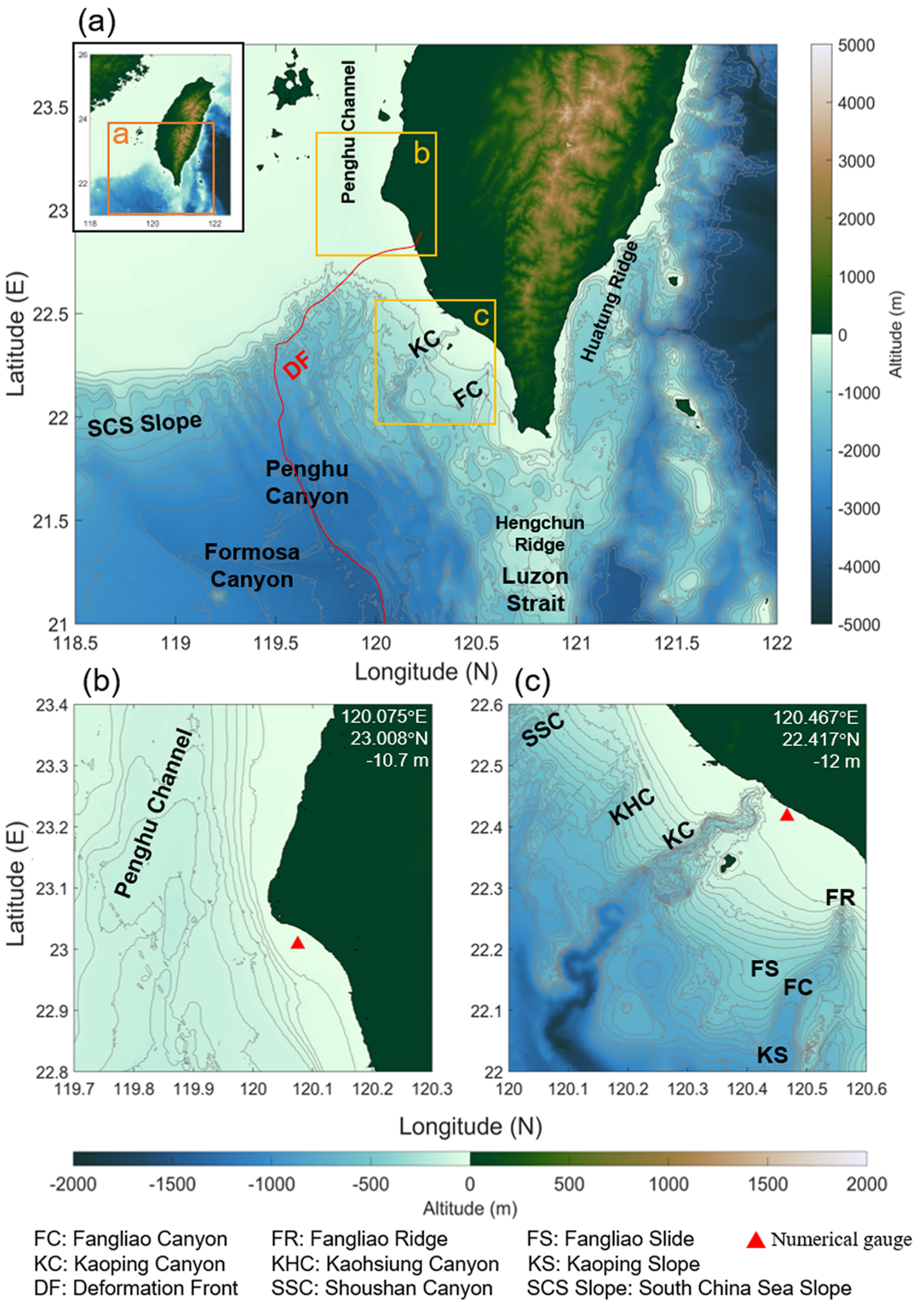

Figure 1. The area of study. **(a)** Bathymetry and related structures off southern Taiwan with 250 m contour interval. **(b, c)** Zoomed maps of Tainan and Pingtung (i.e., Jiateng Harbor location). The contours are plotted with 20 and 50 m, respectively. Red triangles denote the numerical gauges in this study, and the gauge information is marked in the right corner of each figure.

Go, 1984). Other similar descriptions such as the long duration of the natural hazard, impact area (Tainan), coastal inundation, and the imperial edict should also be highlighted.

In this paper, we assessed the tsunami hazard of southwest Taiwan with a new analysis method and conducted numerical simulations to study the 1781 Jiateng Harbor flooding and the 1782 tsunami event. The impact intensity analysis (IIA) method and the modeling approaches of the tsunami scenarios are introduced in Sect. 2. Numerical simulation results are analyzed in Sect. 3, and the discussions through the literature records and the model results are presented in Sect. 4.

