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Numerical Modelling of a Potential Major Tsunami in the Arakan Subduction Zone (Bay of Bengal)

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ABSTRACT

A major earthquake (Mw 8.8) occurred in the Arakan subduction zone on 2 April 1762 generating a tsunami. Another similar earthquake in future cannot be ruled out. In this paper initial tsunami levels for a potential Mw 8.5 earthquake have been generated using the MIKE21 Toolbox developed by DHI [1]. Then numerical modelling of tsunami propagation has been carried out using the MIKE21 Flow Model [2]. Sample results from the modelling study are presented in the paper. The model could be used to simulate any tsunami generated anywhere within the Bay of Bengal. The methodology described in this paper for generating initial tsunami levels and tsunami propagation in the Bay of Bengal could also be applied to this type of events at other sites around the world.

Key words: Tsunami, Natural Hazards, Arakan Subduction Zone, Bay of Bengal, Numerical Modelling, Port Development, Royal HaskoningDHV

1. INTRODUCTION

1.1 The Arakan Subduction Zone

The Arakan Subduction Zone (ASZ) is situated in the north-eastern part of the Bay of Bengal along the Bangladesh-Myanmar coastline as shown in Figure 1 [3]. This is the northern extension of the Andaman-Sunda Trench.

1.2 Past Major Tsunamigenic Earthquakes in the Arakan Subduction Zone

Gupta and Gahalaut [4] reported from Aung et al. [5-6] that the great tsunamigenic earthquakes have not occurred in the region. The only reliable evidence of a great earthquake in the region is the 2 April 1762 Arakan earthquake.

As reported in Gupta and Gahalaut [4], great earthquakes are not common in the region [5]. Infact, no great earthquake has occurred in the region after the 1762 earthquake and the last great earthquake prior to 1762 possibly occurred more than 800 years before 1762 [6].

Gupta and Gahalaut [4] found the following:

a) The northern Bay of Bengal does not have a tectonic environment conducive for the occurrence of a megathrust tsunamigenic earthquake.
b) The region is characterised by oblique plate motion leading to strike-slip dominated earthquakes with low tsunami generating potential.
c) The deformation front associated with the plate boundary between the India and the Sunda plates in the northern Bay of Bengal is either landward of the coast or under shallow water in the Arakan region and, therefore, even a large oblique slip during a future great earthquake is unlikely to displace large amounts of water to create a significant tsunami.
d) Convincing evidence that the 1762 Arakan earthquake generated a large tsunami is lacking. They concluded that this earthquake did not generate a giant or even a major tsunami.
e) No large tsunami has affected the region in the past 2000 years.
f) While a great earthquake could occur in the Arakan region, the physiographic situation may not lead to generation of a large tsunami.

Nevertheless, tsunami from a major earthquake in the Arakan subduction zone cannot be ruled out considering its potential devastating effects on the coastal community in the region.