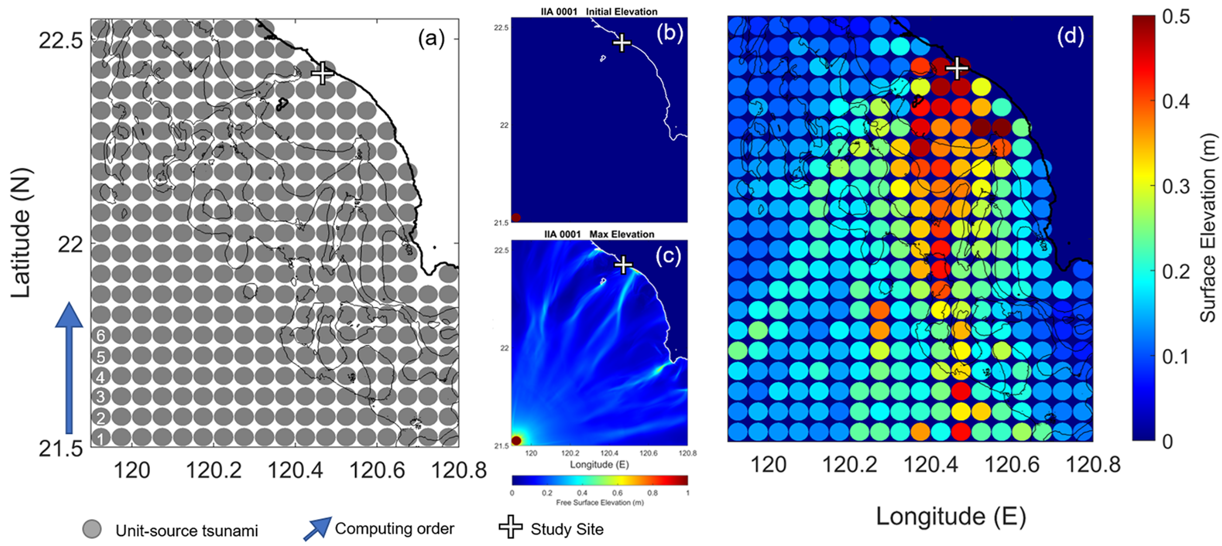

Figure 2. IIA method procedure. **(a)** Unit-source tsunamis are set in the discretized domain of the numerical simulation and conducted individually. **(b, c)** The results of the first unit-source tsunami are presented here as an example. The initial elevation **(b)** and the maximum wave height **(c)** are the essential data that should be saved for each simulation. **(d)** Each simulation's source location is colored by the maximum wave height recorded at the study site (marked by the white cross). Together they form a map comparing the impact of tsunamis in the study area.

2 Methods

2.1 Impact intensity analysis

In order to investigate and reconstruct the 1781 Jiateng Harbor flooding and the 1782 tsunami, we need to find out the possible respective source of the two events. To do so, the impact intensity analysis (IIA) was applied to quantify the effect of potential tsunamis and eliminate the source locations at which the generated tsunami waves are less influential on the study sites. This method has been adopted to reconstruct the 1867 Keelung tsunami event (Chung, 2018; Lee, 2014), as well as to analyze the potential tsunami threats in Taiwan (Wu, 2017).

Unit-source tsunamis have been used for tsunami early warning and forecasting studies (Greenslade and Titov, 2008; Horspool et al., 2014; Liu et al., 2009; Matias et al., 2013; Percival et al., 2011). Since the IIA method aims to compare the effect of same-size tsunamis generated at different locations, the shape of unit sources was therefore set up as a cylinder to ensure the isotropy of initial elevation. With the unit sources distributed evenly, the analysis method enables us to examine thoroughly the study areas. The IIA method is performed with the Cornell Multi-grid Coupled Tsunami Model (COMCOT) (Liu et al., 1998; Wang and Power, 2011), and the process is presented with an example in Fig. 2. As unit-source tsunami simulations were conducted individually in the discretized region (Fig. 2a), we preserved only the initial elevation and the maximum wave height (Fig. 2b and c) for computational efficiency. The maximum wave height at the assigned location would be extracted from each numerical scenario and colored at its source location, forming a map which compares the impact of tsunamis on the study site in the specific area (Fig. 2d).

Referring to the Qianlong Taiwan Map which was drawn between 1756–1759, the study site of Jiateng Harbor is located at 22.417° N, 120.467° E at today's Donggang Township of Pingtung County, while the Tainan study site is located at 23.008° N, 120.075° E (Fig. 1b and c). Model domains cover the southwestern coast of Taiwan (18.7–23.40° N, 117.80–20.00° E), the near-field area (21.50–22.55° N, 119.90–120.80° E), and the far zone (15.35–23.35° N, 117.65–121.75° E) at resolutions of 0.5, 0.05, and 1 arcmin, respectively (Table 1). To ensure the accuracy of bathymetry settings, the bathymetric data at a resolution of 100 m which were gained fundamentally through compilations of data from different marine cruises (Hsu et al., 1996, 1998) were adopted for the first two models. On the other hand, the far-field analysis was conducted with 1 arcmin bathymetric data from ETOPO1 from the National Oceanic and Atmospheric Administration (NOAA).

By the IIA result of Jiateng Harbor, tsunamis generated in the offshore region had stronger impacts on the study sites on the southwestern coast of Taiwan (Fig. 3). The areas where submarine structures are located, including the Fangliao Canyon, Kaohsiung Canyon, Kaoping Canyon, Shoushan Canyon, and the upper part of Penghu Canyon, should be highlighted. With source locations placed from the study site all the way to the Formosa Canyon, tsunami waves had significant impacts on the ancient location of Jiateng Harbor, whereas for Tainan, the possible source locations were lim-

Table 1. Parameters of the unit sources adopted in the IIA method for the three domains.

	Southwestern coast 18.70–23.40° N 117.80–120.00° E	Near-field 21.50–22.55° N 119.90–120.80° E	Far-field 15.35–23.35° N 117.65–121.75° E
Diameter (km)	10	5	40
Elevation (m)	10	1	1
Total number	1504	378	200