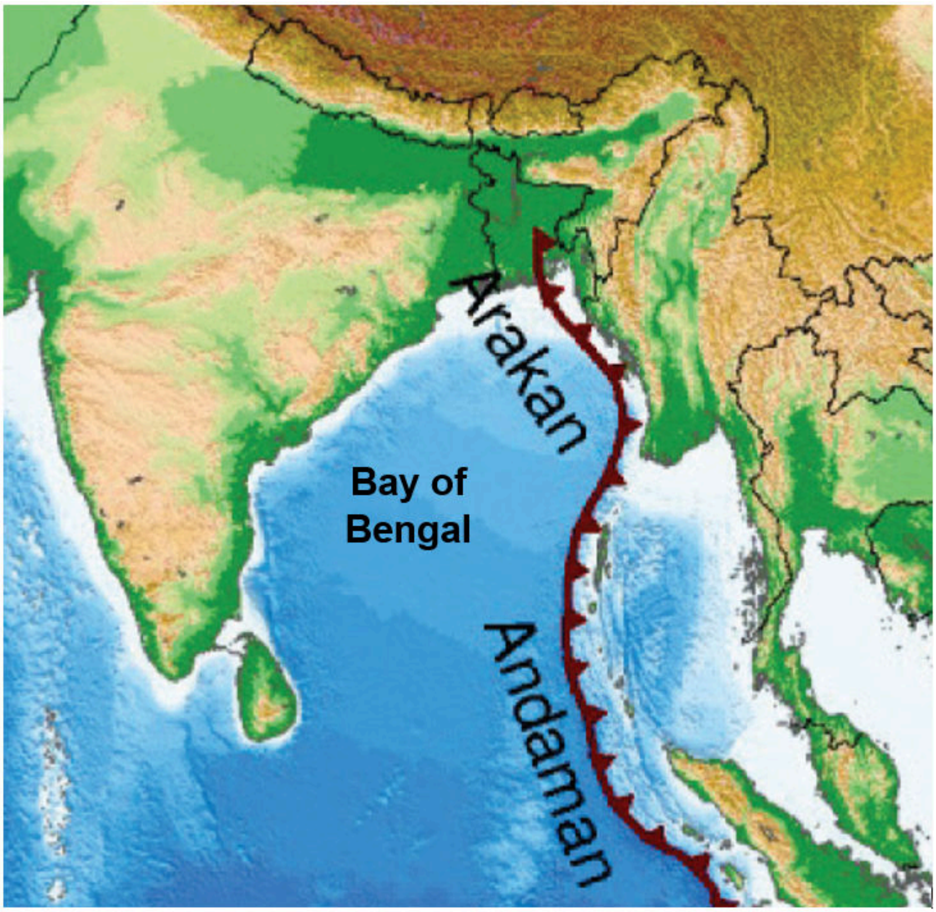

Fig. 1 Location of the Arakan Subduction Zone [3]

1.3 The 1762 Arakan Earthquake, Tsunami and Damage

The text in this section was obtained from Wikipedia [7].

The 1762 Arakan Earthquake

The 1762 Arakan earthquake occurred at about 17:00 local time on 2 April 1762. The epicentre was at 22.0°N, 92.0°E (see Figure 2). The epicentre was somewhere on the coast from Chittagong (Bangladesh) to Arakan in Myanmar (Mondal et al. 2018). It had an estimated magnitude (Mw) of as high as 8.8 on the moment magnitude scale and a maximum estimated intensity of XI (Extreme) on the Mercalli intensity scale. It triggered a local tsunami in the Bay of Bengal and caused at least 200 deaths. The earthquake was associated with major areas of both uplift and subsidence. It is also associated with a change in course of the Brahmaputra River to from east of Dhaka (Old Brahmaputra River) to 150 kilometres to the west via the Jamuna River [8].

The earthquake lasted for about four minutes in Chittagong. The epicentre is not well-constrained and likely locations have varied from near Chittagong to along the Arakan coast. The extent of the rupture is uncertain but may have been as much as 700 km along the plate interface. This is based both on the extent of uplift, which was recorded along the coast of Myanmar from Foul Island to Ramree Island, and the area of subsidence around Chittagong, further north. The 700 km extent combined with an estimated displacement of 10 m gives a maximum estimated magnitude of Mw 8.8 on the moment magnitude scale [9]. Other workers have pointed out that neither the subsidence, which could be due to lateral spreading, nor the uplift, which is not unequivocally linked to the 1762 earthquake, necessarily provide a reasonable estimate for the size of this event and prefer to regard this as a magnitude Mw 7–8 earthquake [10].

Figure 2 – Location of the 1762 Earthquake [7]

Studies of uplifted marine terraces along the Myanmar coast have found evidence for three uplifts, the most recent of which is interpreted to be from the 1762 earthquake. The Saint Martin's Island has been uplifted by 2.0-2.5 m during that earthquake [10]. A repeat period of about 500 – 700 years has been suggested for earthquakes similar to that in 1762 [10].

Tsunami

A tsunami was reported along the north-eastern coast of the Bay of Bengal and at Dhaka and Kolkata [12]. This is regarded as a local tsunami, as no effects were recorded on the western side of the bay [10].

Damage

In Chittagong, it was reported that no buildings or walls built of brick had escaped either destruction or serious damage. The East India Company's factory inside the fort was so badly damaged that it could no longer be safely used [13]. An area of about 160 km^2 permanently subsided beneath the sea along the coast near Chittagong. At Bar Chara, just north of Cox's Bazar, the land sank and 200 people were killed. Chittagong was said to have "suffered severely" with soil liquefaction effects such as sand volcanoes and ground fissures [14].

The above text was obtained from Wikipedia [7].

1.4 Previous Numerical Modelling Studies on Tsunamis in the Arakan Subduction Zone

Numerical modelling of tsunami from the 1762 earthquake (Mw 8.8) was carried out by Cummins [9], Gupta and Gahalaut [4] and Srivastava [15].

Sarker [16] carried out numerical modelling of potential tsunamis in the Arakan subduction zone with Mw 8.0 and 8.5.

1.5 The Present Study

In this paper initial levels of a potential tsunami from earthquake Mw 8.5 have been generated using parameters from Sarker [16]. The MIKE21 Toolbox was used for this purpose. Then numerical modelling of tsunami propagation has been carried out using the MIKE21 Flow Model. Sample results from the modelling study are presented in this paper.

The general definition of tsunami level and tsunami wave height is illustrated in Figure 3. The flowchart in Figure 4 illustrates the steps and the software involved in a typical tsunami modelling study. The MIKE21 Toolbox was used to generate the initial tsunami levels.

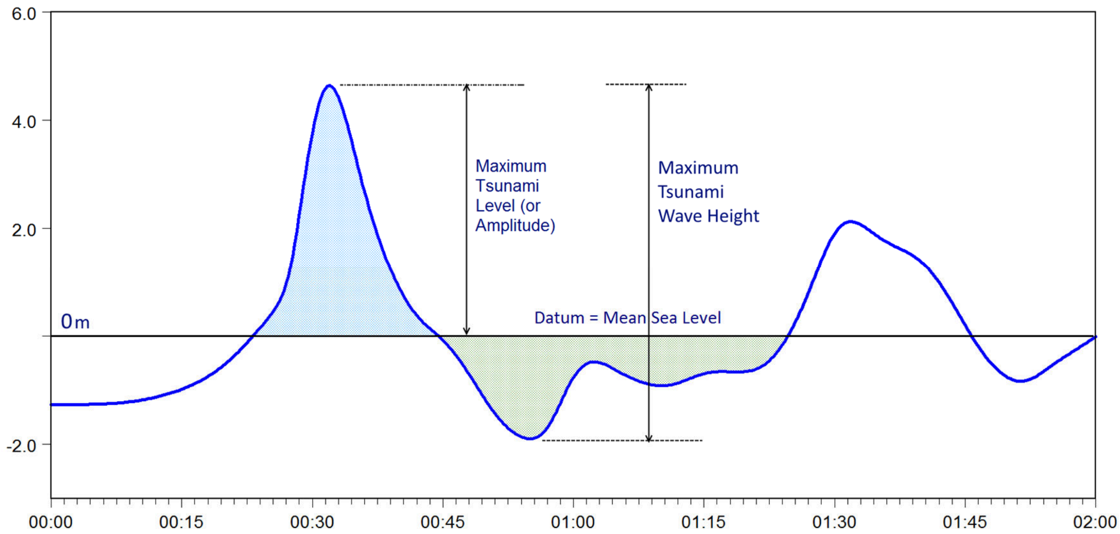

Fig. 3 General definition of tsunami level and tsunami wave height

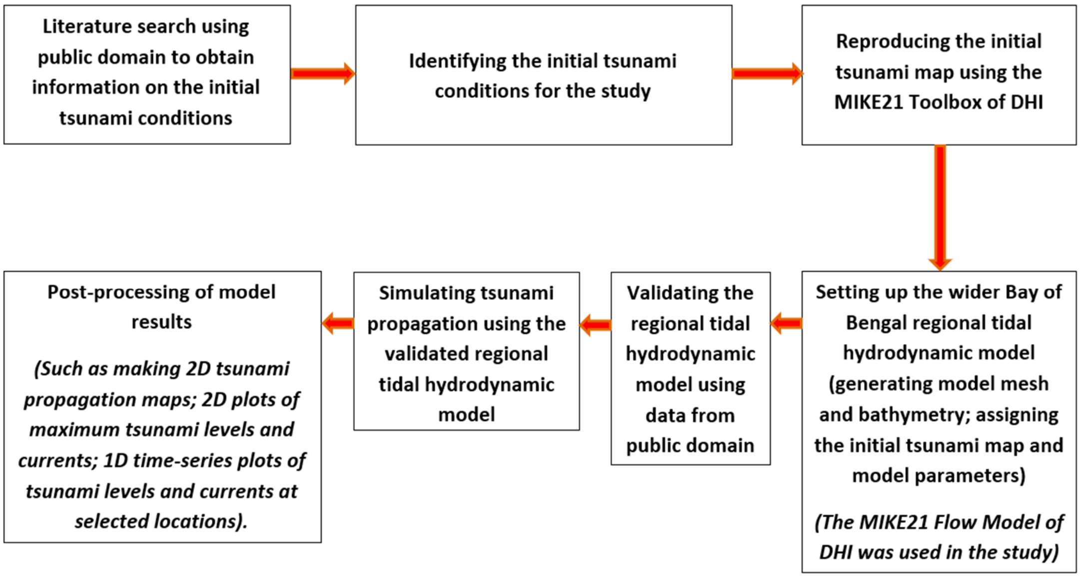

Fig. 4 Steps and software used in a typical tsunami modelling study