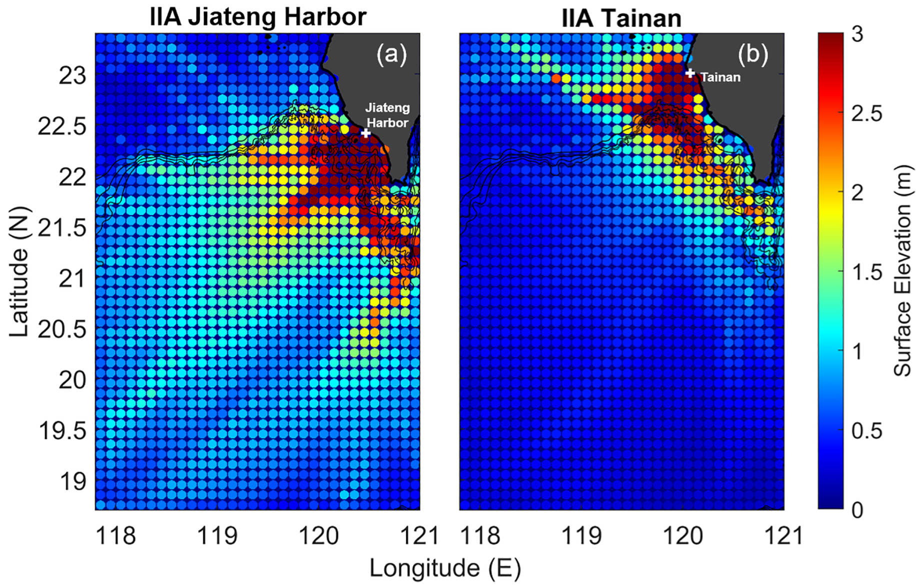

Figure 3. IIA results of the southwestern coast of Taiwan. Panels **(a, b)** show the IIA result of Jiateng Harbor and Tainan, and the white crosses denote the location of the study sites. The circles represent the locations of unit-source tsunamis, with colors showing the value of maximum wave height recorded at the study site.

ited. Moreover, tsunamis with the source located at the northern Penghu Canyon and in specific parts of the Penghu channel and South China Sea Shelf lead to a greater impact on the study sites in Fig. 3. However, tsunamis triggered in the overlap-highlighted area of the Penghu Canyon caused effects to both the study sites.

From the result of near-field analysis, it is clear that the study site is mostly affected by the tsunamis generated nearby (Fig. 4). The area from the Jiateng Harbor study site to Liuqiu Island is highlighted. Note that the maximum wave heights recorded at the Jiateng Harbor decrease rapidly with the distance. Similar to the result of southwestern coast analysis, tsunamis with sources located at the South China Sea Slope, Kaoping Canyon, and Kaoping Slope would have greater influence on the Jiateng Harbor study site. Nevertheless, with a broader region in Fig. 5a, the IIA method revealed that tsunamis generated in the Luzon Strait would also have an influence on Jiateng Harbor. Hence, a dramatic effect of tsunamis triggered by the Manila Trench could be expected at the study site. The far-field IIA of Tainan showed patterns that look like the local result as well in Fig. 5b. With an expanded study area, not only the tsunamis that take place in the upper Penghu Canyon and the Kaoping Slope should be taken into consideration but also the ones that occur in the Luzon Strait. Meanwhile, since tsunamis triggered along the Hengchun and Huatung ridges should contribute a larger wave height to the study site of Jiateng Harbor, we also pay attention to this region.

2.2 Modeling approaches

In addition to the analysis method, tsunami scenarios were performed with COMCOT as well for the purpose of examining tsunami effects on the coastal regions of Taiwan. Tsunamis caused by SMFs were designed referring to the results of the IIA method and previous research through the submarine morphology of Taiwan (Chen et al., 2018; Chiang and Yu, 2006; Chiang et al., 2020; Hsu et al., 2018; Liu et al., 1993; Su et al., 2018). Since having a reasonable initial free-surface elevation for the source is crucial, the amplitudes of SMF tsunamis (Table 2) were obtained by the length and thickness of the mass failure along with the local water depth

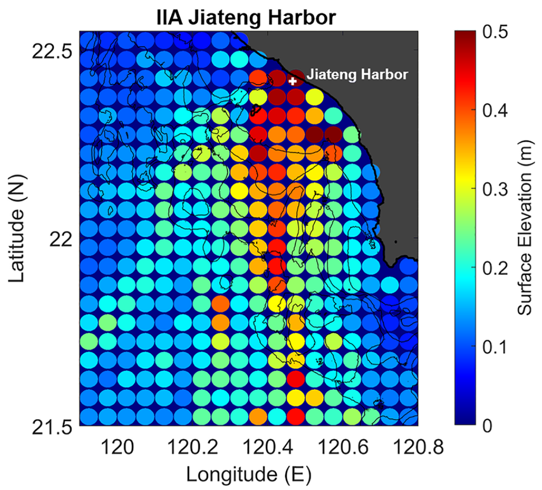

Figure 4. High-resolution IIA results of the Jiateng Harbor. The circles represent the locations of unit-source tsunamis. Color denotes the value of maximum wave height recorded at the study site.

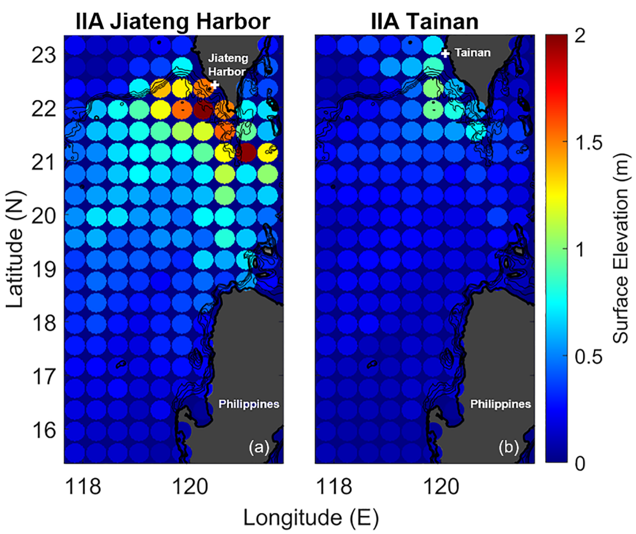

Figure 5. IIA results of the far-field region. Panels **(a, b)** show the IIA result of Jiateng Harbor and Tainan. The white crosses stand for the location of the study sites. The circles are the locations of unit-source tsunamis, with colors showing the value of maximum wave height recorded at the study site.

and slope (Watts et al., 2005):

$$\eta_{2\mathrm{D}} \cong 0.0286T(1-0.750\sin\theta)\left(\frac{b\sin\theta}{d}\right)^{1.25}, \quad (1)$$

where T and b denote the thickness and length of the mass failure, respectively, d represents the water depth at the center point of the mass failure, and θ is the slope angle.