2. SELECTION OF MW 8.5 EARTHQUAKE PARAMETERS FOR THE PRESENT STUDY

Parameters of a potential Mw 8.5 earthquake in the Arakan subduction zone have been obtained from Sarker [16] who has divided the fault line into six segments as in Figure 5. The focal depth of 3 km in Sarker [16] seems too shallow and, therefore, a focal depth of 30 km was used from Srivastava [15] in line of the 1762 great earthquake. The final parameters are provided in Table 1. It should be noted that the MIKE21 Toolbox requires the coordinates of the middle point of the fault area and, therefore, latitudes and longitudes of the middle point of the six segments were extracted from the plot in Sarker [16].

Table -1 Sub-fault parameters for Mw 8.5 earthquake used in the present study

Sub-faults	Latitude (°N)	Longitude (°E)	Length (km)	Width (km)	Depth (km)	Slip (m)	Strike (°N)	Dip (°)	Rake (°)
1	13.5862	93.0000	213.79	106.89	30	6.19	32	10	160
2	15.2069	94.0867	213.79	106.89	30	6.19	32	10	160
3	17.3922	94.2200	213.79	106.89	30	6.19	335	10	120
4	19.0980	93.3000	213.79	106.89	30	6.19	330	10	115
5	20.8065	92.4200	213.79	106.89	30	6.19	337	10	125
6	22.1515	91.9286	213.79	106.89	30	6.19	345	10	127