In this research, besides the local SMF tsunamis, seismic tsunamis generated by the deformation front, the northern part of Manila Trench, and the Hengchun Fault were chosen. Since the upper part of Penghu Canyon was highlighted by

Table 2. Parameters of 1781 SMF scenarios.

SMF scenario	Fangliao Ridge (FR)	Fangliao Slide (FS)	Kaoping Canyon (KC)
Longitude (° E)	120.56	120.40	120.23
Latitude (° N)	22.22	22.083	22.341
Length (km)	4.0	12.0	4.0
Width (km)	5.0	12.0	5.0
Initial elevation (m)	8.0	5.0	4.0

the results of IIA (Fig. 3), a scenario of a M_w 7.5 earthquake with focal mechanism of strike of 194°, dip of 20°, and rake of 90° was designed referring to the 1661 Tainan Earthquake (Han et al., 2017; Ma and Lee, 1997; Okal et al., 2011) for studying the impact of tsunamis generated at the deformation front. Additionally, tsunamis generated at the Manila Trench have been viewed as a threat to the South China Sea area (Li et al., 2016; Liu et al., 2009; Megawati et al., 2009; Okal et al., 2011; Qiu et al., 2019; Wu and Huang, 2009). Hence the upper part of the Manila Trench was selected to study the tsunami effect on the southwest part of Taiwan. Following Wu (2012) and Qiu et al. (2019), two scenarios of the Manila Trench were conducted to compare the tsunamis generated with different seismic parameters.

Wu (2012) presented a series of scenarios for estimating the tsunami hazard in Taiwan. The information of rupture area and slip was obtained with the source-scaling of Yen and Ma (2011). For the worst-case tsunami hazard assessment, Wu (2012) also applied the asperities, which are regions on the fault that have larger slips compared to the average slip on the rupture area (Somerville et al., 1999) in some of the tsunami sources in his study. In this research, we selected T02, the M_w 8.2 Manila Trench earthquake of Wu (2012), to study the tsunami effect. On the other hand, two models (A and B) explaining the plate movements on the Manila megathrust and other faults on Luzon Island have been proposed by Hsu et al. (2016). From the geodetic analysis, Hsu et al. (2016) found that the magnitude of earthquakes in the Manila subduction zone could reach $M_\mathrm{w} = 9+$ with an assumption of a 1000-year return period. To assess the potential tsunami hazard of SCS, Qiu et al. (2019) selected scenarios which release 1000 years of accumulated strain and studied the plausible events. Results showed that model B generated larger tsunami impacts than model A did in both near-source and far-field regions (Qiu et al., 2019). Hence, the initial surface displacement of the Gaussian slip distribution with a 50 % coupling ratio scenario of Qiu et al. (2019) was chosen and modeled as well. Meanwhile, although limited damage at the coastal area was expected when the inland earthquake was mainly generated at Hengchun Fault (Wu, 2012), the simulation was conducted based on the descriptions of the foreign reports of Jäger (1784) and Perrey (1862) ("subterranean movements causing the whole island to shake and be devastated; the earthquake lasted for 8 h") and its location at the southern tip of Taiwan (Lin et al., 2009).

To model the evolution of tsunamis, nonlinear shallow water equations were used with a bottom friction Manning coefficient value of 0.013 for SMFs and seismic scenarios. Since SMF tsunamis are generally local events, high-resolution bathymetry of 100 m was employed, focusing on the study area at 0.05 arcmin numerical resolution. To model the evolution of tsunamis triggered by SMFs, nonlinear shallow water equations were used with a bottom friction Manning coefficient value of 0.013. On the other hand, nested grids were set for the seismic tsunami scenarios. The first layer was conducted with 1 arcmin bathymetric data of ETOPO1 from NOAA. Covering Taiwan (21.50–22.50° N, 119.10–122.50° E), the second layer bathymetry was extracted from the data downloaded from the Ocean Data Bank of the Taiwan Ministry of Science and Technology (http://www.odb.ntu.edu.tw/, data acquired in October 2014) at 200 m resolution. Finally, bathymetric data of the third layer were adopted from the fine coastal area data of Wu (2012). Combining the topographic data from the Department of Land Administration of the Ministry of Interior and the Research Center for Space and Remote Sensing of the National Central University, together with the bathymetry provided by Taiwan Ocean Research Center, the resolution of the third layer was interpolated to 27.5 m numerically from the original resolution of 0.0004 arcdeg.

3 Results

3.1 The 1781 Jiateng Harbor flooding

With the detailed descriptions documented in the report, it is possible to reassess this historical event. From the sentences "Giant wave appeared and the water rose for tens of zhang high (1 zhang approximately equals to 3–1/3 m); People were swinging on top of bamboos; In few quarters, the water retreated quickly; The fisherman sailed on top of bamboos on raft; When the wave ebbed, the rafters of the thatched roofs were all gone" (Text S1 from Li et al., 2015), it was assumed the wave height that stuck Jiateng Harbor was about 2 m, close to the wave height that could affect the coastal infrastructure (Yu, 1994) or even higher, and ebbed in few quarters.

Li et al. (2015) considered that SMFs in the Kaoping slope region could have been the major contributor to the 1781/82 tsunami event according to the available historical records at that time, the numerical results, and the fact that offshore southwest Taiwan is a SMF-prone environment. Submarine landslide tsunami scenarios were then designed to investigate and reconstruct the 1781 Jiateng Harbor flooding.

The maximum wave heights of SMF tsunami scenarios (Fig. 6a) showed that the tsunamis with sources located at FR and FS traveled directly to the Jiateng Harbor study site, whereas the waves of KC traveled north of Kaohsiung. The numerical gauge (Fig. 1c) records of FR and FS held also higher values amid the scenarios (Fig. 6b). Moreover, the wave crest reached to 3.5 m for the simulation of FS. The results that the half cycles of the first waves were all less than 10 min support the description "in few quarters" in the historical report of the 1781 Jiateng Harbor flooding.

3.2 The 1782 tsunami event

To investigate the 1782 tsunami, we conducted four numerical scenarios in order to reproduce the devastating event that matches the historical reports described as "no part of the flooded island remains visible except for the foot of the mountains" (Jäger, 1784; Perrey, 1862). During the simulation of the deformation front, which was generated by a M_w 7.5 earthquake near the Penghu Canyon, the tsunami wave mainly impacted on the coast of Tainan and Kaohsiung (Fig. 7a). However, the wave heights recorded by the numerical gauges at the Jiateng Harbor and Tainan were less than 0.5 m (Fig. 8a and b), far from matching the disastrous event described in the historical reports of the 1782 tsunami event.

In contrast to the scenario of the deformation front, the results of the Manila Trench indicated how destructive tsunami scenarios could be. In particular, massively impacted areas include the northern Philippines, southeast China, and the southern part of Taiwan (Fig. 7b and c). In Fig. 8, the surface fluctuations reached the height of 1.02 m at the Jiateng Harbor and of 0.76 m at Tainan with the parameters of Wu (2012), yet the study sites were impacted by tsunami waves over 5 m in the other scenario of the Manila Trench. With the initial surface elevation of Qiu et al. (2019), the maximum wave height of the tsunami appeared over 5 m along the coastline of Tainan, Kaohsiung, and Pingtung (Fig. 7c). Time series of the numerical gauges showed that tsunami waves arrived at the Jiateng Harbor study site after 20 min, impacting with a wave height of 6.59 m at first, then the second wave arrived after 1 h and 10 min with a height of 6.56 m (Fig. 8a). On the other hand, the first wave arrived at Tainan 39 min after the tsunami's occurrence. The wave height recorded was 5.6 m, and the height of the second wave was reduced to 4.06 m (Fig. 8b). The fluctuations of the free surface decayed to less than 1 m after 4.5 h, about half of the time (8 h) described in the historical reports.

Finally, fault parameters of the Hengchun Fault (Wu, 2012) were employed to investigate the 1782 event with sensible seismic movements (Fig. 7d). Limited tsunami waves generated by the M_w 7.6 Hengchun Fault earthquake were expected for its location. Although parts of the Pingtung coast faced tsunami waves over 3 m high, the maximum wave height was less than 1 m in Tainan and less than 2 m in Donggang area. Tsunami waves recorded by numerical gauges at both study sites of the Jiateng Harbor and Tainan did not exceed 0.6 m (Fig. 8a).

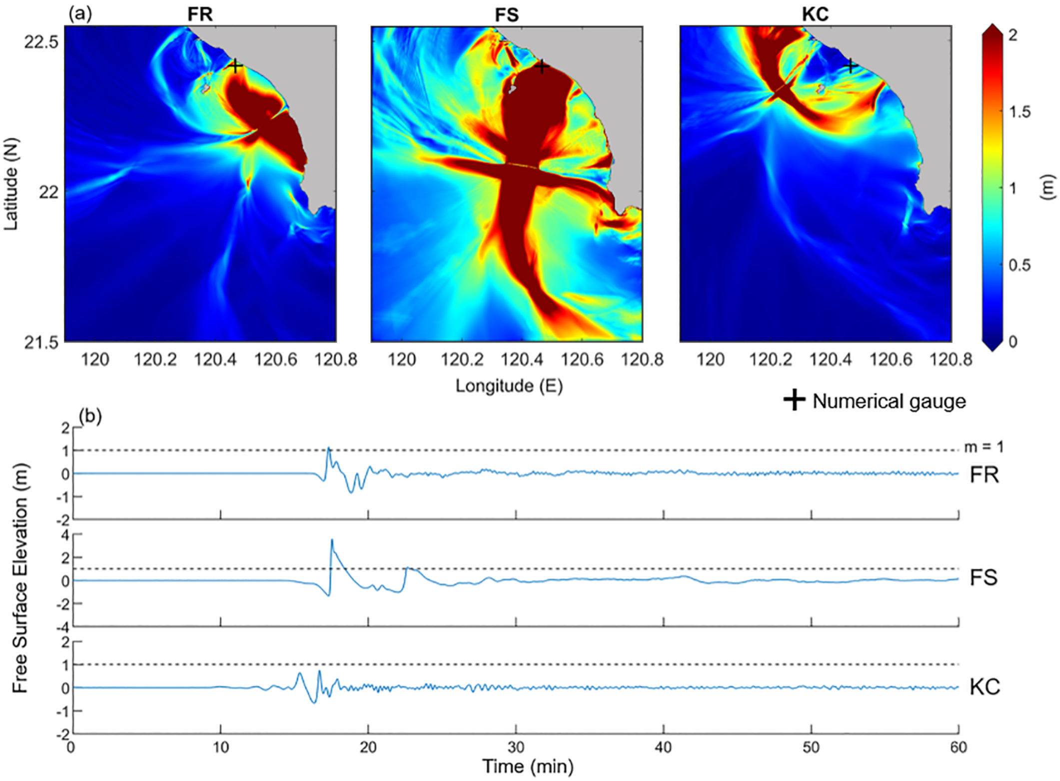

Figure 6. (a) Maximum wave height of the 1781 SMF tsunami simulations. The black cross denotes the numerical gauge of Jiateng Harbor (22.417° N, 120.467° E). **(b)** Numerical gauge records at the Jiateng Harbor study site for the SMF scenarios of FR, FS, and KC. The 1 m elevation is marked with dashed lines for comparison.