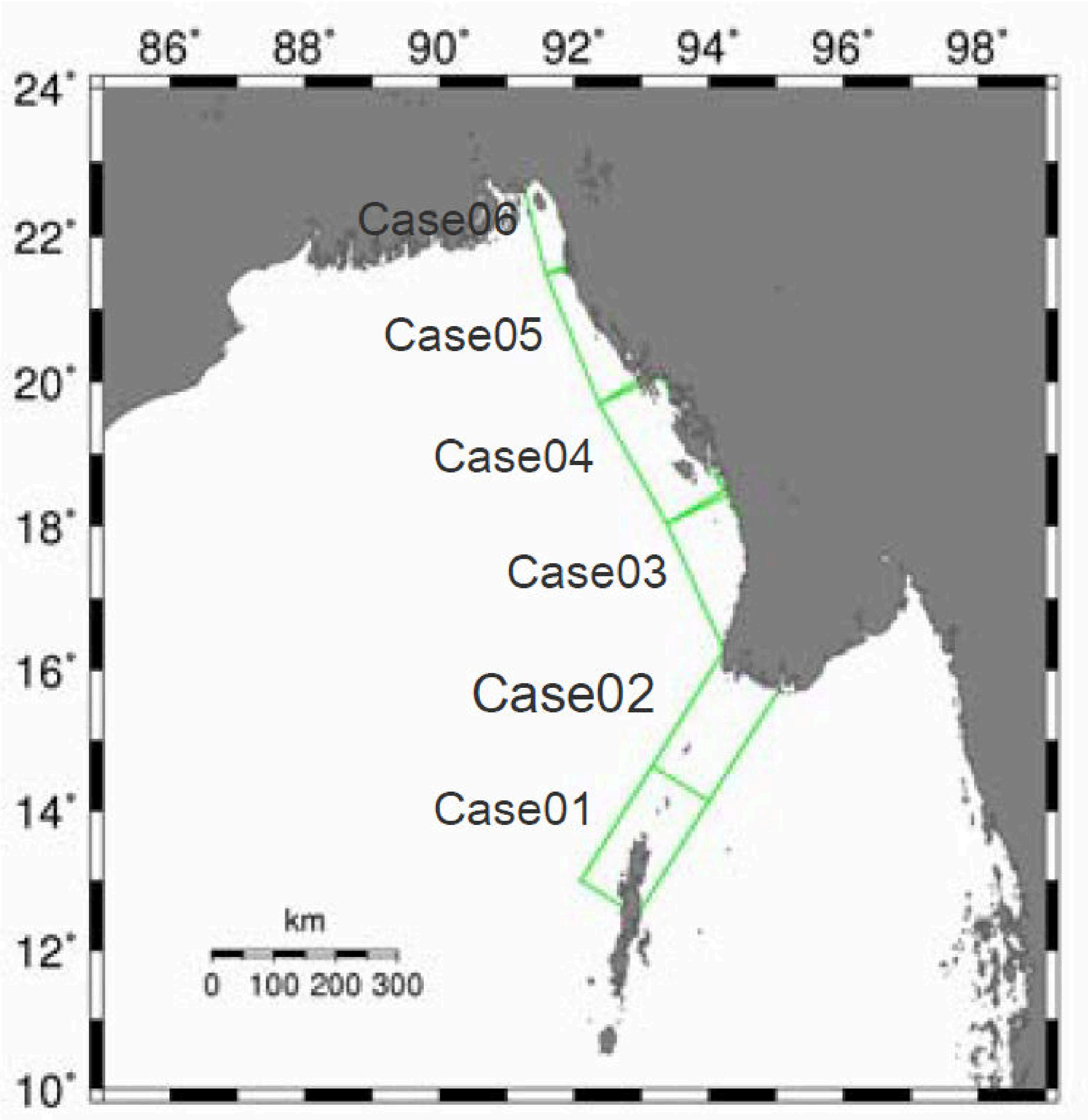

Fig. 5 Sub-faults distribution from Sarker [14]

3. GENERATION OF INITIAL TSUNAMI LEVELS

It is assumed that the initial sea surface rise is the same as the final seafloor deformation after the earthquake. This is a reasonable assumption because the duration of an earthquake is generally short and the size of the rupture area is much larger than the water depth. Consequently, there is not enough time for the water above the deformed seafloor to drain out. The seismic rupture is much faster than water wave propagation.

Initial tsunami levels were generated for the earthquake parameters in Table 1 using the MIKE21 Toolbox. Square grid size of 2 km x 2 km was used for the domain to generate the initial tsunami levels. Figure 6 shows the initial tsunami levels generated using the earthquake parameters in Table 1.

The maximum initial tsunami levels along the coastline was 3.3 m (in between Segments 5 and 6). It should be noted that the maximum initial tsunami level and its location for a given Mw will vary due to the distribution of the length, width and dislocation (slip) of the fault.