4 Discussion

The findings from historical reports suggest that the 1781 Jiateng Harbor flooding and the 1782 tsunami should be two independent incidents. Based on a comprehensive investigation of the historical reports, it is conspicuous that the descriptions are pointing to different events, although the time of year is close. First of all, there is not any seismic movement mentioned in the Chinese record of the 1781 Jiateng Harbor flooding (Chen, 1830), while shaking movements and tremors are documented in the German report for the 1782 incident (Jäger, 1784). Secondly, there are different descriptions on the severity of the resulting damage. It is recorded that the whole island of Formosa was inundated by ocean water till the foot of the mountains, and 40 000 people were killed in the 1782 tsunami event (Jäger, 1784). However, despite the fact that the coastal area was impacted by the waves, only one person died in the 1781 Jiateng Harbor flooding (Chen, 1830).

The results of numerical simulations performed with COMCOT seem to indicate that the 1781 Jiateng Harbor flooding and 1782 tsunami are two different events. In the SMFs study, tsunamis generated in southwest Taiwan, especially from the south-southwest direction, could be the main source of the 1781 Jiateng Harbor flooding. The wave height of the FS scenario fits best the historical description, in particular the half cycle less than 10 min and the duration of "in few quarters". Nevertheless, the SMFs alone could hardly generate tsunamis that submerge Taiwan. In this study, the disastrous scenario of Qiu et al. (2019) suggests that tsunamis triggered at the Manila Trench could contribute to the 1782 tsunami event. However, historical records are not found for the tsunami waves in southeast China and northern Philippines at a time compatible with the event. Moreover, it is unlikely that a severe tsunami in 1782 was not reported by any Chinese document. Therefore, the existence of the 1782 tsunami is less possible and remains doubtful.

Li et al. (2015) were the first group who read, translated, and reported the French record as documented by Perrey (1862). In this study, for the first time the historical documents (Gazette de France, 1783; Jäger, 1784) cited by Perrey (1862) are fully translated and reported together. By analyzing the historical records, the 1782 tsunami event is clarified not to be a typographical error of the 1867 Keelung tsunami proposed by Lin (2006) since the literature records (Gazette de France, 1783; Jäger, 1784; Mallet, 1854; Perrey, 1862) had existed already before the year 1867. Incoherence was found amid historical reports of the 1782 tsunami event since seismic movements were not mentioned in the text of Gazette de France (1783) or Mallet (1854). While exam-

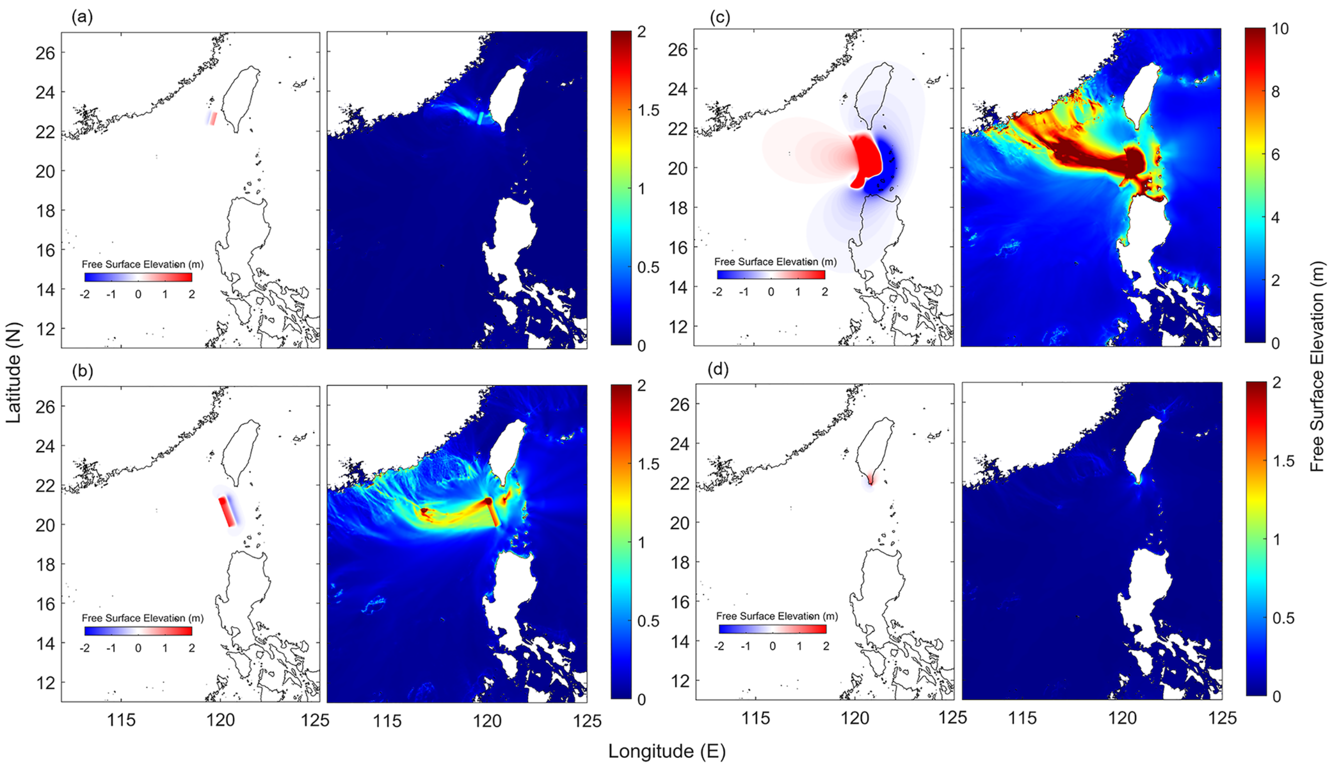

Figure 7. The initial elevations and the maximum wave heights of the seismic tsunami scenarios of **(a)** the deformation front, **(b, c)** the Manila Trench and **(d)** the Hengchun Fault.

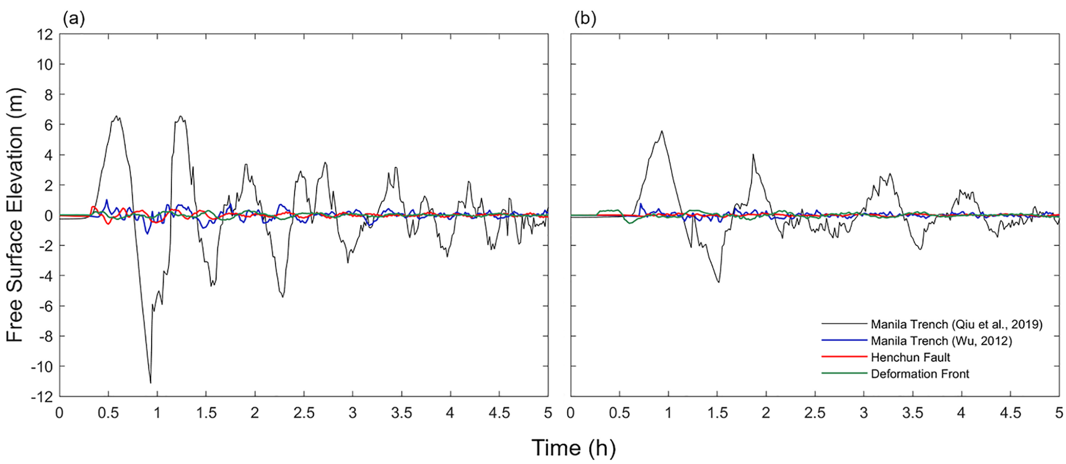

Figure 8. The numerical gauge records at the study sites of **(a)** Jiateng Harbor and **(b)** Tainan.

ining the historical documents, records of Griffiths (1785), Grosier (1785), and Davidson (1903), which reported the storm event on 22 May 1782, also put the existence of the 1782 earthquake in doubt by following the procedure of validation of Mak and Chan (2007). Together with Chinese records and foreign documents of the year 1782 (Davidson, 1903; Griffiths, 1785; Hsu, 2007; Rees, 1820; Yin, 2013), the fact that the significant water level was determined by the storm surge should not be ignored. Meanwhile, since active submarine mud volcanoes were observed in the offshore area of southwest Taiwan (Chen et al., 2014; Mai et al., 2021), we shall neither rule out the possibility of multiple hazards occurring coincidently or very close in the same period (e.g., the eruption of Mount Pinatubo and Typhoon Yunya in 1991). Therefore, numerical simulations of storm surges or complex hazards should be taken into consideration in future studies.

This research suffers some limitations, including the lack of gauge records of the two incidents and the evolution of coastal bathymetry and topography. In the past 200 years, the coastline of southwest Taiwan has changed a lot due to the sediment transportation and the erosion (Chang et al., 2018). Without knowing the exact bathymetry in the 18th century, the accuracy of the numerical gauges may not be satisfied. Therefore, the figures of the maximum wave height, with which the tsunami flux propagation could be traced, should be taken into consideration in the first place. Moreover, the landslide tsunamis require SMF dating to confirm the sources. Hence, further marine surveys are indispensable for fully reconstructing the 1781 Jiateng Harbor flooding.

Examining the historical events allows us to assess the tsunami hazard and to prepare for natural disasters that could possibly occur in the future. Results of the study based on the IIA method show that the offshore region of southwest Taiwan and the Luzon Trench could generate tsunamis that affect most of the southwestern coast of Taiwan. In fact, tsunamis generated locally could impact the coastal area within a very limited time. Hence, a proper evacuation plan is needed for the residents at the seaside.

Appendix A: Translations of Gazette de France (1783) and Jäger (1784)

A1 Text A1

Original text from Gazette de France.: De Paris, le 12 Août 1783.

> Une lettre de la Chine fait mention d'un évènement arrivé l'année dernière, & peut-être plus terrible encore que ceux qu'ont éprouvés la Sicile & la Calabre dans le commencement de celle-ci féconde en désastres. En attendant une relation plus détaillée, voici ce que l'on en raconte: Le 22 Mai de l'année dernière, la mer s'éleva sur les côtes de Fo-Kien à une hauteur prodigieuse, & couvrit presqu'entièrement pendant huit heures l'île de Formose qui en est à 30 lieues. Les eaux, en se retirant, n'ont laissé à la place de la plupart des habitations que des amas de décombres sous lesquels une partie de la population immense de cette Isle est restée ensevelie. L'Empereur de la Chine, voulant juger par lui-même des effets de ce désastre, est sorti de sa capitale; en parcourant ses provinces, les cris de son Peuple excités par vexations de quelques Mandarins, ont frappé ses oreilles; & on dit qu'il en a fait justice en faisant couper plus de 300 têtes.

(Translated from French to English by Tien-Chi Liu, June 2020.)

> A letter from China mentions an event that happened last year, and perhaps it's more terrible than those experienced in Sicily and Calabria which at the beginning of this year suffered many disasters. Pending a more detailed narrative, here's what they tell us: on 22 May 1782, the sea level rose to a prodigious height on the coast of Fujian, covering almost the entire island of Formosa for 8 h, which is situated 30 leagues[1] away. The water ebbed, leaving most of the residential areas nothing but piles of rubble, under which a part of the huge population stayed buried. Wanting to inspect the effects of this disaster by himself, The Emperor of China left the capital. During the journey going through his provinces, the cries of his People, whipped up by the irritation of some Mandarins, struck his ears, and it is said that he executed over 300 people.

A2 Text A2

(Translated from German to English by David Demes, June 2020)

§116

Following the changed order [of the text] mentioned in the Scholion [i.e. commentary] of §112, the submerging of the Island of Formosa into the sea[2] will constitute the third point.