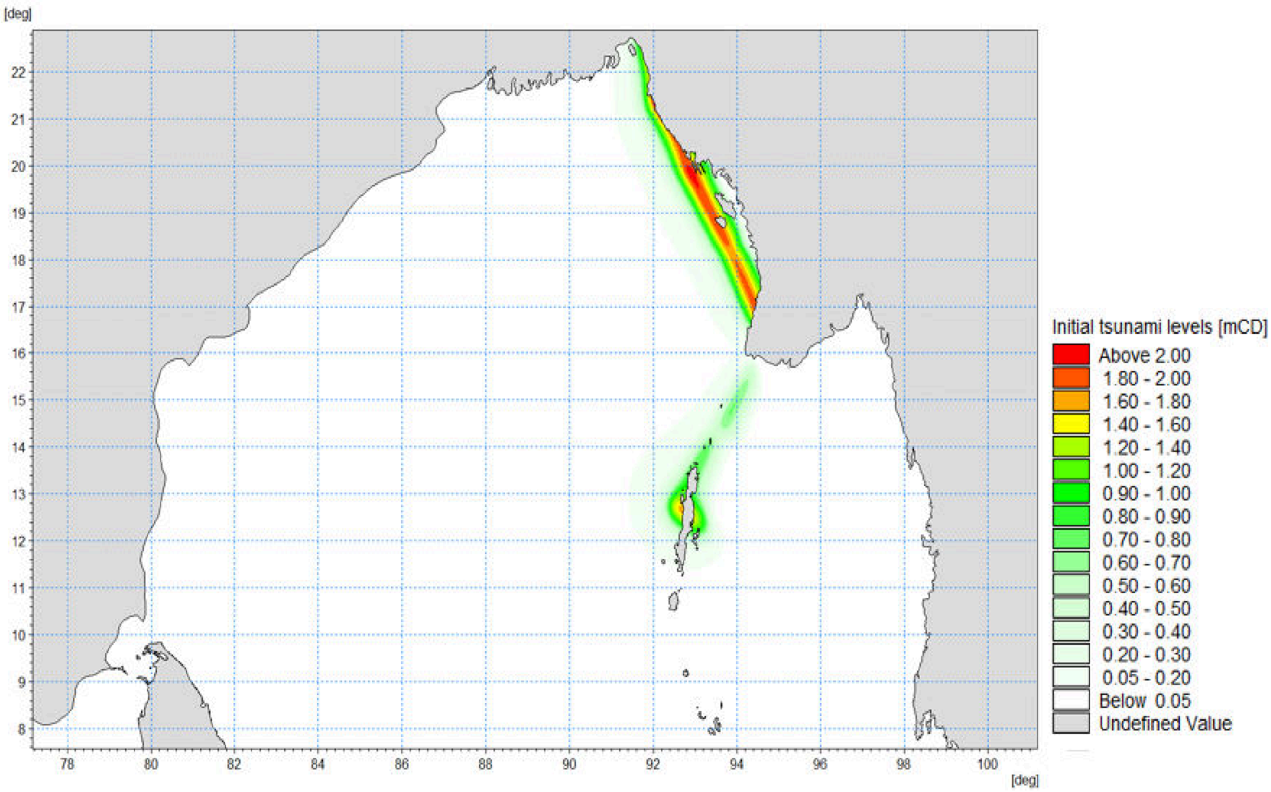

Fig. 6 Initial tsunami levels (mCD)

4. NUMERICAL MODELLING

4.1 The Tsunami Model

The MIKE21 Flow Model was used to simulate the tsunami propagation. The modelling system is based on the numerical solution of the two-dimensional shallow water equations - the depth-integrated incompressible Reynolds Averaged Navier-Stokes (RANS) equations. Thus, the model consists of continuity, momentum, temperature, salinity and density equations.

4.2 Tsunami Model Domain, Mesh and Bathymetry

Royal HaskoningDHV (RHDHV) has set up a regional tidal hydrodynamic model based on the MIKE21 Flow Model. The model covers the Bay of Bengal as shown in Figure 7. This model was used to hindcast tsunami in the study.

A flexible (triangular) mesh was used with variable mesh size distribution of required resolution and smooth transition to obtain accuracy in the model results. Particular attention was given to the study site and around the fault line. A smaller mesh size was also maintained in the areas where seabed slope is steep. Generally, 20-30 grids per wave length are recommended for simulating a tsunami, however, about 40 grids per wave length was used in the study to obtain higher accuracy in model results.

The mesh size distribution was generally as below:

- 50m grid size at 1m depth
- 150m grid size at 10m depth
- 500m grid size at 100m depth
- 1500m grid size at 1000m depth
- 3000m grid size for the remaining deeper areas

The bathymetry was obtained from the C-Map Database [17]. Figure 7 shows the model bathymetry with respect to Chart Datum (CD).

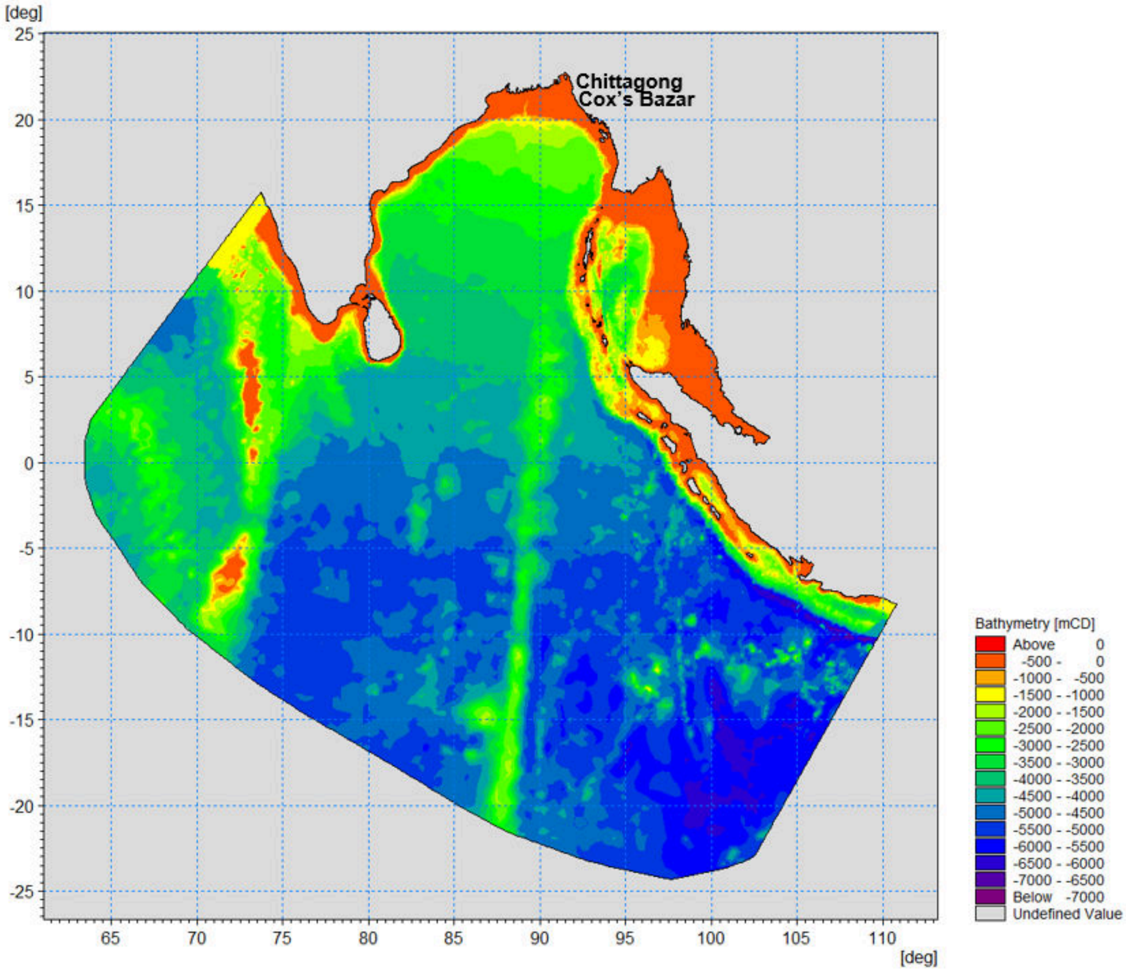

Fig. 7 Model domain and bathymetry (mCD)

4.3 Tsunami Model Parameters

Some other major model parameters are given below:

- Time step = 15s;
- Run duration = 3 hours;
- Higher order numerical scheme used; and
- Coriolis force = varying in domain.

4.4 Model Validation

Maximum tsunami level of about 2.5-3.5 m were extracted at the fault area from the colour plots in Cummins [9] and Srivastava [15] for the 1762 earthquake. In the present study the maximum tsunami level was found as 3.3 m close to the fault area for the 1762 earthquake.

A good agreement was found in the maximum tsunami level both in the present study and the previous studies for the 1762 earthquake. Therefore, it is concluded that the present model can predict the tsunami levels and arrival time from the proposed potential Mw 8.5 earthquake at anywhere within the model domain with an acceptable level of confidence.

4.5 Model Results

Figure 8 shows the maximum tsunami levels during the entire passage of the tsunami. Higher tsunami levels were found at the north-eastern part of the Bay of Bengal with the maximum tsunami level of about 3.3 m close to the fault area.

Tsunami levels at the Smith Island (Andaman and Nicobar Islands) were much smaller with a maximum value of about 1.7 m.

Maximum tsunami level at the Bangladeshi coastline was 2.1 m. Maximum tsunami levels in Chittagong and Cox's Bazar were 1.2 m and 2.0 m respectively.