The French Foreign Minister [Ministre d'État] Bertin[3] received a letter from a missionary in Beijing, which contained the most unfortunate news that, in October of 1782, on the Island of Formosa, situated right off the coast of China, fire-breathing mountains and maws unexpectedly burst open. Accompanying their harrowing eruption were subterranean movements, causing the whole island to shake and be devastated. The ocean waves, which were pushed from east to west, evenly covered the whole of the submerged island so that no part of the flooded island remains visible except for the foot of the mountains. The shaking movements and tremors continued for more than 8 h. The three most noble cities of this island (whose names we cannot inquire about on the submerged island) alongside 20 market towns are buried beneath the rubble and their remains were carried away by the force of the sea. More than 40 000 residents, some of them native, some of them Chinese, who found their graves in this accident, have been counted. All promontories that had projected into the sea have been washed away and the locations where they had been situated have now been turned into reservoirs and dregs of water. The forts Seeland[4] and

[1] The ancient measurement unit "lieue" is about 4 km in length.

[2] The German *Untergang* may also refer to "doom", "demise", or "downfall". In this context, a sinking or submerging into the sea seems more appropriate.

[3] Henri Léonard Jean Baptiste Bertin (1720–1792).

[4] Fort Zeelandia, built in 1634 by the Dutch East India Company (VOC) in Anping.

Pingschingi as well as the hills they were built on have vanished. In short, everything has been leveled by the water. Formosa in 1782 and Messina in 1783[5] have shared the same destiny and both have ceased to be what they once were.

Scholion. The Island of Formosa is located in the Asiatic Sea, between Japan, China, and the Islands of the Philippines, 24 mi [176 km] off the Chinese coast. It is about 17 mi [125 km] in length and 15 mi [110 km] in width. Just like Piccando and Legneto it is very fertile and rich in gold and silver ore. In the past, this island had its own king, up until around 200 years ago when it was conquered by the Tartars[6]. And after it had rid itself of their yoke, it was subdued by the Japanese 60 years ago. Of the Europeans, especially the Dutch have settled here and on the small isle of Taiwan built the Fort Seeland, which was in their possession for a long time until it was taken from them in 1661 by the Chinese pirate Coxinga[7].

§117

The information designating the time when this disaster struck the island is not consistent. Then, a letter comes to mind supposedly sent to the former Minister of War Monsieur Bertin from Beijing by a Chinese who had been to Paris many years before. Therein it states:

> In December of 1782, various fire-breathing mountains on the Island of Formosa began to open their fiery jaws. Their dreadful eruption was accompanied by a massive subterranean movement, which shook the whole island and let it be submerged by the seas rolling from east to west. The tremor lasted longer than 8 h. More than 40 000 residents have been counted that found their graves in this horrific accident.

And yet another message reported the following: a second letter from Beijing arrived in Versailles that confirmed everything that had already been reported on the disaster of the Island of Formosa. The suffering of a few thousand who had escaped the stormy waves is said to be unspeakable – as one can imagine.

The emperor of China is said to have sent the following letter to the viceroy of the region of Feu-kim[8] which we indent here because of its rather strange content (one may doubt whether this letter was really written by the emperor):

> I have heard of the disaster that has befallen my Island of Ray-Onan (i.e. Formosa) on 22 May 1782. I hence order you to inquire in detail about the damages the remaining inhabitants of this unfortunate island were forced to suffer and report back to me immediately so I can swiftly render aid. The homes and buildings devastated by the water shall be rebuilt at my expense, and those damaged shall be repaired. You shall provide those unfortunate people with all necessary food at my cost. You shall afford everyone with my help without exception. It would pain me if you neglected just one of them. They should know that I am watching over all of them and that I love all of them fondly. You shall tell them that it is me who is helping them, their lord and father. Also, you shall use funds from the treasury to rebuild as many warships and magazines as this almighty arm has taken from me through the storm and the waves. Do not shirk [from your duty], I forbid it, and report back to me how you have obeyed my will.

Scholion. Because three different months have been given, namely the months of October, December, and May, the actual timing of when the Island of Formosa was destroyed cannot be determined. It is enough for us to know the year. And from the letter sent by the missionary from Beijing to Monsieur Bertin in the year of 1783 we can gather that during the eruption of the subterranean fires, the sea on the coast of China towered to an unnatural or unusual height and flooded and submerged the whole island so that not the tiniest bit could be seen for several days. And after the water had retreated, one could make out no sign at all, not of the human population nor of any four-footed animals.

In all of history, one cannot find an incident so horrific like the ones that happened in Formosa and Messina.

[5]Reference to the 1783 Calabrian earthquakes.

[6]Reference to the Manchus, i.e. the Qing Dynasty.

[7]Zheng Chenggong (1624–1662).

[8]Probably a variant spelling of Fukien or Fujian Province. During the Qing Dynasty, the Governor General of Taiwan, Fujian, and Zhejiang was known as the Viceroy of Min-Zhe.

Code availability. The COMCOT version 1.7 conducted in this research is currently not an open-source model but is available from the corresponding author upon reasonable request.

Data availability. The bathymetry data of ETOPO1 are publicly accessible at https://www.ngdc.noaa.gov/mgg/global/ (NOAA National Geophysical Data Center, 2009). Meanwhile, the bathymetric data of Taiwan used in this research are not open to the public due to homeland security, yet the one with 200 m resolution can be access at https://www.odb.ntu.edu.tw/bathy/ (Ocean Data Bank, 2022) upon official applications. The results data of IIA and numerical simulations are available from the first or corresponding author upon reasonable request.

Author contributions. TRW conceptually designed the study and supervised the research. TCL performed and analyzed the numerical simulations and wrote the paper. SKH provided the fine bathymetry data and provided constructive suggestions to the study.

Competing interests. The contact author has declared that none of the authors has any competing interests.

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