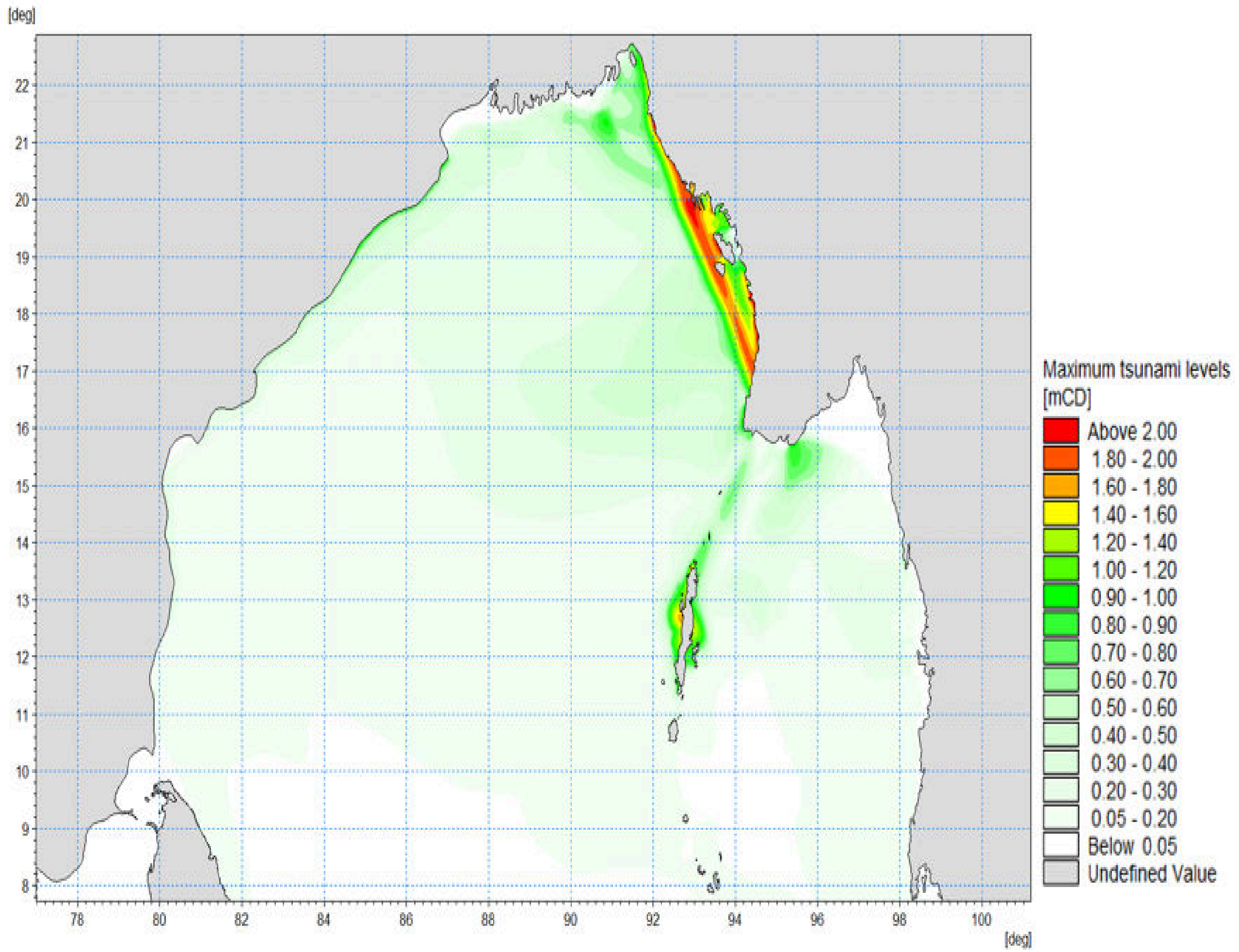

Fig. 8 Maximum tsunami levels (mCD)

5. LIMITATIONS ON THE MODEL RESULTS

Model results presented in this paper are for illustration purposes only. These should not be used for any practical project work for which use of local survey bathymetry data and detailed local calibration are essential.

6. SUMMARY AND FINDINGS

Literature search suggested a repeat period of about 500 – 700 years for earthquakes similar to that in 1762. Maximum initial tsunami levels of 3.3 m was found near the fault area. The maximum initial tsunami level and its location for a given Mw will vary due to the distribution of the length, width and dislocation (slip) of the sub-faults.

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